MODELLING AND SIMULATION TECHNIQUES FOR BUSINESS PROCESS ANALYSIS AND RE-ENGINEERING

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Abstract: Recent business developments in the light of globalization and increased competition have caused many organisations to rethink their business processes. In this evolving context, business process analysis and re-engineering are key to the successful implementation of the necessary adaptive changes. This paper investigates the benefits of business process modeling and simulation as means to address the challenges of such changes. While alternative implementation scenarios can be tested and quantitatively assessed by means of simulation, suitable design of experiments techniques are needed to guide the specification of the implementation details. Following this discussion, an application case is presented to illustrate the role and the benefits of simulation in business process analysis and re-engineering. The concept of combining AI techniques based on Genetic Algorithms with simulation to iteratively guide the design of simulation experiments and progressively improve the performance of the solution is presented and discussed. A summary of the observed benefits and an overview of the remaining challenges are proposed in the conclusions.

Keywords: Business Process Modelling, Business Process Re-engineering, Discrete Event Simulation.

INTRODUCTION

Changes in the ways of doing business, whether radical or incremental, have historically been part of the life of business organizations. However, it was in the 1990s that business process analysis and re-engineering became the focus of organizational management's attention, (Tumay 1995) and structured approaches for its understanding and implementation started to be widely investigated (Hlupic and de Vreede 2005). The figures, as described in (Hlupic and de Vreede 2005), show that while a large proportion of the existing companies (75% of the companies surveyed in (Jackson 1996) understand the benefits of business process analysis and re-engineering, and make the effort to undertake them, the rate of failure in their implementation is discouragingly high (for instance, according to a recent study by Hammer and Champy (1993), over 50% of the projects surveyed failed). Many are the difficulties encountered by companies when choosing to undertake business process analysis and re-engineering, and many are the reasons for failure. At the analysis stage, when the current processes need to be understood and assessed, there are inherent difficulties in capturing their interdependencies in a way that is structured yet representative. One of the key difficulties in the structured representation of business processes is the choice of the level of detail that is appropriate and relevant for the analysis. Another key difficulty is the representation of the inherent process dynamics. At the re-engineering stage, the inability to anticipate the full impact of radical changes along with the inability to fully specify, and the cost of analyzing and evaluating, the wide range of business process design options available are major causes of failure.

According to several researchers adequate tools are not yet available for the systematic assessment of business process alternatives prior to their implementation (Tumay 1995, Barber et al. 2003, Greasley 2003, Paolucci et al. 1997). When business process changes are implemented without a full understanding of their implications, major risks are incurred, as late corrections are often very costly and time-consuming.

Among the many tools available to support business process analysis and re-engineering, simulation offers the great advantage of capturing both the dynamic and the stochastic aspects of the processes. For instance the frequency of incoming orders, the different ways of servicing different types of customers, or the dependency of downstream processes on the outcome of upstream ones, can easily be incorporated into a simulation model.

After a brief overview of business process modelling methods, the paper will discuss the role of simulation in business process modeling for analysis and re-engineering purposes. The opportunities and challenges of simulation in this area are illustrated referring to an example from the retail business. The concept of combining Genetic Algorithms and simulation is presented in the context of this case study. Based on these considerations, conclusions on the current and future role of simulation in business process modeling are presented.

BUSINESS PROCESSES AND THEIR RE-ENGINEERING

Prior to engaging in the discussion of business process modelling, analysis, and re-engineering, it is important to establish a common understanding of business processes. Although different authors have formalised different definitions of business processes, an overview of which may be found in (Hlupic and de Vreede 2005), there is a general consensus on some common elements: the process itself, whether it is referred to as a transformation of input, as a work flow, or as a set of activities, its input, and its output, often referred to as value to the customer, or business goal (Hlupic and de Vreede 2005, Hlupic and Robinson 1998).

The re-engineering of business processes is typically a response to either internal changes within the organisation or changes in the business environment, and may reflect in a combination of changes in the human resources (e.g. type, skills, number), in their involvement (e.g. working hours, schedule, and patterns), in the process activities (e.g. types and sequence), and in the technology (e.g. use of IT and/or business-specific equipment). It should be observed that not only do these changes impact the process activities and the way they are executed, but they also alter the interactions among human resources, process activities, and technology (Hlupic and de Vreede 2005). As discussed in detail in the following sections of the paper, while many tools are available in the market to support business process analysis and re-engineering, simulation is especially well-suited to capture the dynamics of these interactions.

BUSINESS PROCESS MODELLING TOOLS

Considering the widespread impression among authors that suitable tools are not available to fully support business process modelling, and the increasing number of companies undertaking business process analysis and re-engineering (Grover and Kettinger 1998), it is important to understand the benefits and the limitations of existing tools. Given the increasing demand for such tools, a variety of software applications for business process modelling have been distributed in the market (Swain 2003). Many of these, for instance Microsoft Visio, are static mapping tools (Feldman 1998), in that they provide a graphic representation of the process activities and their sequential relationships, but offer limited computation facilities. Other modelling tools that are frequently used are deterministic in nature, for instance Microsoft Excel, and thereby unable to capture the process dynamics, especially in the presence of change. In contrast, discrete event simulation tools, such as ProModel or Simprocess, are quite well suited for the dynamic modelling requirements of business process analysis (Tumay 1995, Paolucci et al. 1997) for a number of important reasons. First they account for the stochastic variability of the key process parameters, such as resources availability. Second, they can capture the dynamic interdependencies among process activities. Third, they typically have built-in animation options that enable to visually monitor the business processes as they evolve over time. This feature is quite useful at the business process analysis stage, to highlight problem areas such as bottlenecks, and thereby set the focus of the redesign project. In spite of these benefits, and of its wide application in manufacturing, logistics, and telecommunications, just to mention a few of the relevant sectors, the use of simulation as a business process modelling tool is not as well-established as expected (Hengst et al. 2004).

Most organisations (over 80% (Gladwin and Tumay 1994, ProSci's 1997) still choose static flowcharting tools that are highly inflexible as far as the modelling of process changes, and thus are unable to assess the impact of business process alternatives. Other options include project management tools, and very basic multipurpose tools such as spreadsheet, word processing and database development tools. While researchers appreciate the value of simulation in business process modelling (Barber et al. 2003, Melão and Pidd 2003, Omrani 1992, Robinson 2003, Lee and Elcan 1996), both cultural and technical barriers still limit its use within business organisations (Barber et al. 2003, Kettinger 1997). The next section of the paper will illustrate the opportunities and the challenges that organisations are faced with when approaching business process modelling using simulation.

SIMULATION FOR BUSINESS PROCESS MODELLING

The two following subsections will highlight the opportunities and the challenges of discrete-event simulation in business process modelling for the purposes of analysis and re-engineering.

Benefits of Simulation as Business Process Modelling Tool

One important role of simulation in business process modeling is that of generating consensus among the stakeholders in their understanding of the business operations in relation to the business environment. Specifically, because unlike other available tools, simulation can capture the dynamics of business processes and, more than other tools, can provide output in quantitative rather then qualitative format, it offers objective grounds for discussion and supports informed decision making.

The ability of simulation to support 'what if'analysis finds a fertile ground for application in business process analysis and re-engineering. Changes in business processes are often risky and their outcomes are difficult to correct after implementation. The ability to test their effects off-line is invaluable to business managers, and this is one of the core strengths of simulation techniques.

Challenges of Simulation as Business Process Modelling Tool

While many approaches may be followed in the development of business process models using simulation, the main steps in the development and in the use of this technique will necessarily include the following:

- Definition of Modelling Objectives and Scope
- Data Collection and Analysis
- Simulation Implementation
- Model Verification and Validation
- Design of Experiments
- Analysis of Simulation Results

The first step, definition of modeling objectives and scope can be a quite challenging to start with. The scope of the model is especially hard to determine when dealing with the less tangible aspects of business processes such as the transfer of information between activities and the level of detail to which the behaviour of human resources should be captured.

Issues arise especially in the execution of task two, as modeling requires the quantification of aspects that may be difficult to measure in a business context. For instance measuring how long a certain activity will take may be extremely difficult because many factors, such as the impact of communication delays or the lack of communication, are very hard to quantify. A significant variability in such measurement can also be expected due to the difficulty to filter out these effects from the sample data, which in turn will lead to distributions that are difficult to fit.

The implementation of the simulation model may be costly and time-consuming, depending on the scope and on the required level of detail. Cost but especially timing issues may have serious impact on the ever rapidly evolving business scenario, as they can quickly translate into missed business opportunities. Model verification and validation may be quite difficult to pursue especially in the analogical way. This approach requires the availability of data that is traditionally not tracked and recorded in business contexts. Some of the relevant data may only be available at the aggregate level, which may not be suitable for model testing purposes. The high variability of the measured data, for instance in the durations of process activities (as mentioned before), can cause the simulation results not to converge, thus requiring several iterations over the data sets collected to model the stochastic behaviour of the variables involved. The design of experiments can also prove quite challenging due to the high measured variability in the stochastic parameters of the model. Even when the model is brought to convergence it may still require several replications of the same simulation experiment to produce significant and reliable output. Once the model has been accredited and suitable experimentation has been carried out it is still necessary to translate the simulation results into management actions. Frequently, in order to isolate the problem areas, a reverse engineering approach is needed to map the aggregate results to their local causes.

Limitations of Simulation in Business Process Re-Engineering

Simulation is a powerful approach for scenario testing in business process re-engineering projects, which can be used directly to test the different implementation alternatives of the change management programme when these are limited in number and detailed enough to customize the simulation model for each implementation scenario. In practice, when new management concepts are to be introduced in a business context, and feasibility studies are carried out, the implementation details of the change are often not fully specified. For testing purposes these details need to be identified and customized for the particular context of application. In addition, the range of implementation alternatives can be very wide, and simulation alone could not efficiently guide the choice among possible solution in a way that is both cost and time effective Supporting techniques including design of experiments or more specialized search techniques are required to guide the choice. An example of these techniques, based on Artificial Intelligence (AI) will be proposed in the case study.

BUSINESS PROCESS MODELLING: AN EXAMPLE APPLICATION

The role of simulation in business process modeling for analysis and re-engineering can be best illustrated with reference to an example application. The remainder of this section will describe the business context, the modeling approach and the outcome of the re-engineering project focusing on the benefits and on the challenges in the use of simulation for this business application. The context of reference for this example is that of retail businesses. The objective is to conduct a study by means of simulation to assess the feasibility, specify the implementation details, and evaluate the performance impact of a new business model for the management of human resources and their allocated times. The idea is to shift from a traditional fixed schedule approach to one that is based on flexible working hours and flexible resources allocation to activities. The nature of the study suggests the use of simulation as a modeling tool for several reasons. First the study needs to evaluate the current performance of the business operations, referring to the traditional, fixed schedule approach as a baseline solution. For the purposes of this study performance is multi-attribute, as it consists of different measures such as the quality of customer service, the cost of resources overtime and the level of resources satisfaction with their work schedule and jobs allocations. Because of this definition of performance, the first step of the study requires a tool that supports the monitoring of the business activities according to variable resources requirements, availability, and utilization, in a context such as the retail sector where the demand on resources time varies according to stochastic daily and weekly patterns. The second and third steps require the isolation of suitable resources allocation plans and the customization of the simulation model for these resources allocation scenarios for the purposes of assessing both their feasibility and their impact on the performance of the business. This is again a dynamic modeling task because the performance of each solution needs to be tested in the real conditions of variable resources availability and customer flows into the store.

The Business Context of Analysis and Re-Engineering

The study introduced in the earlier part of this section was conducted with reference to a prototype retail store based in Italy of the size of approximately 40 employees. The new business concept to be tested in this context mainly consists of the aggregation of human resources around clusters of responsibility on the basis of complementary skills and schedule preferences. Within each cluster the resources manage their own time and job allocation, in that they get to choose their working times and duties on a bi-weekly basis, under the sole constraint that the overall work-plan for the cluster should be feasible and should cover the designated workload for the entire 2-week period. Interviews with the store managers provided the criteria for the clustering of resources into suitable workgroups: the daily activities of the resources can be classified as product preparation, product handling and display, customer service, and cashier’s duties. It is apparent that clustering could take two approaches: either by skills and thus by type of activity, or by product category. Because in the ‘as-is’ situation some product categories require special skills in the preparation and handling, the resources are not yet interchangeable to the level required for clustering by activity type, so in the first instance it was decided to generate clusters around product categories. Each cluster would then include a number of interchangeable resources for each of the activities pertaining to a particular product category, which should be capable of covering the man-hour requirements for that product category. A total of 6 clusters were defined as aggregations of duties and workloads by product category. Duties and workloads were assessed in-store for a typical 2-week period of operation, excluding special periods such as major holidays, strikes, or other public events. Because cashier’s duties are not product-specific it was not possible to include them in a particular cluster of responsibility. It was then decided that all of the resources should allocate 20% of their working time to cashier’s duties. The resources allocated to each cluster were then asked to produce an agreed schedule of preferred working hours and duties, subject to the common cashier’s duty constraint, by filling a workload chart suitably designed around the assessed workloads. This chart would provide a starting point for the definition of a resources allocation schedule that is both feasible and effective under the new business process model.

Simulation and AI-based Approach for the Definition of the Scenarios

Once the clusters have been designed as aggregations of dynamic workloads it is necessary to build a schedule of resources allocations to workloads to cover the designated bi-weekly scheduling horizon: such an allocation represents a complex combinatorial problem which needs to achieve feasibility and cost-effectiveness: the efficient allocation of a specific resource to a job on a given work-shift is highly dependent not only on the expected performance of such an allocation, but also on the implications that this choice may have on the performance of all the remaining allocations.

These interdependencies are mainly due to the fact that the number of available resources per skill/area of competence is limited.
Therefore the allocation of a first choice resource to a job may leave second or third choice resources available for allocation to other jobs, which could produce a sub-optimal resources allocation plan from the perspective of the service as a whole. Each resources allocation scenario can be thoroughly tested taking into account the secondary and tertiary effects of each allocation choice by means of simulation. However, as the number of resources becomes large, the computational times and requirements for the exhaustive testing of all possible combinations make an approach based on simulation alone practically unfeasible.

For the purposes of the case study, Artificial Intelligence (AI) techniques based on Genetic Algorithms (GAs) are employed for the choice of resources allocation scenarios to be tested through simulation. Simulation-based testing is used to assess the feasibility and the performance of each scenario, and the output is fed back into the GAs as reference for the identification of improved allocation plans. The procedure is iterated until a satisfactory solution is identified.

Genetic Algorithms for the Screening of Resources Allocation Plans

The resources allocation problem examined in the case study is especially complex because a global performance standard is sought building from multiple interdependent allocation decisions, which cannot be separately optimised: the efficiency of a particular allocation is reflected in the performance of other workloads and through them in the performance of the whole service. Genetic Algorithms (GAs) are well-suited techniques to address complex combinatorial problems involving multiple variables (Bruzzone et. al, 2001; Goldberg 1989). GAs iteratively seek performance improvements by trial and error (Bruzzone and Signorile, 1998; Koza 1992; Goldberg, 1989). At each iteration an "evolutionary" step is made where the worse performing solutions are discarded, and attempts are made to improve the better performing ones by mixing (cross-over) and modification (mutation) (Goldberg, 1989). The major advantage of using GAs in this process is that the search for a satisfactory solution begins from an entire population of scenarios (Goldberg, 1989) and, thus, from multiple points in the space of the possible solutions, which highly increases the chances of finding the actual optimum rather than a sub-optimum. In addition their internal processes of mutation and cross-over are based on stochastic rather than deterministic rules, which further reduces bias in the search and increases the chances of success.

The GAs module was designed to handle binary input/output strings where the "1" bits indicate the allocation of the corresponding resources for the current scheduling interval and the "0" bits indicate that the corresponding resources are not required during this same interval. The target function for the process was defined as a performance indicator combining job satisfaction (as a percentage of the preferred duties and schedule actually met) and overtime costs (as a percentage of the ideal cost in the absence of overtime requirements). A binary resources allocation string is associated to each cluster and the allocation is re-evaluated for each time interval included in the scheduling horizon.

The Implemented Business Process Simulation

Prior to the implementation of the business process model as outlined above it was necessary to conduct a feasibility study to anticipate the impact of the new model on the key aspects of business performance. In consultation with the store managers it was agreed that the performance measures, on which to base the evaluation of the new solution, should be the quality of customer service, the cost of resources overtime, and the level of resources satisfaction with their work schedule and job allocations. These measures would encompass both the feasibility and the effectiveness of the analyzed solution.

Feasibility is simply the ability to meet customer demand to a user-defined extent (desired quality of customer service), for instance 95% of the customers serviced with wait time under 6 minutes, which also defines the reference for the quality of customer service. Resources' satisfaction is measured as the overall percentage of workers' preferred schedule and duties actually met (i.e. in the real situation of dynamic workloads and other resources' availability). Finally, the cost of resources' overtime is measured as a percentage of the ideal cost of the resources in the absence of overtime requirements.

Because of the complexity of the modeling task and for increased flexibility of representation it was decided to develop an ad-hoc simulator in the JBuilder development environment. The environment, which is Java-based, offers the degree of flexibility required to address the numerous technical challenges that are specific to the modeling context and to the type of analysis.

A first modeling challenge was the representation of the daily and weekly workload patterns as determined by the dynamic patterns of customers' flows across the different areas of the store. The main sources of information to model such patterns were the electronic records of the cashiers' receipts. Two years' worth of cashiers' receipts were sorted to extract suitable distributions for the number of customers accessing the different areas of the store, differentiating among periods during the day (e.g. morning, mid-day, afternoon) and days of the week (e.g. weekdays or weekend). This data was then mapped into daily and weekly patterns of workload.

Because the clustering of resources around product categories implies some degree of interchangeability among resources, it was necessary to create resource profiles capable of holding information about the suitability of the resource for each type of activity (yes/no) and a corresponding skill/experience level, namely a coefficient capable of influencing the duration of each activity and, thereby the number of customer serviced or the number of product units handled in the time unit of reference. A suitable temporal resolution for the purposes of the simulation study was agreed to be the hour, as it would not be efficient in business terms to consider resources re-allocation for shorter time periods.

A final modeling challenge was the handling of scheduling emergencies, intended as the unavailability of the scheduled resources. A common unavailability rate was defined for all of the resources, based on store records and management estimates. At the beginning of each simulated work-shift the pool of resources actually available is updated. For the purposes of the current work-shift the duties of the missing resources are shared and re-assigned to the suitable resources actually present, with an impact on the efficiency of the service to the customers (e.g. customer queuing time). For the purposes of the following work-shifts, and for the entire duration of the resource shortage, a spare resource is introduced at overtime cost.

Because of the stochastic nature of the simulated processes a number of simulation replications are required to obtain reliable output from the simulation model. The classic methodology based on the Mean Square pure Error (MSpE) was used to obtain the minimum number of replications required. The evolution of the MSpE for the three designated output variables was mapped as a function of the number of simulation replications and used to graphically determine that 9 simulation replications were needed to assess the performance of each allocation scenario. It should be observed that 9 replications of 2-week periods correspond to 126 days of store operation.

Simulation Results

The implemented simulation model discussed in the previous section was customized to represent both the current business practice (i.e. fixed work schedule) and the new business scheme (self-managed work-groups). As illustrated in Figure 1 simulation enables the comparison of the two alternatives in quantitative terms, and thereby provides objective grounds for discussion among the business stakeholders. As shown by the comparative study, significant benefits can be expected from the introduction of the cluster-based scheme, especially as far as reducing the cost of resources overtime (by 68% in this case). Resources satisfaction may also be increased (by 32% in the example) and the quality of customer service may be improved (by 11% in this study).

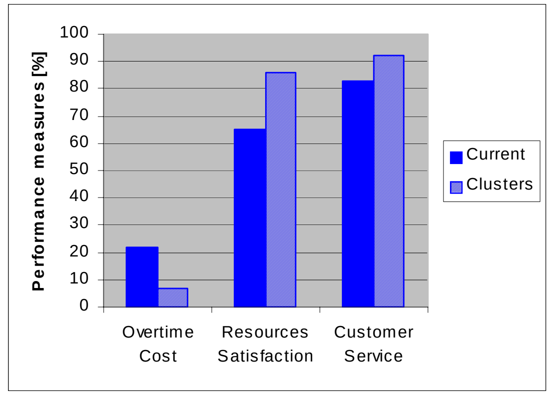

Figure 1: A Comparison between the Current and the New Model of Human Resources Management

These output values correspond to the average of each output calculated over the 9 simulated replications. The level of confidence associated to such estimates can be measured through the dispersion of the punctual data about each average value. For this application it was found that each punctual value would fall within the range of ± 5.8% of the corresponding average: specifically, ± 5.1% for the quality of service, ± 4.6% for job satisfaction, and ± 5.8% for overtime cost.

It is important to notice that these improvements are marginal improvements that may be obtained at zero cost, maintaining exactly the same pool of resources currently available. Further use of the simulation may explore the benefits of changes in the pool of resources in terms of number and type, or even the benefits of resources cross-training to increase their degree of interchangeability within and/or among clusters.

CONCLUSIONS

The use of simulation for business process modelling has been discussed in application to business process analysis and re-engineering projects. The paper argues that simulation modelling tools are well suited for this purpose and that business organisations can significantly benefit from a wider application of this approach. It also argues that design of experiments or suitable search techniques can be paired with simulation to maximise these benefits and overcome the inherent limitations of simulation. The example presented in the paper illustrates and supports these claims. Specifically, the example clarifies the benefits of simulation-based testing of business process alternatives prior to their implementation, in terms of quantifying their impact on business performance. It also shows that Artificial Intelligence (AI) techniques based on Genetic Algorithms (GAs) can guide the choice of the scenarios to be tested by simulation to efficiently converge to the identification and specification of suitable implementation details that ensure both the feasibility and the performance of the new management scheme. In summary, not only can feasibility studies based on simulation estimate the cost of implementation ahead of time, but they can also reduce the risks associated to the implementation of novel solutions. While the benefits of conducting 'what if' analysis are in principle recognised by business management, there are clear barriers to the extensive use of simulation for business process analysis and re-engineering, as shown by the limited number of business organisations currently making use of simulation tools. Considering the important role of simulation in business process modelling, it is critical to promote a wider diffusion of this tool within the business community. To this effect a number of actions may be considered. For instance creating awareness and promoting involvement within the business community to build a 'critical mass' of business users, will attract more business organization to the use of this tool. This effect will also boost the technology, so that more 'business friendly' simulation tools will appear on the market. Time is often a constraint on the business side, as business situations tend to change rapidly, to the extent that delayed solutions quickly reflect into missed business opportunities. While there are inherent technical challenges, which are specific to the modelling of business processes, the availability of tools supporting higher degrees of reusability and ease of customisation may address some of the challenges related to long development times. Most importantly, communication and cooperation among business organisations and subject matter experts, sharing business process modelling resources, will dramatically reduce development times and costs by opening the access to a pool of problem-specific knowledge and solutions.

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