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A Structural Reliability Business Process Modelling with System Dynamics Simulation

C. Y. Lam, S. L. Chan and W. H. Ip
The Hong Kong Polytechnic University
Hong Kong

1. Introduction

A business process reflects how an organization is organized, and the modelling of it can enable the organization to manage its workflow properly. Business process modelling can systematically map the business activity flow, thus allowing the corresponding analysis and simulation to be carried out.

Business process modelling, analysis, and simulation are recognized as tools that can help an organization to improve their business process from a macro view that help management to work efficiently and to locate problem areas easily (Lam et al., 2009). Moreover, these tools allow the business process to be revolutionized, redesigned or reengineered (Lam et al., 2008). Thus, the better the business process modelling, analysis, and simulation, the better the performance and competitiveness of the organization can achieve.

Business process research falls primarily into two inter-related areas, process modelling and workflow analysis. Process modelling research ranges from process case, task, routing to enactment (Kusiak et al., 1994; Thalhammer et al., 2001; Thorpe and Ke, 2001; Jung et al., 2004; Rosemann et al., 2006; Royce, 2007; Khanli and Analoui, 2008), whereas workflow analysis research includes reachability analysis, structural analysis, performance analysis, sensitivity analysis, and reliability analysis (Bause and Kritzinger, 2002; Haas, 2002; Azgomi and Movaghar, 2005; Cardoso, 2005; Barbosa et al., 2009; Yang and Chen, 2009; Zhao, 2009). All of these approaches have advantages and disadvantages.

System dynamics is a type of modelling and simulation methodology used to investigate and manage complex feedback systems, including business, political and social systems, by gaining an understanding of their structures and dynamics. System dynamics builds on information-feedback theory, which not only provides diagrams and equations for mapping business systems but is also a programming language for computer simulation. Its application provides decision makers with enhanced ability to manage the complex business world by means of visualization and simulation. It also allows them to rehearse business plans and alternative futures through scenario development and strategy modelling, thus providing insight into business situations of dynamic complexity and those characterized by

policy resistance. System dynamics is therefore increasingly adopted in business process improvement, managerial problems and organizational policy setting. The literature provides a range of examples (Towill, 1993; Berry et al., 1994; Strohhecker, 2000; Lai et al., 2003; Zhang et al., 2007; Morecroft, 2007; Chan and Ip, 2008).

This chapter provides an alternative structural reliability modelling and optimization approach to the business process by using a communication network of probabilistic graphs, and further simulates and analyzes the business process network model using system dynamics. An example of the proposed modelling and simulation method applied to a customer management process is also presented.

2. Modelling the Business Process

Organizations have many different types of business activities, such as accounting, purchasing, order management, design, manufacturing and so on, which are discrete in nature. That is, each activity has a beginning and an end, and each can be distinguished from every other activity; however, to achieve ultimate business objectives, the interactions between activities must be continuous and interrelated. Within the business process, different activity routing combinations can have different effects on overall organizational performance, and thus numerous researchers and practitioners have attempted to determine the best combinations.

In this structural reliability model, business activities are modelled as the communication network of probabilistic graph $G = \{V, E\}$, which comprises a set of vertices, $V = \{v_i \mid 1 \le i \le n\}$, with a number of n nodes and a set of edges, $E = \{e_j \mid 1 \le j \le m\}$, with a number of m edges, such that nodes $v_i \in V$ indicate the business activities and edges $e_j \in E$ indicate the connections among business activities.

In modelling the business process, it is assumed that the network and edges have only two states, normal and failure mode, and that all of the nodes are perfectly reliable, with only the edges subject to failure, and the probability of any edge being in a certain mode known. Moreover, in network graph $G = \{V, E\}$, p_i and q_i (or $q_i = 1 - p_i$) represent the normal mode and failure mode probability of edge e_i, respectively, and the in-degree and out-degree processes of the activity are represented as $\lambda_I(v_i)$ and $\lambda_O(v_i)$, respectively. With this notation for the proposed structural reliability modelling approach, the six basic types of business activities can then be modelled, i.e., Start Off Activity (SOA), Serial Activity (SEA), Merge Activity (MEA), Split Activity (SPA), Merge and Split Activity (MSA), and Final Activity (FIA).

Start Off Activity (SOA)
SOA is an initial activity in the business process that leads to the development of subsequent out-degree activities; its nodes in structural reliability modelling can be represented as

$$\left\{v_i \middle| \lambda_I(v_i) = 0 \quad and \quad \lambda_O(v_i) \ge 1\right\}, \text{ for } i = 1, 2, \ldots, n. \tag{1}$$

Serial Activity (SEA)
SEA is a straightforward serial activity in the business process. It interacts directly with its single previous in-degree activity and single succeeding out-degree activity, and its nodes in the proposed approach can be represented as

$$\{v_i | \lambda_I(v_i) = 1 \quad and \quad \lambda_O(v_i) = 1\}, \text{ for } i = 1, 2, \ldots, n. \tag{2}$$

Merge Activity (MEA)
MEA is a collection of activities in the business process. It combines the activities from the previous in-degree activities and then processes them to the single succeeding out-degree activity. Its nodes can be represented as

$$\{v_i | \lambda_I(v_i) > 1 \quad and \quad \lambda_O(v_i) = 1\}, \text{ for } i = 1, 2, \ldots, n. \tag{3}$$

Split Activity (SPA)
SPA is a splitting activity in the business process; that is, it splits a single previous in-degree activity into its succeeding out-degree activities. Its nodes in the proposed modelling approach can be represented as

$$\{v_i | \lambda_I(v_i) = 1 \quad and \quad \lambda_O(v_i) > 1\}, \text{ for } i = 1, 2, \ldots, n. \tag{4}$$

Merge and Split Activity (MSA)
MSA is a combination of merge and splitting activities. It merges the previous in-degree activities in the business process and then splits them into succeeding out-degree activities. Its nodes can be represented as

$$\{v_i | \lambda_I(v_i) > 1 \quad and \quad \lambda_O(v_i) > 1\}, \text{ for } i = 1, 2, \ldots, n. \tag{5}$$

Final Activity (FIA)
FIA is the concluding activity in the business process, and its nodes in the proposed structural reliability modelling approach can be represented as

$$\{v_i | \lambda_I(v_i) \geq 1 \quad and \quad \lambda_O(v_i) = 0\}, \text{ for } i = 1, 2, \ldots, n. \tag{6}$$

Key Activities
Among these six basic types of business activities, the key activities can be identified as those that have dense connectivity, i.e.,

$$\{v_i | \lambda_I(v_i) \geq 2 \quad or \quad \lambda_O(v_i) \geq 2\}, \text{ for } i = 1, 2, \ldots, n. \tag{7}$$

3. Analyzing the Business Process for Improvement

A map of business activity flow enables an organization to use and manage structured business processes, and analysis of that flow can help it to improve business process performance with regard to completion time, capacity utilization, service level and so on.
For the business activities that are modelled using the approach proposed in Section 2, the reliability analysis of the network can be defined as *R*, which is the probability of the existence of a minimal set of operational links such that all of the nodes in the network communicate. Because a business process is constructed as a connected sub-graph of *G = {V, E}* that contains all of its nodes without cycling, *R* can be defined by evaluating the

probability of the union of activities that represents the operational state of the spanning trees, i.e.,

$$R = P_r\left(\left(F_1\right)\cup\left(F_2\right)\cup\left(F_3\right)\ldots\cup\left(F_r\right)\right) \tag{8}$$

$$= P_r\left(\left(e_i \in E|F_1\right)\cup\left(e_i \in E|F_2\right)\cup\left(e_i \in E|F_3\right)\ldots\cup\left(e_i \in E|F_r\right)\right) \tag{9}$$

$$= \left(e_i \in E|F_1\right)\oplus\left(e_i \in E|F_2\right)\oplus\left(e_i \in E|F_3\right)\ldots\oplus\left(e_i \in E|F_r\right) \tag{10}$$

$$= \left(p_i, q_i \in e_i|F_1\right)+\left(p_i, q_i \in e_i|F_2\right)+\left(p_i, q_i \in e_i|F_3\right)\ldots+\left(p_i, q_i \in e_i|F_r\right) \tag{11}$$

where P is the probability of possible flow F for activities *1, 2, …r*; p_i and q_i *(or = 1 – p_i)* represent the normal mode and failure mode probability of edge e_i, respectively; and $\oplus$ represents a disjoint sum operation.

As the business activity flow can be sequential or parallel, in addition to defining the reliability of the business process in terms of probability, that reliability can also be analyzed by the proposed approach of a *k-out-of-n* system with redundancy, i.e., a system that consists of n identical independent components, of which at least $k < n$ of the activities must succeed for the system to succeed. This analysis is carried out under the assumption that some activities will be suspended whenever the system fails, i.e., some failures will occur when the system is down. Formulas are derived from various reliability indices of the system, including mean time between failures, mean working time during a failure, mean downtime, etc.

Probability concepts are also employed in the structural reliability analysis approach to compute the reliability of the business process in terms of the reliability of the network's activities. The success of the business process in a sequential structure depends on the success of all of the activities; therefore, the reliability, R_A, of a process with n number of activities x, in which x_i denotes that the *i-th* activity is successful and $\overline{x_i}$ denotes that it is not, can be further defined as

$$R = P(x_1\, x_2 \ldots x_n) \tag{12}$$

$$= P(x_1)\, P(x_2 \mid x_1)\, P(x_3 \mid x_1x_2) \ldots P(x_n \mid x_1x_2 \ldots x_{n-1}) \tag{13}$$

$$= P(x_1)\, P(x_2) \ldots P(x_n) \tag{14}$$

$$= \prod_{i=1}^{n} P\left(x_i\right) \tag{15}$$

The success of the business process in a parallel structure depends on at least one successful activity; therefore, the reliability of that process can be defined as

$$R = P(x_1 + x_2 + \ldots + x_n) \tag{16}$$

$$= 1 - P\left(\overline{x_1}\,\overline{x_2}\ldots\overline{x_n}\right)) \tag{17}$$

$$= 1 - P\left(\overline{x_1}\right)P\left(\overline{x_2}\middle|\overline{x_1}\right)P\left(\overline{x_3}\middle|\overline{x_1}\,\overline{x_2}\right)\ldots P\left(\overline{x_n}\middle|\overline{x_1}\,\overline{x_2}\ldots\overline{x_{n-1}}\right) \tag{18}$$

$$= 1 - \prod_{i=1}^{n} P\left(\overline{x_i}\right) \tag{19}$$

Compatible with the six basic types of business activities that are proposed in Section 2, the aforementioned *k-out-of-n* structural reliability analysis approach is a network approach that consists of n identical independent activities, of which at least $k < n$ of those activities must be successful to ensure the success of the network. Therefore, if p is the probability of the success of an activity, then the reliability probability, R, of exactly k successes and $(n - k)$ failures in n activities is defined as

$$R = \binom{n}{k} p^k (1-p)^{n-k} \tag{20}$$

4. System Dynamics in Business Processes

System dynamics, which was conceived in the late 1950s, is a system modelling and computer-based simulation method that provides valuable insights into the dynamic behaviour of complex feedback systems and aids in decision making.

Referring to the six basic types of business activity that are proposed in Section 2, business activities are correlated and interacted with one another; while the decisions from one activity also create feedback loops with previous and succeeding activities. These loops react to the decision maker's actions in ways both anticipated and unanticipated. System dynamics can then be used to emphasize the multiloop, multi-state and non-linear characteristics of the feedback system in the business process. The method can also be used to simulate that process.

In system dynamics modelling and simulation, the dynamic feedback loops in the business process need to be determined and represented, along with the stock and flow structures, time delays and nonlinearities. All of the business process dynamics arise from the interaction of the business activities to form feedback loops, in which the feedback may be either positive or negative. Positive feedback loops tend to reinforce or amplify whatever is happening in the system, and generate such feedback as the ambition to achieve certain business objectives or overall excellence to facilitate organizational growth. Negative feedback loops, in contrast, counteract and oppose change. They tend to be self-limiting processes that seek balance and equilibrium, such as the balancing of inventory management or accounting. In addition, system dynamics builds from single events and entities, and takes an aggregate view based on objectives. Then, the system behaviour of a business process's network model, such as the number of interacting feedback loops, balance or reinforcement, the delay structure, the accumulation and movement of resources (including information and materials), and the like, is described in a stock-flow map, thus allowing that network model to be simulated and analyzed.

Constructing a high-level map of an organization's business processes using system dynamics is an extremely useful part of process analysis. A system dynamics model based on business process scenarios can be used to test and analyze alternative policies and strategies through computer-based simulation, followed by a redesign of the system or process to achieve improved efficiency.

4.1 An Illustrative Example of Modelling and Simulation in the Customer Management Process

Maintaining a long-term relationship with customers is one of the critical success factors for an organization, as it is difficult for competitors to understand, copy or displace. An effective customer management process thus not only improves customer service, but also facilitates business growth by enhancing customer retention, increasing the number of referrals and satisfied customers, and improving service flows to allow teams to work efficiently and smoothly.

The customer management process involves information sharing between the organization, its customers and the market. This information is discrete to each party, but the interactions between the parties are continuous and interrelated and together form the customer management process. Such information sharing is also dynamic in nature and often results in unexpected or counterintuitive feedback within that process. Probabilistic graphs are thus useful in the modelling and analysis of communication networks, and system dynamics is often adopted to model and simulate the customer management process within an organization.

The proposed approach benefits the organization by structurally identifying and analyzing the customer management process, as well as the critical factors in managing customer relationships.

As noted in Section 2, despite the differences in the characteristics of activity flows, these flows can be modelled using the aforementioned six basic types of activities. An example of the customer management process with the mapping of business activities is given in Fig. 1.

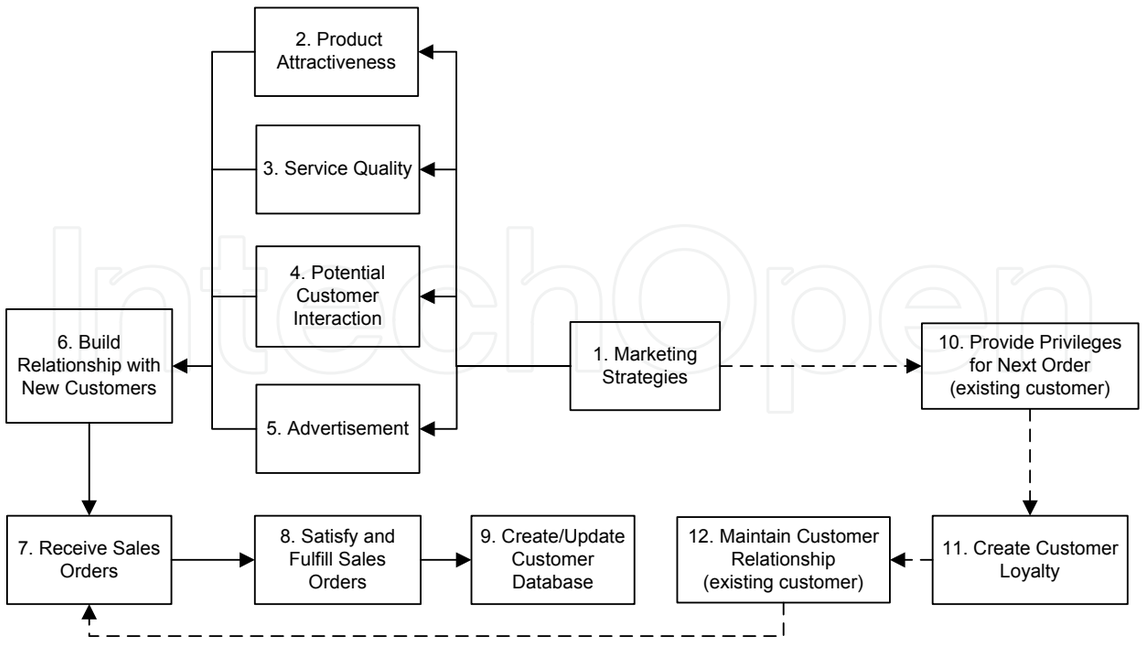


Fig. 1. An example of the customer management process with the mapping of business activities

As noted in Section 2, Activities 1 and 9 are the Start Off Activity and Final Activity, respectively, and Activity 1 is also a Split Activity. Activities 2-5, 8 and 10-12 are Serial Activities, and Activities 6 and 7 are Merge Activities, as well as Key Activities. A system dynamics model is adopted to simulate the customer management process, as illustrated in Fig. 2.

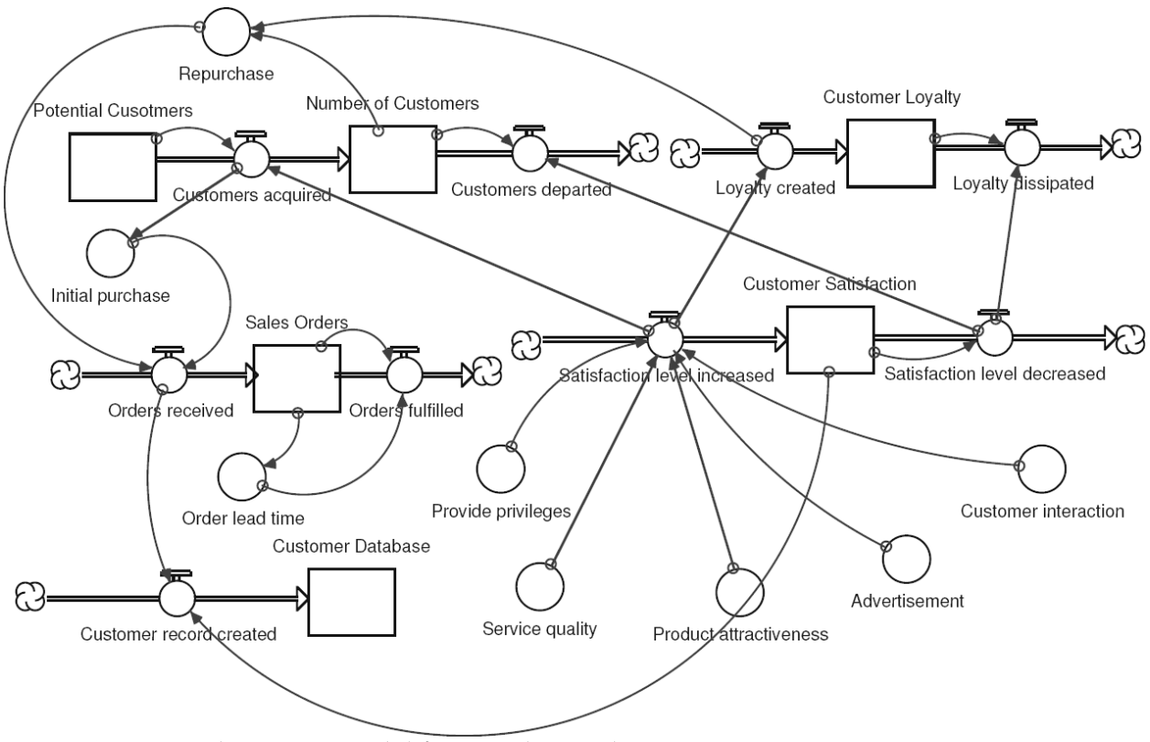


Fig. 2. A system dynamics model for simulating the customer management process

The system dynamics model makes use of a stock and flow diagram to map the customer management process exhibited in Fig. 1, in which a stock is defined as the supply accumulated, and the flow describes the inflow/outflow of stock. After constructing the system dynamics model by defining the inter-relationships and information flow between the variables, the foregoing equations with full explanations and assumptions and the dimensions of each variable must be provided for computer simulation. During the customer management process, customers interact with the company, which serves them in a manner designed to satisfy their needs and establish a good relationship with them. This process is conceptualized by the development of an information feedback system such as that shown in Fig. 2, from which it can be seen that customer satisfaction is affected by four major factors: product attractiveness, service quality, advertisements and customer interaction. Any changes in the value of these four factors lead to changes in the customer satisfaction level. Customer satisfaction plays an important role in customer relationship management, as it is closely associated with customer purchasing behaviour. It not only motivates potential customers to make purchases, but also creates loyalty to the company among existing customers and motivates them to make further purchases. By using the simulation shown in Fig. 2, a company can easily vary the values of any of the variables

based on a particular business scenario to test potential strategies. This enables decision makers to execute the most competitive strategies for improving the customer management process and customer relationships.

5. Conclusion

Business activity flow analysis enables organizations to manage structured business processes, and can thus help them to improve performance. The six types of business activities identified here (i.e., SOA, SEA, MEA, SPA, MSA and FIA) are correlated and interact with one another, and the decisions from any business activity form feedback loops with previous and succeeding activities, thus allowing the business process to be modelled and simulated. For instance, for any company that is eager to achieve profitability, a customer-centred orientation, as well as the creation and maintenance of customer relationships and customer loyalty, will be a high priority. The customer management process illustrated herein elucidates the mapping and modelling of the six kinds of business activity based on computer simulation. The proposed system dynamics model helps to evaluate the effectiveness of the customer management process and to examine the factors that affect customer satisfaction, customer loyalty, the number of customers and the number of sales orders received, factors that are essential to company profitability. The proposed structural reliability modelling approach, with the system dynamics simulation of the business process, thus enables decision makers to select the most favourable business strategies and to make the right decisions about policy by simulating the dynamic behaviour of information feedback systems. Sensitivity analysis can also be carried out based on the system dynamics model to determine the optimal value of each variable.

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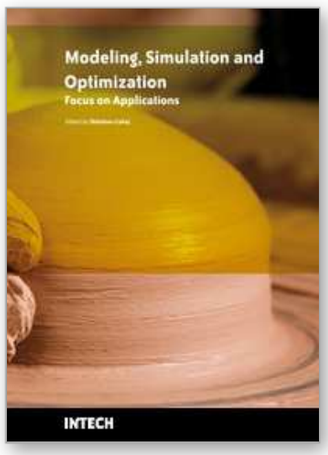
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The book presents a collection of chapters dealing with a wide selection of topics concerning different applications of modeling. It includes modeling, simulation and optimization applications in the areas of medical care systems, genetics, business, ethics and linguistics, applying very sophisticated methods. Algorithms, 3-D modeling, virtual reality, multi objective optimization, finite element methods, multi agent model simulation, system dynamics simulation, hierarchical Petri Net model and two level formalism modeling are tools and methods employed in these papers.

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Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
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