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SUPPORTING SIMULATION-BASED DECISION MAKING WITH THE USE OF AHP ANALYSIS

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ABSTRACT

Traditionally decisions made based on simulation models have been the outcomes of complicated statistical analyses and having confidence in them is a subjective matter. Hybrid simulation offers an improved approach to better model real life systems and increase confidence in their outcomes. In particular hybrid discrete-continuous simulation has the potentials to reduce the impact of statistics in building models in addition to other significant benefits. In this paper we use hybrid models of discrete-event simulation and system dynamics to analyze global supply chain decisions. And to increase the decision makers' confidence as well as to make use of their experiences we apply the Analytic Hierarchical Process (AHP) analysis to the simulation results in order to reach better decisions. We describe the benefits of the use of the hybrid simulation and the added advantages of using AHP in order to maximize shareholder value.

1 INTRODUCTION

With the increased levels of integration in manufacturing and service industries and global supply chains the simulation models used to model such systems are not easy to build. Verification and validation of these models, in addition, becomes a more critical issue, which would impact the willingness of the managers to accept and implement decisions suggested by these models. This is particularly significant at the higher levels of management, where decisions are mainly based on qualitative considerations drawn mainly from scenario-planning. Add to that the lack of accurate data at these levels of management to build reliable models and the unacceptability of the very detailed/statistical analyses usually associated with traditional discrete simulations (Anthony and Govindarajan 1998, Zulch et al. 2002, Rabelo et al. 2005).

For that, Rabelo et al. (2005) have combined discrete-event simulation with the system dynamics methodology to develop hybrid discrete-continuous simulation models that are simple, yet comprehensive enough to model large integrated systems while being able to fit the different needs of the different management levels. In this hybrid approach system dynamics (SD) is used to model the overall system of the organization that is mostly the strategic and tactical management levels, while discrete-event simulation (DES) is used to model the manufacturing functions and the operational and shop floor tasks. SD is a system thinking approach that is not data-driven which makes it appropriate to model the higher levels of management where data are not usually accurate and/or available. In addition, SD focuses on how the structure of the system and the taken policies affect its behavior, not on making detailed analyses, which is preferred by top managers (Forrester 1965, Lyneis 1980, Sterman 2000). Forrester viewed SD as an approach to corporate policy design and to understand and solve top management problems. SD models are relatively easy to develop and the complexity of the models seems to be in-creasing linearly as compared to the DES models, which increases exponentially in complexity (Sterman 2000). SD also can address the qualitative issues in manufacturing systems efficiently and as a continuous simulation methodology, models are more intuitive than the discrete models (GroBler et al. 2003, Gregoriades and Karakostas 2004, Levin and Levin 2003). Meanwhile, SD could not prove effective enough in modeling high resolution situations at the operational levels of the manufacturing systems (Lee et al. 2002, Barton et al. 2001, Godding et al. 2003).

On the other hand, DES models are mainly flow models that track the flow of entities through a system. DES has been mostly applied at the operational management level; to planning and scheduling activities (Law and Kelton 1991, O'Reilly and Lilegdon 1999). DES al-lows analysts to track the status of individual entities and resources and to estimate numerous performance measures under a wide range of operating conditions. How-ever, it only establishes estimates of and correlations among variables and performance measures using statistics. Understanding the differences between correlation and causality is not always easy, especially when modeling the contemporary large-sized integrated manufacturing systems. DES also has been criticized for being a data demanding technique. Data can be available for most of the manufacturing activities but when dealing with business level decisions, data is not usually available or available as rough estimates and approximations. This makes DES not appropriate for investigating many business decisions or the interactions between business and production branches of the enterprise. Investigating these interactions is inevitable in the current integrated manufacturing systems. And as mentioned, at the higher management levels, the detailed approaches of DES are not well appropriate. (Anthony and Govindarajan 1998, Baines and Harrison 1999, Zulch et al. 2002).

In the current paper we utilize the SD-DES hybrid simulation approach to model a value chain system. The value chain system is the traditional production/assembly supply chain system with service components added to it. SD is used to model the extended enterprise system while DES is used to model the manufacturing and service subsystems. The hybrid simulation works by having SD estimates the demand for the product and the service, quality of each, reactions of the customers, investment issues, overhead costs, and new product and service development functions. This data is exported to the DES models to assess the performance of the manufacturing and service facilities and estimate the associated costs. Costs and units produced as well as services that could be offered are fed back to SD to re-evaluate the overall performance of the entire system. The models are used to assess a number of alternatives for outsourcing the manufacturing function or keeping it in-house.

Since SD is the main model while DES models are basically subsystems of it, the output of the value chain simulation is the projected performance of the enterprise for a period of five future years, which comes from SD. For top level managers to make such decisions, various trade-offs are considered by them, which include the social and political situations as well as future technological impact of outsourcing. Simulations can not handle such trade-offs satisfactorily, especially when they are based on many judgmental and qualitative considerations in additions to quantitative data. To support managers in deciding using the simulation results while being able to utilize their experiences and consider other related trade-offs we propose using the analytical hierarchy process (AHP) analysis to make the final decision. Thus simulation out-put conceptually provides better quantification of the alternatives and their future projections while AHP allows decision makers to incorporate other trade-offs as well as overcome the potential limitations inherent in any simulation model. In addition, the feeling that the decisions are made by the managers with their own personal experiences and qualitative assessments increase the level of confidence in these decisions. For this purpose we utilize an enhanced form of the AHP analysis in this paper.

Since in real applications using AHP the pair wise comparisons are usually subject to judgmental errors and are , sometimes, inconsistent and conflicting with each other, the weight point estimates provided by the eigenvector method are necessarily approximates. The uncertainty associated with subjective judgmental errors may affect the rank order of decision alternatives. A new stochastic approach is employed for handling the propagation of uncertainty in the AHP and for capturing the uncertain behavior of the global AHP weights. This approach could help decision makers get insights into how the imprecision in judgment ratios may affect their choice toward the best solution and how the best alternative(s) may be identified with certain confidence. This enhances the confidence of decision makers in the outcome of an ensuing AHP synthesis (Saaty and Vargas 1987, Zahir 1991, Saaty 1994, Rosenbloom 1996) .

In the following sections, we give a brief definition of the value chain system and then describe the development of the SD-DES simulation models of it. We then describe the outsourcing situation and the use of the hybrid model in evaluating the alternatives. We, then, describe how the modified AHP analysis is used to make the final decisions and discuss the advantages of the use of this modified AHP over making the decisions based on simulation results only.

2 THE VALUE CHAIN SYSTEM

Supply chains can be defined as "life cycle processes supporting physical, informational, financial, and knowledge flows for moving products and services from suppliers to end-users" (Ayers 2002; Mentzer 2004). The strategic management of these supply chains has one major goal: the creation of value for both customers (Nix 2001) and chain members (Murman 2002). For customers, this value comes in the form of high quality products; for the chain members, it comes in the form of increased profits.

A recent survey reports that the full potential of these benefits, especially for the chain members, has not been realized (Poirier 2004). We believe that generating and sustaining growth are keys to realizing that potential. Process innovation, product development, outsourcing, and global expansion are part of a new strategy for achieving this goal. In this paper, adding a service component to the traditional production/assembly supply chain is called a value chain. There are important decisions for this value chain. Hybrid simulation can support this decision-making by using system dynamics to capture the financial, global economy, and more qualitative elements and discrete-event simulation to simulate the discrete and stochastic elements such as manufacturing (Rabelo et al. 2005).

We applied hybrid simulation to an actual value chain of a construction equipment corporation that has two strategic business units. The name of the company has been omitted and some of the information has been disguised. The first Strategic Business Unit (SBU1) manufactures existing products; the second Strategic Business Unit (SBU2) provides services for existing products and generates new services when needed. The top management of this organization had three different alternatives to make a decision:

1. Alternative A: To keep SBU1 and SBU2 under the enterprise and in continental USA.
2. Alternative B: To outsource the majority of the manufacturing of SBU1 to South East Asia (but to keep the core competency of design, and new product and service development in house) and keep SBU2 under the organization.
3. Alternative C: To outsource the majority of the manufacturing to China (but to keep final manufacturing performance testing in Continental USA and the core competencies of design, and new product and service development in house) and keep SBU2 under the organization.

For top management of this organization, the evaluation of alternatives is done based on four major considerations: profitability, customer satisfaction, responsiveness, and political stability based on recent scenario planning sessions. Profitability in the model is simply measured as the net total profits after all costs. If the company is profitable then 30% of profits is used to pay taxes. Then, from the net income, one third is used for dividends and the rest is used to improve performance. The DES sections of the hybrid model of the value chain system estimated product and services costs while other considerations for new product and service development costs and general administration costs are handled in the SD section of the model. Customer satisfaction is measured using different dimensions based on returns mainly, and other related factors, as a part of the SD section.

Yet the political circumstances related to the two outsourcing options were not parts of the simulation model. Decision makers had to assess them themselves. In this regard, China was considered relatively stable and strongly emerging economical superpower, which offers a trustable business environment. Meanwhile other parts in Southeast Asia were seen as experiencing few instabilities due to some military and violence activities in addition to less stable governments in some places as compared to China. Added to that was the economical crises that has hit southeast Asia less than a decade ago, and still in the memory. The responsiveness was described as the average lead time required for the replenishment of a single unit produced at any of the proposed three locations.

AHP was able to support the different weights of these factors and then make the analysis of each alternative based on those factors (see Figure 1). But before that, an analysis of the hybrid modeling results were provided to top management to discern the behavior of the two units, their relationships to one another, and their interactions with the marketplace under the different conditions. We discuss this analysis and the lessons learned.

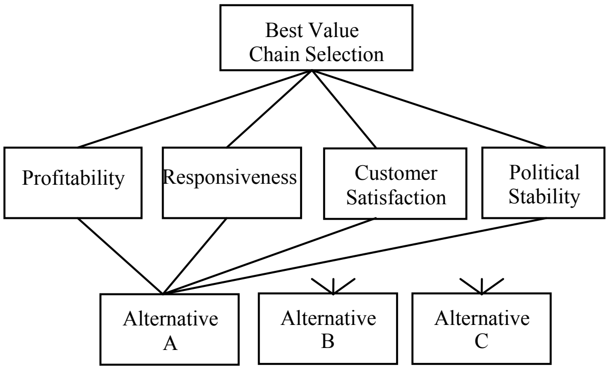


Figure 1. The Hierarchy Structure of the Supply Chain Selection Problem

2.1 Hybrid Modeling of the Value Chain

We adopted the SD model of the value chain with two supply chain components (one for manufacturing/assembly and the other one for service) that was introduced and validated in Rabelo et al. (2004). That generic has the following units (see Figure 2):

1. Group 1: Strategic Business Unit 1 (SBU 1) Manufacturing.
2. Group 2: Strategic Business Unit 2 (SBU 2) Services.
3. Group 3: Customer Request for Proposals.
4. Group 4: Customer Acquisition, Loss, and Recovery.

As the SD model did not have the finer details of the different supply chains with their respective components (e.g., manufacturing facilities) and elements of variation, this was added using one set of discrete models, three models capturing the supply chain of the manufacturing organization and its respective alternatives, and one to represent the supply chain of the service organization. In addition, other groups of stocks and flows related to the financial environment to calculate costs and profits and the productivity and human resources of the new product and service development organizations were added to the generic SD model.

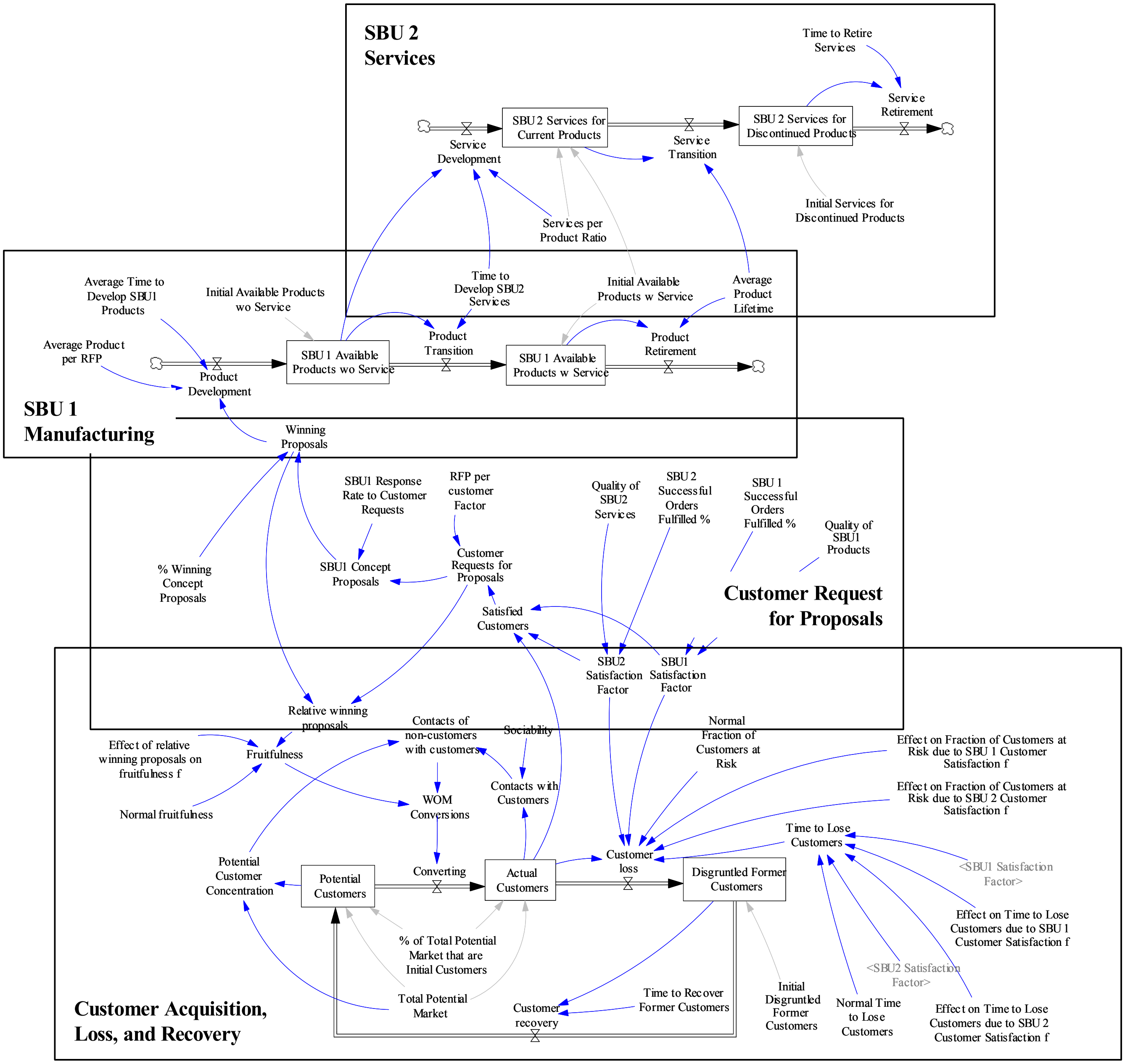


Figure 2: System Dynamics Core Model for a Company Having Both Manufacturing & Service Strategic Business Units

2.1.1 Supply Chain of SBU 1 Manufacturing

A DES model block was connected to the SD model to represent the supply chain of SBU1 as shown in Figure 3. We actually used three DES models: one to simulate the SBU 1 under the organization (i.e., without outsourcing), a second to simulate using manufacturing facilities in Southeast Asia (i.e., with outsourcing), and a third for the option of manufacturing in China and testing in the US. These models were developed utilizing the Supply Chain Operations Reference (SCOR) Model to guide the modeling process (See Figures 4, 5, and 6) and were then converted to ARENA. SCOR provided the basic structure and the functions that needed to be modeled within an organization (Bolstroff and Rosenbaum 2003).

The SCOR model is a process reference model that was introduced in 1996 through the Supply Chain Council (SCC) and supported by more than 800 academic and industrial organizations to become an industrial standard for supply chain management. The SCOR model is intended to describe the business activities, operations and tasks corresponding to all levels of satisfying supply chain internal and external customer demands. According to

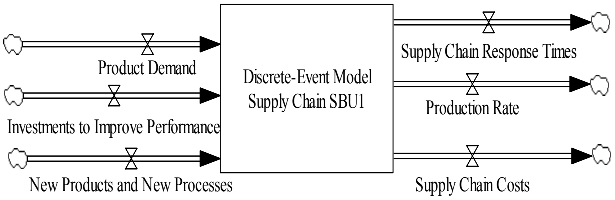


Figure 3: The Supply Chain of SBU 1 Is Simulated Using Discrete-Event Simulation

Huang et al, (2005), The Process reference modeling enables organizations to communicate using common expressions and standard descriptions of process elements and tasks that aids in understanding the SCM processes, best practices and available options aiming to reach the optimal overall performance of the supply chain. The SCOR model is the first model that could be utilized to organize the supply chain based on business strategy. This is achieved by providing, among various other useful outcomes, the performance measurements and supporting tools suitable for evaluating each activity. The SCOR model combine various techniques such as Business process reengineering, bench marking, and process measurement into a cross functional structure that describes and evaluates the relevant supply chains.

The three manufacturing alternatives presented in this paper were modeled separately using SCOR level 2 process thread diagrams as follows:

1. Alternative A – local processing of SBU 1 under the organization (i.e., no outsourcing): As shown in Figure 4 below, the manufacturing facility handles the sourcing of stocked raw materials (S1), from stocked raw material suppliers (D1), process the make-to-order manufacturing (M2), the deliver-to-order finished products (D2), the sourcing of returned defective products (SR1) & the sourcing of maintenance required operations (MRO) for sold products (SR2) from all local warehouses, and the delivery of MROs back to warehouses (DR2). Moreover, the warehouse handles the sourcing of make-to-order products from SBU 1 (S2), the delivery of the Make-to-order products to end customers (D2), the sourcing of returned defective products (SR1) & the sourcing of (MRO) for sold products (SR2) from customers, and the delivery of MROs back to customers (DR2).
2. Alternative B – outsourcing SBU1 to a country in South East Asia: As shown in Figure 5 below, all process categories are similar to Alternative A, except that the manufacturing facility does not handle MROs (SR2 & DR2) and product returns (SR1), as they are all handled locally at the warehouse & service facilities. In the other hand, delivery of make-to-order products from SBU 1 to local warehouse (D2) consumes a relatively longer duration (130 days) due to maritime transport and customs operations in California.

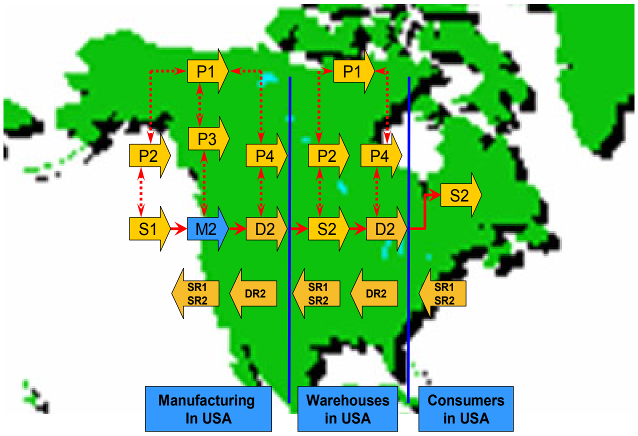


Figure 4: SCOR Representation for Alternative A

3. Alternative C – outsourcing SBU1 to China: As shown in Figure 6 below, all process categories are similar to Alternative B, except that delivery of make-to-order products from SBU 1 to local warehouse (D2) consumes the longest duration (155 days) in comparison to alternatives A & B. Moreover, the local warehouse handles an extra QC inspection for the incoming products prior to delivering to customer (D2).

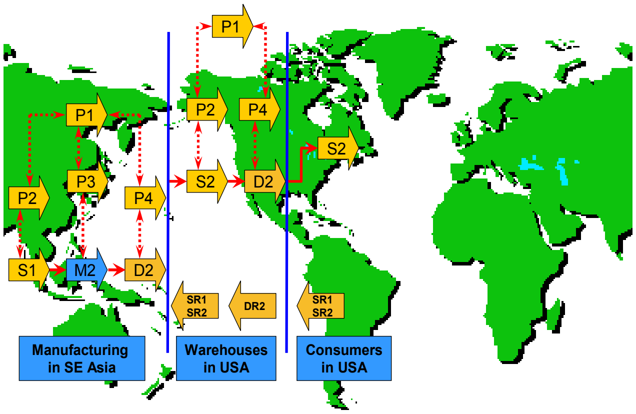


Figure 5: SCOR Representation for Alternative B

2.1.2 Modeling Supply Chain of SBU 2 Services

The discrete-event simulation block added to the SD model to represent the supply chain of SBU2 by using a discrete-event simulation model embedded in the system dynamics structure is shown in Figure 7.

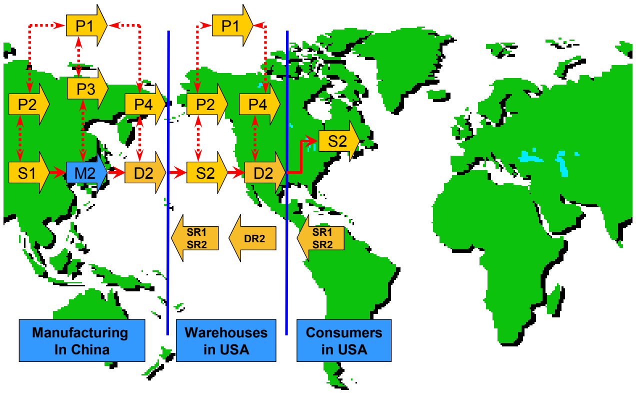


Figure 6: SCOR Representation for Alternative C

2.1.3 Modeling Supply Chain of SBU 1 Manufacturing

We began by modeling a causal loop diagram for the profits and related to costs and the rate of investments. This causal loop is based on the comments provided by the managers of the consulted businesses such as:

1. The members of the Service Staff usually have to travel constantly to service customers (sometimes over the World). This traveling causes high turn over rates.
2. Having a good ratio of "Services Staff/Customer" usually means good customer service. This has increased the number of customers ("word of mouth").
3. More investments in the service organization (SBU 2) cause more investments in service staff and more development of services. Investments in service staff increase the recruitment and training of the service force. Recruitment and training of the service force take more resources than the development of services.
4. More services, more customers, and more products increase the sales and therefore profit in the organization.
5. It is important to invest in the services and product organizations. However, it is essential to keep a balance. Services are very dependent on "good" products.

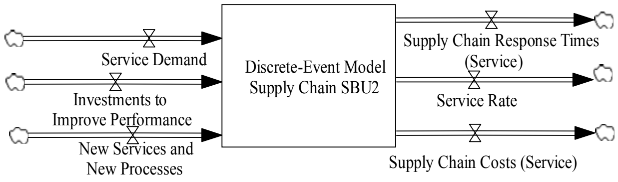


Figure 7: The Supply Chain of SBU 2 Is Simulated Using Discrete-Event Simulation

2.2 Hybrid Modeling Mechanics

According to Jay Forrester (Forrester 1965), a manufacturing system consists of five types of flows: Order flow, material flow, money flow, personnel flow, and the capital equipment flow. All these are interconnected and integrated using a network of feedback information. These flows and the information network represent the grossly different types of variables that will be encountered in the system. Some of the variables will be in the DES models while some will be in the SD model. The information flowing between models and among the various kinds of flows will relate and define the relationships among the various parameters for the models to interact. For the purpose of the current paper we modified and extended the value chain SD model shown in Figure 2 by adding the performance assessment in terms of profits and customer satisfaction. Causal relationships representing the modifications are depicted in Figure 8.

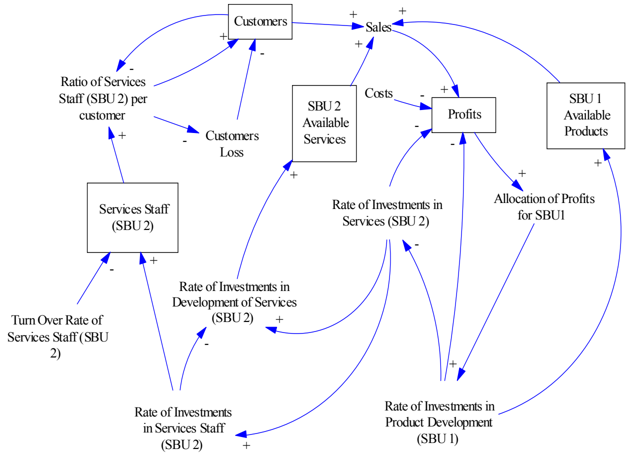


Figure 8: Causal Loops for Extensions to the Model of Figure 2

Since the model encompasses the three levels of decision making in many simulations then there will be overlapping of data used for the hybrid model constituents. For example current capacity is used at the operational levels and the production planning at the tactical level as well as in strategic planning to plan for potential capacity needs. Some data will be used in different forms and resolutions. For example machine productivity is a detailed data at the operational levels, where the speed and conditions of each machine must be known. At the SD level only gross productivity is needed to be known. Types of data can be represented as in Figure 9. It shows that some data are common (A), some are unique for certain uses at certain system parts (D), some are used as is at more than a level (G and F) and some can be used in different forms at different levels (C and B).

As mentioned some data are used in different forms at different levels or for different uses. This is a result of fact that data requirements at the various levels are not the same in terms of the level of details and frequency of use. Data are more detailed at the operational levels that at higher levels. The SD level requires aggregated data. Aggregation and disaggregation processes are needed to communicate such levels. In addition, the SD model sends periodically information and commands to the DES models. Some of the mathematical relationships that map the stocks-and-flows model follow are supplied by the discrete event simulation models based on a polling frequency using the Nyquist theorem. One important issues in the replications required and the intervals.

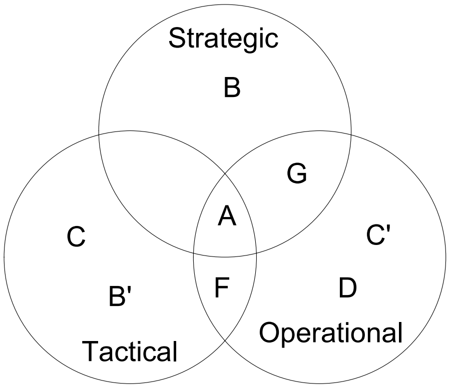
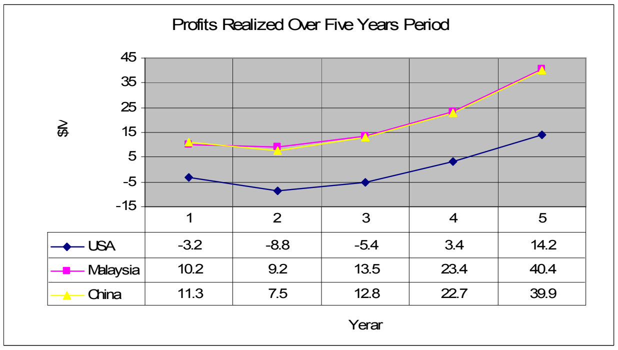


Figure 9: The Different Types of Variables in a Hybrid Structure.

The validation of the SD-DES hybrid model is one of the its advantages. SD models are basically mathematical models that are valid if they replicated the behavior of the molded system as described by the references behavior modes of the system. The validation is conceptually qualitative and based on logical assessments and is relatively easy (Sterman 2000). The DES are normally validated and verified based on statistical assessment which can easily be a difficult task. The DES models in the hybrid modeling are small models as they are built for specific, small uses. The validation of these models is simple based on the logic of their behaviors. Consequently the validation of the whole hybrid model of a system is conceptually the validation of the SD part of it, which constitutes most of the hybrid model. The SD used in this paper was calibrated in Rabelo et al. (2004).

3 SIMULATION RESULTS AND ANALYSIS

The integrations of system dynamics and the discrete-event simulation models allowed the simulation of the value chain. Figures 10, 11 and 12 show the profits, customer satisfaction, and responsiveness for the three different alternatives. These Figures show that all alternatives could lead to good growth rates. However for profitability (Figure 10) two alternatives were much better than the other one. For Alternative A (Figure 11) the expected customer satisfaction was the worst, while either of the other two alternatives would be acceptable. On the other hand, the expected replenishment time of Alternative A was the best (Figure 12). This information is provided to the different decision makers to proceed with the AHP method. In our case, the three decision makes represent different areas of the corporation: The Chief Financial Officer (CFO), the Chief Operations Officer (COO), and the Vice-President of Sales/Marketing.

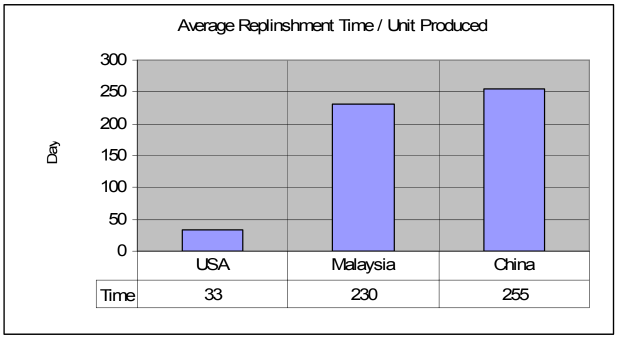


	1	2	3	4	5
◆ USA	-3.2	-8.8	-5.4	3.4	14.2
■ Malaysia	10.2	9.2	13.5	23.4	40.4
▲ China	11.3	7.5	12.8	22.7	39.9

Figure 10: Results for Profits

	1	2	3	4	5
◆ USA	0.85	0.77	0.72	0.71	0.74
■ Malaysia	0.92	0.94	0.96	0.97	0.97
▲ China	0.85	0.86	0.87	0.89	0.90

Figure 11: Results for Customer Satisfaction



	USA	Malaysia	China
Time	33	230	255

Figure 12: Comparison of the Response Times

4 USING THE AHP ANALYSIS

In this paper, a framework is implemented for the AHP problem formulation with the measure of global weight variance in order to obtain a confidence interval of the global AHP weight rather than global weight point estimates. A stochastic approach is used to calculate the global weight variances accounting for individual errors from inconsistent pairwise comparisons. Utilizing the global AHP weights and their corresponding estimated variances, Monte Carlo simulation is employed for handling the related uncertainty in the global AHP weights to allow the investigation of whether the differences among the decision alternatives are statistically significant. This type of analysis provides more information for the decision makers in order to make more precise discriminations among competing alternatives (Hauser Tadikamalla 1996, Levary and Wan 1998).

According to the conventional group AHP using weighted geometric mean method, alternative B, manufacturing in South East Asia, should be selected as the preferred option with the highest global weight point estimate of 0.448. Alternative A is ranked second with the next highest global weight point estimate of 0.288 followed by alternative C, outsourcing in China and performance test in USA, with the global weight point estimate of 0.264 (see Table 1). If we consider no judgmental uncertainty in the input data, the analysis yields the preference ranking of [B, A, C].

Table 1: Some Statistics for Global Weights of Decision Alternatives

Alternative	Mean	Standard Deviation	Confidence Interval (95%)
A	0.288	0.023	(0.242, 0.334)
B	0.448	0.037	(0.376,0.520)
C	0.264	0.021	(0.222,0.306)

Looking at the obtained 95% confidence interval of the global weights gained by the stochastic AHP methodology, we see that there is considerable overlap between alternatives A and C. Figure 13 provides graphical representation of the global weight ranges of alternatives A, B, and C indicating some degree of judgmental uncertainty. This overlap implies that alternatives A and C are tied to occupy the second rank position. Although it is expected that alternative A has more chance to occupy the second position, further analysis is required to estimate the probabilistic superiority. However, some statistical analysis should be provided to check whether there are significant differences between alternatives A, B and C.

Using the simulation approach, the summary of output results of 10000 replications is given in Table 2. We can see that alternative B occupied the first place 99.99%. Alternative B does dominate alternative A and C with the confidence level of much more than 95%; thus, the null assumption that alternative B is probabilistic optimal (versus the alternate assumption that it is not) is accepted. However, the summary shows that alternative A and C ranked second 77.5% and 22.5% of the time, respectively, indicating that the null assumptions that alternative A is probabilistically superior to alternative C is rejected. In other words, with the confidence level of 95% we cannot say that alternative A is preferred to alternative C. In this case, the stochastic analysis yields the preference ranking of [B, (A, C)] considering the degree of judgmental uncertainty found in the input data.

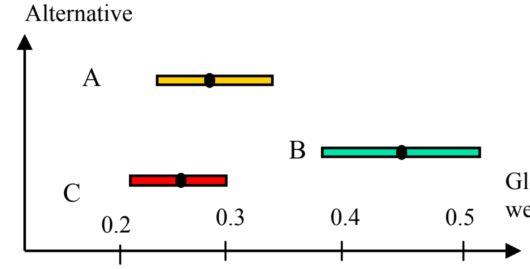


Figure 13: Range of Global Weights of Decision Alternatives due to Judgmental Uncertainty

Table 2: Summary of the simulation results for the Final Ranking of Alternatives A, B, and C.

	Rank		
Alternative	1	2	3
A	1	7747	2252
B	9999	1	0
C	0	2253	7747
Totals	10000	10000	10000

	Rank		
Alternative	1	2	3
A	≈0.0%	≈77.5%	≈22.5%
B	≈100%	≈0.0%	0.0%
C	0.0%	≈22.5%	≈77.5%
Totals	100%	100%	100%

5 CONCLUSIONS

In this paper, we analyzed a value chain, one that incorporates both production and service as major contributors to growth. We used a SD model and two DES models. We did a case study for a construction equipment corporation to show management the importance of the products and services divisions working very closely.

We have expanded the original core model to include several other causal loops to add workforce training, financial structures, and the competitive environment. We have introduced an AHP that takes into consideration the uncertainties resulting from the inconsistent comparison matrices.

We believe that the lessons learned from this paper can provide a good decision-making model that integrates the qualitative criteria of the strategic supply chain formulation level (i.e., senior executives) which makes emphasis on the long-term with the SD model representing medium-or long term planning and the DES models supporting the short-or medium term tactical planning. This decision-making model has the potential to mitigate the current rigid structure used by managers to make decisions in supply chain management and provide a better path to shareholder value.

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