Journal of International Technology and Information Management

Volume 15 | Issue 1 Article 5

2006

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ABSTRACT

A credible performance measurement system is imperative to evaluate SCM systems effectiveness. However, commonly accepted measurements for evaluating pharmacy supply chain management (SCM) are yet to be developed. This study models the dynamic behavior of pharmacy supply chains to include managerial policies and performance measuring systems based on a well-established theoretical framework. The system dynamics methodology is adopted to simulate three scenarios: (1) demand forecasting policy, (2) market need, and (3) manufacturing errors. Simulation results lead to important policy implications of pharmacy SCM.

INTRODUCTION

As the global economy develops, firms face increasing competition, making alliances a necessary strategic concern. Supply Chain Management (SCM), with its powerful value-added capabilities, is a concept for integrating companies within a production line in order to reach superior efficiency, competition, and flexibility. The importance of supply chain management cannot be neglected, as industry has indicated that 60% to 80% of business costs are associated with supply chain management. Therefore, it is imperative that firms use appropriate performance measures to evaluate SCM, although a commonly accepted measurement for evaluating SCM is yet to be developed. Several researchers (Beamon, 1996; Brewer, 2000) point out that the construction of an appropriate performance measurement is one of the most important parts of efficient SCM since a credible performance measurement system aids in the evaluation of SCM systems effectiveness.

Indeed, there is a lack of research on modeling performance measurement, especially on market interaction. Lee (1997) indicates that if managers take actions without appreciating the dynamic behavior of supply chains, they risk producing local benefits in the short term and creating liabilities in the long term. The dynamic behavior of supply chain management should be taken into account. Use of a system dynamics approach to observe the complicated characteristics of SCM, such as time delays and feedbacks, could better explain the cause and effect of the performance. This research aims to construct a systemic model, using system dynamics methodology, to measure the SCM performance in the pharmaceutical industry, examine the value of dynamic supply chains, and improve policy forecasting for the industry.

RELATED LITERATURE

Performance Measurement for SCM

The construction of an appropriate performance measurement is important to evaluating the efficiency of SCM. Performance measurement relies on the identification of those measures that drive supply chain success. Previous research identifies benchmarking and balanced scorecards as two of these measures.

(1) Benchmarking

When developing an understanding of existing supply chains and their associated processes, benchmarking analysis is considered an effective means to evaluate the supply chain's performance. Cook (1995) defines benchmarking as the process of identifying, understanding, and adapting outstanding practices from within the same organization or from other businesses to help improve performance. She suggests an 8-step process for benchmarking:

1. Identify and understand current processes
2. Form benchmarking team
3. Determine what to benchmark
4. Identify benchmarking partners
5. Collect data
6. Analyze data and identify performance gaps
7. Take actions to improve
8. Review results

Further, some researchers (Tan, 1999; Toper, 2000) suggest that competitive benchmarking should have a continuous measurement of the company's products, service, processes, and practices against the standards of best competitors and other recognized leaders. By continually measuring performance, a firm is able to adjust its policy and strategy toward dynamic variation in the market.

Supply Chain Council devised a useful framework for benchmarking known as Supply Chain Operations Reference. Four major processes—plan, source, make, and deliver—comprise the foundation of this model. These processes cover key elements of the supply chain, from identifying customer demand, through delivering the product and collecting payment (Tan, 1999; Stephens, 2000). This model provides a standard way to measure supply chain performance and to use common metrics to benchmark against other competitors.

(2) Balanced scorecard

Supply chain management requires that the member organizations have a means to assess the performance of the overall supply chain in meeting the requirements of the end customer. In addition, it is necessary to assess the relative contribution of the individual member organizations within the supply chain. This evaluation requires a performance measurement system that operates at several different levels and links or integrates the efforts of these different levels to meet the objectives of the supply chain. The balanced scorecard approach (Kaplan, 2004; Kaplan, 1996a; Kaplan, 1996b) incorporates both financial and operating performance measures used at all levels of the supply chain. The balanced scorecard addresses four key performance areas: financial, customer, business processes, and learning and growth. Within each of these areas, the authors identify key objectives that are driven by the aims and strategies of the next higher level in the scorecard hierarchy; specific performance measures associated with the objectives, performance targets, and initiatives to achieve the targets are then developed.

Although benchmark and balanced scorecard are popular methods, some other models also provide certain insights. Scannell Vickery and Droge (2000), and Tan, Kannan, and Handfield (1999) look into the interaction between companies and their suppliers. These studies indicate that selected purchasing practices and customer relation practices are strongly associated with the perceived financial and market success of firms responding to the survey. Their findings imply that there is a dynamic interaction in the supply chain.

System Dynamics

A holistic view of an interorganizaitonal information ecology, such as the pharmacy supply chain, can give "a more complete picture of the issues, benefits, costs and consequences surrounding the introduction of new technologies for creating or enhancing information sharing relationships" (Fedorowicz, Ray and Gogan 2004, p.83). System dynamics theory originates from the fields of physics and biology and can offer a holistic view of pharmacy supply chain (Von Bertalanffy, 1950). Management scholars adopted this theory as a methodology, a tool, or a concept in 1956 (Forrester, 1980), in order to study and manage feedback mechanisms of business and social systems. MIT's System Dynamics Society (2005) emphasizes the importance of studying systems as "feedback systems" in order to gain a better understanding of how they work. The accurate identification of internal interactive relationships between system elements is key in a feedback system. Quantitative means have been assimilated to investigate the dynamic behavior of socio-technical systems and their response to policy (Starr, 1980; Hsieh, 1970). Musaphir (1999) further suggests that system dynamics can be treated as a rigorous method for qualitative analysis of complex systems that facilitate quantitative simulation of system structure and control.

Applying System Dynamics Theories in SCM

System dynamics integrate knowledge about the real world with the concepts of how feedback structures change performance through time. Forrester's (1980) industrial dynamics theory is built on the concept of system dynamics and examines the feedback mechanisms of supply chain elements and their influences on the success of a business. The advancement of information and communication technologies (ICT) has enabled many innovative SCM practices, such as Vendor Managed Inventory (VMI), Collaborative Planning Forecasting and Replenishment (CPFR), Efficient Consumer Response (ECR), Enterprise Resource Planning (ERP), and Enterprise Applications Integration (EAI). These practices address the increased complexity of physical and virtual buyer-supplier relationships. Since a supply chain is consisted of many players with complex and dynamic behavior and spatial dimension, system dynamics theory is applicable to the study of the dynamic identity of SCM (Lee, 1997; Towill, 1992) Moreover, system dynamics theory is pertinent to understanding these supply chain relationships without risking misinterpretation.

To cope with the scaled-up complexity of today's supply chains, many companies resort to the help of computer simulation programs as a modeling technique to study the complex dynamic behavioral characteristics. Computer simulation programs have advantages over alternative analysis methods, such as optimization and business scenarios, in incorporating more variables into the analysis process without substantially increasing cost. When the time horizon is longer and the future has a higher degree of uncertainty in scheduling, tactical planning, and strategic planning process, simulation can outperform other alternative analysis approaches (Ingalls, Winter, 1998). Many mathematical models are assimilated into simulation programs to help analyze and project dynamic behaviors of the supply chain over time, such as "synergy" and "bullwhip effect" (Giannakis, 2004). It is imperative to understand the constituents of the supply chain (e.g. goals, number of suppliers, people, materials, information, financial, and technical resources) and depict their dynamic behaviors before running the simulation. Supply chain dynamics vary with the industry and services provided by a company. For instance, a service that employs standard and low cost resources, has routine and short life cycles, and focuses on the measures of customer service and long-term goal accomplishment is more likely to favor supply chain strategies that provide and match customers' demands. A service that favors intangible resources: unrouting, working process, and resource utilization characteristics, is more likely to adopt strategies that influence and control customers' demands. The pharmacy supply chain falls into the category of influencing and controlling market demands because it is imperative to educate customers about the medical products. The following section of Research, Framework, and Variables will discuss major elements of a pharmacy supply chain and their dynamic relationships and behaviors from the system dynamics perspective.

METHODOLOGY

Previous research indicates that a supply chain behaves dynamically. Moreover, simulation would better depict the relationships in a dynamic SCM environment. This research modifies previous models based on the specific market operation. Validity tests for the model are conducted and followed by a simulation for the pharmaceutical industry.

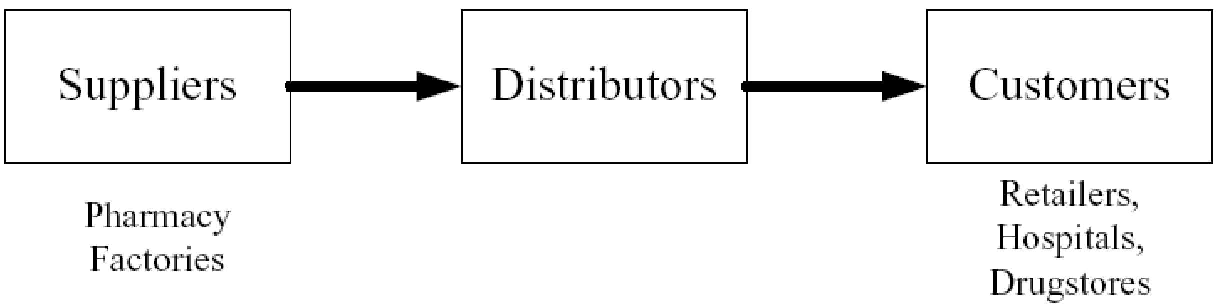
System dynamics software is useful to model and simulate dynamic behaviors of a wide variety of systems such as business, economic market, team dynamics, electrical engineering, natural environment, and scientific systems. These software packages incorporate five principal elements of a system dynamics model into the simulation process: stocks, flows, converters, decision-making process, and connectors. "What-if" sensitivity analyses can be conducted via the simulation to better understand the impacts of certain policy changes on the dynamic behaviors of a system over time. System software packages available in the marketplace are AnyLogic, Simile, Vensim, MapSys, Consideo, Powersim, Forio, Stella, and iThink.

We adopted Stella because it allows us to model the major elements of the pharmacy supply chain (stocks) and their interrelationships (flows). Policy changes made by key players of a pharmacy supply chain can also become a converter to help us construct a better understanding about the complex dynamic behavior of a pharmacy supply chain. Stella is a visual tool allowing us to present findings in diagrams, charts, and animations, which can communicate with our readers in a more effective way. Potential weaknesses to the Stella, as well as other system software packages include: (1) unverified assumptions against the reality, (2) false representation of the stocks, flows, and converters, and (3) inappropriate interpretation about the simulated models. Mitigating these human errors can lead to a more accurate representation of dynamic behaviors of a system.

Subject of the Research

This study is based on a pharmacy supply chain which owns more than ten percent of the market in Taiwan. The company has implemented electronic SCM for many years. Capital is constantly invested in constructing an environment that allows information to flow without barriers. The pharmacy supply chain is comprised of three major key players: suppliers, distributors, and customers (Figure 1). Pharmacy and factories are major suppliers of drugs and other health-related products. Distributors will deliver finished products to retailers, hospitals, or drugstores.

Figure 1: Supply chain of the pharmaceutical industry.

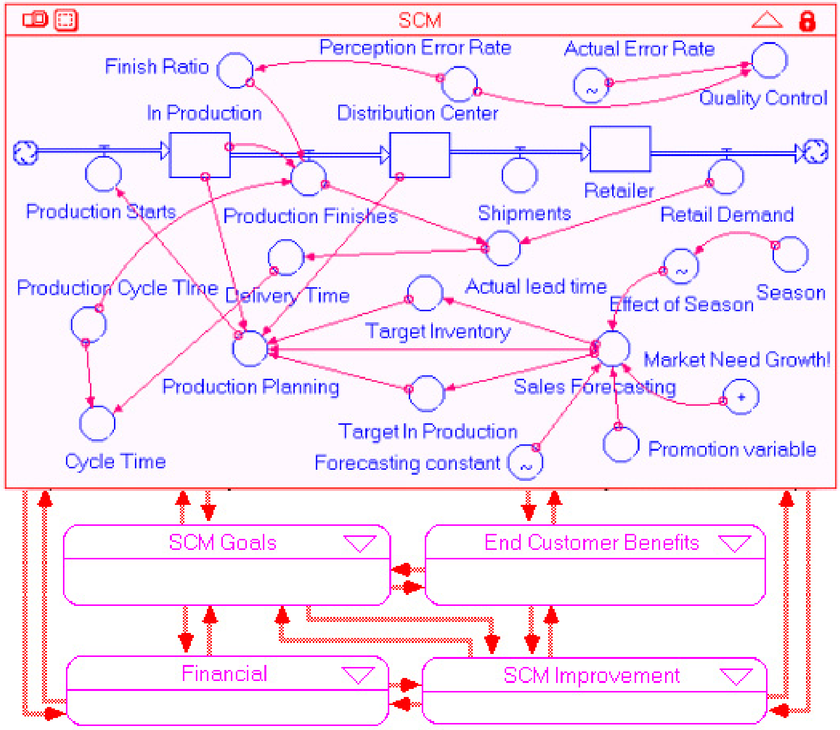


Research Framework and Variables

A framework (Figure 2)—modified from Lee (1997), Brewer and Speh (2000) —is used to guide this research. The SCM sector on the top depicts the real supply chain elements. It includes the procedures, states, and managerial policies along the supply chain; the other four sectors represent the performance measuring system.

A pharmacy supply chain needs to address the dynamic behavior of the procedures, states, and managerial policies. Information about customers' demand and the supplying capability of pharmacy and factories can help determine the actual lead-time. Information about the actual lead-time can be used to decide when the products can be delivered to final customers. Information about production cycle time of factories and delivery time of distributors together can lead to the cycle time. Production cycle time, and the number of products in a production line, as well as the ratio of finished products to products in progress can help determine production finishing time. The actual lead-time needs to be created based on the feedback information of the production finishing time to complete the core elements of the pharmacy value chain.

Figure 2: Research framework.



Two kinds of key information from factories and distributors are indispensable for the success of these core elements of a pharmacy value chain. First, is the information about production planning. Seasonal sales, market demand, promotion strategies, and forecasting data are incorporated into the calculation of forecasted sales. The projected sales amount will be used to decide the targeted inventory and works in progress. This information can help derive the production planning schedule. The second key is the finish ratio. This ratio can be calculated based on the quality control policy, which can be determined based on the information on the actual and perceived error rates.

The pharmacy supply chain can incorporate new operating procedures and managerial policies into its elements. For instance, variables used in the sales forecasting and quality control policies can have impacts on the inventory control and finish ratio, eventually impacting the actual lead time. A pharmacy or factory that needs to comply with environmental management standards, such as BS5720 and BS7750, will need to continuously improve environmental control and reduce waste. The Life Cycle Analysis is one of many effective approaches to assess the environmental impact of a product over its lifetime, from the stage of raw materials to the stage of recyclability or ultimate disposal (Whyte, 1994). In compliance with these standards, a pharmacy must adjust the actual and perceived error rates in the production line. This adjustment will affect the entire pharmacy supply chain.

Based on the previous research and interviews with executive directors of pharmacy companies, some indicators and variables are determined for each sector in the model. For SCM goals, there are four indicators: waste reduction (variables: duplication control and quality enhancement); time compression (inventory control, lead time compression, delivery time compression, and efficiency); unit cost reduction (total supply chain cost, value-added productivity, and low production cost); and flexible response (flexibility on service and product) (Brewer, 2000; PTRM Consulting, 1954; Scannell, 2000; Tan, Summer, 1999).

For the end customer benefits sector, there are four indicators: improved quality (delivery-to-commit date, product quality, service quality, return and allowances, product durability, product reliability, and conformity to specifications); improved timeliness (source/make cycle time, supply chain response time, and production plan achievement); improved flexibility (order handling, exceptional services, non-regular deals, order configurations, order size, and product variety); improved value (service level and customer satisfaction) (Brewer, 2000; PTRM Consulting, 1954; Scannell, 2000; Tan, Summer, 1999).

For the financial perspective, there are four indicators: higher profit margins (price recovery and productivity); improved cash flow (inventory turnover rate, and AR turnover rate); revenue growth (market share and market growth); and higher return on assets (asset performance, cash-to-cash cycle time, inventory control, and forecast accuracy) (Brewer, 2000; PTRM Consulting, 1954; Scannell, 2000; Tan, Summer, 1999).

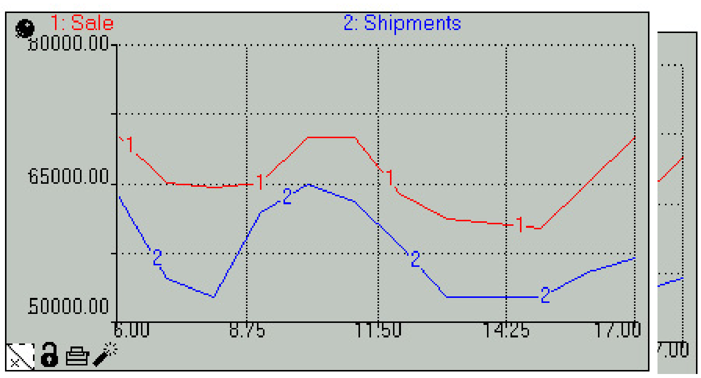
For the SCM improvement sector, the indicators are partnership management (number of suppliers, percent of certified suppliers, percent of acceptable materials, on-time delivery, total purchase costs, trust of partners); threats/substitutes (government forces and counterfeits); product/process innovation (product innovation, design quality, and process innovation); and improved information flows (information feedback, inventory control, demand planning and correctness) (Brewer, 2000; PTRM Consulting, 1954; Scannell, 2000; Tan, Summer, 1999).

RESULTS AND ANALYSIS

Validity Tests

Before using the proposed model to evaluate SCM, three validity tests are performed: stability, time phase, and pattern of oscillation. 1) Stability: the function of the stability test is to identify the extent to which the model parallels the real system. In the test, the model is convergent to a stable situation after a period of oscillation. 2) Time Phase: one of the dynamic system's characteristics is that variables' motions have obvious time phase relationships. The base run shows that the sales (shipments curve) always correspond to the orders (production-starts curve). This situation supports the validity of the time phase test. 3) Pattern of Oscillation (Figure 3): the dynamic system always oscillates. To verify the adequateness of the model, this research examines whether the oscillation pattern fits the real system's pattern (based on past records). The curve of the real system is compared with the shipment curve of the proposed model. Although the quantities are not identical, the oscillation patterns of the real system and the model do correspond. This result indicates the pattern of oscillation of this proposed model is valid.

Figure 3: Comparison with the real system.



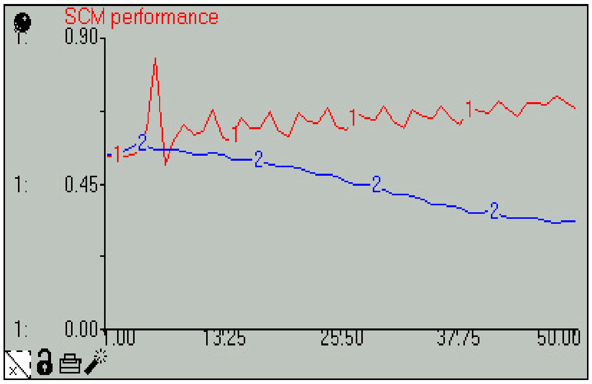
Simulation

Three different scenarios are simulated: (1) demand forecasting policy, (2) market need, and (3) manufacturing error rate.

Demand forecasting

Demand forecasting plays an important role in many supply chain decisions. All parties in the supply chain should reach consensus regarding forecast assumptions, techniques, and final forecast numbers. Based on this policy, suppliers determine the quantity in which to invest. Demand planning typically takes into account the history of the item, stability of demand, completeness of information about promotion expectations, and other product-specific data (Simchi-Levi, 2000). In the first simulation on policy changes, the first curve (Figure 4) shows a policy of maintaining a target inventory level while the second curve depicts average demand. The simulation shows that maintaining inventory levels results in more fluctuations in performance for its complicated characteristics and repetitive modifications. By contrast, if a constant inventory level is disregarded, the process may fluctuate less but performance may be lower as indicated by curve 2.

Figure 4: Effect of policy on performance.

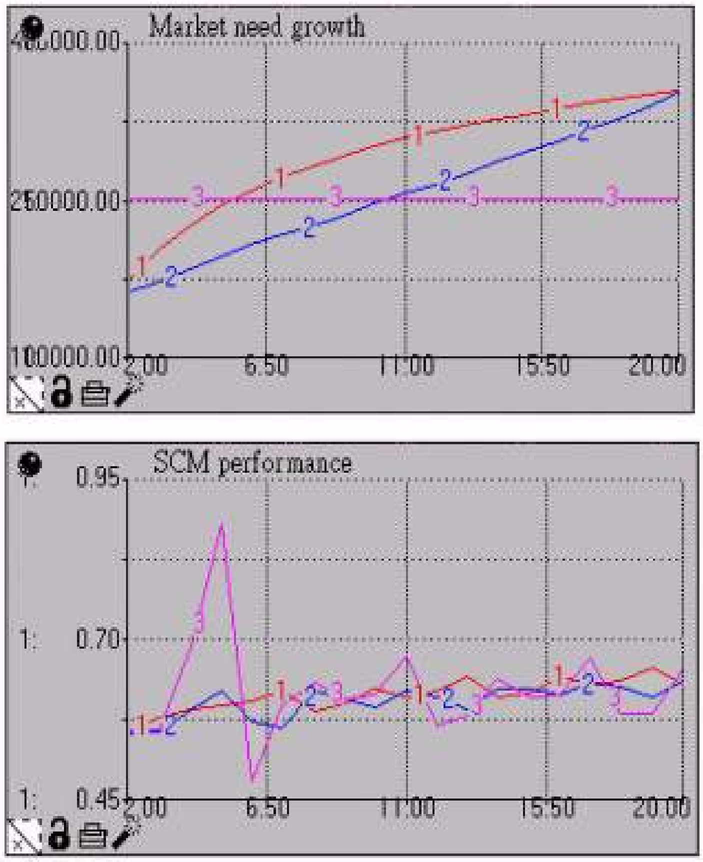


A more precise demand forecasting policy is a converter that can help improve the efficiency and performance of a pharmacy supply chain by controlling a constant inventory level. A study on the pharmacy supply chain efficiency at the retailer of Longs Drug Stores showed that the simulation software package could help craft out a better demand forecasting policy by incorporating seasonal market demands during flu or allergy seasons (Brookman, 1997). Up to 65% of reduction in inventory cost (from 135 to 47 days) was achieved via demand forecasting simulation in this study.

Change in market need

In the second scenario, the market need changes (Figure 5). An interview reveals that the market demand in the pharmaceutical industry does not show significant growth. A gentle-market need growth curve (curve 1) represents this situation where performance rises slowly. Two more scenarios with a stable-growing market (curve 2) and a non-growing market (curve 3) are also simulated. The performance of the stable-growing market improves smoothly. When markets stop growing, SCM performance becomes difficult to maintain.

Figure 5: Comparison of performance in different market.

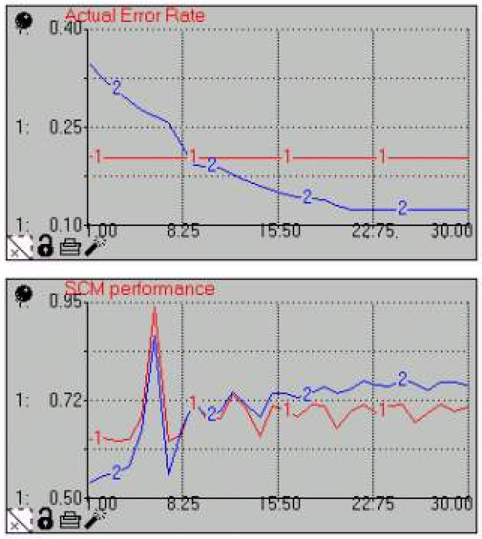


Many institutions, such as PhRMA and the Food and Drug Administration, are progressive in promoting the use of radio frequency identification (RFID) technologies to stop counterfeits and better predict the market demand through collaboration with parties in the pharmacy supply chain. Many federal and state policy makers are collaborating to unify RFID standards throughout the United States (Frederick, 2005). Successful deployment of RFID standards will streamline the pharmacy supply chain by making a wide variety of information (error rates, number of products in stock and in production line, as well as seasonal demands) available to different parties. Simulation software can incorporate this timely updated information generated by RFID technology into the decision-making process throughout the supply chain. Changes in the market demand can be efficiently assimilated into the daily decision-making process for pharmaceutical factories, distributors, and retailers.

Change of manufacturing error rate

The third scenario, where the actual error occur rate is set to be a constant (Figure 6), represents the average rate at which the errors may occur (curve 1) at all stages of the supply chain. Nevertheless, it is reasonable that the error rate can fall over time due to accumulated learning (curve 2). It is reasonable to expect the performance of a learning system to be higher than the system with a fixed error rate. Yet, the results from this simulation do not significantly support this assumption. However, it is safe to conclude that a lower error rate results in higher SCM performance, while the higher error rate results in lower SCM performance.

Figure 6: Effect of error rate on performance.



Medical errors in the pharmacy supply chain can translate to human death. The reduction of errors at all stages of a pharmacy supply chain can prevent this loss of life. Some pharmaceutical companies have applied the Six Sigma approach and the Lean concept to improve product and process quality. In compliance with Lean and Six Sigma quality control policy, key players of pharmacy supply chain can translate the policy requirements into the actual and perceived error ratios, which can trigger changes in the existing supply chain.

CONCLUSION

Since Forrester (1980) proposed his "Industrial Dynamics" four decades ago, systems dynamics theory has gained attention from researchers. Forrester's model is a benchmark for recent supply chain management. The dynamic nature of the interactions among components in the supply chain are best described by using system dynamics theory. The research described here provides means by which to examine the dynamic supply chain's behavior of a pharmacy supply chain by constructing a model to simulate and measure its managerial effect.

Validity of the proposed model is proven in three tests: stability, time phase, and pattern of oscillation. It is suggested that this model can perform supply chain performance evaluation and be used as a consultation tool for policy forecasting in the real business world. Based on the simulations from this research, there are two issues that deserve attention from management: (1) Demand planning policy that ignores inventory adjustment can lower the supply chain's performance; (2) The growth of market needs impacts the growth of supply chain performance.
This research provides a simulation model for measuring supply chain management in the pharmaceutical industry. The dynamic property in a supply chain should not be ignored when pursuing successful supply chain management. Although this model is proposed for the pharmaceutical industry, it can be modified to fit other industries as well. Furthermore, a friendly graphic user interface tool could be designed to accommodate executives use of this tool.

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