MODELS FOR EVALUATION OF SUPPLY CHAIN RISK WITH APPLICATION TO

HEALTHCARE MANAGEMENT

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FORD GUANGFU ZENG

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ABSTRACT

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Ford Guangfu Zeng, PhD

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Supervising Professor: Jamie Rogers

Over the past two decades, supply chain management has come to be a key component of organization competitiveness and effectiveness. In the same period, most organizations have put a great deal of effort into improving their own and their supplier's supply chain performance. To a large extent, much of this effort has been aimed at improving the efficiency of supply chain operations. However, organizations have ignored or played down the risks from supply chain disruptions when developing supply strategies, which focus on cost reduction. We found that some of the measures, which companies take to improve the efficiency of their supply base, may increase their exposure to technological and strategic risk by increasing their reliance on the remaining pool of suppliers.

It is proposed, therefore, that one such standard measure should measure the risk involved with organizations and their supply chains. In this context, the intent of this research is to develop a new methodology in supply chain performance and risk analysis, and build several models for evaluation of general supply chain performance and risk. To this avail, healthcare supply chain structures are investigated, and a methodology for evaluating the relative risk associated with the supply chain designs is undertaken.

We first propose a comprehensive methodology to estimate the significance of the risk against performance, and consider all risk and performance elements incurring in each component of the supply chain, then develop two new multi-tier DEA models that can be applied to evaluate the relative effective values of the supply chain by optimizing weights of each component in the supply chain. The models not only provide the overall efficiency of supply chain but also show the efficiency of each component, which is valuable information for analysts to consider in improving the supply chain. We integrate classical DEA and rough set theory into a Rough Data Envelopment Analysis (RDEA) method, and identify the main uncertainty risk factors in supply chain.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Supply Chain is the integration of all activities associated with the flow from raw materials to end users. The activities include planning, sourcing, making, and development of processes with its constituent parts to include material suppliers, production facilities, distribution centers, and customers. Supply chains are becoming more complex with the numerous physical and information flows that involve worldwide companies. To succeed in this environment, firms may pursue a high level of performance while continuously reducing costs. For this reason, practices such as lean manufacturing, just-in-time and low-cost-country sourcing have become familiar to supply chain managers and have gained growing attention in academia. Nonetheless, the trend to designing lean supply networks which are tightly coupled and operated at minimum levels of time and material's buffers makes them vulnerable to local disturbances. These practices can be an existential threat to global or networked supply chains and may have negative effects on costs, quality, flexibility, and reliability on image and ultimately the valuation of all the participants in the network. These negative effects can engender potential detrimental consequences due to the risks they induce, which can lead to supply chain disruptions with subsequent financial losses. Supply chain risk, therefore, becomes a critical success factor on supply chain performance.

Supply Chain Risk Management (SCRM) is viewed as a strategic management activity in many firms. SCRM may affect operational, market and financial performance of supply chain. Christopher and Lee (2004) recognized the increasing risks in the supply chain context and the need for new responses to manage these. Underlying these developments in SCRM is the

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imperative to devise and develop appropriate performance measures and metrics to evaluate, educate and direct the operational and strategic decisions. Therefore, the essence of SCRM is to make decisions that optimally align organizational processes and decisions to exploit opportunities while simultaneously minimizing risk.

SCRM includes risk identification, risk evaluation, risk monitor, and risk mitigation. Risk evaluation is to estimate the significance of the risk, judge the acceptability of risk, and compare risks against benefits. Its purpose is to decide on the most appropriate management response for each risk/combination of risks and which party is most appropriate to manage each of the risks identified.

There are number of conceptual frameworks and discussions on supply chain performance measurements or supply chain risk assessments; however, there is a lack of evaluation of the associated potential performance in terms of benefits, costs and risks. Performance and risk are interconnected and require deliberate and robust implementation of supplier management tools and controls to maximize performance whilst controlling the consequential risks. The objectives of this research are to: (1) highlight supply chain risk management as an important area of investigation in operations and supply chain performance management; (2) present a new ground in addressing methodological and theoretical issues dealing with supply chain risk evaluation; (3) investigate healthcare supply chain structures and risks.

<u>1.2 Background</u>

During the past two decades, supply chain management has come to be a key component of firm competitiveness and effectiveness. Most of firms have put a great deal of effort into improving their own and their supply chain performance. To a large extent, much of this effort has been aimed at improving the efficiency of supply chain operations. However, as Hendricks and Singhal (2005) argued organizations have ignored or played down the risks from supply chain disruptions when developing supply strategies, which focus on cost reduction.

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Cousins et al (2004) suggested that some of the measures, which companies take to improve the efficiency of their supply base, may increase their exposure to technological and strategic risk by increasing their reliance on the remaining pool of suppliers.

Risk management is "an integral part of supply chain management" (Christopher, 2004). With respect to the various supply chain goals discussed above, it is helpful if risk is understood as a multi-faceted phenomenon. For example, from the financial perspective, the management of supply chain risks involves the management of cash-flow variations that result from operational activities; moreover, from the perspective of corporate governance. Evaluating risk in supply chains has emerged as an important topic in supply chain management. The topic derives its importance due to several industry trends currently in place: increase in strategic outsourcing by firms, globalizations of markets, increasing reliance on suppliers for specialized capabilities and innovation, reliance on supply networks for competitive advantage, and emergence of information technologies that make it possible to control and coordinate extended supply chains. These trends have manifested themselves in an increase in outsourcing and off-shoring of manufacturing and R&D activities, low cost country sourcing, and collaboration with international supplier partners. While these increase the strategic options for firms, they also increase the probability of experiencing adverse events in supply chains that significantly threaten normal business operations of firms in the supply chains. Along with the increase in these initiatives, there has been an increase in the potential and magnitude of supply chain risks (Blackhurst et al., 2005). Recent events involving food supply chains (for example, Melamine in infant formula and powdered milk sourced from China) underscore risks of extended supply chains. Supply chain disruptions can also adversely affect the financial performance of firms. From the perspective of business continuity and crisis management, SCRM is an integrated management approach along the whole chain (Adams et al., 2002) – with a view to managing "the exposure to serious business disruption, arising from risks within the supply chain as well as risks external to the supply chain."

The purpose of SCRM is to make decisions that optimally align organizational processes and decisions to exploit opportunities while simultaneously minimizing risk. Currently, SCRM approaches seek to measure either supplier attributes or the supply chain structure, use the findings to compare suppliers and predict disruption. The results are then used to prepare proper mitigation and response strategies associated with these suppliers. Supply chain disruptions can ''materialize'' either inside or outside a supply chain. As Wagner and Bode (2008) point out, "the financial default of a supplier and an earthquake that destroys production capacity are situations with completely different attributes and therefore have different effects on the supply chain''.

Every company maintains a variety of different relationships, and may not be willing or capable of developing close ties with all parties due the resource intensiveness and the financial risk. They also increase the vulnerability of the involved parties by exposing them to opportunistic behaviors and the potential weaknesses or failures of the other parties. With greater complexity in the supply chain, trust becomes a growing concern and organizations should routinely reexamine their relationships with respect to future strategies and position. In addition, Choi and Krause (2006) found that reducing the complexities in the supplier base may alleviate costs, but that the buying competitiveness of a company may be reduced. They suggest that, by examining the effects of supplier reduction on transaction costs, supply risk, supplier responsiveness and supplier innovation that transactions costs may be lowered, but supply risk may increase with a simultaneous decrease in supplier responsiveness. Ritchie and Brindlye (2007) developed a framework for supply chain risk management in which they conclude the inclusion of risk management influencers affects management responses to certain situations. They also state that there is a "need for the Operations Research discipline to evolve a more diverse set of risk management tools and approaches to effectively address the diversity of issues and contexts".

Data Envelopment Analysis (DEA) was first introduced by Charnes and Cooper (1978) as a Linear Programming (LP)-based methodology for performing analysis of how efficiently a company operates. Its analyzed units are denoted as "DMU," which stands for decision-making units. It is a non parametric programming approach to frontier estimation. In other words, it means DEA does not require the existence of a particular function to specify the relationships or tradeoffs among the performance measures in the computation of efficiency and it utilizes the concept of efficient frontier as an empirical standard of excellence. DEA methodology was selected over the regression approach for estimating efficiencies for several reasons. First, no initial estimates of distribution center efficiency (performance) were available. Second, we also found that other potential input variables (like vehicle transportation cost, and operating expenses) were highly correlated and thus a regression approach would be problematic. Third, there are characteristics of this problem environment that influence the ability of management to transform inputs into outputs, and in this context inefficiency has various components. Understanding the source and the nature of inefficiency is important for designing policies to improve resource allocation. In light of the output variables, we arrived at a DEA-based method for benchmarking efficiency shortfalls among distribution centers and supply chain managers. These advantages of DEA enable managers to evaluate any measures efficiently as they do not need to find any relationship that relates them. In addition, the concept of efficient frontier proves to be a valid measure of performance comparison.

DEA is able to measure multiple inputs and outputs, which mean that it can operate as a Multi Criteria Decision Making (MCDM) tool. In comparison of this inherited feature of DEA to other MCDM tools such as the Analytic Hierarchy Process (AHP), DEA does not require assigned numeric weights or modeling preferences for analysis, although these could be introduced if/when desired. This helps to prevent discrimination of criteria used in the analysis based on different perspectives of analysts. Similarly, incorporating decision makers' value-judge into the DEA approaches provides comparable results to those found by the traditional

MCDM approaches. Hence, the advantages of DEA compared to other MCDM methods are that it requires less information from decision makers and analysts and it provides ranked alternative valuations which may be useful for some decision makers. For supply chain managers in general and strategic managers in particular, this study demonstrates that the DEA methodology can be used to help empirically separate three recognized, important and yet different causes of performance shortfalls which have been generally difficult for managers to identify. They are: (1) managerial effectiveness; (2) scale of operations and potential for a given market area, and efficiency of resource allocation given that scale; and (3) understanding resource heterogeneity via programmatic differences in efficiency.

Knowledge Discovery in Databases (KDD), in general, is the nontrivial extraction of implicit, previously unknown, and potentially useful information from data. At an abstract level, the KDD field is concerned with the development of methods and techniques for making sense of data. The basic problem addressed by the KDD process is one of mapping low-level data into other forms that might be more compact, more abstract, or more useful. The central question in knowledge discovery research is how to turn information, expressed in terms of stored data, into knowledge expressed in terms of generalized statements about characteristics of the data. Some machine learning techniques are appropriate for analyzing databases. Knowledge discovery methods based on the principles of machine learning must provide computational efficiency to deal with very large databases and robustness to cope with superfluous or "noisy" data. The rough sets theory (Pawlak 1991) offers a new approach to reasoning from data. This methodology, which is complementary to statistical inference, provides new insights into properties of data and has been successfully applied in knowledge acquisition, forecasting and predictive modeling, expert systems, and knowledge discovery in databases.

There is a growing national concern that poor design for healthcare delivery systems combined with constantly growing number of patients and overcrowding are often the major reasons causing risks for patient safety and creating wastes to the hospital. With the supply

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chain costing as much as 40 percent of the typical hospital's operating budget, the strategic importance of hospital supply chain management is evident (McKone-Sweet et al 2005). It is estimated that the potential benefits of an efficiently managed healthcare supply chain range from 2 percent to 8 percent of hospital operating costs (Haavik 2000). An efficient, user-friendly supply chain can also impact the hospital's revenues by engendering physician loyalty and staff retention and providing better customer service. Despite the recognized importance of managing the hospital supply chain, many variables exist in execution and measurement. Unlike the commercial sector, which has long viewed the supply chain as a key strategic activity and used it as a way to differentiate itself, gain market share and generate profits, health care has lagged behind in supply chain management. In part this is because of the nature of health care: it is a cottage industry whose key players—doctors—are independent contractors with considerable clout and specific preferences for supplies and where some variation in supplies and processes must be accommodated to ensure patient safety. Health care is starting to adapt the lessons of other industries, such as retail and automotive, to improve product flow. One example is the notion of an extended supply chain, where organizations take into account not only their own operations, but also all of their upstream and downstream partners to maximize efficiency. To address the healthcare supply chain performance issues, a methodology for evaluating the trade-offs between supply chain performance and risks needs to be developed.

1.3 Statement of the Problem

The existing supply chain risk evaluation methods and quantitative models require some risk parameter values like the probability that events occur, the impact of detrimental events, and the weight/importance values of risk factors. In addition to the usual financial measures used to measure risk, the supply chain risk now also needs to take into consideration other specific indicators such as the delivery rate and percentage of order fulfillment. This measurement is further complicated by the influence of manufacturing capacity and other influential operational constraints. In view of the increasing risk measures in supply chain, not

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many companies will know how to gauge the risk of their supply chain. The rise of multiple risk measures has rendered the efficiency measurement task difficult and challenging. Hence, a tool to effectively measure the supply chain risk is greatly needed.

DEA has been proved to be a useful tool in evaluating relative efficiency of homogeneous Decision-Making Units (DMUs) in a multiple-input multiple-output setting. Some measures linked to supply chain members cannot be simply classified as outputs or inputs of the supply chain. For example, the supplier's revenue is an output for the supplier, and it is in the supplier's interest to maximize it; at the same time it is also an input to the manufacturer who wishes to minimize it. Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not properly model and resolve the inherent conflicts. Cook et al. (2007) developed a DEA model for evaluating the joint efficiency of supply chains with multiple tiers or members**.** However, Cook et al. didn't specify what are the supply chain inputs and outputs in DEA model, and didn't mention supply chain risk.

Healthcare supply chain distributors have tried to reduce overall costs by implementing Just-In-Time practices and managing the supplier and hospital inventory levels. By instituting supplier-managed inventory and stockless systems, the distributors attempt to control the flow of materials through the supply chain. Healthcare supply chain manufacturers, of course, would prefer the distributor to hold more of its inventory and to push product to the hospitals. The hospitals, with limited room for storage, encourage careful management of inventory but also must give up valuable data to distributors (McKone-Sweet et al 2005). Pharmaceutical supply chain consists of one or more of manufacturer, whole sale, hospital/clinic/drug store, and consumer/patients. Clinical trials also must consider supply chain risks as the associated supply chain encompasses producing, distributing and administering the volunteer patients located in different geographic regions. Since there are many factors in healthcare supply chain risk, we need to use Knowledge Discovery in Database (KDD) tools like rough data sets theory.

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<u>1.4 Research Objectives</u>

It is proposed, therefore, that one such standard metric should measure the risk involved with organizations and their supply chains. The objective of this research, then, is to develop a new methodology in supply chain risk analysis, and build several quantitative models for evaluation of general supply chain risk, by using Data Envelopment Analysis (DEA) and rough set theory. To this avail, health care supply chain structures are investigated, and a methodology for evaluating the relative risk associated with the supply chain designs is undertaken to develop a measure of risk.

We consider supply chain risk as in the risk associated with performance variability of supply chain. A generic and well-established definition of performance and risk is used, dividing this construct into efficiency and effectiveness. Efficiency is regarded in a resource input-output sense such that the greater volume of outputs for a given volume of inputs then the greater the efficiency. Effectiveness relates to the degree to which the planned outcomes are achieved. Achievement of the target market share may be seen as highly effective although the use of advertising expenditure in doing so may be regarded as inefficient in performance terms.

There are four phases in this research. Phase 1: Initially, the investigations are directed at structuring the problem of risk evaluation of supply chain and identifying analytical techniques, which would be amenable to the encountered problems and would provide meaningful insights from the standpoint of theory and practice. Phase 2: We have developed a series of methods in supply chain risk analysis, and have built several quantitative methods for evaluation of general supply chain risk. Phase 3: We have conceptualized health care as a bundle of goods, services, and experiences. We adopt a macro, end-to-end, and supply chain-centric view of the health care sector to link the risk management. Phase 4: We have applied the models developed in phase 2 to health care supply chain risk management. We collect some data from several healthcare agencies/hospitals to evaluate the risk, and use the computed results to evaluate the

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effectiveness of healthcare supply chains. For phase 2, a series of methods include: Data Envelopment Analysis (DEA), and Rough Set Theory.

<center>1.5 Organization of the Dissertation</center>

This dissertation is composed of four chapters. A brief description of each chapter is presented as follows:

Chapter 1 consists of 5 sections. The first section explains an overview of supply chain risk management, the importance of supply chain risk, and identifies the necessity of risk measurement. The second part provides background information about supply chain risk, Data Envelopment Analysis (DEA), rough set theory, and healthcare. The third section talks about the problems of supply chain risk evaluation. The fourth section states the research objectives for the dissertation. The organization of the dissertation is depicted in this final section.

Chapter 2 reviews many useful published articles related to the concept of supply chain risk management, the importance of risk for supply chain management, the relationship between risk and supply chain management, the approaches to managing supply chain risk, data envelopment analysis, the rough data sets theory, and healthcare management.

Chapter 3 provides the methodology that is employed in this dissertation research. The DEA model that is employed in this study evaluates the supply chain risk, including mathematical relations and the data mining methodology of the supply chain data using rough set theory.

Chapter 4 illustrates how to apply the methodology proposed in chapter 3 with three cases studies. Both of them are related to healthcare supply chain risk management. Case study 1 illustrates simple scenarios which consist of pharmaceutical supply chain inside hospital, while case study 2 and 3 shows complex scenarios which are composed of more parameters and more components for the risks in pharmaceutical supply chain and healthcare clinic supply chain. We also analyzed 10 domestic pharmaceutical supply chain cases are based on real-world supply chain data.

Chapter 5 provides an overview of this research and discusses the case studies, including advantages and disadvantages of the methodology proposed. The conclusion and contribution of this dissertation is summarized and future research direction is recommended.

CHAPTER 2

LITERATURE REVIEW

2.1 The Concept of Supply Chain Risk Management

Risks are all those things that keep us away from the perfect path and perfect outcomes. Supply chain risk management (SCRM) is a discipline of risk management which attempts to identify potential disruptions to continued manufacturing production and thereby commercial financial exposure. SCRM attempts to reduce supply chain vulnerability via a coordinated holistic approach, involving all supply chain stakeholders, which identifies and analyses the risk of failure points within the supply chain. From our supply chain perspective, these uncertain variations or disruptions affect the flow of information, materials or products across organization borders (LaLonde, 1997). For the purpose of our research, supply chain risks hence comprise of any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user. In simple terms, supply chain risks refer to the possibility and effect of a mismatch between supply and demand. Risk sources are the environmental, organizational or supply chain-related variables that cannot be predicted with certainty and that impact on the supply chain outcome variables. Risk consequences are the focused supply chain outcome variables like costs or quality, i.e. the different forms in which the variance becomes manifest.

Sodhi (2005) proposed two risk measures, one for not meeting end-consumer demand and the other for a customer having excess inventory. Both are taken across all customers by week for the 26-week horizon. Using the analogy of the so-called value-at-risk (VaR) measures in financial risk management, Sodhi adopted a "demand- at-risk" (DaR) measure to quantify this unmet demand across customers. For a particular probability p for any week in the horizon,

DaRp can be defined as that value for which there is a p percent chance that unmet consumer demand across all customers can exceed this value for a particular week in question. The same applies to the total inventory across customers at the end of each period to give an "inventory-atrisk" (IaRp) measure. (Instead of VaR as analogy, we can use another measure, "conditional value-at-risk" or cVaR—mean excess loss—that is well suited as an objective for linear programming. Associated with suppliers and in-house production and distribution are possible disruptions due to political risk and 'acts of god' or 'acts of man' in terms of war or terror. Associated with the demand side are risks pertaining to unanticipated changes in demand possibly stemming from loss of reputation for quality, from loss of technological or design competitive edge, from unpredictable changes in customer preferences, and even from a worldwide recession. There are also supply chain wide contextual risks that cut across the supply chain especially impacting companies with global supply chains. These include cultural differences in multinational operations, environmental risk, regulations risk, and exchange rate risk across multiple countries. Supply chain and its management consist of the management of a network of facilities, the exchange of communications, distribution channels and the supply chain entities that procure materials, transform these materials into intermediate and finished products, and distribute the finished products to customers. As a result of these wide range of functions, a supply chain can be viewed as an emerging operational and organizational form integrating all firms and entities that cannot, either by design or by economic interest, pursue by itself all these activities. Due to this inclusiveness, supply chain management is a potent and important alternative to the common use of centralized and authoritarian-based approaches to management. Sodhi then defined cDar and cIaR similar to cVaR, but Sodhi did not explore these risk measures. The risk measures, DaR and IaR, compete in one sense, but not in another. One could always reduce the DaR at the expense of increasing IaR or vice versa. So, Sodhi needed to balance these for a given uncertainty level and a given flexibility level of the plants in revising their production schedule and of the warehouse allowing customer order

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revisions. However, both risk measures can be reduced if uncertainty were reduced or if the plants' supply schedule or customers' order schedule were allowed greater flexibility. Another risk measure useful for considering capacity reallocation at the plants among different products is the expected "cost" of unmet demand as well as excess inventory for each product summed over customers as a function of a multiple of the supply from the plants, as Sodhi said. This multiple, reflecting reallocation of capacity can be anywhere between 0.8 and 1.2 to show an increase or decrease in capacity. So, if the allocated capacity were to suddenly decrease by 15% resulting in a proportional drop in replenishment to the warehouse over the next 26 weeks, then we know the increased expected cost due to the increase in unmet demand across all customers. We can use this to compare the cost and benefit of allocating capacity among the different products using each product's importance rating as a proxy for its profitability.

The risk associated with all commodities are evaluated for their impact on "earnings before interest and taxes" (EBIT) and reported on a quarterly basis to the coordinator of the risk assessment process. Zsidisin et al. (2004) stated there are 13 categories that are evaluated within the supply risk assessment and measurement process:

(1) Additional costs for cancellation due to lack of planning.

(2) Additional costs for transportation due to lack of planning.

(3) Additional costs for material obsolescence.

(4) Unexpected material price increase due to allocation.

(5) Unexpected material price increase due to yield problems.

(6) Unexpected material price increase due to change of specification.

(7) Missing parts due to late delivery.

(8) Missing parts due to supplier quality defects.

(9) Missing parts due to instability of supplier's country.

(10) Additional material costs due to single sourcing during ramp-up phase.

(11) Contractual risk.

(12) Investing in supplier improvement.

(13) Currency risk.

Zsidisin et al. (2004) also stated each supply risk category is assessed using an 11-step process:

(1) What is the impact on EBIT in millions dollars (before management implementation) for the current fiscal year?

 (2) What is the probability of occurrence before risk management implementation (in percent) during the current fiscal year?

(3) What is the impact on EBIT in millions dollars for the next fiscal year?

(4) What is the probability of occurrence before risk management implementation (in percent) for the next fiscal year?

(5) Insert explanations for the key risk factors.

(6) List risk handling measures to avoid the risk.

(7) Rate the implementation status of risk management: very low (0-20 percent);   low (20-40 percent); medium (40-60 percent); high (60-80 percent); very high (80-100 percent).

(8) What is the impact on EBIT in millions dollars (after risk management implementation) for the current fiscal year?

(9) What is the probability of occurrence after risk management implementation (in percent) during the current fiscal year?

(10) What is the impact on EBIT in millions dollars for the next fiscal year?

(11) What is the probability of occurrence after risk management implementation (in percent) for the next fiscal year?

Among practitioners, risk taking is generally perceived as an integrated and inevitable part of management (March & Shapira, 1987). In their view, risk taking equals decision-making under uncertainty and hence any strategic choice has certain risk implications. For supply chain contexts, Braithwaite & Hall (1999) emphasized that the relationship between corporate strategy,

risk and the implications for supply chain management is poorly understood and in need of further exploration.

In defining the concept of supply chain risk management, we make a distinction between supply chain risk drivers and risk mitigating strategies. Several writers propose that some of the influences on contemporary supply chain management in the last decade, such as the globalization of supply chains or the trend towards outsourcing, have exacerbated the risk exposure as well as the impact of any supply chain disruption (Juttner and Burns 2003). As Hendricks and Singhal (2005) showed, not only can the failure to manage supply chain risks effectively lead to a sharp downturn in an organization's share price, which can be slow to recover, but it can also generate conflict amongst the organization's stakeholders. Cousins et al. (2004) identify the wider consequences of a failure to manage risks effectively. These include not just only financial losses but also reduction in product quality, damage to property and equipment, loss of reputation in the eyes of customers, suppliers and the wider public, and delivery delays. Since competitive pressures are often the drivers of risk, Svensson (2002) used the term ''calculated risks'' that a company takes in order to improve competitiveness, reduce costs and increase or maintain profitability. Risk-mitigating strategies on the other hand, are those strategic moves organizations deliberately undertake to mitigate the uncertainties identified from the various risk sources (Miller, 1992).

Supply chain vulnerability is the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences (Juttner and Burns 2003). This lack of knowledge is not surprising given the complexity of today's typical supply chain. Yet, as we will argue, the complexity of the chain - which is tending to increase rather than diminish – brings with it higher levels of risk and hence vulnerability. Whereas from a single firm's perspective, the adverse consequences affect a firm's goal accomplishment (Svensson, 2002), in a supply chain context, they can jeopardize the supply chain's ability to serve effectively the end customer market. Supply chain risk management aims to identify the

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potential sources of risk and implement appropriate actions to avoid or contain supply chain vulnerability. Consequently, it can be defined as: the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole (Juttner and Burns 2003).

<u>2.2 The Importance of Risk for Supply Chain Management</u>

Supply-chain risk management plays an important strategic role in the operation of successful businesses, protecting their most valuable assets while creating a unified, high-performance risk mitigation model. There are many examples that failure to manage supply chain risks effectively can have a significant negative impact on organizations (Mitchell, 1995). As Hendricks and Singhal (2005) showed, not only can the failure to manage supply chain risks effectively lead to a sharp downturn in an organization's share price, which can be slow to recover, but it can also generate conflict amongst the organization's stakeholders. Cousins et al. (2004) identified the wider consequences of a failure to manage risks effectively. These include not just only financial losses but also reduction in product quality, damage to property and equipment, loss of reputation in the eyes of customers, suppliers and the wider public, and delivery delays. There is also evidence that economic, political and social developments over the past decade appear to be increasing the risk of supply chain disruptions as supply chains are getting longer and more complex and are involving more partners due to the increase in global sourcing (Hendricks and Singhal, 2005). Also, the threat of terrorism (such as 9/11), military action, the war in Iraq, diseases (such as H1N1; sometimes called "swine flu") in Mexico, and natural disasters (such as hurricane Katrina which devastated New Orleans) all have the power to disrupt, or cause uncertainty in, supply chains (Elliott, 2005; Peck and Juttner, 2002). In addition, we now appear to be living in an era of rapid change in technologies and product markets, and increasing customer expectations in terms of better products, lower prices, and quicker response times (Hallikas et al., 2002; Handfield and Nichols, 1999). By all the information and evidences together, supply chain risks and external risks impact the

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vulnerability of the supply chain. In addition, although both supply chain and external risks have independent sources, simultaneous occurrence of both risks and interactions between them intensifies the damage to the supply chain.

<u>2.3 The Relationship between Risk and Supply Chain Management</u>

Supply chains that comprise hundreds or even thousands of companies, extending over several tiers, present numerous risks. Broadly, those risks can be classified into two types: risks arising within the supply chain and risks external to it. Risk within the supply chain arises from interaction between constituent organizations across the supply chain. It is caused by sub-optimal interaction and co-operation between the entities along the chain. Such supply chain risks result from a lack of visibility, lack of ownership, self-imposed chaos, just-in-time practices and inaccurate forecasts. External risks arise from interactions between the supply chain and its environment. Such interactions include disruptions caused by strikes, terrorism and natural catastrophes. Any disruption at any stage in a supply chain that can be linked to environmental causes is ascribable to external risks.

The relationship between many aspects of risk and supply chain management has been well documented, especially in the literature on industrial buying behavior (Feldman and Cardozo, 1975). Research in the 1970s indicated that perceived risk and the choice of risk-handling strategies are significant elements in industrial buying decisions (Peters and Venkatesan, 1973; Sheth, 1973). More recent research by Carr and Smeltzer (1997) identified the willingness to take risks as a key component of strategic purchasing. Similarly, Smeltzer and Siferd (1998) maintained that managing risk is central to purchasing management. Perhaps, the most established body of work dealing with risk and industrial purchasing comes from the work of the IMP (Industrial Marketing and Purchasing) Group (Ford et al., 2003). Grounded in the field of industrial marketing, the IMP Group built on Williamson's TCE approach to show that inter-organizational relationships are interactive as opposed to being purely reactive and that an interaction is both interpersonal and inter-organizational (Juttner and Burns 2003). The Group's

work has shown that a key component of managing networks of interactions (i.e. supply chains) is the development of strategies to reduce the risks posed by the inappropriate behavior or performance of particular network members (Ford, 1980; Gadde and Hakansson, 2001). One typical example isEricsson'scrisisin2000.Since a single-source policy was used, a fire accident in its chips' supplier immediately disrupted the material supply. Ericsson's loss was estimated to reach USD 400 million in the T28 model (Norrman and Jansson, 2004).

<div align="center">2.4 Approaches to Managing Supply Chain Risk</div>

Risks from supply chains are sometimes difficult to manage. First, risks are difficult to identify, and their complex interactions with business processes makes them difficult to characterize. Managers often have to be satisfied with qualitative assessments based on little more than intuition. Second, unlike risk management in the financial service industry, there are fewer well-defined tools and techniques for supply chain risk management. Firms typically manage supply chain risks in an ad hoc fashion. Third, risks can arise virtually anywhere in an enterprise's supply chain. They affect – and are affected by – all of a firm's business processes. Successful risk management can play a critical role in improving business performance from the moment a new product is conceived until its end of life. However, supply chain risk sources fall into three categories: 1) environmental risk sources comprise any uncertainties arising from the supply chain-environment interaction that may be the result of accidents (2) organizational risk sources lays within the boundaries of the supply chain parties; and 3) network related risk sources such as lack of ownership, chaos, and inertia, arise from

In this research, we think supply chain risk management processes include risk analysis, risk assessment, risk sharing, risk transfer, and risk reduction. The detail explanations are in the following.

Risk analysis is an important topic in most risk management literature. Risk analysis encompasses the examination of the supply chain and the environment in which the company operates. Different members, dependencies, and the processes within a company need to be

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identified. The data of which would be based on risk discussion workshops to identify potential issues and risks ahead of time before these were to pose cost and/ or schedule negative impacts. The outcome of the risk analysis would be the creation or review of the risk register to identify and quantify risk elements to the project and their potential impact.

Risk assessment is the next step after risk analysis. Risks are appraised, and their consequences are estimated. Statistical methods may be used to determine the probability of a risk occurring, its consequences, and hence its risk level (acceptable, unacceptable, or catastrophic). Risks can be ranked according to the gravity of their consequences as they affect and disturb the supply chain. Risk assessment should be thought of as an ongoing process, not as a one-time project. The process is described as a set of steps that are continually repeated. At the outset, however, there is a startup process that usually is not repeated.

Risk sharing is a self-insurance method of managing or reducing exposure to risk by spreading the burden of loss among several units of an enterprise or business syndicate. Risk retention pools formed with the contributions of participants are often utilized as a way to self insure risks among multiple entities. Risk sharing can be achieved through contracts made with other members of the supply chain as well as through improved cooperation. Risk transfer exists in the form of insurance contracts. For example, responsibility for warehousing and its risks can be transferred to suppliers through just-in-time deliveries and outsourcing can be utilized.

Risk reduction can be achieved through several different means. The methods reduce the financial burden of loss so that, in the event of a catastrophe, a company can continue to function without severe hardship to its financial stability. Miller (1992) presents five main techniques for risk management: (a) control, (b) cooperation, (c) imitation, (d) flexibility, and (e) risk avoidance. The first four can be considered risk reduction techniques. To acquire control of uncertainties for the purpose of reducing risks, companies can engage in political lobbying, acquire market power, and control competitors through different means. A cooperative strategy

is a less strict form of control. Cooperation includes contracts and alliances between different companies, but the level of interaction is not as intense as the cooperation during risk sharing. Imitation of other companies' strategies, including pricing and product development, can reduce risk as well. Flexibility includes diversification and operational flexibility. An organization can attain flexibility by having a diversified product line and making use of several different suppliers (Miller, 1992).

<u>2.5 Quantitative Models of Risk in Supply Chains</u>

Supply chain is a complicated production system. One important change in managing supply chain is the emphasis on integrating activities into key supply chain processes instead of individual functions. With regard to SCRM, managerial aspect may not be the same when considering the inbound and outbound sides. For instance, when we discuss the risk in terms of supplier selection, a major concern is to sustain the flow of raw material. However, on the demand side, financial risk (such as customer's possibility of bankruptcy) may appear more important. The risk in a supply chain is the potential variation of outcomes that influence the decrease of value added at any activity cell in a chain, in which the outcome is described by the volume and quality of goods in any location and time in the supply chain flow (Bogataj and Bogataj, 2007). Christopher and Lee (2004) recognized the increasing risks in the supply chain context and the need for new responses to manage these. Because all business processes carry with them some attendant risks that may affect the whole enterprise, risk management should become a part of the business process analysis tools across a broad range of assets (Seshadri and Subrahmanyam, 2005). Along with the increase in these initiatives, there has been an increase in the potential and magnitude of supply chain risks (Blackhurst et al., 2005). New models and effective coordination schemes for the supply chain are needed to handle disruptions (Yu and Qi, 2004). Choi and Krause (2006) found that reducing the complexities in the supplier base may alleviate costs, but that the buying competitiveness of a company may be reduced. They suggest that, by examining the effects of supplier reduction on transaction costs,

supply risk, supplier responsiveness and supplier innovation that transactions costs may be lowered, but supply risk may increase with a simultaneous decrease in supplier responsiveness. Some of the recent research papers (Faisal et al. 2007) dealing with quantitative models related to risk management in supply chains are presented in Table 2.1 in the following page.

Table 2.1 Quantitative models for supply chain risk management

Authors	Models	Functions
Desheng Dash Wu, Yidong Zhang, Dexiang Wud, and David Olson (2010)	Fuzzy multi-objective programming for supplier selection and risk modeling	Possibility multi-objective programming models are obtained by applying possibility measures of fuzzy events into fuzzy multi-objective programming models.
Neureuther and Kenyon (2008)	Risk Index calculation of supply chain	The index measures the supply chain's vulnerability. Larger index value suggests major and negative affects to the supply chain's competitiveness.
He and Zhang (2008)	Risk sharing in supply chain	Present models for risk-sharing contracts that distribute the random yield risk among parties and evaluate the supply chain performance.
Goh et al. (2007)	Stochastic model for risk management in global supply chain networks	Design an algorithm for treating the multistage global supply chain network problem with profit maximization and risk minimization objectives.
Xiao et al. (2007)	Coordination of supply chain afternoon demand disruptions	Focus on the coordination of supply chain
Gaudenzi and Borghesi (2006)	Measuring risks in the supply chain using the Analytical Hierarchy Process (AHP)	An AHP model is processed to identify supply chain risk factors with a view to improving the objective of customer value
Nagurney et al. (2005)	Supply Chain network model in which both supply side and demand side risk are included in the formulation	Model the optimizing behavior of the various decision makes considering both profit maximization and risk minimization.
Sodhi (2005)	Demand side risk in supply chain planning	Provide two risk measures
Kleindorfer and Saad (2005)	Managing disruption risks in supply chain	Propose two dimensions: first on the strategies aimed at reducing the risk, and second increasing supply chain partners

<u>2.6 Data Envelopment Analysis (DEA)</u>

DEA was first introduced by Charnes, Cooper and Rhodes (1978). DEA is a linear programming-based technique that converts multiple input and output measures into a single comprehensive measure of productivity efficiency. DEA is a nonparametric method for quantitative analysis. DEA is employed to evaluate the efficiency of decision making units (DMUs). DEA has proven to be an effective approach in estimating empirical tradeoff curves (efficient frontiers), and in measuring the relative efficiency of peer units when multiple performance measures are present. However, such an efficiency approach cannot be applied directly to the problem of evaluating the efficiency of supply chains, because some measures linked to supply chain members cannot be simply classified as "outputs" or "inputs" of the chain. In fact, with respect to those measures, conflicts between supply chain members are likely present. For example, the supplier's revenue is an output for the supplier, and it is in the supplier's interest to maximize it; at the same time it is also an input to the manufacturer who wishes to minimize it. Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not properly model and resolve the inherent conflicts.

Narasimhan et al. (2001) proposed a methodology for effective supplier performance evaluation based on data envelopment analysis. The efficiencies derived from the DEA model are utilized in conjunction with managerial performance ratings in identifying supplier clusters, which are categorized into high performers and efficient, high performers and inefficient, low performers and efficient, and low performers and inefficient. They also proposed a variation to the Doyle and Green model, which compares a pair of DMUs each time. In this model, the target DMU (evaluator) not only maximizes its efficiency score but also minimizes the efficiency score of each competitor, in turn. Therefore, the optimal weights of the target DMU may vary depending on the competitor being evaluated. In essence, the target DMU can involve multiple strategies (optimal solutions or the input and output weights), that is, it emphasizes its strengths,

which are weaknesses of a specific competitor. These results can be incorporated into some good overall performers.

DEA also calculates inefficiency values for each supply chain. The inefficiencies are the degrees of deviance from the frontier. Input inefficiencies show the degree to which inputs must be reduced for the inefficient supply chain to lie on the efficient practice frontier. Output inefficiencies are the needed increase in outputs for the supply chain to become efficient. If a particular supply chain either reduces its inputs by the inefficiency values or increases its outputs by the amount of inefficiency, it could become efficient; that is, it could obtain an efficiency score of one. Various types of DEA models can be used, depending upon the problem at hand. The DEA model we use can be distinguished by the scale and orientation of the model. If one cannot assume that economies of scale do not change as the size of the service facility increases, then a variable returns- to-scale (VRS) type of DEA model, the one selected here, is an appropriate choice (as opposed to a constant-returns-to-scale, (CRS) model). Furthermore, if in order to achieve better efficiency, managers' priorities are to adjust their inputs (before outputs), then an input-oriented DEA model rather than an output-oriented model is appropriate. Yang (2003) proposed the facilities layout design methodology by applying Analytic Hierarchy Process (AHP) together with DEA. Layout alternatives were generated by a computer-aided, layout-planning tool. Quantitative decision making unit (DMU) outputs were computed by the same tool. AHP technique was used to evaluate qualitative DMU outputs, and then modified DEA was applied to identify the performance of each alternative.

Liu (2005) modified the DEA method with AHP and fuzzy set theory to develop a more effective performance evaluation method. Normally, the traditional DEA method cannot be used with a small number of business units but their proposed methodology is very efficient when used for comparing and choosing among many small units. In this paper two new target setting DEA approaches are proposed. The first one is an interactive multi-objective method that at each step of the process asks the decision maker (DM) which inputs and outputs he wishes to

improve, which ones are allowed to worsen and which ones should stay at their current level. The local relative priorities of these inputs and outputs changes are computed using the analytic hierarchy process (AHP). After obtaining the candidate target, the DM can update his preferences for improving, worsening or maintaining current inputs and outputs levels and obtain a new candidate target. Thus continuing, until a satisfactory operating point is computed. The second method proposed uses a lexicographic multi-objective approach in which the DM specifies a priori a set of priority levels and, using AHP, the relative importance given to the improvements of the inputs and outputs at each priority level. This second approach requires solving a series of models in order, one model for each priority level. The models do not allow for worsening of neither inputs nor outputs. After the lowest priority model has been solved the corresponding target operating point is obtained. The application of the proposed approach to a port logistics problem is presented.

Zhang (2006) proposed a model for selecting a Third Party Logistics vendor in Fourth Party Logistics. A Fourth Party Logistics is a single organization that provides an entire set of supply chain process. The Third Party Logistics vendor search process is very important because it is a part of Fourth Party Logistics. The authors applied the concept of AHP together with a DEA framework. Both subjective opinions (qualitative data) from decision-makers and quantitative data can be evaluated at the same time with this proposed method. In the context of warehouse performance assessment, DEA would allow a particular warehouse--let's call it the candidate warehouse--to be compared to a large set of other warehouses. DEA would construct a hypothetical composite warehouse from the input and output data for all other warehouses, and this composite warehouse would be compared to the candidate warehouse. The composite would be constructed in such a way that it produces at least as much output as the candidate warehouse, but uses the minimum possible resources. In this sense, it would be a hypothetical "best practices" warehouse. The DEA "score" for the candidate warehouse would be reported as a percentage. Suppose the score was 75%. The interpretation would be that the

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composite warehouse used no more than 75% of any single resource used by the candidate warehouse. In other words, based on the "best practices" composite warehouse, it could be argued the candidate warehouse could reduce its resource usage by 25%.

A fundamental assumption behind this method is that if a given producer, A, is capable of producing Y(A) units of output with X(A) inputs, then other producers should also be able to do the same if they were to operate efficiently. Similarly, if producer B is capable of producing Y(B) units of output with X(B) inputs, then other producers should also be capable of the same production schedule. Producers A, B, and others can then be combined to form a composite producer with composite inputs and composite outputs. Since this composite producer does not necessarily exist, it is typically called a virtual producer. Tavares (2002) collected the data about DEA publications from 1978 to 2001. He found more than 3200 publications, including research papers, dissertations, journal papers, and book chapters, related to DEA in many areas. Some of them related to logistics and performance measurement, but there were very few related to reverse logistics.

DEA has proven to be an effective approach in estimating empirical tradeoff curves (efficient frontiers), and in measuring the relative efficiency of peer units when multiple performance measures are present. However, such an efficiency approach cannot be applied directly to the problem of evaluating the efficiency of supply chains, because some measures linked to supply chain members cannot be simply classified as "outputs" or "inputs" of the chain. In fact, with respect to those measures, conflicts between supply chain members are likely present. For example, the supplier's revenue is an output for the supplier, and it is in the supplier's interest to maximize it; at the same time it is also an input to the manufacturer who wishes to minimize it. Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not properly model and resolve the inherent conflicts. Zhu (2003) proposed that DEA methodology be used to measure a supply chain's efficiency. A supply chain's efficiency is evaluated as a whole system and each member individually. This

model helps users determine how to improve the current system to reach the best practice. The advantage of this model is no requirement of ideal assumptions, such as constant demand and known lead-time for delivery. The general supply chain model, composed of suppliers, manufacturers, distributors, and retailers, was presented to test this methodology. Supply chain system is considered as an integrated input output system. To consider the performance of the supply chain, inputs and outputs of each member need to be considered. In this case, inputs and outputs are classified in two categories, direct inputs/outputs and intermediate inputs/outputs. Direct inputs/outputs are independent variables while intermediate inputs/outputs are dependent variables. For example, intermediate outputs of a supplier can be considered as intermediate inputs of a manufacturer.

Wong et al. (2007) developed two DEA models – the technical efficiency model and the cost efficiency model in supply chain performance measurement. The models are further enhanced with scenario analysis to derive more meaningful business insights for managers in making resource planning decisions. Evaluation of supply chain efficiency, using DEA, has its advantages. In particular, it eliminates the need for unrealistic assumptions inherent in typical supply chain optimization models and probabilistic models; e.g., a typical EOQ model assumes constant and known demand rate and lead-time for delivery. These conventional approaches typically fail, however, to consider the cooperation within the supply chain system. Using a seller-buyer supply chain as an example, the current paper develops two classes of DEA-based models for supply chain efficiency evaluation. The first assumes that the relationship between the buyer and the seller is modeled as a non-cooperative two-stage game, and the second assumes the buyer and seller act in a cooperative sense.

2.7 Rough Data Sets Theory

Rough data sets theory has been introduced in the early 1980s by Pawlak (1982). The theory was based on the discernibility of objects, and it has become a well researched tool for knowledge discovery. The rough set philosophy is founded on the assumption that with every

object of the universe of discourse we associate some information. The rough set method classifies multiple objects into similarity classes containing objects that are indiscernible with respect to previous occurrences and knowledge information. The principle of the rough sets is a new mathematical approach to imprecision, vagueness and uncertainty in data analysis. The basic assumption of rough data sets theory is that information is presented and perceived up to a certain granularity. The main goal of the rough data sets analysis is induction of approximations of concepts. The rough data sets theory can be used for feature selection, feature extraction, data reduction, decision rule production, and pattern extraction. It also helps to reduce the number of factors with applications primarily within the data mining. Rough set theory has advantages over other approaches for data-mining that typically utilize multivariate statistics that require specific parametric assumptions. The rough set theory provides efficient algorithms for finding hidden patterns in data, minimal sets of data or data reduction, evaluating significance of data, generating sets of decision rules from data.

Greco et al (2001) explained Rough Data Sets Theory in mathematical terminology as follows:

Any subset X of the universe may be expressed in terms of these blocks either precisely (as a union of elementary sets) or approximately only. In the latter case, the subset X may be characterized by two ordinary sets, called lower and upper approximations. A rough set is defined by means of these two approximations, which coincide in the case of an ordinary set. The lower approximation of X is composed of all the elementary sets included in X (whose elements, therefore, certainly belong to X), while the upper approximation of X consists of all the elementary sets which have a non-empty intersection with X (whose elements, therefore, may belong to X). Obviously, the difference between the upper and lower approximation constitutes the boundary region of the rough set, whose elements cannot be characterized with certainty as belonging or not to X, using the available information. The information about objects

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from the boundary region is, therefore, inconsistent or ambiguous. The cardinality of the boundary region states, moreover, to what extent it is possible to express X in exact terms, on the basis of the available information. For this reason, this cardinality may be used as a measure of vagueness of the information about X.

Greco et al (2001) presented two extensions of the classical rough set approach based on generalizations of the basic concept of indiscernible state: "the first is the similarity relation and not necessarily symmetric and transitive; the second is a specific indiscernible relation handling missing values in objects' description". They also introduced a distinction between classification and sorting problems as follows:

The sorting problem involves preference-orders on domains of considered attributes (criteria) and among decision classes. To deal with multi-criteria sorting problems rough set approximation based on dominance is proposed in this section. Furthermore, in order to handle missing values in multi-criteria sorting problems a specific dominance relation is proposed. The choice and ranking problems are considered. They are based on pair wise comparisons of objects, so the rough set approach concerns in this case approximation of a preference binary relation by specific dominance relations. These dominance relations can be multi-graded, when the preferences with respect to considered criteria are cardinal, or without any degree of preference, when the preferences with respect to criteria are ordinal. They also presented some results about equivalence between preference models of conjoint measurement and preference models expressed in terms of decision rules induced from rough approximations. Some important characteristics of the rough set approach make of this a particularly interesting tool in a number of problems and concrete applications. With respect to the input information, it is possible to deal with both quantitative and qualitative data, and inconsistencies need not to be removed prior to the analysis. With reference to the output information, it is possible to acquire a

posteriori information regarding the relevance of particular attributes and their subsets to the quality of approximation considered in the problem at hand, without any additional inter-attribute preference information. Moreover, the final result in the form of ``if..., then...'' decision rule, using the most relevant attributes, is easy to interpret.

Rough set based data analysis starts from a data table called a decision table, columns of which are labeled by attributes, rows – by objects of interest and entries of the table are attribute values. Any set of all indiscernible or similar objects is called an elementary set, and forms the basic elements of knowledge about the universe. Any union of some elementary sets is referred to as a crisp or precise set – otherwise the set is rough or vague sets. Attributes of the decision table are divided into two disjoint groups called condition and decision attributes, respectively. Each rough set has boundary-line cases, e.g. objects which cannot be with certainty classified, by employing the available knowledge, as members of the set or its complement. If a decision rule uniquely determines decision in terms of conditions, then the decision rule is certain. Otherwise, the decision rule is uncertain. Decision rules are closely connected with approximations. Rough set theory provides systems designers with the ability to handle uncertainty. If a concept is not definable in a given knowledge base, rough sets can approximate with respect to that knowledge. Generally speaking, certain decision rules describe lower approximation of decisions in terms of conditions, whereas uncertain decision rules refer to the boundary region of decisions.

Jaaman et al (2009) found that rough sets can be an applicable and effective tool for stock market analysis through a case study on trading Kuala Lumpur Composite Index and individual firms listed in Bursa Malaysia,

The ability of rough set approach to discover dependencies in data while eliminating superfluous factors in noisy stock market data deems very useful to extract trading rules. Predictive modeling is a form of data mining. Data mining is a computational intelligence discipline that contributes tools for data analysis, discovery of

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new knowledge, and autonomous decision making. The task of processing large volume of data has accelerated the interest in this field. As mentioned in Mosley data mining is the analysis of observational datasets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data owner. Predictive modeling takes these relationships and uses them to make inferences about the future. One approach for data mining is to use rough sets. Rough set can be used to analyze incomplete or uncertain information. The rough set theory is normally used for reduction of data sets, finding hidden data patterns and generation of decision rules. In application, rough set techniques are often applied to stored data to produce a set of rules that can be used to predict values.

Joseph Herbert and JingTao Yao at University of Regina, Saskatchewan, used time series data from the New Zealand stock exchange, rough set analysis was used to create rough rules. The rules, after being tested for accuracy, were used as a forecasting tool to predict future configurations of data. Rough sets succeed in this task since they are able to describe uncertain data from information derived from precise, certain data and apply rough set theory in the analysis of New Zealand stock exchanges. A general model for time series data analysis was presented. The experimental results show that forecasting of the future stock movement, with reasonable accuracy, could be achieved with rough rules obtained from training data.

Kusiak (2001) reviewed the basic concepts of rough set theory and other aspects of data mining are introduced; then found the rough set theory offers a viable approach for extraction of decision rules from data sets; the extracted rules can be used for making predictions in the semiconductor industry and other applications. This contrasts other approaches such as regression analysis and neural networks where a single model is built. One of the goals of data mining is to extract meaningful knowledge. The power, generality, accuracy, and longevity of decision rules can be increased by the application of concepts from systems engineering and evolutionary computation introduced. A rule extracted from a data set and the

corresponding features can be considered as one of many models describing a data set. This property contrasts other approaches such as regression analysis and neural networks where essentially one model with a fixed set of features is constructed for the entire population. The existing concepts of data mining were expanded with rule structuring and data engineering. All these concepts follow the evolutionary computation approach extending longevity of the knowledge. Kusiak pointed out the patterns formed by the rules extracted with rough set algorithms differ from the patterns generated by algorithms of other types, e.g., decision tree algorithms. The limited overlap among features included in the rough set rules make them suitable for forming meta-structures of interest to semiconductor applications.

2.8. Healthcare Management

Healthcare is an expensive, complex, universally used service that hugely affects economies and the quality of life (Berry and Bendapudi, 2007). In 2010, the most recent year for which figures are available, the U.S. spent $2.6 trillion on healthcare, or $8,402 per person, according to the Centers for Medicare & Medicaid Services. However, the U.S. spent about $2 trillion, or $7,000 per person, on healthcare in 2006 (Berry and Bendapudi, 2007). The healthcare industry in the U.S. accounts for 16 percent of GDP, whereas the European Union average is about 8 percent (Baltacioglu et al., 2007). There are several reasons for the growth of the healthcare industry. The most important one is decreasing fertility rates and increasing life expectancy. Several challenges like the complexity of processes, the need for efficient utilization of resources, the need to control the workload of the healthcare employees, and the public pressure on healthcare institutions to control costs while increasing the quality of services are involved with the healthcare industry (Baltacioglu et al., 2007). Healthcare is ubiquitous with emotionally and politically charged debate regarding its design and accessibility to the public at large, yet one point that most people agree on is that there exists much potential for improving the efficiency and effectiveness of health care delivery. All these challenges prove the importance of implementing the supply chain management topics in healthcare organizations.

Most of the discussion in literature focuses on supply chain operations in the healthcare industry from a manufacturing viewpoint (Fineman and Kapadia, 1978; Bier, 1995; Rivard-Royer et al., 2002), but there are few discussions about applying service supply chain management principles to healthcare organizations.

Mice Associates (http://www.miceassociates.co.uk/files/baseline_model_1.pdf, 2008) described and summarized the healthcare supply chain as following diagram:
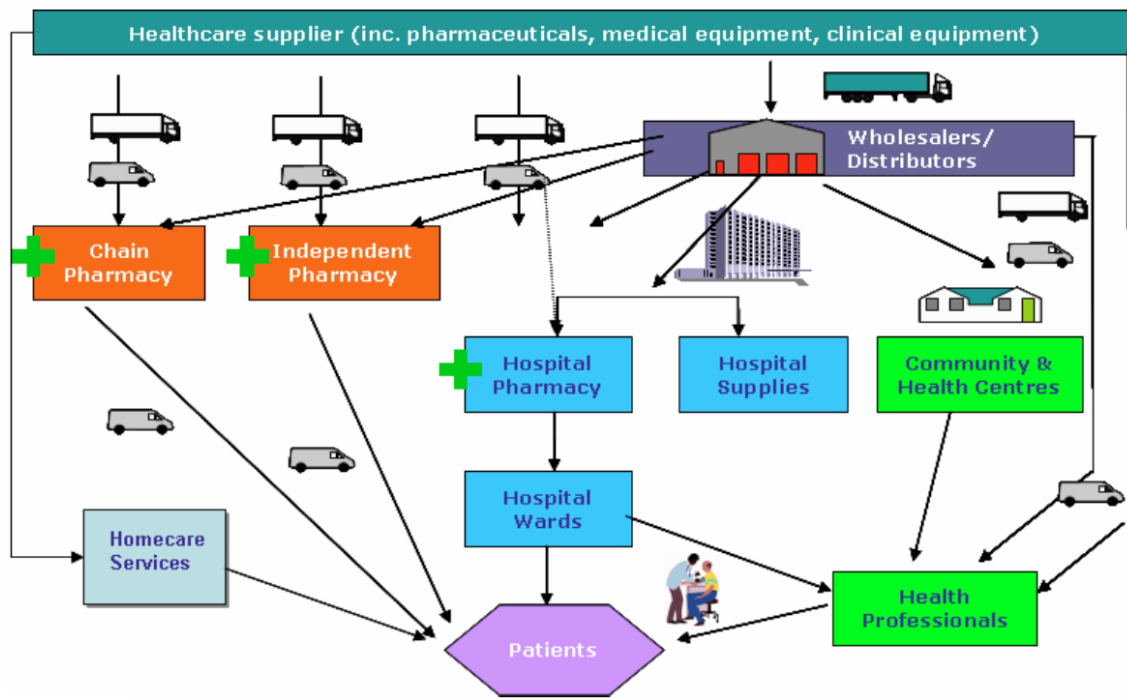
Figure 2.1 Healthcare supply chain (Mice, 2008)

McKone-Sweet et al (2005) showed that supply chain management is not readily adaptable in the health care industry for the following reasons: continually changing technology, difficulty in predicting patient load and required products, lack of standardization, lack of capital, and lack of training/education in supply chain management practices. In addition, there are other environmental, organizational, and operational barriers some of which include the role of

GPO's, unclear executive commitment, lack of metrics and limited use of data/IT. McKone-Sweet et al corroborated the conclusions from the lit review in that the most often cited barriers were lack of executive support, misaligned incentives, lack of education, and data collection and measurement. Responses raised an interesting question regarding the value of Group Purchasing Organizations (GPO) in the supply chain. Outcomes were mixed with respect to the GPO's ability to deliver cost savings. McKone-Sweet et al recommendations for managers are outlined in a table by environmental, organizational and operational contexts. Environmental highlights include having a clear strategy, pursuing standardization, and possibly using GPO's to better educate. At the organizational level, it is critical that upper management promote and engage in the supply chain management process, recognizing that implementation will not just cut costs, but will raise customer and clinician satisfaction. Finally, developing metrics will promote improvement operationally. Other ideas are also mentioned. McKone-Sweet et al pointed to some potential further research on the following topics: the relationship between levels of executive commitment to supply chain management and supply chain performance, fees and structures of GPO's, how supply-chain performance is affected by cross-organizational involvement, the effect of metrics and review processes on supply chain performance, how the use of information systems in decision making will affect supply chain performance, the correlation between higher levels of certification and/or executives who possess supply chain knowledge and supply chain performance, and which types of hospitals best benefit from GPO's.

Baltacioglu et al. (2007) proposed a general supply chain model for services. The model includes some managerial activities to be performed for effective management of service supply chains. These activities are demand management, capacity and resources management, customer relationship management, supplier relationship management, order process management, and service performance management. The proposed model is implemented for the healthcare industry. Reducing the variations in every supply chain is another important

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challenge for supply chain managers. This research focuses on analyzing the amplification effects and variations in the interior hospital service supply chains.

Shah et al (2008) via case study explored relational coordination theory that financial incentives and contractual mechanisms are commonly used as governance mechanisms in supply chain relationships. Shah et al explored this mechanism in the context of a health care service supply chain focused on treating elevation myocardial infarction, the most severe kind of heart attack. This context is chosen because the key service providers in the service supply chain are not part of an integrated health care organization and do not have contractual or financial obligations to one another. Rather, each actor in this supply chain is contracted with and paid by a separate 3rd party entity. Shah et al identified a case in Minneapolis, MN, USA where such a supply chain underwent a transformational improvement project with resulting performance metrics significantly better than the average of other similar supply chains. Shah et al used parallels with lean production to inform their analysis of the improvements achieved in this health care service supply chain. Lean production is a process used in manufacturing to eliminate waste and drive continuous improvement through employee participation, leadership commitment and continuous improvement teams. Its application in services has mostly been confined to repetitive back-office type work. This case study, however, takes a unique approach by applying the lens of lean principles to the front office part of a service supply chain – the process that interacts directly with the customer. Through ethnographic interviews, direct observations and analysis of archival database information, Shah et al discovered the critical role that relational coordination theory played in this supply chain's quest for radical improvements. Relational coordination theory is motivated by shared goals, shared knowledge and mutual respect.

Ross and Jayaraman (2009) focused primarily on the purchasing activities in health care and how purchasing managers can most efficiently procure a bundle of products that include remanufactured or refurbished items. The market for refurbished medical equipment

continues to increase. This is due to the fast pace at which the price of new medical equipment is also increasing. While some hospitals prefer to always procure the newest and latest equipment, some try to procure refurbished equipment on non-critical items. One unique challenge faced by suppliers of refurbished medical equipment is achieving economies of scale. Suppliers increasing find that the most viable sales strategy of refurbished equipment is to create product bundles where hospitals purchase a bundle of complementary goods (mixture of new and refurbished equipment) rather than offer sale of individually priced goods. This creates a unique purchasing decision for hospitals that must decide if the benefits of such a bundle exceed the costs of acquiring products that may not be needed in the short-term. Ross and Jayaraman proposed a mathematical model that can be used to balance such benefits and costs when a mixed bundle of new and refurbished equipment is offered. A minimization cost function is first presented that includes the cost of both discounted and non-discounted items, the cost of adding a new supplier to a firm's supplier base and the storage costs of excess items acquired in a bundle offering. The solution to the proposed minimization function is classified as NP-Hard, so the authors propose the application a six-step heuristic process known as simulated annealing. Ross and Jayaraman tested the heuristic by applying the steps to a simplified sourcing problem that is solved using both the optimization function and then the simulated annealing heuristic. The heuristics performs well and its validity is established and then applied to a case study with actual data that the authors acquire from a large health care organization.

Sinha and Kohnke (2009) took a macro perspective to explore the global health care management supply chain and offer three new frameworks that can guide future research in this subject area. The first framework proposed is the concept of health care as a bundle. This framework is presented as a group of multiple concentric circles with the following categories (from center to outer ring): diet & exercise, drugs, devices, invasive procedures, new biologics, travel & lodging, and payment & reimbursement. The second framework proposed is a macro

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perspective on the delivery of health care to the end customer. This model shows the flow of services from the interconnected industry groups – medical devices, pharmaceuticals and biotech companies to health care delivery entities who then deliver care to customers. Health care financial services connect the three industry groups to the health care delivery entities by providing the financial backing necessary to sustain the entire supply chain. While this particular framework is insightful from the standpoint of how the industries interact, there is one conspicuously missing entity that probably deserves recognition as a stand-alone entity - medical schools. Medical schools play a significant role in balancing the macro equation of supply and demand in the global health care supply chain. The third proposal made by Sinha and Kohnke is the 3-A framework. The three components of this framework are affordability, access, and awareness. These components serve as important levers in helping match supply and demand. Affordability is the subject of much debate across nations and drives different solutions in different countries. Access is another issue that draws much global attention and has driven the creation of many non-profit organizations that seek to provide access to those in need. Awareness is the third pillar of this framework and involves the need to educate and increase awareness of the types of services available and the benefits of such services.

Services are different from goods and require different strategies. Healthcare shows how much services can differ. Healthcare is probably the most personal and important service which consumers buy. There are several characteristics common between healthcare and other services. Healthcare services are intangible in essence. Treatment combines intangible services supported by goods (e.g., ER services in a well-equipped emergency room) and tangible goods are supported by intangible services (e.g., pharmacy services). However, there are also several differences: a great risk involved with the healthcare services, customers are sick and reluctant, and employees are stressed (Berry and Bendapudi, 2007). These characteristics make healthcare services differ from other types of services. Thus, managing the healthcare service supply chains of services should also be different.

Enyinda (2008), in his dissertation, applied Analytic Hierarchy Process (AHP) method in modeling risk management for the pharmaceutical industry global supply chain logistics, and indicated the regulation/legislation risk is the most important risk factor, followed by operational risk and reputational risk. Enyinda identified pharmaceutical global supply chain logistics risk sources, estimated risk impact, generated risk priorities and evaluated them in terms of the most important risks. Enyinda pointed the layers of pharmaceutical global supply chain logistics risks are regulatory approval, foreign exchange rates, legal liability, changes in competitive environment, political instability, supplier failure, natural disaster, strategic risk, and intellectual property infringement, etc. Enyinda also showed the following diagram for Convoluted Pharmaceutical Global Supply Chain Logistics:
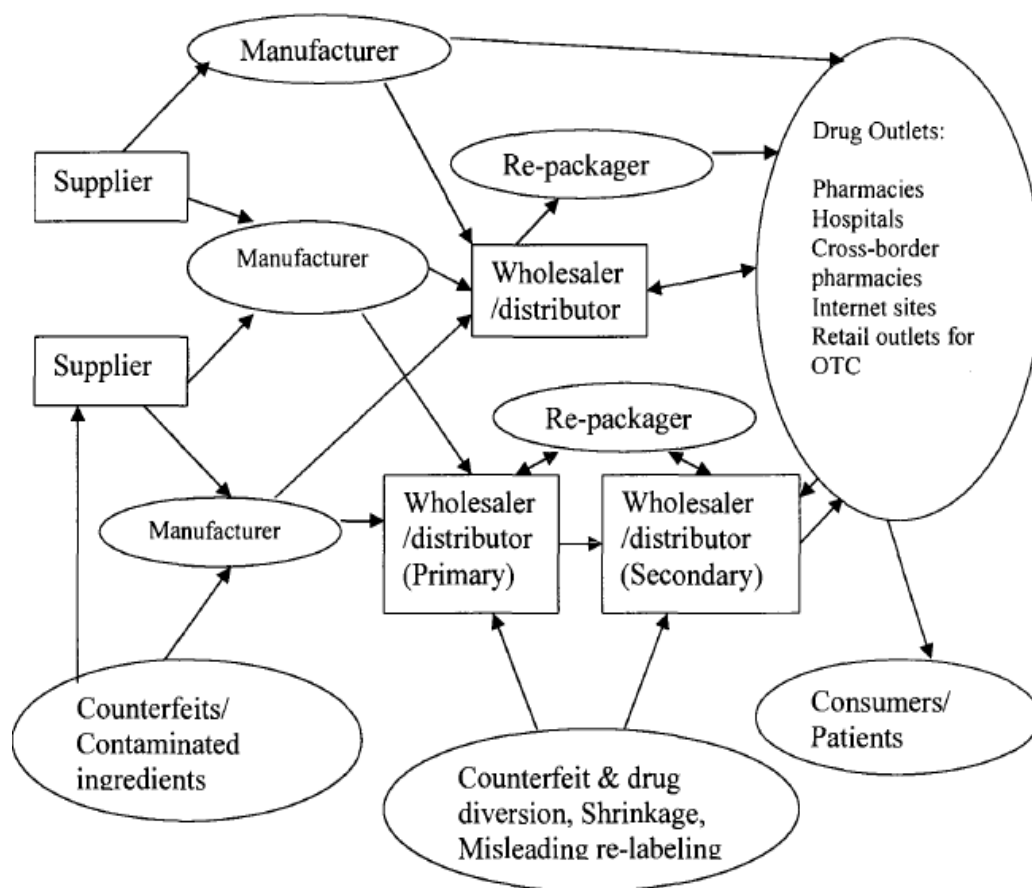
Figure 2.2 Convoluted pharmaceutical global supply chain logistics

Enyinda, Briggs, and Hawkins (2009) analyzed the strategic risk management in pharmaceutical supply chain in Ghana, and found the counterfeit risk is the most important risk; the best strategy to deal with the counterfeit risk is to avoid and reduce the risks.

Fleischhacker (2009) investigated production and inventory decisions made within clinical trial supply chains in order to reduce drug supply costs. He found that drug supply costs frequently account for a significant portion of pharmaceutical companies' R&D spending.

CHAPTER 3

METHODOLOGY

3.1 Supply Chain Risk and Performance

Supply chain risk and supply chain risk management have, along with financial risk and risk management, become dominant features in management. Supply chain risks contribute to the overall business risks. Managers are continuously being challenged, because there are many unexpected and unpredictable disruptions that add to the risks of a supply chain, and therefore, an important measure of management performance is the ability to successfully manage such risks. In practice the principal may seek to specify the performance criteria and identify the associated risks in relation to its portfolio of individual suppliers or distributors. Consequently, each agent will seek to negotiate an agreement (i.e. contract) in terms of performance, risk sharing and reward outcomes. This observation points to the need for effective methodology for anticipating, identifying, classifying and assessing risks in supply chains.

The risks being addressed here are those that potentially influence the ongoing performance of the business in terms of effectiveness and/or efficiency and not just those that may result in a crisis or the failure of the enterprise. The nature of risk assessments can be formal to informal, as well as quantitative or qualitative. The first step in their supply risk assessment approach is determining the probability of a risk event occurring, which can be classified as high, medium, and low chance. The second step consists of estimating the likely problem duration, which can be based on past experience.

Decisions relating to changes in the supply chain structure and relationships should involve the analysis and evaluation of the associated potential outcomes in terms of

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performance and risks. Performance and risk are interconnected and require deliberate and robust implementation of supplier management tools and controls to maximize performance while controlling the consequential risks. Conventional wisdom suggests that risk and performance are directly related, such that higher risk taking will typically generate higher potential returns. This relationship, although initiated within the context of financial markets relating to equity transactions, is generally held to apply more widely within business decision-making. The other step is investigating the business performance impact of the risk event. Use of a multi-functional team is recommended to quantify the size of the potential problem and its effect on business profitability and performance.

Members of the supply chain are becoming increasingly inter-dependent, suggesting an inter-locking of interests. They involve a chain of decision nodes, networked together; each node plays some role in adding value to the performance of every member of the chain, although this may be indirect and often minimal; each node has the potential to contribute to the risk profile of the decision to be taken, both positively and negatively; and correspondingly, each node exerts some influence on the successful implementation of the management decisions and risk resolution. This is interesting, because it clearly illustrates that decisions taken at the individual node have potential chain-wide implications, more often than not these implications are unseen in the immediate vicinity of the node, but may resurface further up or down the supply chain.

There are potentially an infinite number of factors exposing the business to undesirable consequences in terms of performance and risk. The term driver has been introduced to differentiate those factors likely to have a significant impact on the exposure (i.e. likelihood and consequences) to undesirable performance and risk outcomes, or possibly providing the opportunity to improve performance, albeit with increased risk. For example, the decision to develop a new direct channel to the consumer, bypassing existing distribution channel members, would expose the business to new risks both from the reaction of the consumer and the

retaliatory actions of the other channel members, although possibly improving potential performance outcomes. Ritchie and Brindley(2007) developed a model linking supply chain business performance as

Aggregate Business Performance = f {(Profit), (Risk), (Time)}

They illustrated the possible range of outcomes between perceived risk and performance as the following:

Table 3.1 Risk and performance relationship

	Performance outcome	
Risk Perceived	High	Low
High	A	B
Low	C	D

The leading edge supply chain management system is able to consider all the relevant risks and performance in the procurement, manufacturing, distribution, transportation and warehousing operations simultaneously. The range between "high" and "low" risk displayed in above table may incorporate an infinite number of intermediate risk perceptions or a scale. Similarly, performance outcomes may prove equally diverse within the range. Conventional wisdom, like financial investment analyst, suggests that risk and performance are directly related, such that higher risk taking will typically generate higher potential returns, but that doesn't mean higher risk taking will typically generate higher performance in supply chains. Only four out of this infinite set of potential risk-performance outcomes are illustrated as exemplars. Cell A demonstrates the relationship of high risk taking resulting in potentially high rewards/performance, the impetus for risk taking. The very presence of risk also suggests that the outcome may prove less rewarding as displayed in Cell B. Correspondingly, low risk situations and opportunities may typically be perceived as generating low levels of performance

as in Cell D, although high levels of performance outcomes may also be achieved as in Cell C situation.

The existed supply chain risk evaluation methods and quantitative models require some risk parameter values like the probability events occur, the impact of detrimental events, and the weight/importance values of risk factors. In particular, it is not clear to distinguish risk and uncertainty in supply chain operations. Risk sometimes is interpreted as unreliable and uncertain resources creating supply chain interruption, whereas uncertainty can be explained as matching risk between supply and demand in supply chain processes. We believe that two dimensions are important in discussing risk: the outcome of risk impact and expectation of risk sources. In addition to the usual financial measures used to measure risk, the supply chain risk now also needs to take into consideration other specific indicators such as the delivery rate and percentage of order fulfillment. This measurement is further complicated by the influence of manufacturing capacity and other influential operational constraints. In view of the increasing risk measures in supply chain, not many companies will know how to gauge the risk of their supply chain. The rise of multiple risk measures has rendered the efficiency measurement task difficult and unchallenging. Hence, a tool to effectively measure the supply chain risk is greatly needed.

We consider supply chain risk as in the risk associated with performance variability of supply chain. A generic and well-established definition of performance and risk is used, dividing this construct into efficiency and effectiveness. Efficiency is regarded in a resource input-output sense such that the greater volume of outputs for a given volume of inputs then the greater the efficiency. Effectiveness relates to the degree to which the planned outcomes are achieved. Achievement of the target market share may be seen as highly effective although the use of advertising expenditure in doing so may be regarded as inefficient in performance terms. In practical terms, rather than asking, for a given efficient decision making unit, either how much increase in inputs is possible, or how much reduction in outputs is possible, while still retaining

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its efficient status, our model describes the minimum movement in both directions needed to reach the frontier generated by the remaining decision making units.

3.2 Supply Chain Model

A supply chain is composed of 4 main components which are Supplier, Manufacturing Plant, Distribution Center/Warehouse, and Retailers/Customers. The function and assumption of each component's function in this model will be explained as follows:

Supplier – will deliver raw materials to manufacturing plants.

Manufacturing Plant – will manufacture the products by using raw materials from suppliers and will employ returned parts or assemblies from the Recovery Facility.

Manufacturing Plants need to specify the quantity and type of the materials that they need to buy from suppliers at each period that could be determined by the model. Products from manufacturers will be delivered to the Distribution Centers or Warehouses. Not all of the produced products are delivered to the Distribution Center. Plants can decide to deliver all products, or part of them, because plants can keep some inventory (which could be finished goods or just materials used to manufacture products). Manufacturing Plants could use the parts, materials or assemblies from a previous period that are kept in inventories, together with new materials purchased from suppliers to produce the products at that period. We assume that products will be manufactured within the period.

Distribution Center – will collect the demands from customers and retailers and then inform Manufacturing Plants. After receiving products from manufacturers, the Distribution Center will distribute them to retailers or customers to fulfill the demand. In this model, stock-out can happen to the Distribution Center when demands exceed the inventory level. In a stock-out event, this model assumes that insufficient demands will be fulfilled at the next period.

Retailers or Customers – get products from manufacturers via Distribution Centers or Warehouses. Quantities of products depend on demands.

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We hope to get benefits of supply chain performance and risk management from the following areas: 1) throughput improvements: better coordination of material and capacity prevents loss of utilization waiting for parts; 2) cycle time reduction: by considering constraints as well as its alternatives in the supply chain, it helps to reduce cycle time; 3) inventory cost reductions: demand and supply visibility lowers the requirement of inventory levels against uncertainty; ability to know when to buy materials based on the customer demand, logistics, capacity and other materials needed to build together; 4) optimized transportation: by optimizing logistics and vehicles loads; 5) increase order fill rate: real-time visibility across the supply chain (alternate routings, alternate capacity) enables to increase order fill rate; 6) analysis of the supply chain management can help to predict propagation of disturbance to downstream; 6) increase customer responsiveness: understanding the capability to deliver based on availability of materials capacity and logistics.

3.3 Supply Chain Risks

To be able to discuss the risks of supply chain, it is necessary to review briefly the definition of risk. Dictionaries define it as a possibility of losses or harmful consequences. Already this common sense definition reveals the two essential components of risks: losses and uncertainty about their occurrence and amount. The assessment and management of risks require also measurement of risks. A utility theoretic approach measures uncertainties by probability distributions. Transactions between producing and consuming units may become more complex and costly if they are carried out between external plants and companies, rather than within the same plant and company. The transition to external suppliers may cause both administrative and material transactions to become more complex and extensive. This may include orders, order confirmations, delivery notifications, invoices, extra control activities, packing/unpacking activities, and so on, which would not have been necessary with in-house production. Increased co-operation of companies in a supply chain causes transfer of risks between the companies; it may decrease some risks and increase others. As this is always

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dependent on the circumstances of each network, company, branch and even on the economical stat us or cycle, no generic and complete assessment can be given. Thus each company should analyze its status from its own perspective. Risks of the companies are related to their objectives. There are also operative dependency relationships between activities and material flows in procuring organizations and corresponding activities and material flows in the supplying organizations. A reason for strong dependency is that companies avoid different types of safety stocks and safety times in material and information flows. The main objective of the owners is usually that the company should be profit-making. In addition the company may have other objectives, like growth or future position, and the time range viewed may be different for different companies. However, management of profitability is usually also needed to survive and to achieve possible other objectives. The risks initiate from uncertainty. The main uncertainties for companies come from two sources: customer demand and customer deliveries. The demand of the end customer does not guarantee the business for a supplier. Delivery uncertainties are connected to the ability to manage the costs, time and quality as well as the responsibilities for confidential information. An additional uncertainty is the future requirements; how the current orientation, knowledge and resources should be maintained and modified to succeed in the future.

Supply Chain managers assess their suppliers based on past experience and anticipated supply trends. The managers focus on estimating the expected impact on Earning Before Internal Texas (EBIT), the probabilities of risk events occurring, and the measures or activities to be implemented for reducing risk. Estimates are made for both the current and upcoming fiscal year. Within the process there is a trade-off between accuracy and speed. More accurate probabilities and the effects on earnings can be derived if additional information is obtained. However, deriving more exact data means that a significant degree of managerial effort would be required by commodity managers that may not be offset by the benefits from engaging in supply risk assessment and measurement processes. In addition, the purpose of

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estimating supply risk is not to determine exact probabilities or effects on earnings. Instead, the process facilitates the communication of possible supply failures between the commodity and supply line managers, and the risk manager. We may need to consider the following risks: 1) ANSI Compliance, for quality, suppliers must be able to comply with ANSI (American National Standards Institute) standards as a minimum requirement. A more rigorous second, product quality, assesses the likelihood of the supplier not being able to provide an excellent product in terms of quality. Since the ANSI standards represent the minimum acceptable quality levels for the company, product quality is considered to be much more stringent; 2) Product Quality(defective rate); 3) Product Cost; 4) Competitor Cost; 5) Demand Risk; 6) Supplier Fulfillment Risk; 7) Logistics Risk; 8) On-Time and On-Budget Delivery; 9) Order Fulfillment Risk; 10) Wrong Partner Risk; 11) Overseas Risk; 12) Supplier Risk; 13) Supplier's Supplier Management; 14) Engineering & Innovation; 15) Transportation Risk; 16) Sovereign Risk; 17) Natural Disasters / Terrorists. In addition, the process prioritizes supply risk that warrants managerial attention and provides guidance for proactively reducing the chance that risk events transpire. The commodity and supply line managers are responsible for managing supply risk, and headquarters are responsible for reporting incidents and provide additional resources when required.

Traditionally supply chain performance measures were based on price variation, rejects on receipt and on time delivery. For many years, the selection of suppliers and product choice were mainly based on price competition with less attention afforded to other criteria like quality, reliability, etc. More recently, the whole approach to evaluating suppliers has undergone drastic change. The evaluation of suppliers in the context of the supply chain (efficiency, flow, integration, responsiveness and customer satisfaction) involves measures important at the strategic, operational and tactical level. Strategic level measures include lead time against industry norm, Quality level, Cost saving initiatives, and supplier pricing against market.

Tactical level measures include the efficiency of purchase order cycle time, booking in procedures, cash flow, quality assurance methodology and capacity flexibility. Operational level measures include ability in day to day technical representation, adherence to developed schedule, ability to avoid complaints and achievement of defect free deliveries. Suitable metrics are as follows:

(1) Range of product and services: a plant that manufactures a broad product range is likely to introduce new products more slowly than plants with a narrow product range. Plants that can manufacture a wide range of products are likely to perform less well in the areas of value added per employee, speed and delivery reliability. This clearly suggests that product range affects supply chain performance.

(2) Capacity utilization: From the above assertion, it is clear that the role-played by capacity in determining the level of activities in a supply chain is quite important. Capacity utilization directly affects the speed of response to customer demand through its impact on flexibility, lead time and deliverability.

(3) Number of faultless notes invoiced: An invoice shows the delivery date, time and condition under which goods were received. By comparing these with the previously made agreement, it can be determined whether perfect delivery has taken place or not, and areas of discrepancy can be identified so that improvements can be made.

(4) Flexibility of delivery systems to meet particular customer needs: This refers to flexibility in meeting a particular customer delivery requirement at an agreed place, agreed mode of delivery and with agreed upon customized packaging. This type of flexibility can influence the decision of customers to place orders, and thus can be regarded as important in enchanting and retaining customers. Flexibility of the factors by which supply chains compete, flexibility can be rightly regarded as a critical one. Being flexible means having the capability to provide products/services that meet the individual demands of customers. Some flexibility

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measures include: (i) product development cycle time, (ii) machine/toolset up time, (iii) economies of scope.

(5) Customer query time: Customer query time relates to the time it takes for a firm to respond to a customer query with the required information. It is not unusual for a customer to enquire about the status of order, potential problems on stock availability, or delivery. A fast and accurate response to those requests is essential in keeping customers satisfied.

(6) Information processing cost: This includes costs such as those associated with order entry, order follow/updating, discounts, and invoicing. On the basis of survey results from various industries, Stewart (1995) identified information processing cost as the largest contributor to total logistics cost. The role of information technology is shifting from a general passive management enabler through databases, to a highly advanced process controller that can monitor activities and decide upon an appropriate route for information.

Based on the above analysis on the supply chain risk and performance evaluation, we explore the real-world indictors of supply chain risk and performance. The input indicators are:

(1) Additional costs for cancellation due to lack of planning.

(2) Additional costs for transportation due to lack of planning.

(3) Additional costs for material obsolescence.

(4) Unexpected material price increase due to allocation.

(5) Unexpected material price increase due to yield problems.

(6) Unexpected material price increase due to change of specification.

(7) Missing parts due to late delivery.

(8) Missing parts due to supplier quality defects.

(9) Missing parts due to instability of supplier's country.

(10) Additional material costs due to single sourcing during ramp-up phase.

(11) Contractual risk.

(12)   Investing in supplier improvement.

(13) Currency risk.

(14) Bid management cycle time.

(15) Inventory costs.

(16) Lead time for procurement.

(17) Lead time manufacturing.

(18) Obsolescence cost.

(19) Overhead cost.

(20) Process cycle time.

(21) Product development time.

(22) Product service variety.

(23) Stock out cost.

(24) Transportation cost.

(25) Warranty cost.

The output indictors of supply chain risks and performance are:

(1) Supply chain response time

(2) Accuracy of scheduling.

(3) Capacity utilization.

(4) Compliance to regulations.

(5) Conformance to specifications.

(6) Delivery reliability.

(7) Forecasting accuracy.

(8) Labor efficiency.

(9) Perceived quality.

(10) Perceived value of product.

(11) Production flexibility.

(12) Return on investment.

(13)   Selling Price.

(14)   Value added.

<p style="text-align:center">3.4 Assess Risks with Rough Set Theory and DEA</p>

As we can see from the previous section, there are 39 variables (25 inputs and 14 outputs). If we put all the 39 variables into DEA models, there is most likely that all the Decision Making Units (DMU) have DEA efficiency value 1, since the number of DMU may be not much bigger that the number of variables. Inputs/outputs reduction plays a very important role in intelligence information and DEA processing, and it is also vital in rough set theory. In general, the information of DEA inputs and outputs is not always in the same position, even some of the information is unnecessary or we can say they are Redundancy.

The purpose of DEA inputs and outputs reduction is to delete unnecessary information when keep the classification ability unchanged. The reduction process for attributes reduces elementary set numbers, the goal of which is to improve the precision of decisions and delete the extra data. After the attribute dependence process, the DEA reduction attribute sets of inputs and outputs are generated to remove superfluous attributes, so that the set of attributes is dependent. The complete set of attributes is called a reduction DEA attribute set. There may be more than one reduction attribute set in an information system, but intersecting a number of reduction attribute sets yields a core attribute set. The reduction attribute set affects the process of decision-making, and the core attribute is the most important attribute in decision making.

Rough set theory is a method to reduce DEA attribute set; and it is applied as a data mining technique. The rough set philosophy is founded on the assumption that with every object of the universe of discourse we associate some information. For example, if objects are supply chain suffering from a certain risks, symptoms of the risks form information about supply chain. Objects characterized by the same information are indiscernible or similar in view of the available information about them. Firstly, we take the inferior indicator as a conditional property and the superior indicator as decision property. Then we can reduce them by the definition of

rough set. The properties which have been reduced will not be taken into the next computing. Reduction and core attribute sets are two fundamental concepts of rough set theory. Reduction are the most precise way of discerning object classes, which are the minimal subsets provided that the object classification is the same as with the full set of attributes. The core is common to all reduction. All objects with similar information are indiscernible and form blocks, which can be considered as elementary granules. These granules are called concepts and can be considered as elementary building blocks of our knowledge. Any union of elementary sets is called a crisp, and any other sets are referred to as rough or vague. Consequently each rough set has a boundary line, which is the object that cannot be classified as members of the set or of its complement with certainty. The following figure shows the mining methodology of the healthcare supply chain data using rough set theory and DEA.

```
┌─────────────────────────────────────────┐
│     Original Data with All the Attributes │
└─────────────────────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │      Classes of Data      │
        └─────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │     Lower Approximation    │
        │                           │
        │     Upper Approximation    │
        └─────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │     Reduction Algorithm    │
        └─────────────────────────┘
                    │
                    ▼
    ┌─────────────────────────────────┐
    │  Data Set with Less No. of Attributes │
    └─────────────────────────────────┘
                    │
                    ▼
  ┌───────────────────────────────────────┐
  │  DEA model with the Reduced Attributes  │
  └───────────────────────────────────────┘
```
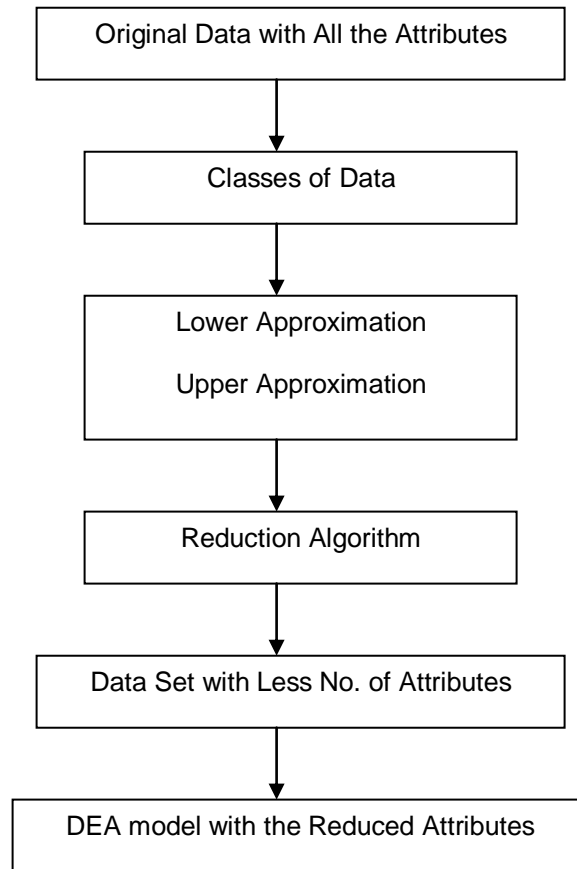
Figure 3.1 Rough set theory and DEA workflow

The original data with all the attributes have been thoroughly investigated in several studies and the structural requirements for high activity have been well known. The rough set theory is applied to this data set in order to induce easily interpretable rules about structures of supply chain inhibitors and their activities. If the set of attributes is dependent, one can be interested in finding all possible minimal subsets of attributes, which lead to the same number of elementary sets as the whole set of attributes and in finding the set of all indispensable

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attributes. Here we use the indiscernible relation, the approximation of sets, and the accuracy of approximation and reduction algorithm (Salem et al., 2005).

1) Indiscernible relation

We at first choose the set of attributes A, that is all the set of attributes except the decision one which is errors, then the data is divided into classes according to the value of the set of attributes A (referred to this classes as IND(A)). After we have applied this relation we will discover that each class contains only one object. In other words we have many different cases where the indiscernible relation will be used next to define basic concepts of rough set theory.

2) Approximation of sets

Let the concept X be defined as the set of all hospitals suffering from risks. From the original source data, some decision making units who suffered from risks, by approximating this data into lower ($\underline{A}X$) and upper ($\bar{A}X$) approximations we found that the lower and upper approximations are equivalent and the boundary line (BNA (X)) = Φ which means that $X \subseteq U$ (the close universe set) is an exact set. With respect to the set of attributes A, the set X is also A definable since it is an A-definable if and only if $\underline{A}X = \bar{A}X$.

3) Accuracy of approximation

We calculate $\alpha A (X) = $ Card $\underline{A}X$ / Card $\bar{A}X$ where A is the set of attributes and X is the set of all hospitals suffering from risks (active set). Also, by calculating $\rho A(X) = 1-\alpha A(X)$ which is the alternative accuracy and it is called roughness, it is found that $\alpha A(X) = 1$ and $\rho A(X)=0$ for an exact set. Then calculate $\mu A(x)=card(X\cap[x]A)/card([x]A)$ where $\mu A(x) \in [0,1]$ for each element in the active set. We found that $\mu A(x)$ for each element in $\underline{A}X = 1$ which is greater than zero, and $\underline{A}X= \bar{A}X$, which ensures that our medical data is exact data.

4) Reduction Algorithm

The process of finding a smaller set of attributes than the original one with the same or close classificatory power as the original set is called attribute reduction. We can easily check whether a given set of attributes A is a reduced item by the proposition (Skowron and

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Rauszer,1992) where this problem considered as NP-hard. NP-hard (non-deterministic polynomial-time hard), in computational complexity theory, is a class of problems that are, informally, "at least as hard as the hardest problems in NP". We apply the reduction algorithm to get minimal subset of attributes is an NP-hard problem of order $O(2^n XN^2)$ where n the number of attributes and N the number of objects, so any increase of the number of attributes or objects implies an increase of time complexity.

 5) DEA model

DEA was developed to measure the relative efficiency of operational units known in the literature as "Decision Making Units"—DMUs (Charnes et al, 1978). DEA has been widely applied to the productivity measurement, in general, and cost efficiency and scale elasticity measurement, in particular, of many organizations in public and private sectors. The estimates of cost efficiency are utilized to advise the decision-makers about the potential savings deriving from the choice of correct input mixes in the light of prevailing market prices, whereas the scale elasticity estimates are used for policy recommendations concerning the restructuring of any sector. Given a pair of observed input-output vectors (X_0, Y_0), DEA assesses its efficiency by comparing it to other choices in the technology set $T = \{(X, Y)\}$, which characterizes the collection of all input vectors X that can produce the output vector Y . It is clear that there is no universal DEA model which is applicable to all or most of applications. Moreover most widely used efficiency notions are sensitive to data manipulations. Thus even a simple data transformation changes efficiency unless the unit is 100% efficient. Also it is important to reflect the preferences of evaluators for some of the inputs or outputs, like profits in productivity analysis. A significant portion of DEA research to date has focused on defining the rules for constructing T, and defining corresponding measures of efficiency. Regardless of the definition of efficiency, most DEA models treat each DMU as a non-separable entity without attempting to probe the internal mechanisms of how each DMU converts its inputs into outputs. With today's information systems it is now much easier to collect data on how capital and labor are used to

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transform raw materials through various stages to produce final products. The availability of such data presents an opportunity to explore efficiency measurement of the stages within complex, multi-stage DMUs.

DEA has proven to be an effective approach in estimating empirical tradeoff curves (efficient frontiers), and in measuring the relative efficiency of peer units when multiple performance measures are present. However, such an efficiency approach cannot be applied directly to the problem of evaluating the efficiency of supply chains, because some measures linked to supply chain members cannot be simply classified as "outputs" or "inputs" of the chain. In fact, with respect to those measures, conflicts between supply chain members are likely present. For example, the supplier's revenue is an output for the supplier, and it is in the supplier's interest to maximize it; at the same time it is also an input to the manufacturer who wishes to minimize it. Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not properly model and resolve the inherent conflicts. In particular, we are interested in DMUs that consist of several stages arranged in series where succeeding stages (or subsystems) are fed by a mixture of external inputs and intermediate factors which are outputs of preceding stages. The focus of the present paper is on how to assess the efficiency of each stage within the aggregate system and how to explore possible tradeoffs of these efficiencies. As a starting point, of course, one can treat each subsystem as a system in its own right. In this manner, the technology for each subsystem is constructed using the relevant input-output data from its own peers, and the technology of the aggregate system is constructed on the basis of aggregated inputs and outputs and without regard to intermediate input-output factors that link the various stages. As we subsequently demonstrate, this approach exhibits the phenomena in which it is possible for the aggregate system to be rated very inefficient, while each subsystem is rated efficient, and for the aggregate system to be rated near efficient, while each subsystem is rated highly inefficient.

We will first define an efficient supply chain using DEA. Our discussion is based upon a two-stage supply chain consisting of a supplier and a manufacturer. The results can be easily generalized into supply chains with multiple members. We derive two efficiency functions for the supplier and the manufacturer. Consider a two-stage supply chain, e.g., supplier-manufacturer supply chain as following figure, where S and M represent the supplier the manufacturer, respectively. X_S is the input vector to the supplier and Y_S is its output vector which is also an input vector to the manufacturer. X_M and Y_M are the manufacturer's own input and output vectors, respectively. Suppose we have N similar supply chain operations or observations on one such a supply chain operation. We treat each supply chain operation or observation as a DMU (Chen et al., 2006).
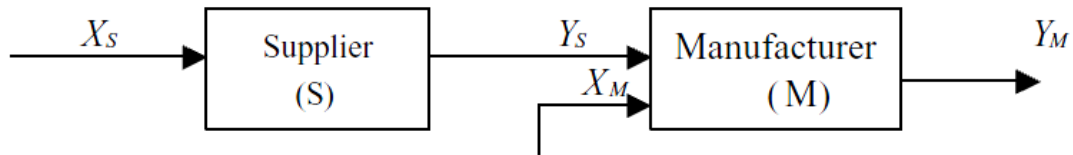

Figure 3.2 Two-stage supply chain (Chen et al., 2006)

Based upon the CCR DEA model of Charnes, the DEA efficiencies for the supplier and manufacturer are defined.

For supplier (S), the DEA efficiency is:

$$\theta_{Sj} = \frac{C^T Y_{Sj}}{V_S^T X_{Sj}} \quad \text{for } j = 1, \dots, N$$

For manufacturer, the DEA efficiency is:

$$\theta_{Mj} = \frac{U_M^T Y_{Mj}}{C^T Y_{Sj} + V_M^T X_{Mj}} \quad \text{for } j = 1, \ldots, N$$

where C, V_S, U_M, V_M represent weight vectors.

When the j_0th DMU (DMU_0) is under evaluation, we denote the DEA efficiency scores for DMU_0 as θ_{S0} and θ_{M0} for the supplier and manufacturer, respectively.

As Chen et al. (2006) said, conflict may exist between the supplier and manufacturer with respect to the intermediate measures of Y_S. For example, if Y_S represents supplier's profit, then the supplier wishes to maximize it while the manufacture wishes to minimize it as it represents a cost to the manufacturer. Thus, it is difficult to define efficiency for the entire supply chain system unless we assume that all decisions are made by a single decision maker with access to all available information. This is referred to as the first-best case, and is often associated with central control.

Cook et al. (2007) developed a DEA model for evaluating the joint efficiency of supply chains with multiple tiers or members. Suppose there are N similar supply chains or N observations on one supply chain, and each supply chain has P supply chain members or tiers as describe in the figure Cook et al. (2007).
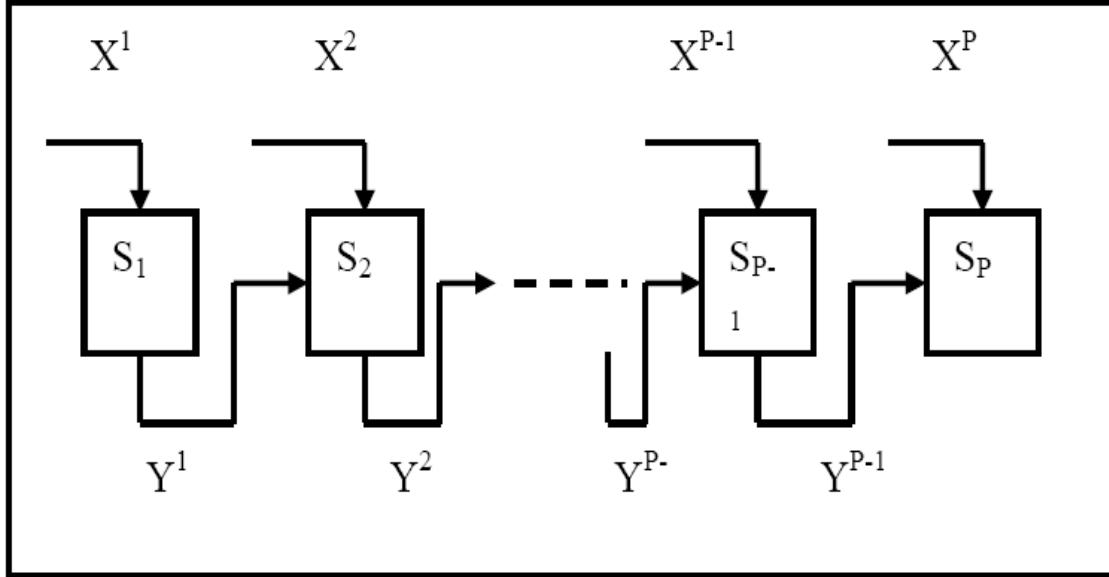
Figure 3.3 Supply chain with multiple tiers

In the j-th supply chain, S_{dj} means the d-th member, X^{dj} means inputs of member d, Y^{dj} are outputs of member d and also inputs of member d+1.

Let N be the number of groups in the supply chain data. Each group has P supply chain members or tiers, input X has I attributes, output Y has S attributes; and $X_{dj} = (x_{dj}^i$, i = 1, …, I_d), $Y_{dj} = (y_{dj}^s$, s = 1, …, S_d), d = 1, …, P, j = 1,…, N. Suppose the weight of x_{dj}^i is v_d^i and the weight of y_{dj}^s is u_d^s, then Cook's DEA model is as following. Please be aware that the values in weights v_{di} and u_d^s are produced via optimization computing.

Table 3.2 Cook et al. (2007) supply chain DEA model

Maximize

$$\frac{1}{P}\left[\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0}} + \sum_{d=2}^{P} \frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1)0}}\right]$$

Subject to

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{dj}}{\sum_{i=1}^{I_d} v_i^d x_i^{dj}} \leq 1 \qquad\qquad d=1, \qquad j=1,\ldots,N$$

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{dj}}{\sum_{i=1}^{I_d} v_i^d x_i^{dj} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1)j}} \leq 1 \qquad d=2,\ldots,P, j=1,\ldots,N$$

The above Cook's model at first summarizes efficiency values from tier 1 as S_1 to tier P as S_p, then the sum is divided by tier number P, to calculate the whole supply chain efficiency value. The model uses average efficiency values of P tiers. We extend the Cook's model now. We apply individual tier weight W_d on tier d efficiency value, with constraint $\Sigma W_d = 1$, and summarizes efficiency values from tier 1 to tier P. Our supply chain DEA mode one is in following.

Table 3.3 Supply chain DEA model one

Maximize

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0}} * W1 \quad + \quad \sum_{d=2}^{P} \frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1)0}} * Wd$$

Subject to

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d j}}{\sum_{i=1}^{I_d} v_i^d x_i^{d j}} \leq 1 \qquad\qquad d=1, \qquad j = 1, \ldots, N$$

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d j}}{\sum_{i=1}^{I_d} v_i^d x_i^{d j} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1) j}} \leq 1 \qquad d = 2, \ldots, P, j = 1, \ldots, N$$

$$\sum Wd = 1 \qquad\qquad d = 1, 2, \ldots, P$$

In our supply chain DEA model one, the weight W_d (d=1, 2, …, P) is determinate by the optimal computation on the model. In the real-world of supply chain, some business managers may think one specific tier is more important than other tier, e.g. the weight of tier 1 W_1 may be greater than the weight of tier 2 W_2 ($W_1 > W_2$). For this purpose, we add more constraints in our supply chain DEA model one; these are $W_i \geq W_j$ (i=1,2,..,P; j=1,2,…,P; i≠j); then we get our following supply chain DEA model two.

Table 3.4 Supply chain DEA model two

Maximize

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0}} * W1 \quad + \quad \sum_{d=2}^{P} \frac{\sum_{s=1}^{S_d} u_s^d y_s^{d0}}{\sum_{i=1}^{I_d} v_i^d x_i^{d0} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1)0}} * Wd$$

Subject to

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d\,j}}{\sum_{i=1}^{I_d} v_i^d x_i^{d\,j}} \leq 1 \qquad\qquad d=1, \qquad j=1, \ldots, N$$

$$\frac{\sum_{s=1}^{S_d} u_s^d y_s^{d\,j}}{\sum_{i=1}^{I_d} v_i^d x_i^{d\,j} + \sum_{s=1}^{S_{d-1}} u_s^{d-1} y_s^{(d-1)j}} \leq 1 \qquad d=2, \ldots, P, j=1, \ldots, N$$

$$\sum Wd = 1 \qquad\qquad d=1, 2, \ldots, P$$

$$Wi \geq Wj \qquad\qquad i=1, 2, \ldots, P; \ j=1, 2, \ldots, P; \ i \neq j$$

Evaluation of supply chain efficiency, using DEA, has its advantages. In particular, it eliminates the need for unrealistic assumptions inherent in typical supply chain optimization models and probabilistic models; e.g., a typical EOQ model assumes constant and known demand rate and lead-time for delivery. The above DEA-based models can correctly characterize multi-member supply chain operations, and can calculate the efficiencies of the supply chain and its members. Because conventional DEA models cannot be directly applied to evaluating multi-member supply chain operations, our models become important tools for the managers in monitoring and planning their supply chain operations, and can significantly aid in making supply chains more efficient and calculating supply chain risks. We also use a weighted

on the tiers of supply chain to reflect the power relationships and importance of supply chain's members. Although the models are nonlinear programming problems, they can be solved as parametric linear programming problems, and a best solution can be found using a heuristic technique.

CHAPTER 4

RISK EVALUATION FOR HEALTHCARE SUPPLY CHAIN MANAGEMENT

4.1 Healthcare Supply Chain Overview

The health care industry has been under extreme political and public pressure and concern to control the rapidly increasing cost for treatment during the last three decades. The cost of healthcare has gained considerable attention in recent years. Over the past decade, healthcare costs have risen significantly faster than the consumer price index. Public opinion has been that the appropriate regulatory price controls have not been instituted in the industry. While the public has demanded price control measures be designed and implemented, there has not been any research to determine, first, why the cost of supply chain has continued to climb or, second, why has the industry been reluctant to implement the same competitive operational processes found in the manufacturing and distribution industries. Operations management problems that arise in the delivery of health care are similar in many ways to traditional problems in operations management. These include strategic planning problems such as design of services (e.g., inclusion of neonatal intensive care units in some hospitals, or provision of free-standing urgent care clinics or rural health workers), design of the health care supply chain (e.g., design of a network of hospitals, outpatient clinics, and laboratory services), facility planning and design (e.g., location and layout of hospitals and outpatient clinics, or design of material handling systems), equipment evaluation and selection, process selection, and capacity planning. Unlike the commercial sector, which has long viewed the supply chain as a key strategic activity and used it as a way to differentiate itself, gain market share and generate profits, health care has laid behind in supply chain management. In part this is because of the nature of health care: it is a cottage industry whose key players—clinicians—are

independent contractors with considerable clout and specific preferences for supplies and where some variation in supplies and processes must be accommodated to ensure patient safety. The health care industry shares many similar business processes with the manufacturing industry, especially in the areas of logistics, supply distribution, inventory control, and product production. The health care industry has historically viewed itself as being operationally different from other businesses. Primarily this thought has developed because health care providers believe that, unlike managers in the manufacturing industry, they cannot control or project their production schedules. Although some emergency care and surgical procedures cannot be accurately projected the supplies used in the route care of most inpatients can be estimated based on average census and seasonal data. Even in the manufacturing and distribution industries the implementation of all products can not be ordered and received just-in-time. A buffer stock of selected items must be maintained based on order and receipt time frames for the replenishment of stock.

According to the Centers for Medicare and Medicaid Services (CMS) 2006 report, healthcare expenditures in the United States have dramatically and rapidly increased from $253 billion in 1980, to $714 billion in 1990, to over $2 trillion in 2006, and are estimated to surpass 20% of GDP or $4 trillion dollars by 2015. Given that approximately 25% of healthcare costs are supply related (Scalise, 2005), many practitioners and scholars are focusing attention on supply chain management as a means of improving outcomes. Facing a multitude of challenges among cost and quality as well as the need for reform, the healthcare industry is actively seeking to implement supply chain management practices by partnering with customers, suppliers, and many other strategic service partners (Naidu, Parvatiyar, Sheth, and Westgate, 1999). Many healthcare supply chains exist as highly fragmented systems in which manufacturers, distributors, wholesalers, group purchasing organizations, and providers operate independently from one another. There are numerous risks to consider and tackle healthcare supply chain inside hospital.

In the pharmaceutical industry, the development activities that are required to bring a new drug to market involve high expense and can take more than 10 years. Clinical trials constitute a critically important and very expensive part of this development process as the associated supply chain encompasses producing, distributing and administering the candidate therapy to volunteer patients located in different geographic regions. Healthcare is starting to engage in "cross-leaning"—adapting the lessons of other industries, such as retail and automotive, to improve product flow and supply chain efficiency. One example is the notion of an extended supply chain, where organizations take into account not only their own operations, but also all of their upstream and downstream parameters to maximize efficiency. Hospitals also are making headway by investing in technologies such as enterprise resource planning software and radio frequency identification, using quality data to drive standardization and streamlining processes. There are the challenges inherent in the healthcare industry. A variety of risks to healthcare supply chain management exist, like 1) constantly evolving technology resulting in short product life cycles and high cost for physician preference items; 2) difficulty in predicting frequency, duration and primary diagnoses for patient visits and the associated product requirements; 3) lack of standardized nomenclature/coding for healthcare products and commodities; 4) lack of capital to build a sophisticated information technology infrastructure to support supply chain management efforts.

The current US healthcare industry has undergone fundamental change in recent years, with huge consequences for providers and insurers. The process is ongoing as President Barack Obama's health reforms are implemented, and is also subject to enormous uncertainty. Depending on electoral results as well as decisions in the US courts, some or all of the legislation might be rolled back, but there is also the possibility of further reforms that will demand yet more changes to business models and practices. We need to be able to react and move in different directions. Even to the point that the health insurance industry could become almost completely new to us and everyone else in our industry around the country.

All of this makes risk management an important and growing priority. In recent years, the company has been developing a compliance culture to help it cope with its industry's steepening regulatory hurdles. But it has also been steadily increasing its compliance expertise in order to mitigate the downside risk and reputational harm that operational and compliance failures could bring. Some companies have spent millions of dollars over the past three years on a major IT overhaul, bringing its systems up to the standards required by regulator and marketplace demands. Awareness of data security and patient confidentiality risks is high on the company's agenda. We also need to study and research more sophisticated risk management approaches as part of a strategy to shore up its earnings in an extremely competitive and fast-changing landscape. It is the best indicator to us that some of our risks are playing out either favorably or unfavorably. The number links directly to our pricing strategies and to an important part of our mission—how much we give back to the community in the way of grants and programs to improve the healthcare of our community—and to our targeted underwriting margin and net income, on both an annual and three year basis. The uncertain future of the US economy and federal healthcare reform top the list maybe have the other main risk factors which we haven't identified.

4.2 Healthcare Supply Chain Inside Hospitals

The pressures on hospital supply chains are changing. In the past, a hospital that managed its purchasing costs well could operate efficiently. Today, the cost of materials management can exceed 35% of a hospital's operating budget, with nearly 20-25% attributable to supply costs alone. Kowalski (2009) stated "Hospitals and health systems may soon spend more on their supply chains than on labor. Historically, total supply expenses (cost of supplies plus all the labor costs related to operating the supply chain, including all the supply inventories in the laboratory, pharmacy, surgery, etc.) have consumed up to 45 percent of the operating budget"

With the supplies and purchased services accounting for the very large cost component for hospital, it is increasingly recognized that supply chain management in hospital is one of the main areas for improvement in hospital performance. There are a number of stakeholders in the hospital supply network. The three key stakeholders in our hospital pharmacy case are the physicians, pharmacists, and the Group Purchasing Organization (GPO). One can identify several relevant conflicts amongst the stakeholders with respect to prescribed drugs. Physicians and pharmacists/pharmacy directors clash over medications offered by the hospital. Kowalski (2009) further stated "The supply chain has always had an enormous impact on both the fiscal and the clinical performance of a hospital. This impact is now reaching a strategic tipping point, as total supply chain expenses overtake labor expenses at the top of the operating budget. With this shift, it is becoming particularly crucial for financial executives to apply close scrutiny to the supply chain and participate in the development of a supply chain management strategy".

We also consign some inventory, meaning we put the cost of ownership on the vendor, so it's not a liability on the balance sheet. As an example, consider hemophilia factors. They are a high-cost, low-volume item that has to be kept on your shelf because you never know when a patient with hemophilia is going to come in. Traditionally, we would carry that cost of inventory on the books without a clear indication of the end point, when use would occur. With consigning, the cost is on the vendors' books for this period. We pay the vendor for the product when we use it, not when we receive it. Currently, we consign inventory for about two dozen products. The front-line user doesn't see any difference under such an arrangement, but the hospital's cost of inventory is decreased. According to Kowalski (2009), "The supply chain should be part of the enterprise strategic plan, incorporated across all components and service lines. A hospital's or health system's strategic plan should include supply chain management as a key strategy for maintaining fiscal goals, improving quality and satisfaction levels, and addressing industry trends and developments".

According to recent Association for Healthcare Resource & Materials Management (AHRMM) studies, the average hospital belongs to 1.2 GPOs, today, down from 2.5 memberships 5 years ago. GPOs are a very valuable reel, assisting with contracts for supplies, information access, and peer collaboration. But at times, GPOs can limit a healthcare organization's ability to self contract and can artificially set prices higher through strong contractual relationships with manufacturers and most favored nation clauses. A hospital must utilize its GPO as but one tool at their disposal, looking at all available options for contracting, sourcing, and supplier management, including self contracting and regional purchasing alliances. Areas impacting inventory management include unofficial inventories found throughout the facility, which can account for as much as 50% of total inventories; central sterile and supply management; accurate, real-time information systems with interfaces to appropriate financial and clinical systems; and collaborative, efficient support from nursing and other internal customers.

Existing supply chain risk evaluation methods and quantitative models require some risk parameter values like the probability that events occur, the impact of detrimental events, and the weight/importance values of various risk factors. In addition to the usual financial measures for risk assessment, the supply chain risk now also needs to take into consideration other specific indicators such as delivery rates and percentages of order fulfillment. We consider supply chain risk as the risk associated with performance variability of supply chain. A generic and well-established definition of performance and risk is used, dividing this construct into efficiency and effectiveness. There are some issues in hospital supply chain management. Most supply departments in hospital settings work on a Monday to Friday schedule, as normal work hours. On the other hand, emergency rooms are open 7 days per week while clinics are operated only two or three days per week. On the supplier side, a few suppliers may deliver several times per week, but most of them deliver only once a week or even less frequently. Therefore, a weekly schedule is the shortest length schedule that we may use, the demand for

products on Saturday and Sunday being aggregated with the Friday if the supply department is closed on weekends. However, the supply chain risk management should accommodate a two week or a one month schedule for more comprehensive supplier planning. The schedule will consist in deciding when each emergency room will be visited and which products will be delivered at each visit; when each supplier will deliver to the hospital and which products they will include at each delivery visit; and, finally, which products are in the category of direct product, and what quantity is shipped directly to the emergency room on the reception day.

According to Kowalski (2009), "the supply chain should be part of the enterprise strategic plan, incorporated across all components and service lines. A hospital's strategic plan should include supply chain management as a key strategy for maintaining fiscal goals, improving quality and satisfaction levels, and addressing industry trends and developments. One critical objective of any hospital is to maintain or improve margins while maintaining or improving quality". Many hospitals focus heavily on increasing revenues to achieve this goal. The first risk evaluation model is a service supply chain inside a hospital and shows the intravenous (IV) preparation procedure inside the pharmacy of the hospital, which is the pharmacy model, represents a service supply chain (Behzad, 2008). It is shown in Figure 4.1 in following.

```
          ┌─────────────────────┐
          │  Order is entered into│
          │  computer system by   │
          │       doctors         │
          └─────────────────────┘
                     │
          IV Order's Hardcopy
                     │
                     ▼
              ┌──────────────┐
              │ Order Is     │
              │ Sorted:      │
              │ Print labels │
              │ Sort Labels  │
              └──────────────┘
                     │
          Sorted Labels
                     │
                     ▼
              ┌──────────────────┐
              │ Order Is         │
              │ Assembled:       │
              │ 1. Get labels    │
              │ 2. Access inventory│
              │ 3. Assemble orders│
              │ 4. Phamacist check│
              └──────────────────┘
                     │
                    IVs
                     │
                     ▼
```
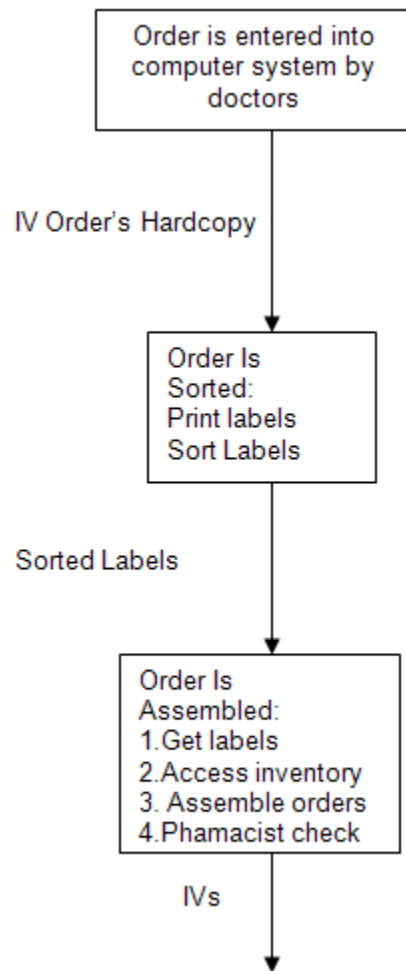
Figure 4.1 Pharmacy service supply chain in hospital (Behzad, 2008)

The ER sends the IV orders to the pharmacy. In the pharmacy the IV orders will be entered into the computer, the labels will be printed and sorted, and finally the IVs will be assembled. Therefore the model contains three main stages: Computer Order Entering, Order Sorting, and Order Assembling. Each stage contains four main risk variables which include capacity, processing rate, backlog, and errors.

The error has been modeled using the workload and experience level. To formulate the workload we need to find the number of employees who work in the pharmacy. We assumed

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that all the jobs in the pharmacy are being done by the pharmacists; in other words, there is only one job position in the pharmacy. The pharmacy's capacity (in person) is modeled using the productivity of inexperienced and experienced pharmacists. The following are the formulas of the variables used to model the error (Behzad, 2008):

• Pharmacy's Capacity (in person) = (Pharmacy's Total Capacity (in job)*Pharmacist Inexperienced Percentage)/Productivity of Inexperienced Pharmacist)+((Pharmacy's Total Capacity (in job)* (1-Pharmacist Inexperienced Percentage))/Productivity of Experienced Pharmacist)

• Pharmacy's Turnaround Rate (in person)= ((Pharmacy's Total Turnaround Rate (in job)*Pharmacist Inexperienced Percentage)/Productivity of Inexperienced Pharmacist)+((Pharmacy's Total Turnaround Rate (in job)* (1- Pharmacist Inexperienced Percentage))/Productivity of Experienced Pharmacist)

• Workload= Total Pharmacy's Backlog/Pharmacy's Capacity (in Person) Total Effective Experience= Pharmacist's Average Experience*Pharmacy's Total Capacity(in Job)

• Error= Reference Error*((Total Effective Experience/Pharmacist's Reference Experience Level)^C1)*((Workload/Reference Workload)^C2)

As Behzad (2008) said, the reference error is the error attained at the reference experience level and reference workload level. The reference experience and reference workload are the normal amount of experience and workload for pharmacists. Where C1=ln(1+fp)/ln(2), fp=Fractional Reduction in Error per Doubling the Experience. Where C2 = ln(1+fw)/ln(2), fw= Fractional Increase in Error per Doubling the Workload.

As Behzad (2008) further said, backlogs will be decreased by the processing rates. The average service delay is the average nominal delay required to complete a backlogged order. Capacity represents the capacity in job, which is the number of IVs which are processed by the pharmacists in each stage per time. The capacity in job changes by the turnaround rate. Turnaround rate could be the rate of hiring and firing and also the rate of changing the position

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of the pharmacists. The capacity adjustment time is the average nominal delay required to adjust the pharmacists in the new position. The error has been modeled using the workload and experience level. To get the workload we need to find the number of employees who work in the pharmacy. We assumed that all the jobs in the pharmacy are being done by the pharmacists.

4.3 Healthcare Pharmaceutical Supply Chain Overview

The pharmaceutical supply chain management not only emphasizes regulatory compliance and safety of products, but also includes leveraging information to be more responsive to the needs of consumers. According to the Council of Logistics Management (CLM), logistics is that part of supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customer's requirements. The pharmaceutical industry can be defined as a complex of processes, operations and organizations involved in the discovery, development and manufacture of drugs and medications. The World Health Organization (WHO) defines a drug or pharmaceutical preparation as: any substance or mixture of substances manufactured, sold, offered for sale or represented for use in the diagnosis, treatment, mitigation or prevention of disease, abnormal physical state or the symptoms thereof in man or animal. Most pharmaceutical products involve primary active ingredient production (often multi-stage chemical synthesis or bioprocess) and secondary (formulation) production. Both of the stages are characterized by low manufacturing velocities and are hampered by the need for quality assurance activities at several points. The pharmaceutical supply chain is the means through which prescription medicines are delivered to patients. Pharmaceuticals originate in manufacturing sites; are transferred to wholesale distributors; stocked at retail, mail-order, and other types of pharmacies; The pharmaceutical supply chain is complex, and involves multiple organizations that play differing but sometimes overlapping roles in drug distribution and contracting. This complexity results in considerable price variability across different types of consumers, and the supply chain is not well understood

by patients or policymakers. Increased understanding of these issues on the part of policymakers should assist in making rational policy decisions for the Medicare and Medicaid programs.

A typical Pharmaceutical supply chain consists of one or more of the following players (Shah, 2004):

a) Manufacturer and/or contract manufacturer,

b) Brand manufacturer and/or generic manufacturer,

c) Primary whole sale and/or secondary whole sale,

d) Hospital, Clinic, and Drug store,

d) Consumer/Patients.

Pharmaceutical products are typically manufactured in two main stages, namely the primary and secondary/contract manufacturing stage. The primary stage is responsible for the production of the Active Ingredient (AI) of the drug. The second stage is responsible for converting the AI to a final product for direct use (e.g. vials, tablets, etc.). The primary manufacturing step is the highest value-added step of the overall process and is considered to be the most critical one for portfolio planning. The contract manufacturer is responsible for the production of the active ingredients. The primary manufacturer is concerned with taking the active ingredient produced at the primary site and adding excipient inert materials along with further processing and packaging to produce the final products, usually in SKU form. For example, a product that is sold in pill form would undergo: 1) granulation: with addition of all the recipient materials; 2) compression: forming the pills; 3) coating; 4) quality control; and 5) packaging.

Healthcare pharmacists purchase the vast majority of their pharmaceuticals through pharmacy wholesalers and most of their remaining needs directly from the manufacturer. Pharmacy wholesalers obtain the overwhelming majority of their medications directly from pharmaceutical manufacturers, but many obtain some medications from secondary wholesalers

or distributors who participate in the alternative distribution channel. In the pharmaceutical supply a high service level is essential. In case of a shortage at a local depot an emergency delivery is necessary and this emergency refill is very costly and can be dangerous for the patient's healing process. There is also a tradeoff among the different drugs in a local depot because of the total space is constrained by the tactical decision The pharmaceutical supply chain diagram is shown in following figure at next page.
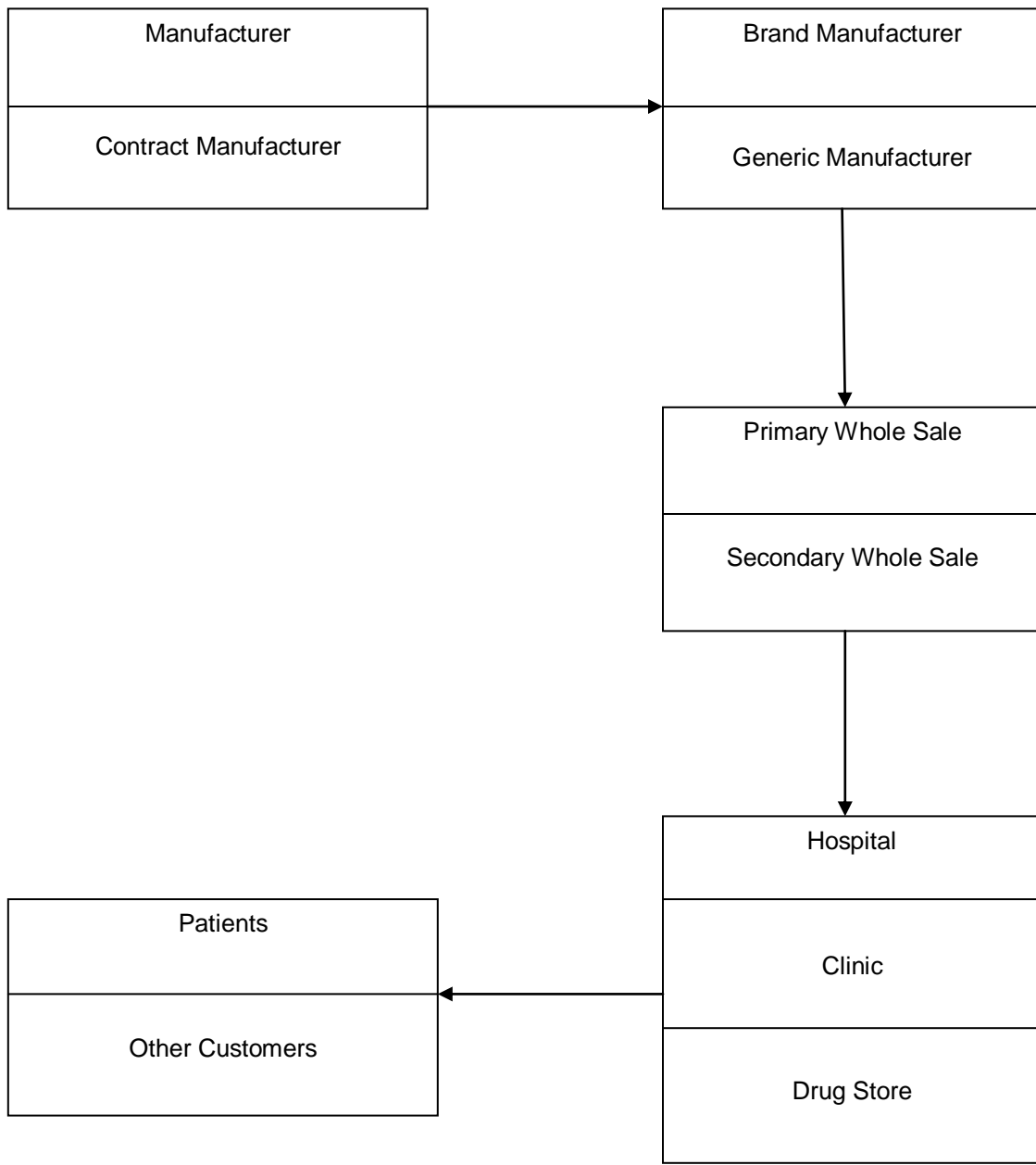
Figure 4.2 Pharmaceutical supply chain

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4.4 Healthcare Pharmaceutical Supply Chain Risk Issues

The goals of the pharmaceutical supply chain obviously emphasize regulatory compliance and safety of products, but also include leveraging information to be more responsive to the needs of consumers. The unique nature of the supply chain for pharmaceuticals makes managing complex information for supply chain effectiveness challenging, but clearly the rewards for doing so are significant. Companies that excel in supply chain operations perform better in almost every financial measure of success. After a drug is launched, a completely different set of objectives, drivers, and constraints become dominant. Now, the focus shifts from agility to high availability. Consequently, there is a dramatic shift in the models and techniques employed to support this phase of drug life cycle. In this phase, the complexity of the pharmaceutical supply chain results from the involvement of multiple large independent organizations of very diverse nature. The issue of drug shortages has been a continuing challenge and source of frustration for all practitioners. Shortages of critical medications, which require finding alternative products, often cause providers to expend more resources and increase the complexity of providing patient care with unexpected drugs.

There are many risks unique to pharmaceutical supply chain management. Indeed, facing the prospect of managing a chain of pharmacies can seem to be a daunting task on first examination. The key stakeholders in this supply chain include multiple government agencies, hospitals, clinics, drug manufacturers, drug distributors, pharmacy chains, retailers, research organizations, and the FDA. To compound matters further, the pharmaceutical supply chain is responsible for the distribution of prescription drugs, over-the-counter (OTC) medicines, generics, as well as biologics. Indeed, there are numerous other organizations, such as insurance companies, healthcare management organizations, and Group Purchasing Organization (GPO) that further increase the complexity. Due to very different business objectives, these organizations make the task of managing supply chain all the more difficult. Furthermore, due to the regulatory nature of the industry and numerous merger and acquisitions

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to acquire more R&D expertise, many pharmaceutical supply networks have grown in an uncontrolled fashion rather than being planned for optimal performance. One of the challenges faced by pharmaceutical supply chain management involves drug ordering for multiple locations. Of course, pharmaceutical supply chain management desires to order in bulk. Thus, wherever possible, pharmacy chain management wants to order for all stores in the entire chain or purchasing groups at one time. But, each store will have its own set of unique needs and requirements. The end result is that the chain management is faced with a very challenging task.

Personnel issues are also extremely important to and for pharmaceutical supply chain risk management, if there is a shortage of qualified pharmacy personnel. Thus, the management of the chain has to work hard to properly allocate its human resources throughout the stores included in the chain. Government regulations and compliance is a sticky and complex issue for pharmaceutical supply chain management. There can be many legal requirements to be adept at understanding and ensuring compliance with the applicable statutes and regulations in all of the jurisdictions where the pharmacy chain operates an outlet or store. When products are obtained from outside the primary distribution channel, the risk of the entry of adulterated or counterfeit products may be increased. Uncertainty about the storage conditions or the distribution path to which the product has been subjected may also raise concerns about the product's integrity and the potential of supply chain. Some hospital, clinic, and drug store may choose not to purchase drugs through the secondary market for economic reasons or because they question the product integrity. However, others may choose to participate in the secondary market regardless of cost, either because they find it convenient or they incur pressure to obtain products that are in short supply.

Some of the pharmaceutical supply chain risk key issues are summarized as follows (Shah, 2004):

1) Multiple categories of medicines.

2) Highly regulated environment requiring extensive data collection and information exchange to ensure chain of custody and monitoring of various controls.

3) Product expiry – for safety, error prevention, reassignment, safe disposal.

4) Cold chain required for temperature controlled product movement.

5) Complex demand patterns: highly unpredictable for new introductions; low volume high mix spread over a large area needing quick response for.

6) Controlled products (prescription drugs – branded or generics) requiring a high level of constant management.

7) Varying regulations across global markets.

8) Drug recall management.

9) Elimination of counterfeits.

10) Deal with data accuracy and related problems.

11) Highly inefficient order management

12) Lack of process standardization in purchasing, inventory management, etc.

13) Lack of collaboration across players.

14) Uncertainty in the demands for existing drugs (due to competition, uncertainty in the ability to extend the protected life through new formulations, etc.).

15) Uncertainty in the pipeline of new drugs—in particular, which ones will be successful in trials, what sort of dosage and treatment regime will be optimal.

16) Process development, driven by chemistry and yield optimization. It often results in inefficient processes that are operated much more slowly than the intrinsic rates—giving rise to batch processes and long cycle times responsible for some of the problems seen at the primary production planning stage.

17) Capacity planning—the long lead times to make capacity effective mean that decisions often need to be taken at times of high uncertainty. Waiting for the uncertainties to be resolved might delay the time to market by an unacceptable amount.

18) Network design—often tax implications take precedence over logistics issues, which result in economic but potentially complicated pharmaceutical supply chains.

<u>4.5 Healthcare Clinical Supply Chain Overview</u>

A healthcare clinical trial is to compare the effect and value of intervention against a control in human beings. A clinical trial is a prospective rather than retrospective. A clinical trial is a systematic study of drugs and medicinal specialties in human volunteers that strictly follows the guidelines of the scientific method. Its purpose is to discover or confirm the effects and identify adverse reactions to the product investigated and to study the pharmacokinetics of the active ingredients in order to determine their efficacy and safety. Public health analysts have traditionally been concerned with risks from infectious disease and from food poisoning. More recently, lifestyle risk factors such as smoking were identified for fatal diseases such as cancer and heart attacks, where the link between cause and effect was harder to establish. In the last 20 years, environmental public health has emerged as a major concern. Risks of exposure to toxic materials such as lead, asbestos and air pollutants have been much studied, and the resulting legislation has greatly ameliorated these hazards. As Colvin and Maravelias (2008) said, Robins-Roth (2001) divided clinical trials in three phases:

Phase I (PI): This usually involves 20–100 healthy volunteers treated with increasingly high doses. The goal is to study how the drug is metabolized, where it goes in the human body, whether it is safe to use it, and what is the best way to use it.

Phase II (PII): The goal of this phase is to provide more information about drug efficacy and how the drug behaves in people. These studies typically include 100–500 patients, divided into several subgroups. The subgroups are administered the drug in different doses, by different routes, and on different schedules.

Phase III (PIII): 1000–1500 patient volunteers are included and the aim is to generate statistically significant data, about effectiveness, patient subpopulations and dosing regiments

that will lead FDA and the international regulatory agencies to approve the new drug. Note that the drug division of FDA often requires more than one Phase III trial.

The life cycle of a pharmaceutical product includes: discovery stage, development stage, commercial stage. In the discovery stage, thousands of molecules are applied to targets developed to simulate various disease groups. Once an active molecule, i.e. a molecule that is identified to have a curative effect on the target, is discovered, various permutations of the structure of the molecule are tested to see if the activity can be enhanced. The most active molecule from these structure–activity relationships is tested for toxicological results on rats or mice. If no particular worrisome toxic endpoints are observed, the molecule is promoted to the status of "lead" molecule and becomes a candidate for development. In the development stage, enormous sums of money and resources are committed to the lead molecule to first, observe its behavior in healthy volunteers, secondly, in patients smitten with the disease and finally, in large scale clinical studies conducted in FDA. Coincident with these studies, process research and formulation work is conducted to both supply the drug for testing purposes as well as to design and construct a commercial plant if the product is launched. Other parallel studies involve extensive long-term chronic studies in animals to identify any indication at different dosage levels. If the drug is effective in the clinical studies, has no unacceptable side effects and is blessed by the FDA, it moves to the commercial Stage. Target markets are identified for a staged launch of the new compound. After a few years, a mature sales level is usually reached and maintained until patent coverage on the molecule expires and/or competition from generics is realized. Once generics are available, an attempt is usually made to get approval of the drug for alternative markets and perhaps in different dosage forms.

The clinical supply chain includes manufacture of product, clinical packaging (including blinding of supplies, where needed), storage, distribution and ultimate disposal of product. Managing clinical trial supply chains is growing increasingly difficult because of geographic expansion (primarily into emerging markets) and the complexity of pharmaceutical and life

science products, including combination therapies, diagnostics, biomarkers and specialist drugs, such as biologics. With the high costs of development for a new drug, no company can afford to further increase costs through inefficiencies in their clinical trial supply chain. A key reason for high costs is due to clinical supply chain and forecasting failures domestically, as well as high patient recruitment costs/challenges. As global clinical trials continue to increase within emerging overseas markets, there has never been a more important time for drug development organizations to effectively manage and optimize their clinical supply chains. The growth of external, complex trials brings a unique set of challenges. These include complying with multiple stringent regulations, cost-effective/validated distribution, clinical product management, risk mitigation, cost effective trial execution, and drug supply management issues.

4.6 Healthcare Clinical Supply Chain Risk Issues

On one side, for just one drug candidate, a company can spend millions of dollars every quarter to produce supplies for the clinical trial. When failure in a clinical trial occurs, every dollar spent on manufacturing, packaging, and distribution of unused clinical trial supplies is wasted and in most cases, unused material must be returned to a proper disposal facility for destruction. On the other side, patient recruitment is the typical bottleneck in conducting clinical trials, shortages of clinical drug is considered an unacceptable delay; Inventory is needed to ensure that as patients are recruited to participate in the study, drug supply is available. Any delays in this phase of testing become one less day of patent protection available to the drug. Only 21.5% of drug candidates entering clinical trials actually achieve FDA approval (DiMasi, Hansen, and Grabowski, 2003).The small success rate of clinical trials is painful to a pharmaceutical company's balance sheet because of the enormous amounts of time, labor, and materials required to perform a clinical trial. The small success rate has some issues for clinical supply chain (Colvin and Maravelias, 2008):

1) The complex trade-offs in the R&D pipeline. For example, the launch date of a new drug depends on the load of the R&D pipeline: if there are many successful products competing

for resources the commercialization of the new drug may be delayed; if promising products fail early, a drug may be launched earlier than initially expected.

2) The highly stochastic nature of the R&D process. Sources of uncertainty include the cost, duration, resource requirements and outcome of clinical trials (technical uncertainty) as well as the revenues from sales (market uncertainty). While market uncertainty is clearly very important, the uncertainty in the outcome of clinical trials is the most significant source of uncertainty in the development process. If a drug is successfully launched, it usually leads to large profits that outweigh development costs; if it fails, all previous investment is wasted and new drugs have to enter the pipeline. Uncertainties in cost, duration and resource requirements may lead to suboptimal solutions but typically require small corrective action.

3) The types of diseases under study do not favor the development of the so called 'blockbuster drugs' and many more drugs are developed for the treatment of orphan diseases than was the case in the past. Even for more common diseases, if more personalized drugs are coming to market, these newly developed drugs will only be targeting a small proportion of patients with a certain disease.

4) There is an increase in regulatory requirements, regarding patient safety and the clinical data supporting the efficacy of the new drug, making the process of drug development even harder and more time consuming than in the past.

5) The patent expiration and increasing market share of generic drugs makes acceptable return on investment more and more difficult. Also, the role of the payers becomes more and more important, leading in some countries to the refusal to reimburse certain new drugs, like cancer drugs, even if there is a proven benefit for the patient. Value for money is becoming a more important deciding factor for reimbursing the cost of new drugs. Companies have to show the added value of their new drug before a definitive reimbursement price can be obtained. Moreover, the medical world in general and the drug industry in particular have received greater political attention in recent years as well.

4.7 Case Study in Domestic Pharmaceutical Supply Chain

The 10 domestic (not global) pharmaceutical supply chain cases are based on real-world supply chain data, which were made available through the "Discovery Challenge" and internal exchange among some members of Association for Healthcare Resource & Materials Management (AHRMM). The data base consists of three tables (T_MANUFACTURERS, T_DISTRIBUTION_CENTERS, T_HOSPITAS). The identification number (ID) connects the pharmacies in these three tables. The table T_MANUFACTURERS contains all the information about pharmacy manufacturers. The table T_DISTRIBUTION_CENTERS contains all the information about pharmacy distribution centers. The table T_HOSPITAS contains all the information about pharmacy hospitals. The 10 pharmaceutical supply chains are as following:
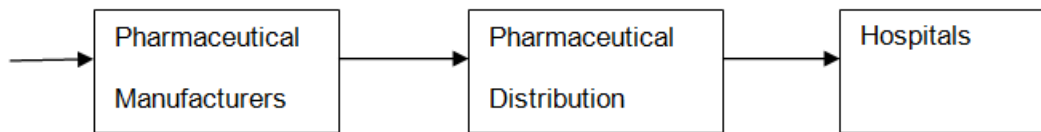

Figure 4.3 Supply chain model for cases studies

At the end we try to discover some sensitive/specific patterns to the target attribute which is risk, where the value of this attribute represents the degree of risk 0:negative (no risk), 1: positive (the most sever one), 2:positive (sever), 3:positive (mild).

Knowledge discovery is a process, which helps to make sense of data in more readable and applicable form. The knowledge data mining process and its data mining tools are becoming the focus of many fields, particularly in data-rich and knowledge poor processing scenario. The knowledge data mining process consists of five steps: Data selection, Data cleaning and preprocessing, Transformation, Data mining techniques, Interpretation and evaluation. Frand (2006) said as following:

Generally, data mining (sometimes called data or knowledge discovery) is the process of analyzing data from different perspectives and summarizing it into useful information - information that can be used to increase revenue, cuts costs, or both. Data

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mining software is one of a number of analytical tools for analyzing data. It allows users to analyze data from many different dimensions or angles, categorize it, and summarize the relationships identified. Technically, data mining is the process of finding correlations or patterns among dozens of fields in large relational databases.

Data mining is primarily used today by companies with a strong consumer focus - retail, financial, communication, and marketing organizations. It enables these companies to determine relationships among "internal" factors such as price, product positioning, or staff skills, and "external" factors such as economic indicators, competition, and customer demographics. And, it enables them to determine the impact on sales, customer satisfaction, and corporate profits. Finally, it enables them to "drill down" into summary information to view detail transactional data.

To choose the data, we first must specify the domain on which we are going to apply the Knowledge Discovery in Database (KDD) process so we have specified the medical domain. Then we downloaded the medical data from the Internet that was in a special form of Microsoft excel sheets consisting of three tables. After we have obtained the data, we selected subset of it as our target data. Then by removing the noise and try to fill the missing values, we obtain the processed data, which are a cleaned data. Then we connect the three tables by the ID attribute using SQL statements and try to choose only the useful attributes to have finally the transformed data, which consists of only one table then we apply the concept of rough set theory as data mining technique in order to reduce some set of attributes which describes the data. The following figure represents the data preprocessing and transformation of KDD process.
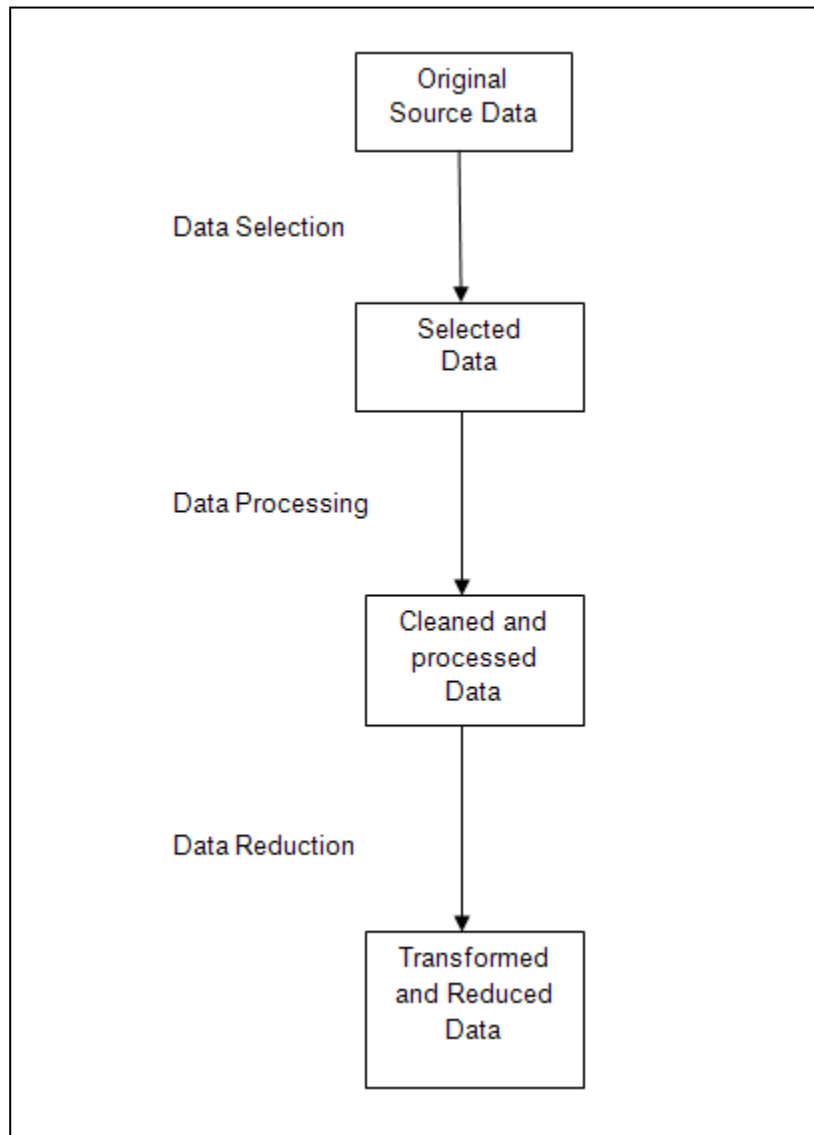
Figure 4.4 Data mining workflow

In the present work the steps of KDD process applied on the supply chain database is as follows:

Step 1: Selection

By using medical data of size in this application and selecting a subset from this data contains almost all the 10 pharmaceutical supply chain cases.

Step 2: Data Cleaning and Preprocessing

By using SQL statements, we remove the noise and collect the necessary information of model or account for noise.

Step 3: Date Transformation and reduction

According to the goal of our work; we tried to choose the useful features to represent the data. Firstly, we have to connect the three tables by the ID attribute using SQL statements. Then we removed from each table the objects with IDs, which are not in the other tables. Secondly, choosing number of attributes from each table in order to reduce the number of variables and try to use the most important features, which represent the data.

Let Q= certain set called universe; A = set of attributes; IND(A) = value of the set of attributes A ;n=number of objects, where n >= 1; N=number of attributes, and (xi , ak) means the value of the attribute ak at the object xi; The rough data theory reduction algorithm (Salem et al., 2005) is in follows:

```
For i=0 to n-1 loop

For j=i+1 to n loop

If xi and xj belong to the same class

then

Mi,j= 0 ;

Else

For k=0 to N loop

If (xi , ak)≠(xj , ak) then

Mi,j= ak+ Mi,j ;

end loop (K);

end if;

end loop (j);

end loop (i);

Let A={a1,a2,…,al} ⊆ Q;

For some i,j

if A ∩ Mi,j ≠ φ and IND(Q-A)= IND(Q)

A is a reduct set

Else

A is not a reduct

End if

end loop(i);
```

Figure 4.5 Data mining algorithm

Step 4: DEA inputs/outputs and efficiency

After we have worked the rough data theory reduction algorithm on the three tables (T_MANUFACTURERS, T_DISTRIBUTION_CENTERS, T_HOSPITAS) for the 10 supply chains, we get the 3 attributes as X1: additional costs due to unexpected cases happened; X2: regular production and operation costs; Y: profits. We apply the X1 and X2 as DEA input, and Y as DEA output. The data are in the following table, and the unit is thousand dollars.

X_{h1} is hospital additional costs due to unexpected cases happened;

X_{h2} is hospital regular operation costs;

Y_h is hospital profits.

X_{d1} is pharmaceutical distribution center additional costs due to unexpected cases happened;

X_{d2} is pharmaceutical distribution center regular operation costs;

Y_d is pharmaceutical distribution center profits.

X_{m1} is pharmaceutical manufacturer additional costs due to unexpected cases happened;

X_{m2} is pharmaceutical manufacturer regular production and operation costs;

Y_m is pharmaceutical manufacturer profits.

We apply our supply chain DEA model one in table 3.3, and compute the DEA values. The inputs, outputs, and DEA values are as following table.

Table 4.1 10 DEA inputs/output and efficiencies on supply chain model one

	X_{h1}	X_{h2}	Y_h	X_{d1}	X_{d2}	Y_d	X_{m1}	X_{m2}	Y_m	DEA values
S_1	477	10781	253	711	11297	374	965	12650	509	0.856
S_2	4734	100907	2686	6971	108855	3962	9248	119550	5392	1
S_3	1273	55360	961	2168	58070	1479	3544	62490	2179	0.986
S_4	261	6313	132	427	6774	198	613	7918	273	0.726
S_5	171	3748	89	247	3606	119	332	3814	164	0.91
S_6	841	21902	525	1241	21475	725	1638	22234	984	0.976
S_7	872	27059	626	1380	26593	847	1924	28495	1157	1
S_8	1802	20869	493	2667	21113	678	3559	21764	924	0.873
S_9	250	4232	79	364	4299	111	483	4508	144	0.656
S_{10}	1241	25327	465	1598	24535	656	2281	26923	903	0.71

The DEA efficiency values for 10 supply chains are on the right side of the above table, and are consistent with our real-world cases. We know the 9th supply chain has most risk, and 2nd and 7th supply chains have least risks. The two companies with least risks are Pfizer and McKesson. We will do analysis for the two companies in next section. We may also apply our supply chain model two in table 3.4, specify the relationship among weights w_1, w_2, and w_3, and compute the DEA efficiency values; we still get the same results that 2nd and 7th supply chains have DEA efficiency value 1, and the other supply chains have similar relative orders on their DEA values, e.g. the values of supply chain 1 is less than the value of 3rd supply chain, even though the DEA values of model two are different from the values of DEA model one.

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However, if we apply Cook's model in table 3.2, and compute DEA efficiency values, the results are different; they are as following.

Table 4.2 10 DEA inputs/output and efficiencies on Cook's model

	X_{h1}	X_{h2}	Y_h	X_{d1}	X_{d2}	Y_d	X_{m1}	X_{m2}	Y_m	DEA values
S_1	477	10781	253	711	11297	374	965	12650	509	0.9313
S_2	4734	100907	2686	6971	108855	3962	9248	119550	5392	0.9566
S_3	1273	55360	961	2168	58070	1479	3544	62490	2179	0.9283
S_4	261	6313	132	427	6774	198	613	7918	273	0.8681
S_5	171	3748	89	247	3606	119	332	3814	164	0.9775
S_6	841	21902	525	1241	21475	725	1638	22234	984	0.976
S_7	872	27059	626	1380	26593	847	1924	28495	1157	0.9836
S_8	1802	20869	493	2667	21113	678	3559	21764	924	0.9611
S_9	250	4232	79	364	4299	111	483	4508	144	0.8671
S_{10}	1241	25327	465	1598	24535	656	2281	26923	903	0.8672

From the table 4.2, we find the 9th supply chain still has least DEA value (most risk), and the 7th supply chains has biggest DEA value (least risks), but the 5th has bigger DEA value than the 2nd supply chain has. We know, from the real-world, the 2nd supply chain has less risk than that the 5th supply chain has.

4.8 The Characteristics of Pharmaceutical Companies with Least Risks

Pfizer, currently the world's largest global research-based, pharmaceutical manufacturer, is one of the first companies to commit to serialization to control the threat of counterfeits. It is leading portfolio of products and medicines that support wellness and prevention, as well as treatment and cures for diseases across a broad range of therapeutic

areas; and Pfizer has an industry-leading pipeline of promising new products that have the potential to challenge some of the most feared diseases of our time, like Alzheimer's disease and cancer Pfizer has had experience with some of its products being counterfeited and sold through the legitimate supply chain. According to IBM Center for Healthcare Supply Chain Research (http://www.hcsupplychainresearch.org/WP/IBM_whitepaper.pdf) document, in 2003, Pfizer's cholesterol-lowering drug, Lipitor, was involved in a very public counterfeit event affecting many patients. This incident led Pfizer to explore options to increase the safety of the supply chain, including implementing restrictions on authorized distributors of record, and developing a pilot about the employment of serialization. Serialization involves applying a globally unique number to each saleable unit. Pfizer has committed to serialization to ensure patient safety, as well as to protect the integrity of its products".

Pfizer works to discover and develop innovative, safe, and effective ways to prevent or treat some of the world's most challenging diseases. Pfizer historically has invested more than $7 billion annually in research and development, and work with more than 250 partners in academia and industry. After analysis of its product portfolio, Pfizer committed to serializing 100 percent of its Viagra product starting in 2004. By the end of 2005, tagged product was being shipped throughout the United States.2 Items are tagged on the manufacturing line at the item level with both RFID and 2D bar code tag, ensuring nearly 100 percent read rates throughout the supply chain as product is read at Pfizer manufacturing and distribution centers, wholesaler distribution centers and, eventually, at retail pharmacies for authentication. As noted by Pfizer, it is difficult to understand true read rates because the process of reading serialized items and cases is presently an exception process. According to a Pfizer spokesperson, Pfizer is not aware of any counterfeited Viagra in the "normal" (i.e., Manufacturer to Authorized Distributor of Record (ADR) to Pharmacy) supply chain since the inception of RFID tagging in 2004.

To ensure we can continue to deliver on our commitments to the patients, customers and shareholders who rely on Pfizer, Pfizer focused on improving the way Pfizer can do

business; on operating with transparency in everything Pfizer can do; and on listening to the views of all of the people involved in health care decisions. Through working in partnership with everyone from patients to health care providers and managed care organizations to world governments and non-governmental organizations, Pfizer's goal is to ensure that people everywhere have access to innovative treatments and quality health care. Pfizer believes in a risk-based approach to serialization and carefully selects which of its product lines will support tagging. Recently, it has expanded its serialization effort to include its Celebrex product. Pfizer recognizes that it takes action and commitment from across the entire supply chain – manufacturers, distributors and retailers – to fully recognize the value and business benefits from exchanging serialization and related data. Sharing information – such as product receive/ship data, lot/expiration data and quantity information based on serialization – will present an opportunity for trading partners to make informed business decisions. A key use case Pfizer is currently assessing is how to gain internal operational efficiency from serialized data. Pfizer's network of distribution centers across the world is already managed by a leading industry inventory management process. In addition, an initiative is underway to learn from the use of serialized data and understand how to leverage that data. Pfizer believes that patient safety and company operational efficiencies will be gained by establishing cross-trading partner data exchange via a standard technology and utilizing data sharing for more than compliance.

As a pharmaceutical distributor and health care information technology company, McKesson provides systems for medical supply management, clinical workflow, practice management, pharmacy automation and care management. McKesson looked to technology and to RFID in particular to improve patient safety and drive down costs within the pharmaceutical supply chain. From an operational standpoint, McKesson was interested in technology that could improve business processes, such as returns, recalls and inventory management and that could help to ensure only authentic products moved within their distribution centers. After an assessment, McKesson concluded that the use of RFID was more

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attractive than 2D barcodes because McKesson employs automated processes within its distribution facility. Serialization with 2D technology requires line-of-sight reading and would result in operational inefficiencies that compromise McKesson's automated environment. At present, most returns come back through the distributor with little visibility regarding the history and handling of the returned product. There is a potential for items to be returned to McKesson that it had not sold initially. From McKesson's perspective, this was unacceptable. On a return, McKesson wants to know whether the medication it is accepting was purchased directly from either the manufacturer, from McKesson or from another Authorized Distributor of Record.

McKesson Pharmaceutical distribution supplies branded, generic and over-the-counter pharmaceuticals to more than 40,000 customers spanning retail chains, independent retail pharmacies and institutional providers such as hospitals, health systems, integrated delivery networks and long-term care providers. McKesson identified serialization as a means to counter potential illicit returns. If a product is serialized, distributors can check its pedigree to validate the product's history. By increasing company controls across the supply chain, these systems protect the patient by eliminating the threat of counterfeit drugs from entering the normal main-stream supply chain. A spokesperson from McKesson also noted an interest in technologies that can drive a more targeted recall notification process. With serialization, manufacturers and distributors will each know exactly what products they sold and to whom. Today, manufacturers control product recall by lots, which can consist of thousands of items. Instead of sending out up to 35,000 notifications for each recall, McKesson looks forward to the day when it can send out specific notifications based on knowledge of where each serialized item in the affected batch/lot was distributed. Further, from a manufacturer and regulatory perspective, it would be helpful to see what percentage is actually returned and what product remains in the marketplace. In addition to operational benefits and patient safety gained through greater visibility and better recall practices, expiry management is another opportunity where serialization and data exchange can be effective in reducing risk and cost in the supply chain. Currently, there is no

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automated way to verify expiration date. McKesson noted that the supply chain is poised to benefit from a better way to manage inventory and ensure that no expired product gets into the hands of patients.

McKesson empowers customers by providing the broadest suite of products and services and deepest range of experience in healthcare. McKesson brings together industry-leading distribution services, packaging, pharmacy automation, clinical decision support, information solutions, and staffing and consulting services to reduce costs and improve the quality for you and your patients. McKesson is a leader in identifying key use cases where serialization can enable business benefits and EPCIS can strengthen automated communication channels across the supply chain. Communication via EPCIS may be leveraged to improve forecasting with upstream trading partners and to increase efficiency of expiry management for downstream trading partners. By enhancing communication and visibility of granular data, supply chain and patient safety benefits are achievable.

McKesson's Healthcare Materials Management Services (HMMS) was created in 1997 to integrate and consolidate supply purchasing, inventory management, logistics and accounts payable for London, Ontario, hospitals and regional affiliates. By using McKesson's supply chain management solutions and adopting leading practices, HMMS has further automated processes and set a new supply chain benchmark for Canadian hospitals. Results include reduced operating costs, improved service levels, better utilization of resources, streamlined business support and enhanced clinical care — which ultimately created more than $2.2 million in savings and annual cost reductions of $1.5 million. HMMS is one of the largest and most successful supply chain management ventures in Canada. With funding from the Ontario government, HMMS recently participated in an e-Supply Project with five other healthcare organizations. The goals: further automate manual processes through expanded use of e-commerce and technologies; implement leading practices; and develop new capabilities to benefit both providers and suppliers.

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More and more, healthcare organizations are turning to supply chain efficiencies to help achieve a healthier bottom line. McKesson supply chain management solution links the entire hospital supply chain into a single, integrated process. From requisitioning through invoice matching, contract compliance and rebate attainment, McKesson supply chain management automates and streamlines all the supply chain management functions. McKesson 's Analytics module for supply chain management provides actionable insight into a hospital's supply chain with business analysis and performance models, plus valuable data tools to organize and interpret the data.

CHAPTER 5

SUMMARY, CONTRIBUTION AND THOUGHT FOR FUTURE RESEARCH

5.1 Summary

Risk in supply chain is defined as a potential future event that may influence the achievement of objectives; this includes upside and downside risks. Effective risk management increases the value of business decisions because conscious choices are made in relation to risks that have an impact on, or result from, these business decisions. The objective of risk management is not, therefore, arbitrarily to reduce or eliminate risk. In general, many people are involved in managing risk, and risk management, which is an integral part of the group's management activities (strategy, planning, execution, operation, monitoring, and appraisal); it is not a separate activity in supply chain management. Risk management is the responsibility of those who are accountable to deliver the associated objective; therefore, the evaluation of the risk can only have value or meaning when explicitly linked to performance.

This research involves the evaluation of supply chain risk by using DEA and rough set theory. We present a model for evaluating risks in the supply chain, and apply the model in healthcare management. The risk evaluation includes estimating the significance of the risk and judging the acceptability of risk. This research is to model the risk management, analyze and evaluate the potential impact of risks, and propose risk treatment in terms of the most important risk to manage and finally select the appropriate alternative options to minimize, such as accept and control risk, terminate or forgo activity.

5.2 Contribution

This research provides many contributions to the body of knowledge in the area of supply chain risk management and also provides the opportunity to improve the current

healthcare supply chain operations. The dissertation is developed from a decision standpoint. Our attempt has been to provide an analytical basis which can be used to link operational and strategic goals and resulting plans of a supply chain firm.

The first contribution is we propose a comprehensive methodology to estimate the significance of the risk against performance, which considers all risk and performance elements incurring in each component of a supply chain.

The second contribution is the development of new multi-tiers DEA models that can be applied to evaluate the relative effective values of supply chain by optimizing weight of each component in supply chain. These models not only provide the overall efficiency of supply chain but also show the efficiency of each component, which is valuable information for analysts to consider in improving the supply chain.

The third contribution is the integration of classical DEA and rough set theory into a Rough Data Envelopment Analysis (RDEA) method, identification of the main uncertainty risk factors in a supply chain.

Finally, the fourth contribution of this research provides the opportunity to analyze and evaluate the risks of healthcare supply chain by using the multi-tier DEA model and RDEA method. The logistics experts or analysts can use these results to improve the efficiency and decrease risk of the supply chain by just varying the significant parameters in the model.

<u>5.3 Future Research</u>

Different approaches can be taken to identify supply chain risks and the approach taken might depend on the complexity of the industry and the volatility of the risk environment. However, the identification of the risks may result in a long list that may not be monitored or managed by risk managers. Admittedly, some of the risks may simply be monitored or managed as part of a daily management routine. Some may be combined, since they address the same underlying issues, or may be managed at a different organizational level. Risk assessment assists in allocating resources and prioritization of actions based on a comprehensive picture of

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all significant risks in the context of the objectives of the relevant entity. There are topics for further research, which include the idea that one echelon can use knowledge about other echelons to decrease its risk or the mutual risks of th**e** members.

Risk evaluation of the supply chain with Rough Data Envelopment Analysis (RDEA) can help analysts, managers, or executives better understand their current operations and also provide a good opportunity for improving their current supply chain with many alternative options. This methodology can be applied in many areas not only for healthcare supply chains. Extending and adapting this methodology to more complicated network supply chain would be interesting but may consume more time and effort. Another interesting future research is to use a more extensive DEA model in evaluating the risk and comparing it with this current model.

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BIOGRAPHICAL INFORMATION

Ford Guangfu Zeng received his Bachelor of Engineering in Agricultural Mechanical Engineering from the Hunan Agricultural University, China, in 1986. He earned three master degrees, including an MBA degree from the University of Houston in 1997. He has had over 10 years of industrial work experience.

Ford Guangfu Zeng focuses on the Supply Chain Risk and Performance Management. For this purpose, he built several models and developed some methodologies. He has published 8 papers in journals and conferences, including journals of Annals of Operation Research, Logistics Spectrum, and conference proceedings of Portland International Conference on Management of Engineering and Technology, INFORMS, and Decision Sciences Institute. He may be reached by e-mail at ford.zeng@gmail.com.