# CLOUD-BASED SOLUTIONS FOR SUPPLY CHAIN MANAGEMENT: A POST-ADOPTION STUDY

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***ABSTRACT***
*More and more organizations have adopted cloud-based solutions to be their primary sourcing applications. Nevertheless, this technology is not without challenges and in order to implement cloud-based solutions successfully with minimal risks organizations need to have practical guidance on this emerging technology. This research examines the post-adoption stage of cloud supply chain solutions from the decision science perspective and intends to provide organizations with practical guidance on how to ensure the efficiency of a cloud supply chain system and control risks associated with cloud-based solutions.*

## INTRODUCTION

Cloud computing is emerging as flexible IT-based solutions and changing the way organizations do business. Cloud computing can provide on-demand computing services with high reliability, scalability and availability in a distributed environment (Xun, 2012). If used properly, cloud computing can become a valuable and inimitable resource that helps organizations create and sustain their competitive advantages (Truong, 2010). As cloud computing is expanding and being adopted in numerous business domains, it starts drawing attention of supply chain practitioners. Supply chain management can benefit greatly from using cloud computing since it promises to enable a wide and powerful range of capabilities in supply chain management including: reducing the startup costs, increasing the supply chain visibility, reducing lead time, enhancing the inter-firm collaboration and supply chain integration, and reducing response time to customers (Shacklett, 2010; Schramm et al, 2011; Marston et al., 2011).

Cloud supply chain solutions have been growing dramatically. A research study conducted by Garner Inc. indicated that within supply chain management sector cloud adoption had increased 40 percent in 2013 compared to 2011 (McCrea, 2013). More and more organizations choose cloud to be their primary way of sourcing applications. However, cloud computing is still new to organizations in supply chains and how this technology can be used effectively to enhance supply chain performance with minimal risks is still in question. Organizations may be interested in cloud-based solutions due to their potential benefits but they may not be fully aware of challenges and difficulties in using cloud computing. Integrating cloud supply chain solutions to in-house systems and applications can be challenging and requires strategic decisions (Truong, 2010). In addition, organizations may have extra and unexpected expenses on employee training, new regulations setup, and transition process. While cloud-based solutions help reduce startup costs, they usually increase recurring costs. These difficulties may affect the efficiency of organizations in a supply chain. All organizations have access to the same cloud servers and solutions but they may behave differently to the cloud environment. The inefficiency in cloud supply chain solution operations of one organization will have a negative impact on the efficiency of the entire supply chain.

Additionally, using cloud-based solutions could create some new risks to the supply chain. Putting an organization’s systems, applications, and customer data on a remote server at a vendor location can be worrisome and raise questions about security and privacy issues (Truong, 2010; Durowoju et al., 2011). Since all organizations in a supply chain share important information about products, orders, inventory, shipment, payment, customer profile, etc. through cloud systems and applications they need to be ensured that there is no data leakage or any potential privacy and legal issues. Moreover, since all supply chain operations are cloud-based a cloud service outage situation will be catastrophic and have dramatic effect on the supply chain performance. Thus, it is important for supply chain executives to assess and control risks associated the use of cloud computing in supply chain management.

These discussions lead to two major research questions: 1) How to evaluate and improve the efficiency of cloud supply chain?; 2) How to assess and control risks associated with cloud supply chain solutions? These issues have not been addressed adequately in existing literature that focuses mainly on benefits of cloud computing in supply chain and factors that affect the cloud supply chain adoption. After adopting cloud-based solutions, supply chain executives need to have practical guidelines to implement these solutions efficiently with minimal risks; something that they do not get from cloud vendors. To fill the gap in the literature this research intends to focus on the post-adoption stage of cloud-based solutions in supply chain management from the decision science perspective. Specifically, the purpose of this research is to provide organizations with guidelines on how to evaluate and improve the efficiency of cloud supply chain systems, and how to assess and control risks associated with cloud-based solutions.

## CLOUD-BASED SUPPLY CHAIN

Lindner et al. (2010) define a cloud supply chain as "two or more parties linked by the provision of cloud services, related information and funds". The cloud supply chain represents a network of interconnected organizations in the cloud computing area involved in the provision of products and services required by customers. Figure 1 presents components of a cloud supply chain. Supply chain execution for the cloud is managing and coordinating the (partly) bi-directional movement of products/materials, information, and financials across the cloud supply chain. This includes, but not limited to, the actual provisioning of on-demand platform, infrastructure services, and application services, and the monitoring and maintaining of these services. Figures 2 and 3 present examples of cloud supply chain in logistics sectors using Keyfort's cloud computing service (keyfort.net). In this cloud supply chain, logistics process is handled using cloud services in which shipping schedule, shipping notice, receiving notice, and payment information is stored and shared through cloud.

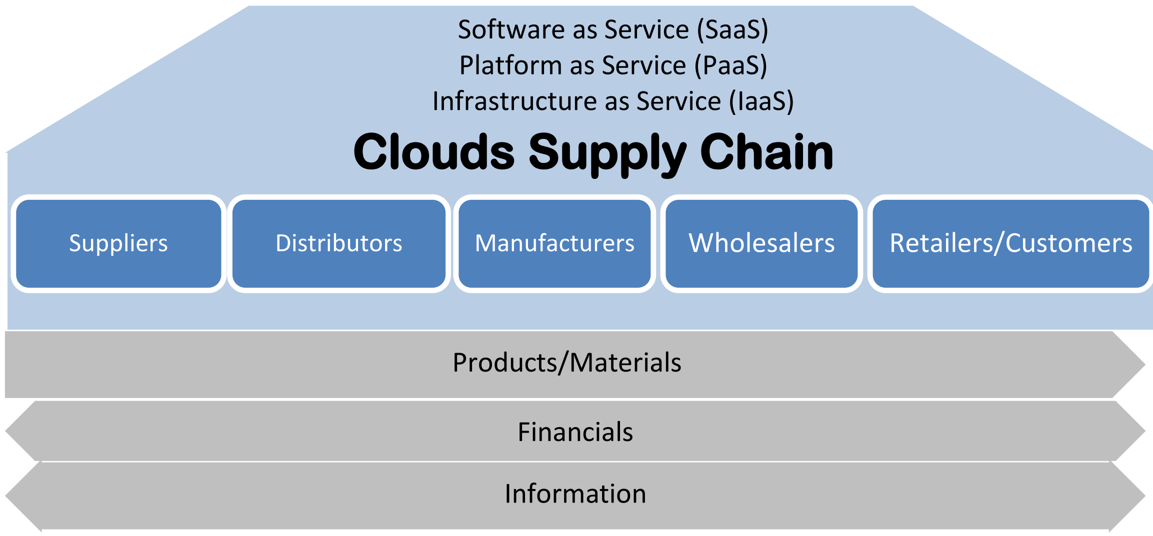


Figure 1: Cloud Supply Chain components

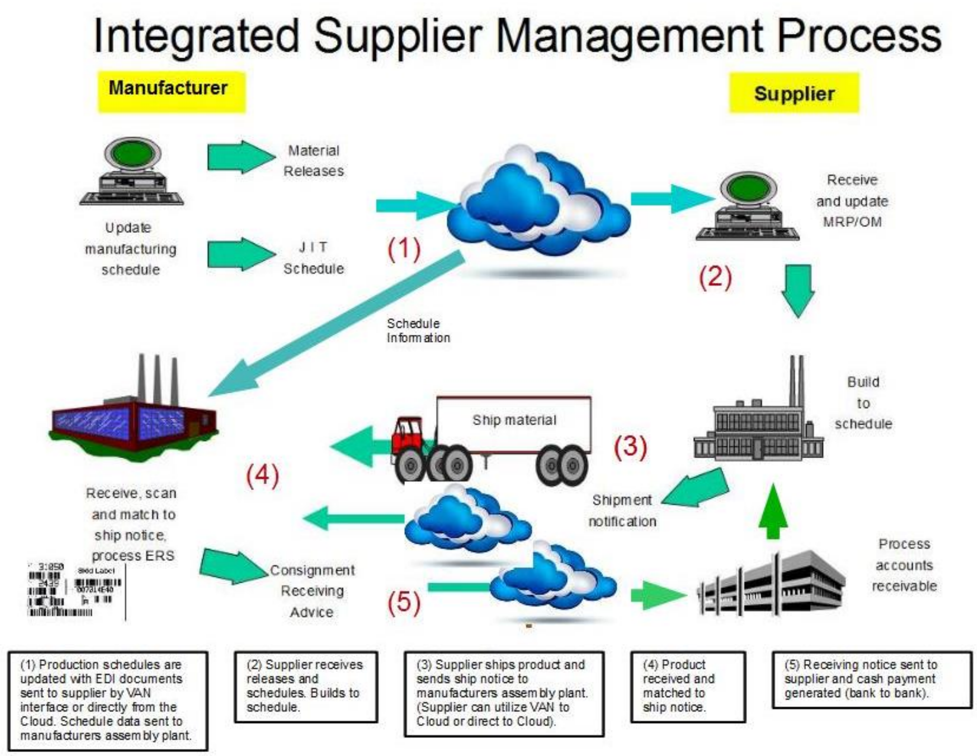


Figure 2: Cloud Supply Chain in Logistics Sector Using Keyfort's Cloud Computing Service (source: keyfort.net).

Among cloud supply chain solutions, SaaS ERP is growing rapidly and many organizations are very receptive of this solution. SaaS are applications that are delivered through the medium of the Internet. Instead of installing and maintaining software, users simply access it via the Internet. This type of cloud service offers a complete application functionality including customer relationship management or enterprise-resource management (examples: SaaS Enterprise Resource Planning, Sales force Customer Relationships Management (CRM) system, NetSuite, and Google Office Productivity application). SaaS is not licensed or owned by the end user, it is provided as a service. Reports show that organizations with the most successful ERP implementations are most likely to consider SaaS ERP deployments. Figures 3 and 4 show ERP deployment selection overall and by company size. It can be seen that more than 44% of companies have decided to use SaaS ERP compared to 56% that use traditional licensed ERP. Large companies have tendency to use SaaS ERP more than small companies and start moving away from traditional licensed ERP solutions.

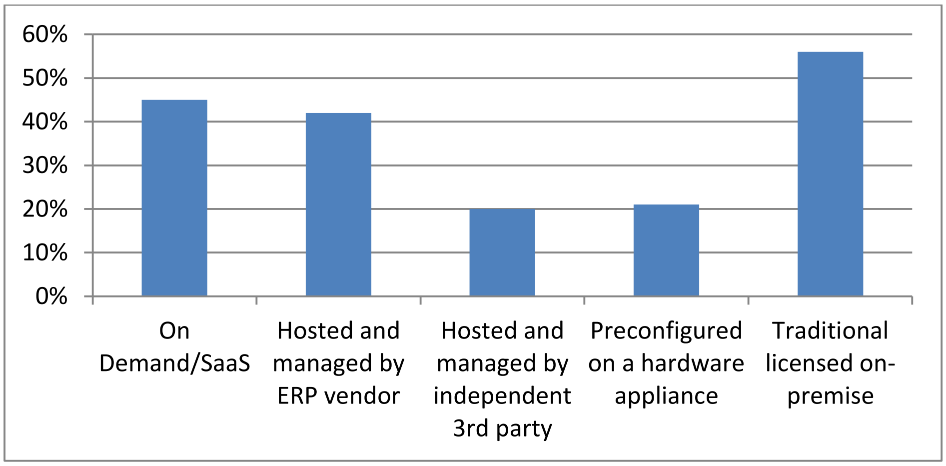


Figure 3: ERP Deployment Selection (source: data from mintjutras.com)

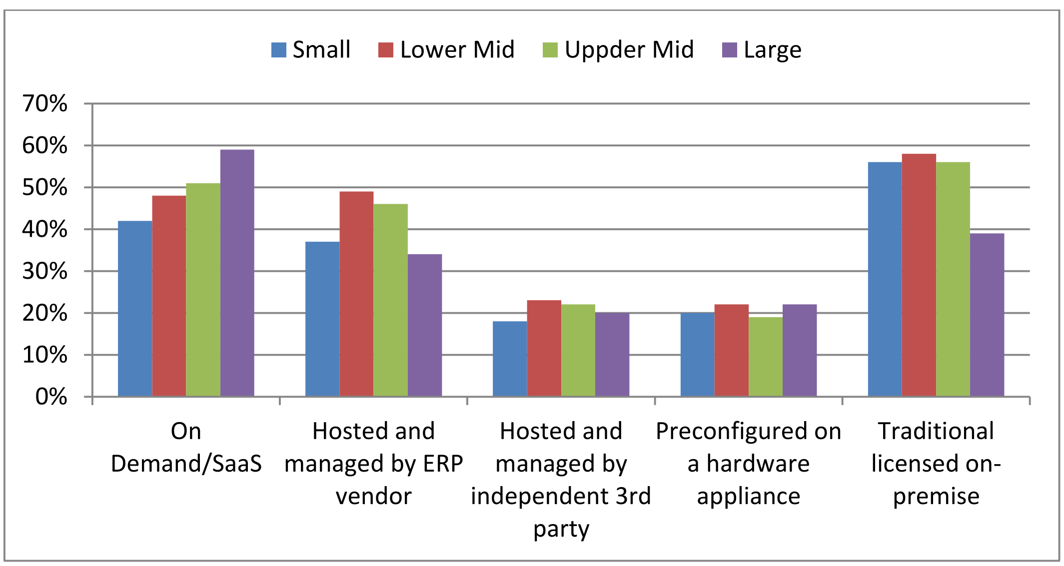


Figure 4: ERP Deployment Selection by Company Size (source: data from mintjutras.com)

## GAPS IN THE LITERATURE

Although there have been several industrial developments related to cloud supply chain solutions, little academic research exists and examines the cloud supply chain from decision making point of view. A review of the published research on cloud supply chain (Table 1) reveals that existing literature is still long on conceptual and descriptive and short on practical guidance from decision making perspectives. Most studies either focus on defining cloud supply chain (Lindner et al., 2010), proposing lists of benefits and challenges for organizations considering cloud supply chain solutions (Singh, 2009; Demirkan et al., 2010; Tsao et al., 2010; Li, 2011; Durowoju et al., 2011; Li et al., 2012), cloud supply chain adoption model (Casey et al., 2012; Wu et al., 2013), or exploring the architectures and applications of the cloud environment (Ferguson and Hadar, 2011; Bu and Wang, 2011 ).

While these studies have some contributions to the literature they are mainly conceptual and focused on the pre-adoption stage of cloud supply chain. In other words, these studies intend to provide organizations with information needed to consider whether to adopt cloud supply chain solutions. The common methods used in these studies are conceptual framework, case study, or survey. Nevertheless, as a new technology emerges adopting decision is just a beginning and what more important is how to use this technology efficiently and effectively with minimal risks. Thus, it is important that scholars begin to realize the need of supply chain executives and examine the phenomena of cloud supply chain in the post-adoption stage. Organizations that adopt cloud supply chain solutions need to make sure the efficiency of cloud supply chain operations given their current resources. Since organizations in a supply chain are interconnected and share the same cloud services, the inefficiency of one organization will affect the efficiency of the entire supply chain. In addition, since cloud supply chain solutions involve various risks that could affect the supply chain efficiency and outcome, decision makers need to effectively assess and control associated. These are important issues in the post-adoption implementation of cloud supply chain solutions, yet have been addressed in existing studies. In order to fill this gap in the literature, this research intends to address these issues and provide supply chain executives with practical guidance from the decision science perspective that help resolve these issues. This guidance will help organizations ensure the success of cloud supply chain implementation.

## DECISION SCIENCE APPROACHES FOR CLOUD SUPPLY CHAIN SOLUTIONS

Decision science approaches have been proven to be useful methods to support executives in making important strategic decisions. Decision science can be defined as a scientific approach to decision making that seeks to best design and operation a system, organization of interdependent components working together to accomplish the goal of the system, under conditions requiring the allocation of given resources (Winston, 2004). Decision science approaches have been applied widely in various business areas as effective problem-solving techniques and methods applied in the pursuit of improved decision-making and efficiency. This research presents important decision approaches for cloud supply chain solutions along with clear and detailed step-by-step guidance for practitioners.

## DATA ENVELOPMENT ANALYSIS METHOD

Since cloud-based solutions play an important role in industries, it is crucial to evaluate efficiency of the supply chain system that uses cloud computing. Data Envelopment Analysis (DEA) is an effective method in decision sciences that can be used to measure the efficiency of Decision Making Units (DMUs) as compared to an estimated production efficiency frontier (El-Mashaleh et al., 2010; Ray, 2004). The applications of DEA can be described in several different scenarios:

ranking DMUs by efficiency, benchmarking to efficient units, and estimating super-efficiency. The DEA model will identify inefficient DMUs based on the composite DMU and compute the necessary improvements required in the inefficient unit's inputs and outputs to make it efficient. Accordingly, a DEA model is very useful for organizations in evaluating and improving the efficiency of cloud supply chain implementation as it allows supply chain decision makers to measure efficiency of each unit in the supply chain network based on identified outputs and inputs, compare the efficiency between these units, identify inefficient units, and determine appropriate strategies to make them more efficient, thereby enhancing the efficiency of the entire supply chain.

DEA is a mathematical programming technique originally developed by Charnes, Cooper, and Rhodes (1978), which can be used to determine the boundary of a production frontier. It is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of decision making units (DMUs). DMUs in this model should be organizations in a supply chain network (suppliers, manufacturers, distributors, wholesalers, retailers). In order to apply this model, output and input metrics of cloud supply chain systems must be pre-determined. Output metrics can be categorized as quality, responsiveness, customer satisfaction, and financials. Input metrics can be categorized as material resources, financial resources, and human resources. Supply chain decision makers must decide which metrics to be used based on strategic goals and objectives of supply chain management. Since DEA is a multi-factor analysis model it can handle multiple input and output factors in the cloud supply chain.

DEA provides each DMU with an efficiency score that has to be viewed as its relative efficiency in the set of all DMUs involved in the efficiency evaluation. The most important advantage of DEA for efficiency evaluation activities is that it is able to identify inefficient DMUs based on the basis of composite DMU (Homburg, 2001). A test DMU is inefficient if a composite DMU (linear combination of units in the set) utilizes less input than the test DMU while maintaining at least the same output levels. The units involved in the construction of the composite DMU can be utilized as benchmarks for improving the inefficient test DMU. DEA also allows for computing the necessary improvements required in the inefficient unit's inputs and outputs to make it efficient.

## RISK ASSESSMENT METHOD

As previously noted, cloud computing enables organizations to align product innovation with business strategy, and create intelligent networks that encourage effective collaboration. Organizations are starting to take advantage of cloud computing because of its economic advantages (Xun, 2012). However, cloud computing is not without risks since it is delivered by external vendors through the Internet medium. Many studies have addressed risks that organizations will likely encounter when they adopt cloud-based solutions. These risk analyses are mainly conceptual and provide a wide range of risk factors from different perspectives. For example, Schramm et al. (2011) address three main risks: collaboration and the partner eco-system, competitive essence, and security. In a detailed managerial report, ENISA (2009) categorized risks of cloud computing into: policy and organizational risks, technical risks, and legal risks. Other studies focus mainly on the security and privacy risks (Steve, 2008; Svantesson & Clarke, 2010; Xun, 2012; Zissis & Lekkas, 2012). Although these studies describe risks associated with cloud computing, they are still in the conceptual stage and lack empirical evidence. Additionally, these risk factors are inadequate and not scientifically analyzed.

While promising benefits of cloud computing lead to the likelihood of adopting cloud-based solutions in supply chain, organizations need to be fully aware of risks associated with this new technology and learn how to control them. Accordingly, an effective risk management model for cloud solutions is crucial for organizations in a supply chain to implementing this emerging technology successfully with minimal risks. Risk management for cloud supply chain solutions requires a structured approach to manage risk factors that can potentially affect cloud users. Simply, this process includes risk identification, risk assessment, and risk control. In this section, the research presents a decision method that identifies and assesses risks associated with cloud-based solutions for supply chain management. This method will enable organizations to identify risk factors for cloud supply chain solutions, prioritize risks, and compute risk values.

The literature indicates some popular risk analysis methods such as Fault Tree Analysis, Event Tree Analysis, Monte Carlo Analysis, Scenario Planning, Sensitivity Analysis, Failure Mode and Effects Analysis, Program Evaluation and Review Technique. Most of these methods use the probabilistic approach to estimate the probability distribution of uncertain parameters. However, probabilistic approach is only applicable given sufficient information and requires reliable data. Since the usage of cloud-based solutions are still in the initial stage at many organizations, this kind of data is difficult to obtain or may not even exist. Without complete and reliable data, these methods are unable to handle uncertainties and subjectivities associated with cloud supply chain systems. Research indicates that fuzzy technique has proven useful to handle complex problems and subjective data and to model the human knowledge (Li et al., 2007; Zeng, 2007; Yucel et al., 2012). In the fuzzy approach membership functions are used to characterize vagueness in human thoughts. This approach has the power to handle the concept of ‘‘partial truth’’ to quantify uncertainties associated with linguistic variables (Yi et al., 2007). Accordingly, the fuzzy approach is well suited to deal with uncertainties when little information is known. Researchers can use the expert elicitation approach to gather input data for the risk analysis. A group of industrial experts with practical cloud computing experience will be asked to participate in a study and provide their inputs regarding risks associated with cloud-based solutions. Since this practice imposes uncertainties and subjectivities in the risk analysis process, it resolves the issues faced by previously mentioned risk assessment methods.

Risk identification and assessment is important to cloud-based solutions implementation as this process enables organizations to reduce probability of risk occurrence through discovering risk in time. This research presents a risk assessment method using fuzzy logic to identify and prioritize risks associated with cloud-based solutions, and calculating risk values. Risk magnitude can be assessed by considering two fundamental risk parameters, risk likelihood and risk severity (Zeng, 2007; Yucel, 2011). These parameters are determined based on aggregation of the scores and importance of risk factors as a result of the expert elicitation process.

First, a risk assessment group is established with a range of experts with relevant background and experience. These experts should have knowledge, expertise, and experience on cloud computing and its potential risks, integrated supply chain network, and supply chain uncertainty. The risk assessment group reviews relevant information and determine risk factors based on their expertise and experience. They also provide the score and weight for each risk factor. Then fuzzy membership functions of factor index (FI), risk likelihood (RL), risk severity (RS), and risk magnitude (RM) are determined using linguistic variables. For example, FI are defined as Very Poor, Poor, Fair, Good and Very Good, RL and RS are defined as Very Low, Low, Medium, High, and Very High, and RM is defined as Negligible, Minor, Major, and Critical. This method seems appropriate since experts usually use linguistic terms to define their logical judgments (Yucel, 2011).

Zeng (2007) suggested using the Analytic Hierarchy Process (AHP) to determine the weights of risk factors based on the assumption that the factors should be independent from each other. However, in the cloud supply chain network, where information and process is shared across the supply chain, risk factors are likely related to each other. To overcome this issue, the use of Analytic Network Process (ANP) is proposed instead of AHP since ANP is able to handle interdependencies between factors (Saaty, 1999; Yucel et al., 2011). ANP is a more general form of AHP and it is used in multi-criteria decision analysis. ANP consists of a network of criteria and sub-criteria that define the interactions, and a network of influences among the elements and clusters (Saaty, 1999). Saaty proposed 1-9 scale for pairwise comparison to measure the weight of risk factors. A score of 1 represents equal importance between the two elements and a score of 9 indicates the extremely more important than the other one. Experts in the risk assessment group use this method to provide their perceived score and weight of each risk factor. Measurements of FI, RL, and RS are fuzzy aggregated from expert opinions (scores and weights of risk factors).

In the next step, the process of fuzzy inference will be conducted in which the aggregated fuzzy numbers of FI, RL and RS are converted into matching fuzzy sets. These aggregated numbers are then input to the fuzzy inference system to decide which rules are relevant to the current situation, then calculate the fuzzy output of RM.

Since the output of the fuzzy inference system is a fuzzy set, the defuzzification procedure is used to convert the fuzzy result into a matching numerical value to represent risk magnitude. The risk value will be evaluated and interpreted by experts and the risk analyst to make right decisions on the implementation of the cloud supply chain. It should be noted that the results may not be final. If the circumstances of risks change due to some uncertainty, experts and the risk analyst need to collect more information related to the risks, review the risk assessment process, and make necessary modification to ensure reliable decisions.

## RISK OPTIMIZATION APPROACHES

As organizations implement cloud supply chain solutions, they must be aware of risks associated with this technology and they need to perform the effective risk management. Risk management is a process used to identify and assess possible risks, and minimize risk impact or set up a strategy to control the risks (Lin & Varadharajan, 2006). While the former can reduce probability of risk occurrence through discovering risk in time, the latter can effectively control the negative impact when risk occurs. This research focuses on risk control through a risk optimization approach for cloud supply chain solutions.

Organizations can achieve risk optimization by controlling the failure probability and/or the failure cost (Beck and Gomes, 2011). Risk mitigation through preparation, education, training, and so on, is out of the scope of this investigation as these activities require a long-term planning, top management commitment, and involvement of all departments. This research focuses on organizations' effort to allocate resources appropriately to reduce the negative impacts of risks and, thereby, minimize the expected costs of failure. Risk factors identified in the risk assessment step along with risk likelihood and risk severity will be used in the development of the risk optimization. The expected costs of failure can be determined as the product of failure costs by a failure probability (Beck and Gomes, 2011). Failure costs include the costs of repairing or replacing cloud supply chain solutions that are damaged and rebuilding the solution, cost of solution unavailability, cost of compensation for business failure or information loss, etc. All failure consequences have to be expressed in terms of monetary units. On the other side, failure probability refers to the probability that risks will occur in the cloud supply chain implementation process. The risk optimization model will determine the optimal safety investment planning to minimize expected costs of failure while keeping the failure probability and cost of safety investment in control. It can be applied widely in industries to enable organizations to control the risks associated with cloud supply chain solutions.

Developing a risk optimization model is the second step in a risk management process. Information collected from risk assessment activity such as risk factors, risk likelihood, and risk severity can be used in the development of the risk optimization model. The objective of this model is to minimize the total expected cost of failure which is calculated as the product of failure costs by failure probabilities (Beck and Gomes, 2011). To control risks, organizations allocate resource investments on safety activities to keep failure probabilities under control.

The optimization model should include random parameters of cloud supply chain, and includes risk likelihood, risk severity, costs of failures, etc. Some of these parameters are random in nature; others cannot be defined deterministically due to uncertainty. Decision variables include safety investment, safety factors, parameters of the inspection and maintenance programs, etc. Failure costs include the costs of repairing or replacing the damaged cloud supply chain solution and rebuilding the solution, cost of service unavailability, cost of compensation for business failure or information loss, etc.

In order to insure the safety of cloud supply chain solutions, organizations need to allocate budget for safety activities. Cost of safety investment increases with the safety coefficients used in design and with the practiced level of quality assurance. More safety in operation involves more safety resources, more redundancy and more conservatism in cloud supply chain operation. Inspection cost depends on intervals and choice of inspection method. Maintenance costs depend on maintenance plan, frequency of preventive maintenance, etc. When the overall level of safety is increased, most cost terms increase, but the expected costs of failure are reduced. Any change in decision variables that affects cost terms is likely to affect the expected cost of failure. Changes in decision variables which reduce costs of safety investment may result in increased failure probabilities, hence increased expected costs of failure. Reduction in expected failure costs can be achieved by targeted changes in decision variables, which generally increase costs of safety investment. This compromise between safety and costs is typical and enterprises can find an optimal solution that will minimize expected costs of failure while keeping the failure probability and cost of safety investment in control.

## CONCLUSIONS

Cloud computing is emerging and it will change the way organizations do business and collaborate with trading partners. Based on cutting-edge capabilities offered by this technology it is safe to assume that it will have the same impact as the Internet did. Cloud –based solutions have been growing rapidly in supply chain management and many organizations have adopted cloud as their major sourcing method. This research focuses on the post-adoption stage of cloud-based solutions for supply chain management and provides supply chain executives with practical guidance on how to evaluate and improve the efficiency of cloud supply chain and how to assess and control risks associated with cloud-based solutions. This research has several important contributions to cloud computing literature. First, this is among first studies that examine cloud-based solutions in supply chain management at the post-adoption stage. After adopting cloud as their primary sourcing applications, organizations face real challenges in implementing these solutions efficiently under uncertainty. This research provides important insights that bridge the gap in the existing literature. Second, while existing studies are mainly descriptive or using conceptual models, this research investigates the efficiency and risk management issues related to cloud supply chain from the decision science perspective. Decision science approaches have been proven to be effective problem-solving techniques in the pursuit of improved decision-making and efficiency. This research proposes important decision approaches for cloud supply chain solutions and add useful insights to the inadequate literature.

Results of this research have important practical implications through the detailed guidance for the industry. Supply chain decision makers, as cloud users, will benefit in several ways. First, they can use the efficiency model to identify inefficient organizations in cloud supply chain implementation and find solutions to improve the efficiency of these organizations which in turn will enhance the efficiency of the entire supply chain. This decision model is very important for industries since many organizations are still new to cloud computing and may not be able to implement cloud-based solutions efficiently given their resources. Second, supply chain decision makers can use the risk assessment model to identify risks, prioritize risks, and calculate risk values for their own situations. This will be a very useful tool to help them determine risk likelihood, risk severity, and risk magnitude; thereby, forming appropriate strategies to reduce the probability of risk occurrence through discovering these risks in time. Third, the risk optimization model will enable decision makers to determine optimal safety investment to minimize expected costs of failures.

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