CJOM, Volume 8, Number 2, November 2010 ISSN: 1542-4006

California Journal of Operations Management

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Sincerely,

Dr. Taeho Park
CJOM Editor

California Journal of Operations Management

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The Influence of Top Management Support and Information Technology (IT) Utilization on Supply Chain Integration (SCI)

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Top management support is recognized as an important determinant for the success of information technology (IT) projects. The primary role of top management is shifting from the supportive of back-office operations to facilitating and in some cases leading strategic initiatives. Recently, IT has been adopted to accommodate customer and supplier involvement in designing process, specifying customized product offerings, enhancing manufacturing flexibility, controlling manufacturing operations, and improving an organization's market position. The confluence of these advances allows the supply chain members to collaborate on activities in order to reach the full benefits of technology investments within a supply chain. While the benefits of IT utilization have been extensively reported in the literature, the roles of IT utilization and top management support on supply chain integration have not been studied. This research proposes that top management support facilitates IT utilization, which in turn positively impacts supply chain integration. Based on responses from 220 firms, this study supports this claim, and it also shows that top management support impacts supply chain integration directly and positively.

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I. INTRODUCTION

A supply chain is a network of companies connected by a set of serial and parallel supplier-customer relationships from the first supplier to the final customer. Supply chain management involves coordinating the logistics of planning activities among supply chain members. A substantial part of this coordination is accomplished through the application of information technology (IT). In addition, firms competing in global markets face many challenges that can be addressed with IT applications including technology and innovation that must be disseminated among supply chain members, higher customer expectations that require more coordination in product design and development across the supply chain, and cost-based competition that is driving process improvement throughout the supply chain. Overtime, these challenges are expected to increase in intensity and complexity.

Top management support is essential to cope with these supply chain challenges, which are interwoven with critical IT applications. Top management support can be defined as the degree to which the firm's leadership understands the importance of supply chains and IT investments and is involved in these efforts. Top management support has been identified as a critical, positive factor that influences the success of many IT projects (e.g., enhancing IT performance, improving IT planning, and increasing IT effectiveness) (King et al., 1989; Raghunathan & Raghunathan, 1988; Seliem et al., 2003; Kearns, 2006).

Top management involvement helps to translate external threats into strategic advantages through appropriate IT investments (Liang et al., 2007). In this process, IT's role is transformed from back-office support to strategic facilitation with top management providing leadership and assessing the business value (Nelson and Cooprider, 1996; Devaraj and Kohli, 2003). Wu et al. (2003) examined strategies for market negotiation, cooperation, coordination, and collaboration and found that top management has a key role in achieving competitive advantage in an information intensive environment.

The relationship between IT utilization and supply chain integration (SCI) has also been reported in the literature. Barut et al., (2002) found that IT is an essential ingredient and backbone for successful SCI. As the concept of competition between supply chains grows in both intensity and scope, IT is being used to facilitate coordination within the firm, enhance external integration with customers and suppliers, and facilitate decision making amongst supply chain members. This phenomenon can be seen by the increased usage of IT for integration, such as, IT infrastructure (e.g., data communication tools, network connection, standard data structure, and unified coding standards), information systems software (e.g., enterprise-wide information system such as SAP), and information systems applications (e.g., centralized database management systems, electronic data interchange, web-based or internet-base information systems).

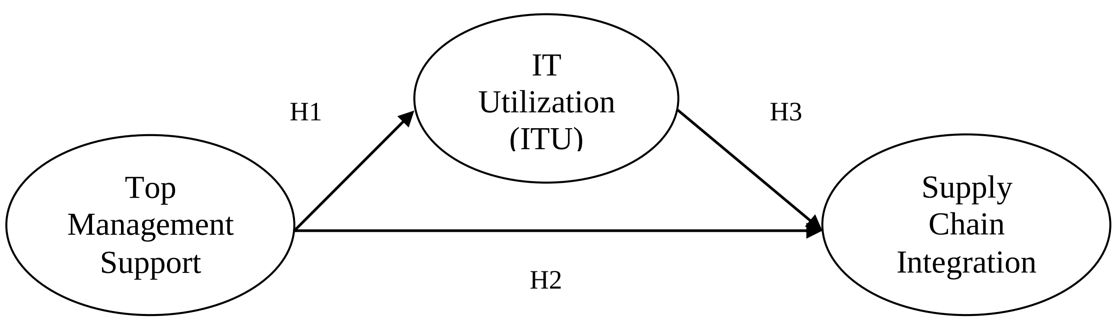
In spite of a general understanding of the impact of top management support for enhancing SCI and performance, empirical studies of these relationships are sparse and under developed. The purpose of this study is threefold. It develops valid and reliable measurement of various aspects of IT utilization, top management support, and SCI. Second, although some studies have pointed out that top management support can lead to successful IT utilization and thus indirectly lead to SCI, studies have not yet shown theoretical evidence of such claim. Therefore, this study seeks to investigate the mediating role of IT utilization on the relationship between top management support and SCI. Finally, this study proposes a conceptual framework to examine causes and effects of IT utilization. From this framework, three hypotheses are considered: (1) the direct impact of top management support on IT utilization; (2) the direct impact of IT utilization on SCI; and (3) the indirect impact of top management support on SCI through IT utilization.

II. THEORETICAL FRAMEWORK AND HYPOTHESES

Top management support is essential for building and operating successful supply chains because a new competitive perspective is required – competition shifts from company versus company to supply chain versus supply chain. This radical change in thinking requires a persistent and consistent message from the top management about its commitment (the company will do this), support (the company will provide resources), and participation (the top management will actively lead this effort). Better supply chain relationships improve coordination and lower transaction costs because suppliers understand the importance of working together to meet the expectations of the final customer. Low transaction cost is an important way to reduce the overall product cost and not reduce the value of the product for the final customer (Williamson, 1995; Subramani & Venkatraman, 2003; Wang & Wei, 2007). Furthermore, better coordination leads to better integration and this creates more valuable and more efficient inter-firm exchanges (Subramani, 2004). More effective integration is associated with the firm's ability to reduce cost, increase productivity, and enhance product quality (Wong and Fung, 1999; Rai, Patnayakuni & Seth, 2006). However, integration does not happen without the right communication tool, because effective and collaborative communication is the mechanism that improves the relations with suppliers and customers (Prahinski and Benton, 2004), and IT provides that mechanism (Ketchen and Hult, 2007). Top management support helps to create the IT base for building better relationships with suppliers (Fawcett at al., 2007).

The research framework in Figure 1 implies that top management support has a direct impact on SCI. In addition, Figure 1 shows the mediating role of IT utilization in the relationship between top management support and SCI. The model suggests that IT utilization is affected by top management's support for IT and that IT utilization, in turn, impacts the level of interaction between the firm and its trading partners (SCI). By adopting enterprise-wide information systems that provide seamless data flow between the firm and its trading partners, the cooperative process provides more than an exchange of information; it becomes an act of joint cooperation and co-creation resulting in high levels of integration (Piller et al., 2004). As a result, IT utilization is thought to mediate the relationship between top management support and SCI.

Figure 1: Impact of top management support on IT utilization and supply chain integration



2.1. Top Management Support for IT Utilization

Top management support is defined as the degree to which top management understands the importance of the IT investments and is personally involved in IT activities. The IT planning literature has consistently emphasized the importance of top management support for the success of many organizational activities (Foster, 1978; Raghunathan & Raghunathan, 1988; Ragu-Nathan et al., 2003). According to

Oh and Poinssenult (2007), the lack of top management support in IT causes restricted return on IT investment. Top management should be actively involved in IT projects because their involvement leads to greater enthusiasm and stronger commitment (Swink, 2000). In this research, top management support is important because IT tools are used not for back office operations but for strategic and broad based operational activities. Support is more likely to exist because top management understands and acknowledges the potential of IT investment (Kearns, 2006).

Cash et al. (1992) pointed out that top management and IT should be closely linked for a company to successfully implement IT projects. Top management support for IT utilization is a critical issue as IT promotes inter-functional and inter-organizational communication that leads to information sharing (Ronriguez et al., 2008). IT utilization becomes a virtual solution for SCI when the physical distance between buyer and suppliers is great. Furthermore, a supportive managerial attitude provides IT executives with an environment in which their work will be recognized and appreciated, and therefore, is likely to motivate them to achieve higher IT utilization (Tu, Raghunathan, and Raghunathan, 1999).

Hypothesis 1: The higher the extent of top management support, the higher the extent of IT utilization

2.2. Top Management Support for Supply Chain Integration

SCI is defined as the extent to which a firm coordinates activities with suppliers and customers (Stock et al., 2000; Narasimhan and Jayaram, 1998; Wood, 1997). SCI links a firm with its customers, suppliers, and other channel members by integrating their relationships, activities, functions, processes and locations (Kim and Narasimhan, 2002). Having an integrated supply chain provides significant competitive advantage including the ability to outperform rivals on both price and delivery (Lee and Billington, 1992).

Narasimhan and Kim (2002) examined the effect of SCI on the relationship between diversification and performance, and their SCI instrument has three dimensions: (1) internal integration across the supply chain, (2) the company's integration with customers, and (3) the company's integration with suppliers. Frohlich and Westbrook (2002) and Frohlich (2002) studied the effects of web-based integration on demand chain management's operational performance. In their study, web-based SCI was measured by two constructs: (1) e-integration with suppliers and (2) e-integration with customers. This study adopted the concept of SCI from these previous research projects and uses two sub-constructs to measure it – integration with suppliers and integration with customers (Frohlich and Westbrook, 2002; Frohlich, 2002).

Top management encouragement and a supportive environment are important ingredients for successful integration (Ragunathan et al., 2003). SCI projects require boundary spanning across functional and company borders while working together toward common goals. Top management has the leading role in aligning workers with diverse backgrounds so they can work together for the same goal. More top management involvement leads to more information sharing, induces collaborative communication, and bridges the gap between suppliers and buyer. Furthermore, SCI promotes the concept of interdependency, the success or failure of SCI is not dependent only on one organization, therefore it is important to have top management involvement and support (Swink, 2007; Das et al., 2006). Relational management support and IT together lead to virtual SCI that benefit information visibility (Wang & Wei, 2007).

Hypothesis 2: The higher the extent of top management support, the higher the extent of supply chain integration

2.3. Information Technology Utilization

Narasimhan and Kim (2001; 2002) propose to measure IT utilization using three sub-constructs including (1) IS for infrastructural support for supply chain management; (2) IS for value creation; and (3) IS for logistical operations. IT utilization as proposed by Narasimhan and Kim focuses on physical and operational aspects of IS. Although these points have significant implications for supply chain activities, they may not fully value the impact of IT utilization on SCI because the strategic impacts of IT may outweigh the operational and physical impacts. This study proposes to measure IT utilization using three sub-constructs: Strategic IT, Operational IT, and Infrastructural IT for SCI; and to examine how firms apply information technology to assist in strategic decision planning and to support operational and infrastructural decision making.

Strategic IT is the extent to which a firm uses IT to formulate, justify, and improve long-term business planning processes. Strategic IT includes how well a firm uses IT for strategic purposes (e.g., long-term technology justification and planning, budget plan, investment justification, capacity plan, project analysis, competitor analysis, and industry study). Strategic IT is valuable for maintaining close alignment between different aspects of strategy, and aligning strategies to enhance the firm's performance and create a competitive advantage (Kearns & Lederer, 2003). Oh & Pinsonneault, (2007) indicate that aligning business strategy and information system strategy in cost saving programs reduces expenses. The application of strategic IT should be made within the firm and across the supply chain and not just in one entity, so that information is effectively shared. Strategic IT leads to strategic information sharing capability that contributes to effective supply chain collaboration (Klein et. al, 2007).

Operational IT is the extent to which firms uses IT for monitoring, justifying, and improving daily operational decision processes. Operational IT involves IT usage, which promotes the improvement of day-to-day activities that meet operational goals (e.g., production and quality control, warehouse and space management, customer and supplier relationship management, inventory management, material planning, and order fulfillment). In operations, IT is considered a valuable asset. IT helps organization to perform better with respect to integrating different technologies in manufacturing and inter-functional information sharing (Takur & Jain, 2008).

Infra-structural IT refers to the extent to which a firm uses IT to facilitate information sharing and data communication, to recommend standards for IT architecture, to implement security, and to coordinate work activities within firms. Infrastructural IT concerns the improvements of information systems and information sharing to harmonize the efforts of managers from different parts of the organization and to enable them to make decision consistent with organizational goals (e.g., setting up file sharing facilities, setting up data communication facilities, plant layout management and control, setting up advanced manufacturing technology, setting up security devices, and setting up an information-based disaster recovery system).

When firms consider mergers and acquisitions, IT is considered an important factor as the firms seek to create synergistic effects by integrating two different business entities (Robbins and Stylianou, 1999; Stylianou et al., 1996; Kearns, 2006). Mudie and Schafer (1985) claim that IT should not only facilitate the process of developing and using data, applications, and technologies; it should provide flexibility to meet the future business demands in workstations, processing types, and applications. In the inter-organizational supply chain context,

information technologies allow "multiple organizations to coordinate their activities in an effort to truly manage a supply chain" (Handfield and Nichols, 1999; Rushton and Oxley, 1994; Williams et al., 1997; Rai et al., 2006). As the supply chain competition is shifting from firm versus firm to supply chain versus supply chain (Vonderembse et al., 2006), IT infra-structural plays a critical role in achieving successful SCI.
Most factors that influenced SCI are related to information processing issues that lead to smooth data sharing. Information processing theory explains how appropriate technology could help in reaching this goal (Garbraith 1973: Gavimeni et. al., 1999' Rai et al., 2006). Effective information sharing enhances SCI in dynamics external and internal environments (Zhou & Benton, 2007). This study hypothesized that high levels of technology utilization help enhance cooperation and coordination between a firm and its external partners (e.g., suppliers and customers); therefore,

Hypothesis 3: The higher the extent of IT utilization, the higher the extent of supply chain integration

III. METHODOLOGY

The development of the instruments for top management support, IT utilization, and SCI constructs was carried out in three phases: (1) item generation, (2) pilot study, and (3) large-scale data analysis and instrument validation. An extensive and comprehensive literature review was conducted to identify the content domain of the major constructs in the research framework. Initial items and the definitions of each construct were generated from the literature review. Next, a pilot study was conducted using the Q-sort method. An analysis of inter-rater agreement about the items' placement identified both bad items and weaknesses in the original definitions of the constructs. These actions helped to establish content validity for the measurements. Finally, data were collected and analyzed.

3.1. Item generation

In empirical research, effective generation of items is essential to develop a valid and reliable instrument. The basic requirement for a good measure is content validity, which means the measurement items contained in an instrument should cover the content domain of a construct (Churchill, 1979). In this study, content validity is achieved through comprehensive literature review, structured interviews with practitioners, and consultation with academic experts. The structured interview is a common technique used in operations management research to gain insights into the subject matters from a panel of practitioners and experts (Flynn et al., 1990). In this study, the panel included 6 individuals from the industry (e.g., operations managers) and academia (e.g., professors and doctoral students of operations management). Each individual was asked to respond to a predetermined set of questions. The responses were scripted and used in the item generation process. From this effort, an initial list of items for each construct was generated. Seven items were developed for top management support, twenty six items were developed for ITU, and twelve items were developed for SCI. Once item pools were created, the items for the various constructs were reviewed by five academicians and followed by structured interviews with two practitioners. The focus was to check the relevance of each construct's definition and the clarity of wording of the sample questionnaire items. Based on the feedback from academicians and practitioners, redundant and ambiguous items were either modified or eliminated. Seven items were developed for top management support, twenty six items were developed for ITU, and twelve items were developed for SCI. Appendix A provides a list of the final measures items.

3.2. Q-Sort Pilot Study

The basic procedure of a Q-sort method was to have eleven knowledgeable informants (four academicians and seven practitioners) judge and sort the items from the first stage into separate sub-constructs, based on construct/sub-construct definitions. Inappropriately worded or ambiguous items were eliminated or reworded. The goals for this stage were to identify and modify any items and to pre-assess the construct validity of the scales being developed. During the three sorting rounds, the inter-judge agreement index was 0.91 and the overall hit ratio was 0.93, thus showing that the placement of items has a high degree of construct validity and reliability. Note: additional results can be provided by authors.

3.3. Content Validity

An instrument has content validity if there is a general agreement among the subjects and researchers that the items cover all-important aspects of the variable being measured (Kerlinger, 1978). The evaluation of content validity is a rational judgmental process not open to numerical justification. Nunnally (1978) stated "content validity rests mainly on appeals to reason regarding the adequacy with which important content has been sampled and on the adequacy with which the content has been cast in the form of test items."

In this study, content validity was assessed by two important processes. First, a comprehensive review (Lee & Billington ,1995; Ho, 1996; Handfield & Nichols, 1999; Frolich 2002; Frolich & Westbrook, 2002; Kim and Narasimhan, 2002; Ragunatham et al., 2003) of the literature was conducted to make sure that the measuring items adequately covered the domain of the variable (Nunnally, 1978). Second, to ensure that the constructs, and the items measuring them adequately covered factors under the domain, an operational example of the instrument was given to a panel for review.

3.4. Survey Methods, Data Collection, and Sample Characteristics

A cross-sectional self-administered mail survey was conducted. All data for the five constructs were generated from questionnaire responses by using a five-point Likert type scale including the "Not relevant/do not know" option where 1 = "Strongly Disagree", 2 = "Disagree", 3 = "Neutral", 4 = "Agree", 5 = "Strongly Agree", and NA = "Not Applicable, or Do Not Know". The sampling frame was obtained from the Society of Manufacturing Engineers (SME), an internationally known organization of manufacturing managers and engineers, with more than 120,000 active members worldwide and in almost every industry. Once the sampling frame was identified, the process of generating random samples was undertaken. The initial mailing list of 4,000 names was randomly selected from the SME members in the East North Central and West North Central regions. 579 surveys did not reach the targeted respondents because of incorrect addresses, 235 responses stated that they would not participate and 14 surveys were returned empty. This left 3,172 in the eligible sample of which 220 surveys were returned providing usable responses. Thus, the response rate for the survey is 6.94% (or 220/3172). Table 1 shows sample characteristics by job titles, job functions, level of education, and years of work.

Response/non-response bias was tested by comparing early respondents and late respondents. From the total of 220 surveys received, 148 responses were from the first wave and only 72 were from the second wave. The non-response bias can also be tested using an indirect approach (Armstrong and Overton, 1977) by comparing results between the subjects who responded after the initial mailing (first wave) and those who responded after the second mailing (second wave). Chi-square tests were used to make the comparisons. The results are shown in the last column of Table 2. There is no significant difference in sales volume between these two groups ($p > .10$) and we conclude non- response bias is not a cause for concern.

Table 1: Sample Characteristics

	Job Titles (220)	
1.	CEO/President	6.82% (15)
	Director	7.27% (16)
	Manager	53.18% (117)
	Supervisor	27.27% (60)
	Engineer	4.55% (10)
	Other	0.91% (2)
	Job Functions (261)	
2.	Corporate Executive	6.51% (17)
	Purchasing	6.13% (16)
	Transportation	2.30% (6)
	Manufacturing Production	41.38% (108)
	Distribution	1.15% (3)
	Sales	6.13% (16)
	Unidentified	13.41% (35)
	Other	22.99% (60)
	Level of Education (220)	
3.	High School	10.45% (23)
	Two-year College	20.00% (44)
	Bachelor’s Degree	31.82% (70)
	Master’s Degree	16.36% (36)
	Doctor’s Degree	1.36% (3)
	Unidentified	15.91% (35)
	Other	4.09% (9)
	Years of Work (220)	
4.	<= 3	0.45% (1)
	4-10	7.27% (16)
	10-15	12.73% (28)
	15-20	10.91% (24)
	> 20	53.18% (117)
	Unidentified	15.45% (34)

Table 2: Test of Non-Response Bias

Variables	First-wave Frequency (%)	Second wave Expected Freq. (%)	Second wave Observed Freq. (%)	Chi-square Test
Sales Volume in millions of $ (220)				
<5	20	7	0	χ^2=10.78 df=6 p>.10
5 to <10	10	5	6	
10 to <25	28	13	11	
25 to <50	13	8	12	
50 to <100	20	9	6	
Over 100	33	17	20	
Unidentified	24	13	17	

IV. LARGE SCALE INSTRUMENT ASSESSMENT AND RESULTS

The Structural Equation Model (SEM) was chosen for the large-scale data analysis in this research. SEM is the most widely used methodology to evaluate the complex interrelations among variables. SEM is a confirmatory rather than an exploratory technique. SEM is suited for the theory testing analysis and most suitable for this research model.

Data from 220 respondents were used to test validities of the constructs using AMOS 16 software. Validity is the degree to which the measurement process assesses the “truth” of the measurement. Reliability assesses the stability or consistency of the measurement. If the same individuals are measured under the same conditions, a reliable measurement will produce the same results. According to Bagozzi (1980), for a measurement to be reliable and valid it should have content validity, internal consistency of operationalization (unidimensionality and reliability), and construct validity (discriminant and convergent validities).

4.1. Unidimensionality

The degree of unidimensionality is indicated by the Goodness of Fit Index (GFI) and the Adjusted Goodness of Fit Index (AGFI). The GFI indicates the relative amount of variance and covariance jointly explained by the model. The AGFI differs from the GFI in adjusting for the number of degrees of freedom (Byrne, 1989). Both range from 0 to 1. Values of 0.9 or more are considered a good fit (Hair et al., 1998). The next set of fit statistics focus on the root mean square error of approximation (RMSEA). RMSEA takes into account the error of approximation and is expressed per degree of freedom, thus making the index sensitive to the number of estimated parameters in the model; values less than 0.05 indicate a good fit, values as high as 0.08 represent reasonable errors of approximation in the population (Browne and Cudeck, 1993), values range from 0.08 to 0.10 indicate a mediocre fit, and those greater than 0.10 indicate a poor fit (MacCallum et al., 1996). Unidimensionality (and convergent validity) requires that there is one single latent variable underlying a set of measurement items (Anderson and Gerbing, 1988).

4.2. Reliability and Validities of Construct Measurement

The measure for reliability was assessed using Cronbach's alpha (Cronbach, 1951), with 0.70 and above being considered acceptable (Nunnally, 1978). For the measure of discriminant validity, the square root of the average variance extracted (AVE) should be higher than the inter-construct correlations; secondly, the items should load higher on their respective constructs than the other constructs (Bagozzi and Phillips 1982; Gefen et al. 2000). A construct with AVE > 0.5 shows an acceptable level of discriminant validity (Fornell and Larcker, 1981). Table 3 shows the correlations, AVE and reliability. The results show an acceptable level of reliability and validity for each construct.

The following presents the large-scale instrument validation results on each of the constructs: top management support, ITU, and SCI. For each construct, the instrument assessment methodologies described in the previous section were applied. Table 4 shows the result for the measurement model. All the values for AGFI and GFI were above 0.9. Values of RMSEA were in the range of 0.00 to 0.09. All values were acceptable for a good fit model-data.

Table 3 : Correlation, Cronbach alpha and AVE.

	TMS	**SIT**	**OIT**	**IIT**	**CI**	**SI**	**Cronbach**	**AVE**
TMS	1						0.91	0.66
SIT	.237**	1					0.89	0.60
OIT	.239**	.413**	1				0.91	0.55
IIT	.261**	.380**	.510**	1			0.83	0.51
CI	.370**	.243**	.248**	.233**	1		0.83	0.50
SI	.141*	.239**	.257**	.227**	.651**	1	0.93	0.61

** p < .01; * p < .05

Table 4: Construct scale validity analysis.

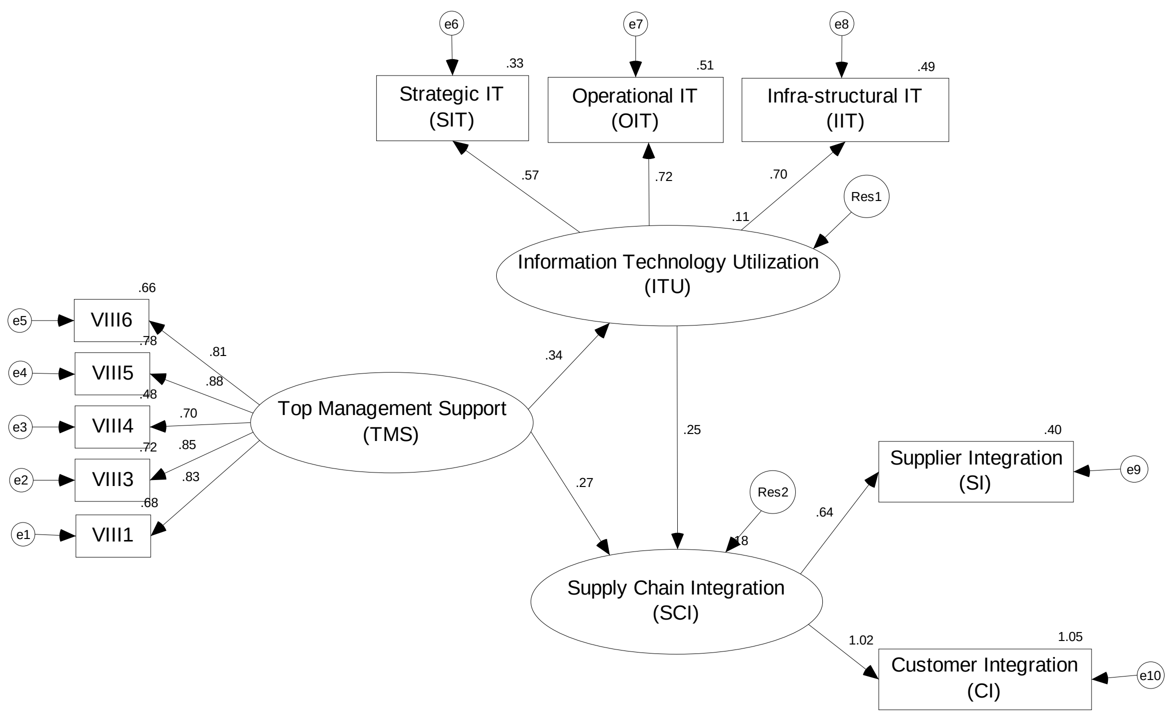
Scale	No. Items	GFI	AGFI	CFI	RMSEA	$\chi 2$/d.f.	P
Top Management Construct							
Top Management Support (TPS)	5	0.98	0.94	0.99	0.07	2.15	0.06
Information Technology Utilization Construct							
Strategic IT (SIT)	4	0.99	0.97	1.00	0.05	1.48	0.23
Operational IT (OIT)	5	0.98	0.93	0.98	0.08	2.42	0.03
Infra-structural IT (IIT)	4	0.99	0.93	0.99	0.09	3.12	0.04
Supply Chain Integration Construct							
Customer integration (CI)	5	0.98	0.93	0.97	0.09	2.74	0.02
Supplier integration (SI)	5	0.97	0.93	0.99	0.09	2.75	0.02

V. RESULT OF THE STRUCTURAL MODEL

Structural model for this research was tested using AMOS 16. Figure 2 shows the result of the study. For hypothesis 1, 2 and 3, the path coefficients are respectively 0.34 (t = 3.72), 0.27 (t = 3.79) and 0.25 (t = 3.04), which are statistically significant at the level of $p<0.001$. The overall fit for the model shows a good fit with chi-square = 65.51 and degrees of freedom is 32. The ratio of chi-square to degree of freedom is 2.04, indicating a good fit model. The model fit indices also indicate the good fit of the structural model with AGFI = 0.90, GFI = 0.94, NFI = 0.94, CFI = 0.97.

The result confirms that top management support has a significant positive impact on information technology utilization. The path coefficient for the impact of top management support on information technology utilization is higher than the impact of top management on SCI. It indicates that the TMS has a greater impact on ITU than on SCI.

Figure 2: Structural Model Paths



VI. DISCUSSION AND IMPLICATION

This research is a large-sample empirical effort to systemically investigate the causal relationships among top management support, IT utilization, and SCI. The results confirms the theory that Information Technology Utilization (ITU) construct contains three sub-constructs namely 1) Strategic IT (SIT), 2) Operational IT (OIT), and 3 Infra-structural IT (IIT). The hypotheses testing results also show the positive relationships between top management support and ITU, between top management support and SCI and between ITU and SCI. The academic and managerial implications of these findings are further explored as follows.

6.1. Managerial Implications

All three hypotheses were significantly supported. The hypotheses include (1) the direct relationship between top management support and ITU, (2) the direct relationship between top management support and SCI, and (3) the direct relationship between ITU and SCI. A high level of IT utilization in the organization may affect the level of customer and supplier integration because the firm uses IT to interact with its customers and suppliers. However, only IT implementation that improves the customer's total value will drive SCI. To successfully implement IT projects, top management must emphasize that the implemented IT must be geared toward the integration of internal activities with its potential customers including infrastructural components (e.g., hardware, software, and standard), operational components (e.g., managing daily operations activities and exchanging information), and strategic components (e.g., justifying business plan, analyzing market position, and setting long term business goals). This process is an important facilitator for successful SCI

The findings of this research assure the practitioners that, to achieve a high level of integration with suppliers and customers, IT utilization is important. Recently, IT has been adopted at explosive rates in terms of both quality (more powerful hardware, database, and networks) and affordable prices (Sophie Lee et al, 2000; Wegener et al., 2010). The newly created infrastructure is the real driver for a feasible integration strategy (Angeles, 2009). The application of IT in manufacturing organizations either adds to efficiency and precision of manufacturing equipment or facilitates in collecting advanced manufacturing technology and flexible manufacturing (Ho, 1996; Angeles et al., 2010). Top management involvement in technology investments must be a high priority for implementing the technologies that have potential to improve cooperative relationship with customer. Investing capital on technologies geared toward customer integration should be viewed from a strategic level and provide long-term benefits (such as SCI and supply chain performance). Therefore, technology investment strategy, customer relationship management strategy, and corporate strategy should be viewed simultaneously when implementing technologies. All strategies must be aligned with the corporate strategy, which should be guided by customer's needs. Forming a close relationship with trading partners brings many benefits to the firm including reduced product development time, improved transparent communication, focused efforts to core businesses, enhanced customer satisfaction, and increased operational and firm performance.

6.2. Academic Implications

As mentioned in the introduction, there is no clear definition of constructs and conceptual frameworks for IT utilization in the current literature. Most empirical research mainly focuses on the physical and operational aspects of IT such as (1) IT for infrastructural support (e.g., network plan and design system, accounting information system, and office information system); (2) IT operating management (e.g., production plan and process control system, sales and price management system, customer service and customer management system, and inventory and warehouse management system), and (3) IT for logistical operations (e.g., transportation management system, forecasting system, automatic ordering system, resource management system, and plant warehouse location selection system). This study expands that perspective by providing a set of measurements for IT utilization consisting of strategic IT, operational IT and infrastructural IT.

The study contributes to our understanding of operations management research in a number of ways. With three sub-dimensions of IT utilization, the new instruments help expand research ideas for researchers who might adopt these measures to study the factors affecting IT utilization such as culture. These measures are also useful to researchers who are interested in studying the effects of IT utilization on other important management variables such as operational performance and firm performance.

6.3. Limitations of the Research

While the current research made significant contributions from both a theoretical and practical point of view, it also has limitations, which are described below.

First, because of the limited number of observations (220), the revalidation of constructs was not carried out in this research. This needs to be addressed in future research. New mailing lists and research methods may be applied to improve the response rate.

Second, in this research, individual respondents (manufacturing managers and top management) in an organization were asked to respond to complex information technology issues dealing with all the participants across the organizations. However, no person in an organization is in charge of the entire process span across the organization: for example, manufacturing managers are mainly responsible for procuring raw materials and parts and managing production, and may not be in an appropriate position to answer the supplier/customer-related questions. The main area of manufacturing managers is production and they may not have a thorough knowledge of their suppliers, customers, and firm performance. Therefore, the use of single respondent responses may generate some measurement inaccuracy.

6.4. Recommendations for Future Research

Definitions and measurement items should be refined based on the results of the measurement model analysis. Future research should not only attempt to develop better definitions and sub-dimensions but also use the least amount of parsimony. Since the usefulness of a measurement scale comes from its generalizability, future research should revalidate measurement scales developed through this research by using the similar reference populations.

Future research should apply multiple methods to obtain data. The use of a single respondent to represent what are supposed to be intra/inter-organization wide variables may generate some inaccuracy and more than the usual amount of random error (Koufteros et al, 2005). Future research should seek to utilize multiple respondents from each participating organization as an effort to enhance reliability of research findings. Once a construct is measured with multiple methods, random error and method variance may be assessed using a multitrait-multimethod approach.

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Appendix A: Construct measures validity and reliability analysis.

With regard to top management support for system integration, please circle the appropriate number that accurately reflects your firm's PRESENT condition.

The Items for Top Management Support (TMS) (Cr = 7.33; AVE = 0.66)		**Standardized item loading**	**t- value**	**Item Code**
1.	Top management is interested in our relationship with our trading partners	0.83	-	VIII1
2.	Top management regards our relationship with trading partners a high priority item	0.84	14.82	VIII2
3.	Top management participates integration with our trading partners	0.69	11.11	VIII3
4.	Top management considers the relationship between us and our trading partners to be important	0.89	15.92	VIII4
5.	Top management encourages open communication with our trading partners	0.81	14.01	VIII5
6.	Top management provides enough training on technology used to communicate with our trading partners (dropped)			VIII6
7.	Top management supports our department with the resources we need (dropped)			VIII7

The following situations describe the extent to which the manufacturing department uses information technology (IT) for strategic, operational, and infrastructural purposes. Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your unit.

The Items for Strategic IT (SIT) (Cr = 6.68; AVE = 0.60)		**Standardized item loading**	**t- value**	**Item Code**
1.	Long-term technology justification and planning	0.80	-	I1
2.	Budget justification and planning	0.82	12.36	I2
3.	Investment justification and planning	0.81	12.24	I3
4.	Long-term project planning	0.65	9.64	I4

5.	Project feasibility analysis (dropped)			I5
6.	Competitor analysis (dropped)			I6
7.	Industry analysis (dropped)			I7
8.	Long-term capacity planning (dropped)			I8
The Items for Operational IT (OIT) (Cr = 6.48; AVE = 0.55)		**Standardized item loading**	**t- value**	**Item Code**
1.	Daily production control	0.78	-	I9
2.	Daily product quality control	0.74	10.73	I10
3.	Daily product movement planning	0.79	11.48	I11
4.	Daily customer analysis	0.65	9.41	I12
5.	Daily material requirement planning	0.74	10.83	I13
6.	Daily warehouse/space management(dropped)			I14
7.	Technology services and training (dropped)			I15
8.	Daily products distribution management (dropped)			I16
9.	Daily inventory management (dropped)			I17
10.	Daily customer relationship management (dropped)			I18
11.	Daily supplier relationship management (dropped)			I19
The Items for Infrastructural IT (IIT) (CR = 7.73 ; AVE = 0.51)		**Standardized item loading**	**t- value**	**Item Code**
1	Setting up file sharing facilities (e.g., network cable, telephone line, wireless network)	0.91	-	I20
2	Setting up data communication facilities (e.g., server, LAN, routers, disk/drive, network computers)	0.90	13.26	I21
3	Setting up information disaster recovery system (e.g., disk redundancy, backup facility)	0.38	5.65	I22
4	Setting up advanced manufacturing technology (e.g., CAD/CAM, Robots, EDI)	0.51	7.73	I23
5	Setting up security services (e.g., control room, video camera, automatic door, intercom) (dropped)			I24
6	Floor plan management (e.g., material flow in/out plans, space management) (Dropped)			I25
7	Plant layout management and control (e.g., locations of machines/tools, line configuration, safety staircase) (dropped)			I26
The following statements describe the extent to which the **manufacturing department** interacts with its customers and suppliers. Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your unit.				
The Items for Supply Chain Integration (SCI) Customer Integration (CI) (CR = 5.38; AVE = 0.50)		**Standardized item loading**	**t- value**	**Item Code**

1	The willingness of customers to share their market demands	0.70	-	IV1
2	The participation level of customers in product development processes	0.72	8.77	IV2
3	The participation level of customers in finished goods distribution processes	0.71	8.70	IV3
4	The level of customer involvement in preparing business plans	0.60	7.58	IV4
5	The extent of follow-up with customers for feedbacks	0.64	8.01	IV5
6	The participation level of customers in manufacturing processes (dropped)			IV6
Supplier Integration (SI) (CR = 7.09; AVE = 0.61)		**Standardized item loading**	**t- value**	**Item Code**
1	The level of supplier involvement in preparing our business plans	0.82	-	IV7
2	The participation level of suppliers in production planning processes	0.70	10.89	IV8
3	The participation level of suppliers in product development processes	0.80	12.91	IV9
4	The participation level of suppliers in logistics processes	0.80	13.08	IV10
5	The level of cross-over of activities between our firm and our suppliers	0.79	12.69	IV11
6	The participation level of suppliers in manufacturing processes (dropped)			IV12

Entropy as a Measure of Uncertainty for PERT Network Completion Time Distributions and Critical Path Probabilities

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This study proposes that the entropy function provides a simple and useful tool for project managers to better cope with project uncertainty, and therefore better manage projects. The entropy function has a long and established history as a measure of uncertainty in information theory. If selected activities on PERT networks are modified by reducing their activity times by one or more time units, simulations on the original and modified networks can generate output on the entropies of completion time distributions and critical path probabilities. Modified networks can be ranked on a scale of decreasing entropy (or decreasing uncertainty) to determine which activities on the original network have the greatest impact on an overall reduction in project uncertainty. In this manner, these activities would be identified as worthy of additional resources in the real world to implement reductions in their activity times.

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I. INTRODUCTION

The objective of this study is to provide project manager practitioners with an additional tool for project control. More specifically, activities on a PERT simulation network modeling a project could be modified with additional resources, such as providing more productive machinery to the team assigned to an activity and/or increasing the size of the team, in order to reduce the time duration of completing the activity. With an appropriate measure for uncertainty, differences in the uncertainty can be measured among the completion time distributions generated by simulations of the original and modified networks, determining which modifications had the greater impact on uncertainty reduction and were deserving of the additional resources. Since critical path probability sets are a second source of uncertainty in PERT simulation, simulation output generating such sets provides an indicator of whether entropy reductions on the network may have impacted critical paths either more or less than completion times.

Achieving the objective requires two considerations: (1) completion time distributions and critical path probability sets must be measured with a high level of precision to assure that they reflect their true values, and (2) a suitable measure must be found that can rank modified completion time distributions based on their impact in reducing the uncertainty (or randomness or noise) of the project.

In reference to the first consideration, the classical PERT technique (Malcolm et a., 1959) is not suitable for this study because it fails to generate valid representations of completion time distributions. The technique is subject to “PERT bias,” which refers to distortions of the true completion time distribution that include a significant understatement of the mean (MacCrimmon and Ryavec, 1964). However, Monte Carlo techniques and PERT Network Simulation where developed to address the shortcomings of classical PERT (Van Slyke, 1966). PERT simulation can generate valid approximations of the completion time distribution where the precision of the approximation is subject to the number of simulated replications on the network. Following Van Slyke's study in 1966, network simulation packages have evolved in the literature for over forty years. GERT (Graphical Evaluation and Review Technique) simulation was an enhancement to PERT which permitted probabilistic branching on AOA (activity on arc) networks (Pritsker and Happ, 1966; Moore and Clayton, 1976). PLANET (Project Length Analysis and Evaluation Technique) was a modification of GERT which accommodated criticality indices (Kennedy and Thrall, 1976). VERT (Venture Evaluation and Review Technique) shares many of the features of GERT and was independently developed for the military (Moeller and Digman, 1981). CAPERTSIM (Computer Assisted PERT SIMULATION) was developed primarily as a project management teaching tool and accommodated cost-time tradeoffs (Ameen, 1987). STARC was developed to allow a duration risk factor to be measured as a percentage over a time range for extended activities (Badiru, 1991). Other studies extended PERT simulation to stochastic forms of CPM (Herbert, 1980; Johnson and Schou, 1990). More recent studies based on PERT simulation include: the development of a set of project management tools which perform simulation on Crystal Ball spreadsheets (Meredith and Mantel, 2002); a Java based CPM simulation package referred to as SPSS (Stochastic Project Scheduling Simulation) developed for construction projects (Lee, 2005), an animation of a PERT network in Arena as a pedagogical tool (Cosgrove, 2006), and the development of Arena-based module groups which permit the quick construction of PERT simulation networks in a Microsoft Windows environment (Cosgrove, 2008). In the practitioner market, several commercial software products have been developed for network simulation. These tools not only employ simulation to address the shortcomings of classical PERT, but also piggyback on the popularity of Microsoft Project (http://office.microsoft.com/en-us/project/default.aspx) as add-on tools, providing extended features such as simulation, probabilistic and conditional branching, and extended graphics enhancements. Some of the most popular products include Deltek Risk+ (http://www.somos.com/files/ds_risk+.pdf), Palisade's @RISK Professional for Project (http://www.palisade.com/riskproject/), and Oracle's Primavera Risk Analysis (http://www.oracle.com/applications/primavera/primavera-risk-analysis-data-sheet.pdf).

The second consideration of the objective relates to finding a suitable measure for uncertainty. While the temptation is to associate risk and uncertainty as the same, two studies that focus on project uncertainty attempt to distinguish between project risk and project uncertainty (Chapman and Ward, 2000; Ward and Chapman, 2003). Both studies place a greater emphasis on developing concepts and processes to cope with uncertainty, rather than developing operational definitions to quantify uncertainty as a phenomenon that can be measured. Consequently, this study addresses the second consideration by proposing the entropy function as a measure of uncertainty that can be applied to completion time distributions and critical path probability sets which are typical outputs from PERT network simulation. Since its introduction in 1948 (Shannon, 1948), entropy has enjoyed a long and rich tradition for over 60 years as a measure of uncertainty in probabilistic information theory (Verdu and McLaughlin, 2000).

In the sections that follow, entropy is proposed as a measure of project uncertainty based on several key mathematical properties found in the literature on information theory. Applications of these properties are demonstrated with simulations on a PERT network employing Arena (Cosgrove, 2008; Kelton et al., 2010).

II. THE ENTROPY FUNCTION

Consider P as a probability set of order R with members p_r such that

$$P = \{p_r |\ 0 \le p_r \le 1;\ \sum p_r = 1;\ r=1,2,...R\}. \quad (1)$$

The general form of the entropy function for any probability set P satisfying (1) is given by (Shannon, 1948)

$$H(P) = -\sum_{p_r \epsilon P} p_r \log_b p_r\ . \quad (2)$$

There are no rigid restrictions on setting the base of the logarithm, which in this study will be taken at the base e (i.e., b=e) at the discretion of the author.

Integral versions of the entropy function exist for continuous distributions, but they are of no use in this study because the output from PERT simulation generates discrete probability sets for critical paths and discrete distributions for completion time.

Several key mathematical properties that follow support the use of the entropy function as a measure of uncertainty. These properties can be found in numerous books and articles on information theory and statistics (Reza, 1961; Jelinek, 1968; Hays and Winkler, 1975; Jones, 1979):

1. Min[H(P)] = 0, which follows if there exists a single value of r such that p_r =1, where the rth state is deterministic.

2. The logarithm of zero is undefined, but Expression (2) is finite since

$$\lim_{p_r \to 0} [p_r \log_b p_r] = 0. \quad (3)$$

3. Max[H(P)] = log R for any discrete distribution with R nonzero probabilities. This property follows intuition in that maximum entropy occurs when all states are equiprobable (i.e., p_r = 1/R for all r where $p_r \neq 0$).

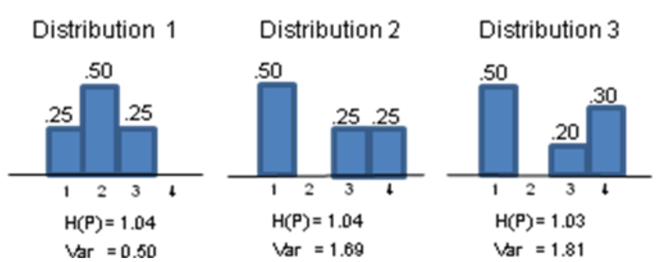
4. H(P) is a function of probabilities and is therefore distribution free. It is suitable for both nominal/categorical, ordinal, and metric data.

5. H(P) is a continuous measure that increases over the range from zero to log R.

These properties support the notion of entropy as a continuous *and relative* measure of uncertainty. In this manner, entropy can be employed to rank random variables on an ordinal scale based on the entropy of their underlying distributions. Note that significant differences in uncertainty between or among random variables are not a topic of this study.

Another characteristic of the above properties follows when distinguishing between variance and entropy for metric data. Consider the distributions in Figure 1.

FIGURE 1. COMPARISONS OF ENTROPY/VARIANCE



Note that the first and second distributions have the same entropy, but the variance of the first is significantly less than the second. This supports the notion from information theory that an observer's knowledge about future events represented by these distributions is exactly the same regardless of the values of their respective variances. An equivalent statement is that the uncertainty about the realization of future events for both distributions is the same. Now consider the third distribution where the variance exceeds that of the other two but the entropy is less. The three distributions have in common a single state with a .50 probability, but differ in that the first two distributions have two states each at .25, and the third distribution has two states at .20 and .30. It is evident that the two equiprobable states of .25 leave the observer less certain about the future realization of these states than the situation represented in the third distribution, where the observer would conclude the third state at. .20 is less likely to occur and the fourth state at .30 is more likely to occur. This added knowledge about the third and fourth states of Distribution 3 leads to its lower level of uncertainty (i.e., entropy). However, the analysis as described above, which compared absolute probabilities over a very short range among only three distributions, would be too burdensome for practitioners working with distributions generated by simulation having much larger ranges. Since entropy values eliminate the need to work directly with subsets of absolute probabilities, the ranking of distributions by their uncertainty is accomplished by simply applying Expression (2).

In the sections that follow, separate entropy functions based on Expression (2) are developed for completion time and critical path. Applications of entropy on simulation output are included to demonstrate that activities undergoing time reduction can be ranked for their impact on project uncertainty, with this ranking based on entropy measurements of completion time distributions and/or critical path probability sets.

III. ENTROPY FUNCTIONS FOR COMPLETION TIME AND CRITICAL PATH

Consider the random variable Y representing the *total completion time* of a PERT network with distribution function P(Y) and variates y_j such that $Y = \{y_j \mid j=1,2,\ldots J\}$. It follows from Expression (2) that the entropy function of P(Y) is given by

$$H(Y) = -\sum_{y_j \in Y} p(y_j) \ln p(y_j). \qquad (4)$$

Likewise, consider the random variable X for *critical path* with probability set P(X) and variates x_i such that $X = \{ x_i \mid i=1,2,3,\ldots I\}$. The entropy function of P(X) is given by

$$H(X) = -\sum_{x_i \in X} p(x_i) \ln p(x_i). \qquad (5)$$

Expressions (4) and (5) provide measures of uncertainty for two key random variables which are typically generated in PERT simulations. Some straightforward applications of these expressions for practitioners are illustrated in the next section.

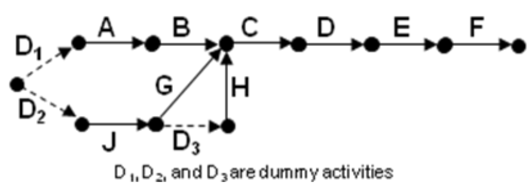
IV. APPLICATION

To assure a high level of precision in the simulation output discussed in this section, each of five simulation runs underwent 10,000 replications which far exceeds the recommended run size of 1,000 (Moder et al., 1983).

It is assumed that opportunities exist to reduce the durations of some activity times on a PERT project network with the intent of reducing the overall uncertainty of the project, particularly by reducing the uncertainty in the completion time distribution. Reductions in activity times assume that resources are available to reduce the duration of one or more selected activities on the network, perhaps by increasing the size of the team assigned to these activities. Activities subject to time reduction would require a reformulation of their activity time distributions followed by a simulation run with the reformulated distributions. As shown in this section, a comparison of completion time entropies from this simulation with the original simulation would lead to a determination of the extent that activity time reductions actually reduced the uncertainty of the project.

Figure 2 includes a PERT network with completion time distributions generated from five simulation runs, with specified time units along the horizontal axes with variates y_1=13, y_2=14, y_3=15,…y_{23}=35. With the exception of dummy activities, activity time distributions and their parameters are specified for all activities on the network and appear below the completion time distributions for each run. Probability sets for critical path appear in Table 1 with top, middle, and bottom paths corresponding to the variates x_1, x_2, and x_3, respectively. As a convenience to the reader, the time units on the horizontal axes for the completion time distributions are vertically aligned in Figure 2, and entropies for critical paths and completion time appear in both Figure 2 and Table 1.

FIGURE 2. PERT NETWORK SIMULATION



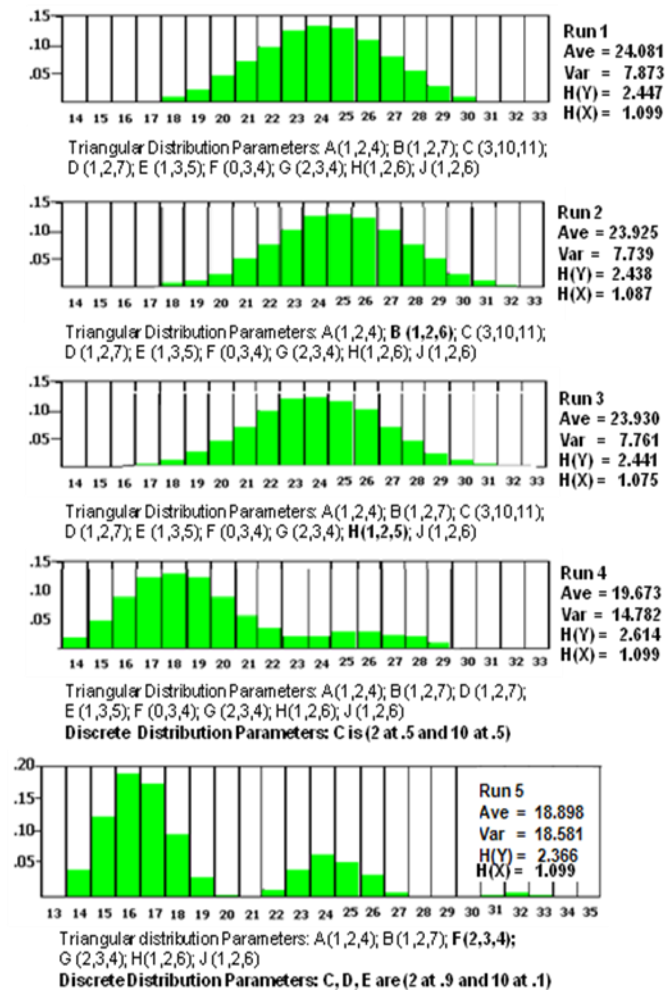


TABLE 1. CITICAL PATH PROBABILITIES/ENTROPIES

Run	Top Path (x_1)	Middle Path (x_2)	Bottom Path (x_3)	H(X)	H(Y)
1	.331	.329	.340	1.099	2.447
2	.263	.368	.369	1.087	2.438
3	.367	.397	.236	1.075	2.441
4	.331	.329	.340	1.099	2.614
5	.331	.329	.340	1.099	2.366

It is assumed that the original simulation is represented by Run 1, and any activity time changes from Run 1 to other runs are shown in bold type under their respective completion time distributions. It is also assumed that the cost for activity time reductions and modifications are the same for all five runs. Note that this includes Run 5, which has modifications on four activities (C, D, E, and F) which combined is assumed to be the same cost for time modifications on each of the activities in Runs 2, 3, and 4 (i.e., on B, H, and C).

Assume that resources are available to reduce the most pessimistic times of activities B or H by one time unit, or replace C's triangular distribution with a discrete distribution. Runs 2 and 3 represent the modifications on B and H and Run 4 the modification on C.

The output in Figure 2 shows that Runs 2 and 3 outperform Run 1 in all the measures shown [i.e, in average, variance, H(X), and H(Y)]. Run 2 outperforms Run 3 on average, variance and H(Y), but underperforms on H(X). This indicates that the time reduction on B in Run 2 has a greater impact on reducing completion time uncertainty than critical path uncertainty, with the opposite occurring with Run 3 from the time reduction on H. Since project managers are more interested in reducing completion time uncertainty over critical path uncertainty, and since Run 2 has a better average and variance than Run 3, the best result for reducing project completion time uncertainty is to direct resources to time reduction on activity B.

Runs 4 and 5 generated multimodal distributions which led to their large variances when compared to Run 1. Since C, D, and E are always on the critical path, the critical path probabilities and H(X) are the same for Runs 1, 4, and 5 (see Table 1). However, while Run 5 exhibits the largest variance, it also exhibits the lowest mean and the lowest completion time entropy of all the alternatives. It would likely be the preferred alternative among the five runs for most practitioners.

V. CONCLUSION

Traditional approaches to simulation output analysis from PERT networks have tended to focus more on completion time and critical paths than on uncertainty. This study argues that the entropy function offers an additional tool to practitioners to ask basic "what if" questions concerning the stochastic nature of projects. This suggests new options to explore tradeoffs with time and uncertainty, better recognizing that the network model, if properly constructed and validated, can be manipulated to reduce some of the random factors that make many projects so difficult to manage and control.

Extensions of this study include multivariate versions of the entropy function which include measures for the interaction between and among random variables (e.g., such as completion times, criticality indices, critical path probabilities, and variations in network structure) to measure information gain and redundancy in project network simulation models. Such measures, while commonly employed in information theory and in the study of communications, are ideal for stochastic project networks that go beyond PERT, such as GERT and VERT networks which are an enhancement of the basic PERT network by permitting probabilistic branching and probability sets for varying network structures.

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An Expected Loss Model for Risk Prioritization in Service FMEA

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Among risk prioritization techniques in service FMEA literature, the determination of RPN is based on the decision maker's intuition. This will make service risk prioritization to be less scientific, which may cause an inappropriate decision making. This paper is presented to propose an improved prioritization of risk in service FMEA on a more scientific basis using conditional probability theory. As the surrogate of severity of failure, cost-oriented loss estimation is embedded into the risk estimation model. An example on how to use our risk prioritization method in practice is also provided.

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I. INTRODUCTION

Correct evaluation of the risk of service failure is an important part toward the efficiency of a firm's resource allocation. In industrial practices, service firms utilized service FMEA(failure mode and effect analysis) as a means to estimate the risk of service failure and to provide an appropriate way of reducing its impact on the end customer. FMEA in service sectors are primarily used in medical service, handling customer complaint, and consumer good trading. Jennifer et al.(2007) used FMEA to reveal difficulty in accessing drug labeling error. Oolkalkar et al.(2009) pinpointed some critical failures and proposed improvements in *Haemodyalisis* treatments. Bosch and Enriquez(2005) integrated FMEA with QFD(quality function deployment) in handling customer complaints. Zhang and Zhu (2009) estimated the critical risk factors in outsourcing. Chuang(2007) combined the service blue printing and FMEA to pinpoint critical service failures in consumer goods trading. And Chuang(2010) incorporated disservice analysis to enhance perceived service quality using FMEA.

In conventional FMEA based on the MIL STD 1629A, prioritizing corrective actions to minimize the impact from a failure is based on the magnitude of RPN (risk priority number). The larger the RPN, the more dangerous the failure would be. And corrective actions are taken in the descending order of the magnitude of RPN. Over the years, several methods have been proposed to improve the quality of risk prioritization method in FMEA. Previous works can be classified into several categories. One is based on fuzzy logic which includes such works as Bowles and Pelaez(1995), Chang et al.(1999), Xu et al.(2002), Puente et al.(2002), Tay and Lim(2006), Sharma et al.(2005), Dong(2007) and Keskin and Ozkan(2008). Cost oriented approach is studied by Gilchrist(1993), Kmenta and Ishii(2004), Karuppusswamy et al.(2006), Ahsen(2008) and Carmignani(2009). Graphic approach is studied by Gandhi and Agrawal(2002) and Hosseini et al.(2006). There are other approaches such as matrix ordered approach(Shankar and Prabhu,2001), data envelopment analysis(Chang and Sun, 2009), Poisson distribution(Senol,2007), analytical hierarchy priority(Braglia, 2004) and so on.

For evaluating the risk priority, the previous works seem to take basically the same method as the conventional FMEA. The ratings of occurrence and detection of failure are determined intuitively with no statistical basis. The severity of failure with 1 to 10 ratings is unable to reveal the magnitude of service failure effect into quantitative basis. In this work, we aimed to propose derivation of RPN from economic perspective. We use the conditional probability theory and quantify the expected loss of service failure using quality cost metric.

II. THE EXPECTED LOSS MODEL

2.1. The RPN of the service FMEA

Service FMEA is a technique which identifies any service failure modes, determines their effects and severities, and takes appropriate actions on their possible causes. The severity of an effect is determined on the basis of the perceived service quality from the eyes of customers. Basically, the objective of FMEA is to prevent the occurrence of the actual and potential failures in future.

In FMEA, the risk of each failure mode is evaluated by RPN, which is obtained as the product of severity ratings (S), detection ratings (D), and occurrence ratings (O). Occurrence refers to the probability that a failure occurs during a specified period of time, detect ability refers to the ability to detect the potential and actual failure before it reaches customers, and severity refers to the seriousness of the failure effect on the customer. The bigger the RPN, the more serious the failure would be. And the preventive or corrective action shall be commenced from the failure mode with the biggest RPN. Table 1 describes the procedure to perform FMEA for service operation. For more detailed information on the ratings in estimating the RPN, the readers are pleased to refer reference manual on FMEA provided by Ford (1988) and AIAG (Automotive Industry Action Groups, 1995).

Table 1. The Generic Steps to Perform Service FMEA.

Step	Questions	Outcome
Identify failure modes, its corresponding root cause, and effect	What can go wrong with the service system?	Failure mode, failure root cause, and its end effect
Estimate the risk of service failure	What is the value of the risk will incur?	The Risk Priority Number = occurrence of failures * detectability of failure * severity of failure
Minimize the impact of service failure	What shall be done to minimize the risk of service failure?	Change standard operating procedure, tighten supervision, etc.
Estimate the effectiveness of corrective action	Are there any reductions in risks after the corrective action is implemented?	Risk Reduction ratio = $(RPN_{initial} - RPN_{Revised}) / RPN_{initial}$

2.2. Risk prioritization by expected losses

We consider here only the occurrence of failure over a fixed period of time. The probability of service failure occurrence can be estimated by the use of the conditional probability theory under the following assumptions:

i) All the failure modes, effects and causes are identifiable in advance.
ii) All the causes of each failure mode can be defined into a set of mutually exclusive and exhaustive events.
iii) All the effects of each mode can be defined into a set of mutually exclusive and exhaustive events.
iv) The failure causes occur independently and the probability of every failure cause is known.
v) The failure mechanism and the conditional probabilities describing cause and effect relationships are known.
vi) The cost components corresponding to the failure effects are known.

In fact, most of the assumptions hold under application of the conventional FMEA. Without assuming i), we cannot even execute the conventional FMEA. For assumption ii), once all the causes of a failure mode F_k are identified, they can be easily redefined into a set of mutually exclusive and exhaustive events $\{C_{k1}, C_{k2}, \ldots, C_{kn_k}\}$ so that $C_{ki} \cap C_{kj} = \emptyset$ and $\bigcup_{i=1}^{n_k} C_{ki}$ covers all the causes of F_k, $k = 1, 2, \ldots, l$. If any two failure causes A and B are not mutually exclusive, we can redefine the failure causes as $C_{k1} = A - B$, $C_{k2} = B - A$ and $C_{k3} = A \cap B$. Similarly with assumption iii), we can define a set of mutually exclusive and exhaustive effects $\{E_{k1}, E_{k2}, \ldots, E_{km_k}\}$ so that $E_{ki} \cap E_{kj} = \emptyset$ and $\bigcup_{j=1}^{m_k} E_{kj}$ covers all the effects for any given failure F_k. As to the assumptions iv), v) and vi), the conventional FMEA provides guidelines for occurrence, detection and severity ratings, which implicitly assumes some knowledge about the probability components and cost or loss components of each failure.

Denote the probability components by $P(C_{ki})$, $P(F_k|C_{ki})$ and $P(E_{kj}|F_k)$, $k = 1, 2, \ldots, l$, $i = 1, 2, \ldots, n_k$, $j = 1, 2, \ldots, m_k$. And denote the cost components corresponding to the failure effects $E_{k1}, E_{k2}, \ldots, E_{km_k}$ by $L_{k1}, L_{k2}, \ldots, L_{km_k}$, $k = 1, 2, \ldots, l$. Then the probability of the occurrence of failure mode F_k, $k = 1, 2, \ldots, l$ can be obtained by

$$P(F_k) = \sum_{i=1}^{n_k} P(C_{ki})P(F_k|C_{ki}). \qquad \textbf{(1)}$$

Note that, under a well established fool proof system, $P(F_k|C_{ki})$ will be of small value. If C_{ki} is detected before F_k occurs, $P(F_k|C_{ki})$ will take 0 as its value. Thus, $P(F_k|C_{ki})$ reflects the detectability of C_{ki}, $i = 1, 2 \ldots n_k$.

If the failure mode F_k can easily be detected and corrected, then $P(E_{kj}|F_k), j = 1,2,\ldots,m_k$ would be small. So each of $P(E_{kj}|F_k)$ represents the detect ability of the failure mode F_k. Large $P(E_{kj}|F_k)$ implies that the failure mode F_k is very likely to result in E_{kj}. The probability $\sum_{j=1}^{m_k} P(E_{kj}|F_k)$ can be thought to reflect the overall detect ability of the failure mode F_k. And the severity can be evaluated by losses incurred due to $E_{k1}, E_{k2}, \ldots, E_{km_k}$. Thus, the conditional expected loss

$$E(L_k|F_k) = \sum_{j=1}^{m_k} L_{kj}P(E_{kj}|F_k) \qquad \textbf{(2)}$$

will represent the overall detect ability and severity of the failure mode F.

By combining Formula (1) and (2), we obtain the expected loss for a given failure mode F_k as

$$E(L_k) = P(F_k)E(L_k|F_k). \qquad \textbf{(3)}$$

Table 2. The FMEA Sheet for the Expected Loss Model.

Failure mode	Effect				Cause				Expected loss
	E_{kj}	Severity (Loss)	Detectability	Conditional loss	C_{ki}	Occurrence	Detectability	Failure occurrence	
F_1	E_{11}	L_{11}	$P(E_{11}\|F_1)$	$E(L_1\|F_1)$	C_{11}	$P(C_{11})$	$P(F_1\|C_{11})$	$P(F_1)$	$E(L_1)$
	E_{12}	L_{12}	$P(E_{12}\|F_1)$		C_{12}	$P(C_{12})$	$P(F_1\|C_{12})$		
	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$		
	E_{1m_1}	L_{1m_1}	$P(E_{1m_1}\|F_1)$		C_{1n_1}	$P(C_{1n_1})$	$P(F_1\|C_{1n_1})$		
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
F_l	E_{l1}	L_{l1}	$P(E_{l1}\|F_l)$	$E(L_l\|F_l)$	C_{l1}	$P(C_{l1})$	$P(F_l\|C_{l1})$	$P(F_l)$	$E(L_l)$
	E_{l2}	L_{l2}	$P(E_{l2}\|F_l)$		C_{l2}	$P(C_{l2})$	$P(F_l\|C_{l2})$		
	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$		
	E_{lm_l}	L_{lm_l}	$P(E_{lm_l}\|F_l)$		C_{ln_l}	$P(C_{ln_l})$	$P(F_l\|C_{ln_l})$		

If we are concerned with the failure mode, the FMEA sheet for our expected loss model can be constructed as Table 2. The failure mode with the largest $E(L_k)$ should be taken care of with highest priority.

In many situations, we are more concerned with the root causes of each failure mode and RPN is calculated for each cause. In such situations, we must calculate the expected loss attributable to each root cause. This can be done by multiplying $P(C_{ki}|F_k)$ and $E(L_k)$. Note that $P(C_{ki}|F_k)$ is the posterior probability given the occurrence of the failure mode F_k. That is, it is the probability that C_{ki} is the root cause once the failure mode F_k has occurred. Thus, the expected loss attributable to C_{ki} can be obtained by

$$P(C_{ki}|F_k)E(L_k) = \frac{P(C_{ki})P(F_k|C_{ki})}{P(F_k)}E(L_k|F_k)P(F_k)$$

$$= P(C_{ki})P(F_k|C_{ki})E(L_k|F_k). \qquad (4)$$

Formula (4) corresponds to the RPN of C_{ki} in the conventional FMEA. Table 3 shows the whole mechanism of evaluating the effects and causes of the failure modes. Once Table 3 is completed, we can identify failure mechanism or root causes of failure modes which have significant effects or losses.

2.3. The probability and cost components

When using equation (4) as a substitute of the RPN in conventional FMEA, the three probability components $P(C_{ki})$, $P(F_k|C_{ki})$ and $P(E_{kj}|F_k)$, $k = 1, 2, \ldots, l$, $i = 1, 2, \ldots, n_k$, $j = 1, 2, \ldots, m_k$ must be known or at least estimated in advance. This can be hardly the real situation. But, as previously mentioned, we usually have some knowledge on these components when we use the conventional FMEA. Even if we cannot obtain perfect estimates for these probabilities from the beginning, continuous updating of FMEA enables us to obtain quite good estimates on the probability components.

Table 3. The Modified FMEA Sheet for the Expected Loss Model.

Failure Mode	Effect				Cause			Expected Loss Attributable to C_{ki}
	E_{kj}	Severity (Loss)	Detectability	Conditional loss	C_{ki}	Occurrence	Detectability	
F_1	E_{11}	L_{11}	$P(E_{11}\|F_1)$	$E(L_1\|F_1)$	C_{11}	$P(C_{11})$	$P(F_1\|C_{11})$	$P(C_{11})P(F_1\|C_{11})E(L_1\|F_1)$
	E_{12}	L_{12}	$P(E_{12}\|F_1)$		C_{12}	$P(C_{12})$	$P(F_1\|C_{12})$	$P(C_{12})P(F_1\|C_{12})E(L_1\|F_1)$
	⋮	⋮	⋮		⋮	⋮	⋮	⋮
	E_{1m_1}	L_{1m_1}	$P(E_{1m_1}\|F_1)$		C_{1n_1}	$P(C_{1n_1})$	$P(F_1\|C_{1n_1})$	$P(C_{1n_1})P(F_1\|C_{1n_1})E(L_1\|F_1)$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
F_l	E_{l1}	L_{l1}	$P(E_{l1}\|F_l)$	$E(L_l\|F_l)$	C_{l1}	$P(C_{l1})$	$P(F_l\|C_{l1})$	$P(C_{l1})P(F_l\|C_{l1})E(L_l\|F_l)$
	E_{l2}	L_{l2}	$P(E_{l2}\|F_l)$		C_{l2}	$P(C_{l2})$	$P(F_l\|C_{l2})$	$P(C_{l2})P(F_l\|C_{l2})E(L_l\|F_l)$
	⋮	⋮	⋮		⋮	⋮	⋮	⋮
	E_{lm_l}	L_{lm_l}	$P(E_{lm_l}\|F_l)$		C_{ln_l}	$P(C_{ln_l})$	$P(F_l\|C_{ln_l})$	$P(C_{ln_l})P(F_l\|C_{ln_l})E(L_l\|F_l)$

The failure mechanism can be well established when sufficient technical information is available. In this situation, $P(F_k|C_{ki})$ and $P(E_{kj}|F_k)$ may be evaluated using this information. The technical knowledge and experiences are usually documented and maintained in most industrial organizations. And, if any kind of failure occurs, it is usually recorded with relevant information of causes attributable to. Thus, $P(F_k)$ and $P(C_{ki}|F_k)$ can be estimated using the past record of failures. Now, $P(C_{ki})$ can be estimated using the following relation

$$P(C_{ki}) = P(F_k)P(C_{ki}|F_k)/P(F_k|C_{ki}) \quad (5)$$
$$k = 1, 2, \dots, l,\ i = 1, 2, \dots, n_k.$$

Assuming the failure mechanism is well known, a more theoretical estimation may be possible using Bayesian estimation method. But, in this paper of application purpose, we are not going deeper into the mathematical aspects of estimation.

To complete Table 3, the loss components $L_{k1}, L_{k2}, \dots, L_{km_k}$, $k = 1, 2, \dots, l$ should also be known. Note that the conventional FMEA implicitly assumes the availability of severity score for each failure effect. When the effects $E_{ki,}$ $j = 1, 2, \dots, m_k$ are identified for a given failure F_k together with their corresponding severities, there is a good possibility to have fair estimates for $L_{ki,}$ $j = 1, 2, \dots, m_k$. The loss amount may be calculated in some situations, or may be estimated by analyzing similar cases.

Let's take an illustration of estimating the cost components. Suppose a logistics firm is perceived *unreliable* in delivering its order to the customers. The *unreliability of delivery* (service failure) will cause customers' dissatisfaction, which eventually results in customers' complaint, claim or switch to another service provider. If customers claim service warranty, it directly incurs the costs to resolve the service claims. If some customers switch to another service provider, it is an opportunity loss to the company. The losses due to a service failure may be classified into three categories; internal failure costs, external failure costs, and opportunity costs. This classification will make it easier to estimate the losses attributable to a service failure. For detailed estimation procedures, refer to Jaju and Lakhe(2009), Krishnan(2006), Chauvez and Beruvides (1998), and Yang and Chen (2000).

III. AN ILLUSTRATIVE EXAMPLE OF APPLICATION

3.1 The application procedure

For practical application of the expected loss model, we need a more detailed step-by-step approach as below;

i) Determine potential and actual service failure modes.
ii) Identify all the service failure consequences together with all the possible causes.
iii) Evaluate the cost and probability components and calculate the expected loss as product of each service failure probability, detect ability, and expected cost using Table 2.
iv) Compare the magnitude of expected loss of each service failure with service firm's acceptable economic criteria.
v) If the expected loss corresponding to a failure mode is acceptable by the firm's criteria, we take no action on the failure mode. Otherwise, go to the next step.
vi) Using Table 3, find out the root causes to which the expected loss is the most attributable.
vii) Implement some appropriate corrective and preventive actions on the key root causes.
viii) Verify the effectiveness of the actions.
ix) Document the result for organizational learning.

3.2 An Example

To illustrate applicability of the expected loss model, an example situation is partly adopted from Chuang(2010). We provide a sketch of using the model for illustration purpose only, without describing all the detailed procedures of identification and evaluation of failures, cost and probability components. All the values of the cost and probability components are assumed to be given for explanation of the expected loss model.

A service firm is aiming to use service FMEA to enhance reliability of their service provision by identifying the critical failure modes and their corresponding expected losses. After conducting brainstorming supported with available data among FMEA members, the team mapped failure root causes, service failure modes, and their end effects. Table 4 illustrates the use of our expected loss model from the case example. FMEA is executed as to the suggested procedure.

i) Five failure modes are identified like "Instability of supply goods", "Unavailability of goods/merchandise", and so on.
ii) For each failure mode, the consequences and all the possible causes are identified. As an example for the failure mode "Instability of supply goods", three effects are identified as "Short of goods", "Lost sales", and "Customer complaint" together with the causes "Inappropriate supply forecasting", "Unreliable supplier", and "Inaccurate demand forecasting".
iii) The cost and probability components are evaluated and the expected loss is calculated for each failure mode using formula (1), (2) and (3). For example, by referring to equation (1), the probability of failure occurrence "Instability of supply goods" is 0.26. Its conditional loss is counted as $3125 by using equation (2). Finally, its expected loss is obtained by multiplying these two values as to equation (3). The expected loss caused by failure mode "instability of supply goods" accordingly is equals to $ 812.5. The expected values of the other service

failures can also be estimated in the same way.

iv) The magnitude of expected loss of each service failure is compared with service firm's acceptable economic criteria. The threshold value of expected loss for the service firm under study is supposed to be \$1000 with each failure mode. That is, the expected loss for any service failure should be no more than \$ 1000. According to this criterion, two critical failure modes are identified as "Nonconforming quality of goods" and "Unavailability of goods/merchandise".

v) The expected losses corresponding to the other three failure modes are acceptable by the firm's criteria. And we take no actions on these failure modes.

vi) For the two critical failure modes "Nonconforming quality of goods" and "Unavailability of goods/merchandise", we use equation (4) to find out the root causes to which the expected loss is the most attributable. For instance, the value of expected loss attributable to "poor warehousing" is estimated by \$ 688.8. The values of expected loss attributable to the other causes can be accomplished in the same way. The result is summarized in Table 5.

Next procedures will be to implement some appropriate corrective and preventive actions on the key root causes, to verify the effectiveness of the actions, and to document the result for organizational learning.

Table 4. Example of modified FMEA sheet Using Expected Loss Model.

Failure Mode	Effect				Cause				
	Failure effects(E_{kj})	Severity (Loss)(\$)	Detect ability $P(E_{kj}\|F_k)$	Conditional loss $E(L_k\|F_k)$	C_{ki}	Occurrence $P(C_{ki})$	Detect ability $P(F_k\|C_{ki})$	Failure Occurrence $P(F_k)$	Expected loss(\$) $E(L_k)$
Instability of supply goods	Short of goods Lost sales Customer complaint	1500 4000 1750	0.7 0.3 0.5	3125	Inappropriate supply forecasting Unreliable supplier Inaccurate demand forecasting	0.5 0.2 0.7	0.3 0.2 0.1	0.26	812.5
Unavailability of goods/ merchandise	Loss sale Customers inability to find goods needed	3450 3700	0.7 0.6	4635	Inappropriate replenishment Inappropriate lay out	0.3 0.2	0.4 0.5	0.22	1019.7
Tardiness of warranty	Increasing customer warranty cost	4000	0.8	3200	Inappropriate warranty schema	0.2	0.1	0.02	64
Non conforming quality of goods	Affect food Safety against regulation Customer claims	3200 10000 200000	0.3 0.2 0.1	22960	Poor warehousing Tightless inspection Supplier error	0.1 0.1 0.05	0.3 0.2 0.1	0.055	1262.8
Inability of finding server in sales floor	Dissatisfied customers Lost sales	1000 3200	0.3 0.1	620	Poor personnel management Lack of empowerment	0.3 0.5	0.5 0.7	0.5	310

Table 5. The expected losses attributable to failure causes.

Failure		Cause			Expected Loss Attributable to C_{ki}
mode	$E(L_k)$	C_{ki}	$P(C_{ki})$	$P(F_k\|C_{ki})$	
Non conforming quality of goods	1262.8	Poor warehousing	0.1	0.3	688.8
		Tightless inspection	0.1	0.2	459.2
		Supplier error	0.05	0.1	114.8
Unavailability of goods/merchandise	1019.7	Inappropriate replenishment	0.3	0.4	556.2
		Inappropriate lay out	0.2	0.5	463.5

The remedial actions may be prioritized by the expected loss attributable to each cause. In some situations, however, the priority may be better determined on the basis of the effectiveness of each remedial action. For illustration, suppose there is only one appropriate remedial action for each failure cause as shown in Table 6. If we take a remedial action for a failure cause, the probability of its occurrence will decrease. The reduced value for each P(Cki) is also assumed as given in Table 6. The most effective remedial action is the one with the biggest amount of expected loss reduction. In this illustrative example, assuming the same cost for implementing every remedial action, the most effective remedial action is "Establish a warehouse control system".

Table 6. The effectiveness of remedial actions.

Failure		$P(C_{ki})$		$P(F_k\|C_{ki})$	Expected loss		
Cause	Remedial Action	Before	After		Before	After	reduction
Poor warehousing	Establish a warehouse control system	0.1	0.01	0.3	688.8	68.9	619.9
Tightless inspection	Add new QA staff	0.1	0.05	0.2	459.2	229.6	229.6
Supplier error	Change supplier	0.05	0.04	0.1	114.8	91.8	23
Inappropriate replenishment	Change replenish method	0.3	0.1	0.4	556.2	185.4	370.8
Inappropriate lay out	Redesign store layout	0.2	0.1	0.5	463.5	231.8	231.7

If profitability is considered in ranking corrective actions, the managers should reprioritize corrective actions with largest profitability. The reader can refer to Carmignani (2009) for details. The greater the profitability of certain corrective action, the more preferred it would be. However, the budget availability may also be a determinant in choosing the best corrective action. In this situation, the cost of implementing each remedial action should also be considered.

IV. DISCUSSIONS ON THE BENEFITS AND LIMITS OF THE MODEL

The main advantage of the expected loss model based on the conditional probability for risk estimation is that it provides a more scientific way of risk evaluation. With MIL STD 1629A as reference, the FMEA practitioners should follow tedious steps by brainstorming among FMEA members to estimate risk. In this situation, seniority and FMEA members' level of working experience will greatly affect the ratings of failure severity, occurrence and detection. Often they have to make consensus to conclude into agreement. Although there are some advancements in determining the risk (Jenap and Dhillon, 2005), it still depends on the practitioners' subjectivity. At the first time, the proposed model may also include many inaccuracies in the estimates of the probability and cost components. But, as relevant information or data are accumulated, they can be more systematically and scientifically reflected into the model. Upon identifying the structural chain of service failures (failure causes, modes, and end effects) based on our proposed expected loss model, we can estimate the probability and cost components in a more objective way.

The advantages of using our expected loss model from both academicals and industrials' perspective may be summarized as follows:

i) The proposed model provides better means to derive risk estimation using the conditional probability theory. While the traditional FMEA depends much on the practitioners' subjectivity in determining RPN, it will substantially improve quality of service failure risk prioritization.
ii) It enables to pinpoint the part of service organization (warehouse, human resource, quality assurance, logistics, etc) that has the lowest detect ability of service failure. This will help managers to prepare better fool proofing techniques to prevent failure occurrence in future.
iii) The use of expected loss that constructed from the internal, external, and opportunity cost will raise management's awareness about the expense of service failure. Also, it enables managers to identify the key service quality attribute from the cost perspective. It will also be useful to show the ownership of service failure cost, which in turn, will increase to the related departments' operational responsibility.
iv) It helps the service firm to diagnose the level of their failure detection power.
v) It enables management to align the most effective and profitable corrective actions to the critical service failure effects. This will not only enhance service quality improvement but also will sustain companies' long term operation as profitability is also considered in making decision.

There surely are many weak points or limits in the proposed model for practical application. Before everything else, we need a more refined and articulate estimation procedure of the probability components. And we only considered the occurrence of failure over a fixed period of time. In order to be more useful in the field, it should be extended to a model that takes account of time horizon. To improve validity and reliability of the approach, extension may be needed in real and various industrial service settings using total of 22 service quality attributes. This study is based on assumption that the occurrences of service failure causes are independent one another, which is impractical. Also, this study assumed that the service quality problems to be resolved have no conflicting situation, which can rarely be the real situation. Besides, the failure cost is usually difficult to access due to company's confidentiality and the cost components may not be easy to estimate.

V. CONCLUSION

Improving risk prioritisation method in service FMEA is important for strategic operational cost reduction and resource allocation efficiency. Previous studies in prioritisation of service risk in traditional FMEA are based on multiplication of 1 to 10 intuitive scales of occurrence, severity, and detection of failures. This makes FMEA less scientific and difficult to reveal the source of quality cost trigger. This paper attempted to reformulate risk estimation in service FMEA in a more scientific way. In this paper, an expected loss model is proposed as a substitute of the conventional service FMEA based on MIL STD 1629A.

Under assumption of independent failure causes and effect occurrence, the conditional probability is used to determine probability of failure cause and effects. To evaluate the magnitude of failure severity in a more quantitative manner, service quality cost is embedded into the expected loss model. A more compact FMEA sheet is also introduced, compared with the previous one. A hypothetical service operation from consumers' good seller is presented to illustrate practical applicability of the model. Based on the criteria of expected loss reduction, we showed how to identify the key service failure causes and their corresponding corrective actions of top priority. The benefits and limits of using the expected loss model are discussed. Some benefits are leaving out service FMEA practitioners' subjectivity, pinpointing critical failure causes, and guiding service FMEA practitioners in choosing the most profitable corrective actions. Some limits are the independence assumption of failure cause occurrences, consideration of limited time span, availability of cost information, and so on.

Future studies are expected to overcome the weak points of the expected model. Some could be dedicated to developing an expected loss model deleting the assumption of independent occurrence of failure causes. Others may replace the service quality cost metrics with non financial metrics. Future researches are also possible under the situation of general time span.

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The Relationship between Inventory Management and Firm Profitability: Sector Consequences of Catastrophic Supply Chain Disruptions

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The study examines the effect of inventory on firm profitability before and after two catastrophic supply chain disruptions. We study the September 11, 2001 terrorist attacks and Hurricane Katrina, with the goal of determining both whether there is evidence that inventory has been used as a means of developing supply chain resiliency and the stability of any such relationship. Using separate three-year periods surrounding the disruptions, univariate analyses are used to examine the macro-level effects on firm profitability, selected growth measures, and inventory levels across manufacturers, wholesalers, and retailers. Regression models are employed to isolate the effect of inventory on profitability by utilizing balance sheet and income statement control variables and also to test whether a change in the relationship between inventory and firm profitability can be detected. The findings indicate the effect of inventory on firm profitability shows a significant decline for manufacturing in the post- September 11 period with no significant change in the post Katrina period.

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I. INTRODUCTION

In recent years there has been increased awareness of the probability of supply chain disruption and associated costs. Supply chain disruptions are unplanned, unanticipated events that result in any part of the supply chain becoming inoperative and affect one or more links throughout the network (Craighead, et al., 2007; Snyder and Shen, 2006). The failure to correctly match supply and demand as the result of a disruption can affect an organization's revenue, short and long term profitability, asset utilization, and costs. Even when disruptions are infrequent, the risk associated with these disruptions may cause both changes to and a lack of confidence in the supply chain with resultant chaos and risk (Christopher and Lee, 2004; Snyder and Shen, 2006). However, research on the effects of supply chain disruption is only beginning to emerge and has not yet clearly established how supply chains can be expected to react to the threat of disruption.

Concern about supply chain disruption frequently focuses on inventory management, because it is an easily deployed strategy for developing resiliency (Christopher and Lee, 2004; Sheffi, 2001). As reported by Loar (1992,

p. 71), "of the three asset bundles managed (fixed assets, labor, and inventory), inventory is the easiest to change". In this spirit, Baker (2007) found the most common risk mitigation strategy noted by individual managers was the use of safety stock. Likewise, Tomlin and Synder (2007) suggest that even within lean supply chains, high risk may necessitate high inventory levels.

However, both Zsidisin, et al. (2004) and Tang (2006) note many organizations make little effort to manage risks of disruption. Many firms at the consumer goods end of the channel are "relatively insensitive to incidents with very low probabilities but potentially catastrophic outcomes" (Jüttner, et al., 2003, p. 204) and continue to respond to pressure to be efficient by lowering inventories.

For supply chain and logistics managers, much of the concern about the aftermath of 9/11 was centered on the management of inventory (Sheffi, 2001). Poor inventory control may lead to loss of customers, higher costs, and a drop in the value of the firm, while effective inventory management can enhance the firm's flexibility in responding to markets, and generate efficiency leading to greater firm profitability and value. For both the manufacturing and retail sectors of the supply chain, U.S. firms struggled with the effects of the 9/11 disruptions on inventories with many supply chain managers calling the impact on their supply chains "dramatic" (Betts, 2001). While the supply chain disruptions following Hurricane Katrina were not as widespread as those of 9/11, they were still significant as disruptions to telecommunications and data gathering equipment affected the operations of supply chains (Santella, et al., 2009) and manufacturers reported price increases of raw materials and difficulties in taking delivery (Preciphs, 2005).

How, or if, supply chains develop and implement strategies to mitigate the probability of disruption is an area of growing interest. However, the majority of the work done in this area has focused on specific firm-level effects. The intent of the current research is to examine the macro-level sector effect of inventory on organizational profitability in the United States before and after major supply chain disruptions, the September 11, 2001 attacks and the August, 2005 Hurricane Katrina that struck the Gulf coast of the United States, with the tentative expectation that changes would be detected. In doing so, we advance the emerging literature investigating supply chain reaction to disruption by testing if inventory is used post-disruption to mitigate risk and develop resiliency. We also add to the literature studying the relationship between inventory and profitability by using a broad cross section of secondary, longitudinal data covering a six-year window centered on each of the two events. This analysis provides a macro, economy-wide view of the effect of supply chain disruption. In the following sections, we discuss the emerging literature on supply chain disruptions and resiliency and provide a brief review of supply chain efficiency on organization performance. We then present our empirical model, data analysis, and conclude with a discussion of results and implications.

II. EMERGING LITERATURE

2.1. Supply Chain Disruption and Resiliency

As noted in Zsidisin, et al. (2004), "risk is perceived to exist when there is a relatively high likelihood that a detrimental event can occur and that event has a significant associated impact or cost" (p. 397). Risk to the supply chain may come from environmental variables such as natural disasters, labor unrest, utility failures, terrorism, cyber-attacks, and structural shifts in markets. Other sources of risk result from the design of supply chains and include globalization, outsourcing, reductions in number of suppliers, and the drive to greater efficiency, through lower inventory levels and JIT responsiveness (Jüttner, et al., 2003; Lee, 2004). Increased costs associated with disruption include expediting freight, inventory and demand mismatches, additional marketing and public relations activities, and loss of organizational reputation (Hendricks and Singhal, 2005a).

While it is essential to an organization's success to recognize the existence of risk, careful analysis of the implications of potential disruptions is difficult because these events may be unpredictable, infrequent, and little research exists to guide managers on expected magnitude of disruption (Hendricks and Singhal, 2005b; Zsidisin, et al., 2004). Despite this difficulty, it is resiliency, the post-disruption resumption of activity, which is, increasingly, viewed as a critical capability in the supply chain. The extant literature on coping with supply chain disruptions expounds numerous means of developing resiliency, including mitigation and redundancy, contingencies, flexibility, and shared risk strategies. Mitigation and redundancy tactics require the organization to take advance action to deal with a disruption and to accept the cost of the action even if the disruption does not occur (Tomlin, 2006). Advance actions include financial mitigation, such as business interruption insurance; or operational redundancies, such as increases in inventory levels and/or number of suppliers; or duplication of facilities and equipment (Lee and Wolfe, 2003).

In contrast, contingency activities are those that take place only when a disruption actually occurs (Tomlin, 2006). These activities may include operational contingencies such as rerouting of shipments, efforts to manage demand, or 'what-if' analysis aimed at the development of robust supply chain strategies (Simchi-Levi, et al., 2002). Similarly, flexibility strategies allow an organization to operate under several different scenarios and include using multiple suppliers in multiple countries, and those who are able to increase or decrease volume quickly. Firms also use buffer inventory, scalable production capacity and develop the ability to move production among multiple sites (Simchi-Levi, et al., 2002). Both contingency and flexibility strategies appear to be more efficient than mitigation and redundancy, yet the necessary investment is not small and implementation time may be extensive.

Finally, it has been suggested that strategies designed to share risk throughout the supply chain may help organizations develop resiliency to disruption. These activities include collaboration, outsourcing, and hedge strategies in which the supply chain is designed so that losses in one area are offset by a combination of gains in another area (Simchi-Levi, et al., 2002). However, while literature suggests that these strategies increase the supply chain effectiveness, there is only minimal research suggesting they help organizations develop resiliency.

2.2. Supply Chain Efficiency and Organizational Performance

Most efforts to manage the supply chain have been focused on lowering costs rather than managing or planning for risk of disruptions (Hendricks and Singhal, 2005b; Sorensen, 2005). Similarly, much of the literature on supply chain performance has focused on efficiency as a key driver of organizational financial performance (for example, Aviv, 2003; Lee and Billington, 1992; Loar, 1992; Zinszer, 1996), with strong emphasis on the effects of inventory management. Christopher and Ryals (1999) examined how time compression in the supply chain, through faster movement of inventory, affected customer service and costs; Aviv (2003) and Milner and Kouvelis (2002) studied how information sharing among members of the supply chain could lead to better inventory practices; Cachon (2001) and Boyaci and Gallego (2002) examined the effects of both inter-organizational competition and cooperation in making inventory policies and pricing decisions; D'Avanzo, et al. (2003) showed those supply chains that excelled in balancing market needs with supply had a market capitalization growth rate higher than their respective industry averages; Fleisch and Tellkamp (2005) analyzed how inventory inaccuracy affected supply performance; and Lee and Chu (2005) pinpointed where decisions about inventory levels should be made within the supply chain. While there are clearly established efforts to improve firm profitability through inventory reductions, the impact of disruption on the management of inventory is not clearly understood. Further, much of the work on the impact of inventory on supply chains and organizational has used limited data sources. As noted by Hendricks and Singhal (2005a), with few exceptions, the substantial body of literature examining supply chain performance, inventory management, and organizational financial performance is based on either hypothetical data or data self-reported to researchers from individual organizations. Thus, there exists a need to expand research to secondary data sources to create a broader view of supply chain performance.

III. METHODOLOGY

3.1. Data Acquisition and Definition

Data describing firm-level profitability, growth and inventory levels were obtained from the Compustat annual file, a standard source for financial statement information used extensively in the finance and accounting literatures. The Compustat annual file provides financial statement information (income statement, balance sheet, and cash flows) from publicly traded firms both active and inactive. Data were accessed through Compustat's Research Insight (2010) and relevant items were extracted for all manufacturers, wholesalers, and retailers as categorized by their 2-digit SIC codes. The selection process identified separate three-year periods of interest: 1998 to 2000 and 2002 to 2004, before and after the extraordinary events of September 11, 2001, and 2002 to 2004 and 2006 to 2008, the three-year periods surrounding Hurricane Katrina.

It should be noted that the three year period, 2002-2004 was used for both the post-9/11 and the pre-Hurricane Katrina analysis. Our requirement that each final data set contains a complete time series for each variable results in a slightly different, but materially overlapping, set of firms across the two events. As we encountered a modest sample size for wholesaling and retailing as compared to manufacturing, we decided against restricting our analysis to a common set of firms and a reduced sample The selected variables use in the analysis are discussed below and shown in Table 1. The final data set across sectors for the period surrounding September 11, 2001 included 1,865 firms, while the final data set for the period surrounding Hurricane Katrina included 1,747 firms.

Table 1
VARIABLE DEFINITIONS WITH BALANCE SHEET ITEMS REPRESENTING YEARLY AVERAGES

ROA	Return on Assets	$\frac{\text{Earnings Before Interest, Taxes, Depreciation, and Amortization}}{\text{Assets}}$
DAYS	Days COGS in Inventory	$\frac{\text{Inventory}}{\text{Cost of Goods Sold/365}}$
GPM	Gross Profit Margin	$\frac{\text{Sales-Cost of Goods Sold}}{\text{Sales}}$
SGA	Sales and General Administrative Expenses	$\frac{\text{Sales \& General Administrative Expenses}}{\text{Sales}}$
CAP	Capital Intensity	$\frac{\text{Net Property Plant and Equipment}}{\text{Assets}}$
PDUM	Period Dummy for 9/11 regression Period Dummy for Katrina regression	0 if 1998-2000; 1 if 2002-2004 0 if 2002-2004; 1 if 2006-2008

Our empirical tests focus upon the affect of inventory on organizational profitability. Because the amount of debt used to finance a firm's assets will vary both across and within industries, an organization's capital structure choice and associated interest expense may confound the analysis of profitability on net income. In addition, accounting flexibility in the treatment of depreciation and goodwill across organizations may further complicate the analysis. To minimize these confounding influences, this study uses a standardized measure of earnings before interest, taxes, depreciation, and amortization (EBITDA) as the dependent variable in our model. Specifically, return on assets (ROA), defined as EBITDA divided by total assets, is used as our measure of organizational profitability.

We develop an empirical model to test the impact of inventory policy on firm profitability before and after each event of interest. Inventory policy is measured as days costs of goods sold in inventory (DAYS). This metric is inversely related to how quickly inventory moves through an organization's control. As DAYS becomes smaller, inventory moves through the system faster and inventory turnover accelerates. Since our dependent variable, ROA, is a function of the income statement, it is important to control for major determinants of profitability outside of effects related to inventory. To this end, two variables directly affecting the flow of sales dollars into EBITDA are also included as control variables: gross profit margin (GPM) and sales and general administrative expenses (SGA).Our profitability measure is also a function of the balance sheet as we standardize by total assets. As such, we include a final control variable to enhance the explanatory power of our model. The three sectors within our sample are characterized by different asset structures. For example, manufacturing organizations, unlike wholesalers and retailers, include a substantial component of machinery and equipment within their asset accounts. In a similar fashion, the current asset accounts for wholesaling and retailing, which include both receivables and inventory, likely comprise a greater portion of total assets than they do in the manufacturing sector. As with capital structure concerns, it is also possible that variation within industry may exist. To control for the potential impact of these differences on organization profitability, we include a final control variable related to asset structure. This is done by employing a measure of capital intensity (CAP) calculated as net property plant and equipment divided by assets.

Finally, we selected measures to minimize the affect of two sources of potential bias. First, due to seasonality within and across sectors, all balance sheet items in this study employ yearly averages calculated from beginning and ending values. Further, it is well-known that the distributions of many accounting ratios depart from normality and, as such, may lead to incorrectly specified test statistics and correspondingly misleading inferences (McLeay and Omar, 2000). Therefore, in this study we trim the top and bottom 1% of each financial statement item in order to minimize this potential.

3.2. Preliminary Data Exploration

Table 2a presents ROA and selected growth measures before and after 2001; Table 2b presents the same measures before and after 2005. Means and medians across industry types are presented for each period of interest. The data suggest that the 9/11 event of 2001 may have adversely affected organizational performance. In particular, both sales and asset growth show significant decreases subsequent to the event across sectors. Further, profitability displays a statistically significant decline in both the manufacturing and wholesaling sectors with the steepest declines occurring in manufacturing. Interestingly, while the retailing sector also shows a reduction in profitability, these changes are more modest and are not statistically significant. In contrast to 9/11, however, changes in the selected profitability and growth measures resulting from Hurricane Katrina showed an inconsistent effect. The retailing sector showed significant declines in profitability, sales growth, and asset growth, while both the manufacturing and wholesaling sectors showed significant *growth* in both profitability and assets. It is noteworthy that the absolute magnitude of the changes reported in Table 2a and 2b do not directly correspond to reported significance levels in all cases. In particular, Table 2b shows a difference in manufacturing ROA means between the post- and pre-Katrina periods of 0.008 which is not statistically significant. A reported difference of half that amount, however, is reported as being significant at the 1% for the medians. Such an occurrence is the result of the variable dispersion which affects the test of the means through the standard error but does not directly affect the rank ordering used by the nonparametric Kruskal Wallis test of the difference in medians.

The observed post-Katrina increases in profitability and asset growth shown within Table 2b for manufacturing and wholesaling were unexpected. These findings suggest that the affect of Katrina may have been more localized than the generalized uncertainties, and concomitant business consequences, of 9/11. It is also possible that the observed increases may have also resulted from increases in the general level of economic activity across the two periods. This hypothesis, however, is not supported by the data at the macro level. In particular, real GDP changes expressed in 2005 dollars were 1.8%, 2.5%, and 3.6% for the years 2002 through 2004 while the corresponding statistics for the years 2006 through 2008 were 2.7%, 1.9%, and 0.0% ("Bureau of Economic Analysis," 2010). A second plausible line of inquiry considers that the base period of our Katrina analysis, as discussed earlier, represents the same calendar interval as the depressed post 9/11 period. Hence, any observed increases in firm metrics could potentially be the result of a reversion to more normal levels of operation. Lastly, we wish to provide the caveat that the impact of 9/11 could potentially have extended into the post-Katrina period and that such contamination is beyond the scope of our empirical design.

TABLE 2a – 9/11
SELECTED PROFITABILITY AND GROWTH MEASURES BEFORE AND AFTER 2001

	Means			**Medians**		
	1998-2000	**2002-2004**	**Difference**	**1998-2000**	**2002-2004**	**Difference**
Manufacturing (n = 1490 firms)						
ROA	.108	.077	-0.031 **	.137	.107	-0.030 **
Sales growth	.157	.090	-0.067 **	.080	.063	-0.017 **
Asset growth	.175	.045	-0.130 **	.087	.028	-0.059 **
Wholesaling (n= 127 firms)						
ROA	.104	.089	-0.015 *	.110	.093	-0.017 **
Sales growth	.173	.090	-0.083 **	.106	.069	-0.037 **
Asset growth	.174	.064	-0.110 **	.116	.034	-0.082 **
Retailing (n= 248 firms)						
ROA	.158	.154	-0.004	.156	.148	-0.008
Sales growth	.180	.079	-0.101 **	.120	.066	-0.054 **
Asset growth	.170	.075	-0.095 **	.119	.065	-0.054 **
*P < .05, **P < .01						

TABLE 2b - KATRINA
SELECTED PROFITABILITY AND GROWTH MEASURES BEFORE AND AFTER 2005

	Means			Medians		
	2002-2004	**2006-2008**	**Difference**	**2002-2004**	**2006-2008**	**Difference**
Manufacturing (n = 1435 firms)						
ROA	.074	.081	0.008	.109	.113	0.004**
Sales growth	.137	.104	-0.033	.080	.076	-0.004
Asset growth	.076	.092	0.016	.038	.060	0.022**
Wholesaling (n = 106 firms)						
ROA	.087	.112	0.025*	.094	.113	0.019**
Sales growth	.160	.121	-0.039	.079	.068	-0.011
Asset growth	.072	.134	0.062*	.043	.076	0.033**
Retailing (n = 206 firms)						
ROA	.156	.138	-0.018**	.157	.139	-0.018**
Sales growth	.102	.072	-0.030**	.077	.055	-0.022**
Asset growth	.107	.084	-0.023*	.085	.057	-0.028**
*P < .05, **P < .01						

Summary statistics and correlations for all test variables, by sector, are shown in Tables 3a and 3b. While the correlation matrix presents a number of significant relationships, it is important to recognize that these measures are bivariate in nature and do not control for the effect of other causal factors. Nevertheless, these correlations show that for time periods surrounding both the 9/11 and Katrina events, inventory levels are negatively related to organization profitability (ROA) for both the manufacturing and retailing sectors. Stated somewhat differently, they suggest that profitability is a positive function of how fast inventory flows through the system. Interestingly, this relationship is not statistically significant around 9/11 for wholesaling and is surprisingly positive around Katrina. We later show that this surprising result disappears when we control for other relevant variables within our multivariate tests to follow.

The estimated correlations of Tables 3a and 3b also indicate that for all sectors, and pertaining to both disruptions, ROA is positively correlated with gross profit margin (GPM) while inversely related to sales and general administrative expenses (SGA). While these relationships can be anticipated directly from a firm's income statement, they remain necessary control variables in order to isolate the partial effect of inventory policy on firm profitability. Lastly, the 9/11 correlation between capital intensity (CAP) and ROA is statistically significant and negative for manufacturing. For all three sectors, this correlation is significant and positive for the Katrina event. We urge caution in the interpretation of these latter specific bivariate relationships as they may lead to incorrect inferences in the absence of relevant controls.

Before proceeding to the multivariate tests, we next examine changes in our test and control variables for each of the disruptive events. This analysis provides additional insights into the changes in performance and growth measures documented earlier in Tables 2a and 2b. Means and medians by period, and across sectors, are provided in Tables 4a and 4b. The data reveal significant changes primarily in the manufacturing sector. In particular, for the 9/11 event, we documented decreases in GPM and increases in SGA. These two developments may partially explain the strong decrease in manufacturing ROA observed across periods within Table 2a.

TABLE 3a – 9/11
1998-2004 DESCRIPTIVE STATISTICS AND CORRELATIONS, EXCLUDING 2001

	Mean	**Median**	**Standard Deviation**	**Correlations**				
				ROA	**GPM**	**SGA**	**CAP**	**DAYS**
Manufacturing (n = 1490 firms)								
ROA	.092	.121	.193	1.000				
GPM	.377	.360	.191	.257**	1.000			
SGA	.323	.253	.404	-.577**	.109**	1.000		
CAP	.282	.200	.320	-.064**	-.239**	.114**	1.000	
DAYS	104.639	87.095	71.006	-.188**	.331**	.317	-0.007	1.000
Wholesaling (n= 127 firms)								
ROA	.097	.102	.095	1.000				
GPM	.223	.206	.121	.217**	1.000			
SGA	.176	.156	.110	-.176**	.886**	1.000		
CAP	.092	.051	.161	.024	.272**	.121**	1.000	
DAYS	64.188	57.085	42.094	.006	.413**	.401**	-.014	1.000
Retailing (n= 248 firms)								
ROA	.156	.152	.086	1.000				
GPM	.310	.302	.120	.188**	1.000			
SGA	.227	.225	.118	-.157**	.901**	1.000		
CAP	.229	.167	.178	.007	-.175**	-.345**	1.000	
DAYS	73.997	62.163	62.912	-.055*	.585**	.619**	-.388**	1.000
*P < .05 ** P < .01								

TABLE 3b - KATRINA
2002-2008 DESCRIPTIVE STATISTICS AND CORRELATIONS, EXCLUDING 2005

	Mean	**Median**	**Standard Deviation**	**Correlations**				
				ROA	**GPM**	**SGA**	**CAP**	**DAYS**
Manufacturing (n = 1435 firms)								
ROA	.077	.111	.191	1.000				
GPM	.386	.368	.197	.181**	1.000			
SGA	.360	.262	.568	-.546**	.080**	1.000		
CAP	.214	.178	.151	.192**	-.271**	-.218**	1.000	
DAYS	104.091	85.479	73.323	-.190**	.348**	.297**	-.251**	1.000
Wholesaling (n = 106 firms)								
ROA	.100	.104	.123	1.000				
GPM	.220	.198	.118	.213**	1.000			
SGA	.169	.149	.106	-.195**	.848**	1.000		
CAP	.146	.110	.129	.084*	.158**	.037	1.000	
DAYS	63.390	53.164	48.107	.109**	.415**	.306**	-.025	1.000
Retailing (n = 206 firms)								
ROA	.147	.149	.099	1.000				
GPM	.310	.306	.114	.217**	1.000			
SGA	.231	.231	.112	-.219**	.861**	1.000		
CAP	.374	.354	.198	.217**	-.213**	-.359**	1.000	
DAYS	72.874	61.496	59.008	-.101**	.565**	.617**	-.437**	1.000
*P < .05 ** P < .01								

TABLE 4a – 9/11
MEANS AND MEDIANS OF EXPLANATORY VARIABLES BEFORE AND AFTER 2001

	Means			**Medians**		
	1998-2000	**2002-2004**	**Difference**	**1998-2000**	**2002-2004**	**Difference**
Manufacturing (n = 1490 firms)						
GPM	.384	.371	-0.013 **	.365	.353	-0.011 **
SGA	.320	.326	0.006	.248	.258	0.010 *
CAP	.287	.276	-0.011	.206	.194	-0.012 **
DAYS	107.820	101.458	-6.362 **	89.958	84.282	-5.676 **
Wholesaling (n= 127 firms)						
GPM	.223	.223	0.000	.210	.204	-0.006
SGA	.174	.178	0.004	.153	.157	0.004
CAP	.093	.091	-0.002	.049	.051	0.002
DAYS	66.137	62.238	-3.899	58.536	56.005	-2.531
Retailing (n= 248 firms)						
GPM	.309	.310	0.001	.297	.306	0.009
SGA	.226	.228	0.002	.222	.229	0.007
CAP	.235	.224	-0.011	.168	.165	-0.003
DAYS	76.069	71.925	-4.144	63.219	61.231	-1.988
*P < .05 **P < .01						

TABLE 4b - KATRINA
MEANS AND MEDIANS OF EXPLANATORY VARIABLES BEFORE AND AFTER 2005

	Means			**Medians**		
	2002-2004	**2006-2008**	**Difference**	**2002-2004**	**2006-2008**	**Difference**
Manufacturing (n = 1435 firms)						
GPM	.386	.387	0.001	.369	.367	-0.002
SGA	.373	.347	-0.026*	.266	.260	-0.006**
CAP	.231	.197	-0.034**	.197	.163	-0.034**
DAYS	106.231	101.951	-4.280**	86.106	84.525	-1.581
Wholesaling (n = 106 firms)						
GPM	.220	.221	0.001	.202	.197	-0.005
SGA	.172	.167	-0.005	.149	.147	-0.002
CAP	.159	.133	-0.026*	.125	.096	-0.029**
DAYS	65.916	60.864	-5.052	55.166	49.775	-5.391
Retailing (n = 206 firms)						
GPM	.311	.310	0.001	.308	.305	-0.003
SGA	.227	.234	0.007	.226	.235	0.009
CAP	.378	.370	-0.008	.357	.349	-0.008
DAYS	72.697	73.052	0.355	61.660	61.135	-0.525
*P < .05 **P < .01						

Significant changes for our tests variables surrounding Katrina are also concentrated in the manufacturing sector although there is evidence of a decrease in capital intensity for both manufacturing and wholesaling. Within manufacturing, SGA displays an improvement (i.e., a decrease in the expense level) which contrasts with the weakening shown for 9/11. This improvement, however, was, in part, a function of the decreased level of sales growth documented earlier for this standardized variable. Inventory policy shows a weak consistency with 9/11 as we observe a significant decrease in the mean levels but a less than significant decrease in the medians. Nevertheless, taken together with the results shown in Table 4a, we find no evidence that management took steps to increase inventory levels in the presence of either disruptive event.

3.3. Model Development

Our empirical model is designed to test for the impact of inventory policy on organization performance and also to investigate whether this relationship is stable surrounding the events of 2001 and 2005. The model takes the following form where the primary explanatory variable of interest is our measure of inventory velocity, DAYS.

$$\begin{aligned} ROA_{i,t} &= a + b_1 PDUM_t + b_2 GPM_{i,t} + b_3 SGA_{i,t} + b_4 CAP_{i,t} + b_5 DAYS_{i,t} \\ &\quad + b_6(PDUM_t * DAYS_{i,t}) + e_{i,t} \end{aligned}$$

$$\begin{aligned} &where \\ &ROA_{i,t} = \text{return on assets for firm } i \text{ during year } t \\ &PDUM_t = \text{period dummy defined as 1 if year is subsequent to 2001} \\ &\qquad \text{or 2005, and 0 else} \\ &GPM_{i,t} = \text{gross profit margin for firm } i \text{ during year } t \\ &CAP_{i,t} = \text{capital intensity for firm } i \text{ during year } t \\ &DAYS_{i,t} = \text{days of inventory for firm } i \text{ during year } t \\ &e_{i,t} = \text{the stochastic error term} \end{aligned} \tag{1}$$

Given the observed changes within the dependent variable ROA documented in Tables 2a and 2b, our analysis employs a period dummy, PDUM. This variable is designed to indicate potential change in either the regression intercept or the slope parameter of DAYS between the respective pre- and post-event periods. In particular, the regression coefficient b_1 measures the change in the intercept term while b_6 performs a similar function for the slope coefficient on DAYS. To aid the reader, we include the following case illustrations on this method:

Case 1: In the pre-2001 period and the pre-2005 period, when PDUM = 0, our model reduces to:

$$ROA_{i,t} = a + b_2 GPM_{i,t} + b_3 SGA_{i,t} + b_4 CAP_{i,t} + b_5 DAYS_{i,t} + e_{i,t} \tag{2}$$

Case 2: In the post-2001 period and the post-2005 period when PDUM = 1, the model becomes

$$ROA_{i,t} = a + b_1(1) + b_2 GPM_{i,t} + b_3 SGA_{i,t} + b_4 CAP_{i,t} + b_5 DAYS_{i,t} + b_6(1 * DAYS_{i,t}) + e_{i,t}\,. \tag{3}$$

This model may be rewritten as

$$ROA_{i,t} = (a + b_1) + b_2 GPM_{i,t} + b_3 SGA_{i,t} + b_4 CAP_{i,t} + (b_5 + b_6) DAYS_{i,t} + e_{i,t}\,. \tag{4}$$

Hence, significance tests on b_1 and b_6 from our model in (1) may be directly used to test for changes between periods in the intercept and slope coefficients, respectively.

IV. RESULTS

4.1. Interpretation of Independent Control Variables

The regression analyses of ROA for manufacturing, wholesaling, and retailing are shown in Tables 5a and 5b. GPM, SGA, and CAP are highly significant for all three sectors. As expected given the nature of the income statement, GPM has a positive coefficient in the regression model indicating that higher margins are positively associated with higher ROA. Similarly, SGA has a negative coefficient showing that failure to control these expenses can significantly lower firm profitability.

The expected affect of our last control variable, CAP, on ROA may best be understood by borrowing a commonly-used technique from financial management. A slight variation of the traditional form of The DuPont decomposition of ROA (see Brealey, et al., 2008, p. 799) algebraically defines our profitability measure as the product of profit margin on sales (EBITDA/sales) and total asset turnover (sales/assets). Since our proxy variable for capital intensity is inversely related to total asset turnover, the anticipated direct relationship between ROA and CAP is negative. Our regression estimates are generally consistent with this anticipation for wholesaling and retailing. Contrary to this anticipation, however, results for the manufacturing sector display a strong positive relationship. We suspect this finding within the manufacturing sector may be the result of interaction effect between capital intensity and the marginal cost of production which is not fully captured by our definition of gross profit margin and model specification. We are aware of no reason, however, that such empirical complications would bias any estimates on our primary test variables related to inventory.

TABLE 5a – 9/11. REGRESSION ANALYSIS OF RETURN ON ASSETS (ROA) ESTIMATED OVER 1998 TO 2004 EXCLUDING 2001
(T Value in parentheses beneath each parameter estimate)

	Manufacturing (n = 1490 firms)	**Wholesaling** (n = 127 firms)	**Retailing** (n = 248 firms)
INTERCEPT	0.076 (15.19) **	0.066 (13.18) **	0.105 (23.98) **
PDUM	-0.036 (-6.72) **	-0.011 (-1.74)	-0.007 (-1.82)
GPM	0.390 (45.15) **	1.541 (46.23) **	1.470 (59.92) **
SGA	-0.280 (-71.00) **	-1.608 (-45.54) **	-1.507 (-57.68) **
CAP	0.056 (11.45) **	-0.169 (-14.56) **	-0.193 (-24.55) **
DAYS	-0.409×10^{-3} (-13.10) **	-0.168×10^{-3} (-2.76) **	-0.196×10^{-3} (-6.36) **
DAYS * PDUM	0.101×10^{-3} (2.38) **	$0.030\ 10^{-3}$ (0.37)	0.005×10^{-3} (0.14)
Adjusted R^2	.461	.749	.716
F	1276.73 **	379.42 **	624.17 **
*P < .05, **P < .01			

TABLE 5b – KATRINA. REGRESSION ANALYSIS OF RETURN ON ASSETS (ROA) ESTIMATED OVER 2002 TO 2008 EXCLUDING 2005
(T Value in parentheses beneath each parameter estimate)

	Manufacturing (n = 1435 firms)	**Wholesaling** (n = 106 firms)	**Retailing** (n = 206 firms)
INTERCEPT	0.014 (2.32) *	0.059 (6.24)**	0.050 (7.38)**
PDUM	0.011 (1.97)*	0.010 (0.88)	-0.002 (-0.32)
GPM	0.287 (31.95) **	1.484 (25.84)**	1.374 (48.47)**
SGA	-0.170 (-56.13) **	-1.598 (-26.71)**	-1.385 (-45.33)**
CAP	0.174 (15.02) **	-0.081 (-3.06)**	0.012 (-1.35)
DAYS	-0.265×10^{-3} (-8.28) **	-0.165×10^{-3} (-1.74)	-0.030×10^{-3} (-0.66)
DAYS * PDUM	-0.032×10^{-3} (-0.73)	0.043×10^{-3} (0.31)	0.072×10^{-3} (-1.34)
Adjusted R^2	.377	.555	.685
F	870.18 **	133.13**	448.85**
*P < .05, **P < .01			

4.2. Inventory

As shown in Tables 4a and 4b, manufacturers experienced a significant decline in the mean levels of DAYS from 107.82 to 101.46, which corresponds to a 5.9% decrease post-2001, and from 106.23 to 101.95, which represents a 4.1% decrease post-Katrina. Wholesalers and retailers also experienced a decline in inventory following both events, although the change was not statistically significant. The results of the regression analysis, (Tables 5a and b) show DAYS to be highly significant, with a negative coefficient for all sectors. In the presence of a positive gross profit margin, the faster inventory moves, the stronger the ROA as a higher yearly sales volume can be supported; while slower inventory movement serves as a drag on ROA. Even when controlling for other variables that affect ROA, inventory policy plays a critical role in the profitability of organizations.

Finally, when examining the artificial slope variable, an interesting picture emerges about changes in inventory's affect on ROA within the manufacturing sector following the 9/11 event. Here we observe a significant change in the sensitivity of profitability to inventory between the pre- and post-2001 periods. As shown in Table 5a, the coefficient on the dummy slope variable, DAYS*PDUM, is both significant and positive. The interpretation of this finding, in conjunction with the larger and negative estimate on DAYS, implies that inventory policy has a diminished negative effect on profitability after the event. To illustrate the practical implication of this finding, consider a specific example holding constant the control variable levels for ease of presentation. A decrease in inventory of 10 days in the pre-2001 period would correspond to an increase in the absolute level of ROA of about 4%. Subsequent to 2001, however, this same efficiency gain would only lead to an increase in profitability of roughly three-quarters of the prior estimate, 3%. Hence, our results show that while days inventory continues to have a significant effect on ROA in the post-2001 period, the potential positive impact from a decrease (higher turnover), or the negative impact from an increase (lower turnover), are both diminished. Neither the wholesaling nor the retailing sector displays significant shifts in either direction around 9/11, nor do we observe any such nonstationarities surrounding Hurricane Katrina.

4.3. Cautionary Notes for Data Interpretation

Several caveats are necessary regarding the interpretation of our results. First, as shown in Tables 3a and 3b, there is a high degree of correlation between the independent variables. In the presence of multicollinearity, estimated ordinary least square regression coefficients will be unbiased although the measured standard errors will be inflated. This condition leads to downward bias in the estimated t statistics and, consequently, the ability to reject the null hypotheses that the slope coefficients are equal to zero. Nevertheless, in most cases, our results display very large t statistics such that the practical impact of this cautionary note is minimal.

Second, for ease of presentation, the model controls only for changes in slope on the inventory variable between periods. Unreported results are similar when we employ an expanded model that allows for shifts in the remaining independent variables. Finally, Tables 5a and b show the R^2 for manufacturing to be considerably lower than for wholesaling and retailing. This indicates the presence of other explanatory variables not incorporated into our model. Such variables may include market size and concentration, product differentiation, import/export intensity and foreign competition, and barriers to entry (Bhattacharya and Bloch, 1997; Jones, et al., 1973, 1977; Martani and Mulyono, 2009). Whether or not the inclusion of these other factors would influence the relationships reported here between inventory levels and profitability in the presence of catastrophic events is a contribution left for future research.

V. DISCUSSION AND IMPLICATIONS

Our regression model accounts for variables that might confound the study of the influence of inventory on ROA by controlling for GPM, SGA, and CAP. As shown in Table 2a, all three sectors studied showed a significant decline in profitability and growth measures in the second period. The same is true for the retailing sector post-2005. Thus, controlling for GPM, SGA, and CAP can help isolate the affect of inventory on firm profitability.

Our regression findings in Tables 5a and b generally support previous research and show that inventory levels are negatively related to firm profitability. However, they do not support micro-level studies showing managerial willingness to use inventory to buffer unexpected and catastrophic events (for example, Baker, 2007). We find no evidence that inventory levels, relative to cost of goods sold, increased after 2001 or 2005. To the contrary, in the manufacturing sector, we observed an intertemporal decrease in inventory levels (see Tables 4a and 4b) across both events.

Our model addresses the issue of developing resiliency by testing if the impact of inventory on ROA experienced a shift from the first to the second period. We find no evidence of such a change for either retailing or wholesaling. Consequently, our data does not support the notion that these industry sectors buffered against supply chain disruption through changes in days inventory. However, our findings for the manufacturing sector do show a shift in inventory's affect on ROA after the 9/11 event and, subsequently, raise some interesting questions.

Our finding of a diminished sensitivity of ROA to changes in inventory within manufacturing raises the question of causation. One explanation may be that manufacturers are encountering a point of diminishing returns, or even a point where the costs of continuing to speed the flow of inventory are no longer outweighed by the benefits. Alternatively, rather than using inventory, manufacturers may be implementing other strategies designed to develop resiliency and cope with potential disruption. These strategies may include non-inventory related mitigation tactics, development of flexibility and contingency plans, and other unidentified techniques designed to share the risk of disruption throughout the supply chain. The question then becomes whether the short-term and long-terms costs of developing resilience through activities unrelated to inventory are greater than those of using inventory. Finally, we must ask if the tactics and strategies that may have been implemented improved supply chain management, in general, to the point where improvements in ROA from these strategies and tactics were also realized.

VI. CONCLUSIONS

A critical factor in explaining organization profitability for manufacturers, wholesalers and retailers is the speed with which inventory moves through a supply chain. While awareness of the possibility and effects of catastrophic supply chain disruption increased following the events of September 11, 2001, and again after Hurricane Katrina, that awareness has not resulted in a shift away from efforts to increase the speed of inventory movement throughout the supply chain as a means of developing resiliency. Our findings suggest that the motivations to protect the supply chain from catastrophic disruption by holding higher levels of inventory are perceived to be outweighed by the costs of holding inventory and the benefits of keeping inventory moving throughout the supply chain. Although the existing literature has questioned the wisdom of this response (for example, see Lee, 2004), the drive to move inventory at high speed and low cost, is deeply ingrained in the management of supply chains. Such inertia may explain why we saw a significant shift in inventory policy only for manufacturing following the 9/11 event.

In conclusion, we find that the influence of catastrophic events on the interaction between inventory levels and profitability is more pronounced for the manufacturing sector than it is for either wholesaling or retailing. Within this sector, our findings demonstrate that inventory levels drop and that the influence of inventory on profitability diminishes for at least one of the two events under consideration. Also noteworthy is that the explanatory power of our empirical model is relatively incomplete for manufacturing as compared to the other sectors analyzed. Jointly, we believe these findings motivate the belief that other mechanisms for resilient supply chain management are beginning to be deployed within manufacturing. To speculate, it appears that managers may have developed methods of trying to secure inventory availability and supply chain resiliency without holding higher inventory levels. An interesting question left for future research is the specific identification and analysis of these methods and whether or not their implementation may have resulted in organizational and supply chain improvements.

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Decision Support Model for Inventory Management Using AHP Approach: A Case Study on a Malaysian Semiconductor Firm

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This paper aims to provide an insight to managers on the availability of simple-to-use Analytic Hierarchy Process (AHP) as a practical tool for inventory management. It provides an example of the useful application of AHP in determining inventory policy for spare parts. It also presents the use of AHP as an analytic planning tool which managers could use to evaluate the feasibility of a desired outcome.

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I. INTRODUCTION

The importance of inventory management and the need for the coordination of inventory decisions and management policies has long been evident. Unfortunately, managing inventory in a complex supply chain is typically difficult and may have a significant impact on the customer service level and supply chain system wide cost. Managers often have to address two important questions in inventory management, which are, "How should inventory be managed in order to minimize stock out problem and hold down inventory costs?" and "When should order be placed for inventory?". Previous works were generally concentrated on the building of mathematical models to optimize inventory costs and service levels; this often includes the quantitative modeling of various parameters used in inventory policy such as the economic order quantity, reorder point and safety stocks. Unfortunately, most of these methodologies are too complex, abstract or oversimplified, thus managers face difficulties in understanding and applying them in their work. In addition, these models only consider the quantitative factors (e.g., EOQ, reorder point, stockout level) and do not take into account the qualitative or intangible elements (such as obsolescence, type and quality of suppliers) in the decision making process of inventory management.

At such, this study aims to introduce to the practitioners in inventory management the analytic hierarchy process (AHP), a technique for integrating qualitative and quantitative criteria in decision making. There have been relatively few applications of AHP in production and operations management. Thus, this study will provide an insight to production managers on the availability of simple-to-use AHP as a practical tool for inventory management. This paper will look into how to use AHP in inventory profiling, the results of which is important for managers to decide which inventory management policy to adopt for their inventory parts.

The paper is organized as follows. The first part of the paper gives a brief literature review on the approaches in earlier spare part logistics research. This is followed by a discussion of the use of AHP in decision making aspects of the inventory policy and the special characteristics of the spare parts with respect to their requirements for inventory management design and control. The model is designed in Section 3 using Expert Choice 2000, and the data is obtained from a semiconductor manufacturing firm. Section 4 discussed the results and implications on managerial decision making based on the designed model. Next, in the second part of the paper, the analytical strategic planning approach is addressed in developing the desired inventory management policy, based on a specific spare part. The forward-backward planning model is used and the results are discussed. Finally, the paper concludes with important implications and suggestions to managers in decision making for inventory management policy.

II. LITERATURE REVIEW

This section discussed on the past literature on AHP (Analytic Hierarchy Process) and the past models of spare parts inventory management.

2.1 Analytic Hierarchy Process

AHP is a simple decision-making tool to deal with complex, unstructured and multi-attribute problems. Most of the early works of AHP has been developed primarily by Saaty (1980). AHP has been applied in numerous fields such as conflict resolution (Vargas and Roura-Agusti, 1989; Bahmani and Blumberg, 1987), project selection (Emshof and Saaty, 1982; Wind and Saaty, 1987), budget allocation (Arbel, 1983; Sinuany-Stern, 1984), transportation (Saaty, 1977; 1981), health care (Odynocki, 1979; Saaty, 1981) and manufacturing (Tone and Yanagisawa, 1989). The strength of AHP is its applicability to the measurement of intangible criteria along with tangible ones through relative importance of different influencing factors and to structure a complex multi-attribute system. AHP consists of four steps as listed below:

(1) Structuring the hierarchy of criteria and alternatives for each criterion.
(2) Assessing the decision-makers' evaluations by pairwise comparisons.
(3) Using the eigenvector method to yield priorities for criteria and for alternatives by criteria.
(4) Synthesizing the priorities of the alternatives by criteria into composite measures to arrive at a set of ratings for the alternatives.

The top level of hierarchy is known as the overall focus or goal. The elements that affect the decision are called attributes or criteria and are included in the subsequent levels, each of which may have several elements. Attributes are mutually exclusive and their priority does not depend on the elements positioned below them in the hierarchy. The lowest level in the hierarchy is known as the alternative (decision options). Once complete the problem decomposition and hierarchy construction, pairwise comparison is carried out. The pairwise comparison feature is one of the major strength of AHP, whereby it derives accurate ratio scale priorities by comparing the relative importance, preference or likelihood of two elements with respect to another element (the goal) in the level above as opposed to traditional approaches of assigning weights which can be difficult to justify. The quantification level of comparison can be carried out using verbal method such as naming the quantification levels from equally important to absolutely more important in a nine-point scale or using preferential numbers (Saaty, 1980; 1982). After the comparison stage has completed, mathematical process will then commence to evaluate the priority weights for each matrix. The consistency ratio (CR) is being determined, whereby if the value is larger than 0.10, which is the acceptable upper limit for CR (Saaty, 1982); it implies that non consistency in decision making has occurred and the comparison must be reviewed. Subsequent mathematical process will then integrate the assigned weights to develop an overall evaluation process. Partovi and Hopton (1994) had reported that the use of expert system has made the mathematical process in AHP simple and accurate to apply.

2.2 Past Research on Spare Parts Inventory Management

Spare parts inventory plays a crucial role in the manufacturing organizations. Any discrepancies or insufficiencies of spare parts can cause stoppages in production line, interruptions in the flow of WIPs (works in progress), bottlenecks in production stages and finally late deliveries to customers. All these bring losses to the organization; the losses which caused by mismanagement of spare parts inventory. It is therefore important to have a systematic and scientific approach towards spare parts inventory management, which can help to minimize the overall costs of management.

In the past literatures, many analytical models of different spare parts inventory control systems have been discussed. However, most of the works were mostly concentrated on using mathematical models to optimize the safety stock level and service levels, without taking much considerations of administrative efficiency on the overall inventory management system. In addition, item classification has obtained much attention from researchers throughout the past works. There has been evident development in the area of inventory categorization/profiling. Simple and straightforward procedure such as ABC (Pareto 80/20 rule) and VED (Vital, Essential, Desirable) analysis have always been the common tools used in inventory profiling. In the 19^{th} and 20^{th} century, there was a trend showing that researchers started to consider intangible factors, apart from the tangible factors derived from mathematical formulation in inventory management decision making. Most of them used AHP for the assessment of the qualitative factors. The author has taken the initiative to compile quite a comprehensive list of previous works that had been carried out on spare parts inventory management. Please refer to Table 1 as listed below.

Table 1: Critical review on past literature on spare parts inventory management

Author	Year	Content	Remark
Nahmias	1981	Managing inventory systems for repairable / spare part items and mathematical models for relevant policies. Policies described are: (S-1,S), METRIC-based, with and without indenture levels, continuous review model, periodic review model, queuing models.	Kennedy -2002
Gajpal	1994	First to apply AHP with VED for spare parts inventory management especially for criticality analysis of spare parts.	AHP + VED AHP apply composite weightage on VED (Vital, Essential, Desirable)
Morris Cohen, Ricardo	1988	Use statistical clustering procedures and operational constraints to generate operations-related groups (ORG) for spare parts inventory. Using ORG, (Q,R) inventory control parameters is specified, where R is the re-order point based on a group	1. ABC method is surpassed by unconstrained ORG in terms of both operational and statistical performance. 2. Inclusion of operational performance constraints in the ORG procedure can

		safety factor and Q is the quantity ordered. This model is used to obtain min. inventory control cost.	take explicit account of managerial priorities such as inventory service, costs and functional similarity and provide statistical performance superior to ABC.
Duchessi	1988	Use 2-dimensional classification scheme combining inventory cost and part criticality as criteria in spare inventory management.	
Flores and Whybark	1989	Use multiple criteria ABC classification in maintenance/spare part inventory control.	
Flores et al.,	1993	Introduce a general grouping method to define group-based operational control policies for spare parts inventory.	
Petrovic	1992	Design an expert system model for advising on spare part inventory control. The heuristic decision rules used in the model were based on several operational characteristics of spare parts i.e. essentiality, price, weight , volume, efficiency of repair etc.	
Aidel Teixeira	2001	Multicriteria decision making as classification approach to maintenance, spare parts provisioning and repair contract selection. – using multicriteria utility function. Sensitivity analysis shows that the results are rather robust within reasonably wide variation of relevant parameters	Use multiattribute utility theory (MAUT). Classic publication by Keeney and Raiffa (1976). Recent classification of this model: Almedia and Souza (1993) and Almeida and Bohoris (1995).
Janne Huiskonen	2001	Discuss 4 basic principles of spare parts that affect the strategic choice of logistics systems and related policies. (Four control characteristics are: criticality, specificity, demand pattern and value of parts). The logistics system elements are – network structure, classification of materials, responsibility of control and control principles.	Emphasize the need to include the aspects of the whole supply chain in the analysis and to increase the collaboration between the parties at planning stages.

Kennedy	2002	Brief literature overview on maintenance/spare part inventories. Stress the importance of analyzing the impact of internet advancement on the inventory management system.	
Marcello	2004	Develop the Multi attribute spare tree analysis (MASTA) for spare part inventory management. 1.1st step: Recognizes 4 parts classes of criticality (Decision at each node is executed using AHP). 2. 2nd step: Cross matrix with different possible spare part inventory management policy strategies (IMP matrix). The model gives a general validity; modifications are possible for different industrial context without altering the basic "philosophy" of the approach proposed.	1. A new multi-attribute technique to define the "best" strategies of spare inventories classification is presented. Methodology is based on 2 instruments: a) Decision Diagram for best criticality (similar to RCM-Reliability Centered Maintenance). To help the analyst during the choice in each node, AHP models are proposed. *AHP is a valid alternative approach to solve problems of decision making step in RCM procedure. (First to propose AHP+RCM).*

One important point that the author would like to highlight is, though there have been numerous works developed in the past on the application of multi attribute method for inventory management, research studies that bridge the higher levels of strategic planning of inventory management policy are still lacking. Questions such as, what inventory policy should the management take once the inventory has been categorized, is the inventory policy good enough, is the recommended decision feasible and cost effective, how well is current inventory management practice coping in current adhoc business environment had not been well addressed. This paper suggests the needs to address all these issues in order to examine spare parts inventory management from the supply chain perspective. The process of assigning groupings to spare parts inventory cannot be done in isolation which is merely looking at intra-organizational issues. Rather, it has to consider the boundary-spanning role of logistics aspect of spare parts inventory management which plays an important role in supply chain.

2.3 Significance of this research

This paper applies AHP to creating an inventory management policy model. Though MarcelloBraglia (2004) has demonstrated the adoption of AHP models in the quantification modes in RCM conventional approach, the author clearly suggest that in order to obtain an effective and useful decision support system (DSS), the framework of the method has to be developed following suggestions obtained from interviews/suggestion of maintenance staff and production managers of the firm. This research is unique in its way that, firstly, it paves the connections of the selected decisions to higher level of strategic planning and secondly, it provides a better communication, leading to clearer understanding and consensus among the members of decision-making groups.

III. METHODOLOGY

This paper suggests the use of AHP in the decision making of inventory management policy with the objective towards 'improvement' and 'value creation' for the organization. This research addressed the decision making from the safety stock perspective. AHP is used in assessing the qualitative factors in determining the safety stock level, as well as to bridge the gap for quantitative modeling (i.e., using mathematical formulation, optimization, linear programming, dynamic programming, heuristic method in assessing safety stock) from previous research to a higher level of strategic planning.

3.1 The AHP Model

In order to determine the optimal spare part inventory management system for the operating environments, a four level hierarchical model is devised. (Refer to Figure 1 below). The first level, focus, sets the main objective, here referred to as the optimal inventory management system. The focus is divided into four main attributes or characteristics, which are value of parts (cost), specificity, criticality and demand pattern. The third level of hierarchy includes sub-attributes for the four above-mentioned objectives as follows:

- Value of parts: High, Low
- Specificity: Standard parts, User specific parts
- Criticality: Low, High
- Demand: Predictable, Volatile

The fourth or the last level consists of four alternatives: no stock (outsource control to supplier), time guaranteed supply with cooperative stock pooling, decentralized safety stock policy and optimal safety stock policy with supplier partnership.

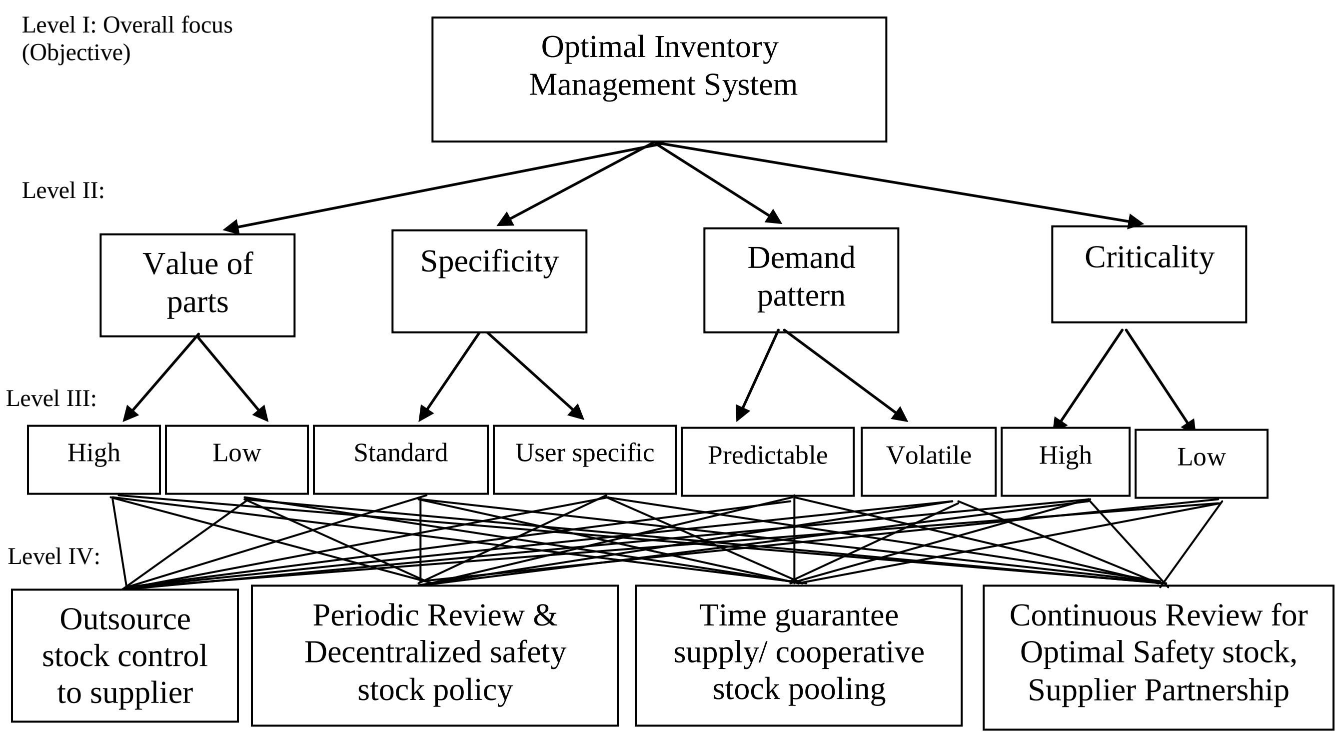

Figure 1: AHP model for inventory management

The four main control characteristics of spare parts are analyzed as follows:

a) *Criticality:* This element comprised of two dimensions, namely process and control. Process criticality refers to the consequences caused by the failure of a part on the process in case a replacement is not readily available. On the other handcontrol criticality relates to the importance of a part in controlling a particular situation such as availability of the part at suppliers and lead time. In this research, criticality is categorized into two levels, which are high criticality and low criticality. High criticality refers to the high urgency need of a part. In contrast, low criticality allows some lead time for the part or refers to the part having no specific time restrictions. Most companies tend to keep stock for high critical parts and avoid holding stock for low critical parts.
b) *Specificity*: The degree of the characteristics of the parts related to the needs of the user is classified as specificity. Generally, there are two types of spare parts; one which is widely used by many users and hence also readily available from several suppliers and another one which is specifically tailored for and used by a particular user only. In this research, specificity is categorized into two levels namely the 'user-specific' and the 'standard part'. For 'User-specific' parts, the suppliers are most probably unwilling to stock the special low volume parts and the responsibility of availability and control remains with the user himself. For 'standard' parts, there will be better availability of stock as the suppliers are ready to hold accountability of them. 'User specific' parts are generally 'made-to-order' and have longer lead-times compared to standard parts.
c) *Demand pattern*: The demand pattern of the parts includes the aspect of volume and predictability which is a control characteristic related to the economies of scale of operations. Predictability of demand related to the failure of a part has an effect on the provision policy. High volume normally attracts suppliers to keep stocks at their side, but not necessarily for low volumes parts. Hence, low volume parts with irregular demands pose the most critical situation for management, whereby they usually need to carry a high amount of safety stock to cover unpredictable situations.
d) *Value of parts*: One of the most common control characteristics of materials is the 'value' of the parts. High value makes stocking a non-attractive solution for any party in the logistics chain. However, if it is not a 'make-to-order' item, stocks have to be held and this complicated objective would have to be overcome through negotiation power and cooperation of the parties in the supply chain. On the other hand, for low-price items, the replenishment arrangements have to be efficient so that the administrative costs do not increase unreasonably in proportion to the value of the items themselves.

3.2 Data Collection

A Malaysian based semiconductor firm manufacturing automotive parts was selected to run this evaluation. The ranking results given to each alternative were obtained from the averages of the responses from 20 persons. In order to reduce bias of the data, the respondents were selected from various related departments such as supply chain, manufacturing, planning and finance. The interviewees range from specialist engineers (assistant managers) to managers level. The manufactured automotive parts generally comprised of six main materials, which can further be categorized into indirect and direct parts, namely the:

1) Direct materials – LEDs, Leadframes, Resistors, PCA
2) Indirect materials – trays, packaging boxes.

AHP model was constructed for the above six materials, each with pairwise comparison carried out and the priority vector is determined for each alternatives. Expert Choice 2000 software was used in the analysis to determine what type of inventory management policy is suitable for each part. The results are enlisted in Appendix A.

IV. RESULTS AND DISCUSSION

Results from AHP analysis showed that the optimal inventory management policy for each part is: LEDS - 'Optimized safety stock', Lead frame – 'Time guaranteed supply', Resistor and PCA – 'Decentralized safety stock', Tray – 'Optimal Safety Stock' and Packaging boxes – 'Time Guaranteed Supply'. The anticipated results are pretty logical and predictable as each policy is fairly associated with the control characteristics of the parts. For instances, LEDs which have high value and criticality, the ideal policy for every company is the optimized safety stock policy. Hence, the question now is, how do managers reduce cost for these parts, if they were to adopt optimal policies such as optimal safety and time guaranteed supply, which apparently will incur a high level of cost for strategy implementation. Hence, the next part that follows discussed each policy in detail addressing each pertaining issues and suggesting possible management strategy for cost reduction.

Firstly, for parts which have high specificity, which refers to the customized parts or user specific parts, the lead times were assumed to be lengthy. Prices are relatively high, volume low and sporadic. In this situation, suppliers are not willing to hold stocks. Hence, user will have to accept the stockout situation or rely on own safety stocking. The control situation here is to look at how lead-times could be reduced and make replenishment more dependable. Possible development strategy is to search for reliable supplier or form some kind of subcontracting partnership in the supply chain. By having a collaboration partnership with the suppliers, information can then be passed on more efficiently and ultimately, this will reduce the lead time of the replenishment.

In another situation where it involves standard parts, the business will be more attractive to suppliers and third-party companies. In most of the cases, there are several suppliers for one part which makes the availability of the supply better and lead-times shorter. Different logistics control situations will then depend on the criticality of the parts for the process. For high criticality standard parts, the user needs to hold a small local safety stock to guarantee availability. Some responsibility can also be pushed to suppliers as they are more willing to hold stock for standard parts. Services such as time-guaranteed delivery can considerably reduce the user's need for holding safety stock even if the criticality is high. This strategy can be implemented typically by using specialized spare part service company that is well established with procedures and reputation to guarantee the service needed. This strategy is especially tempting for high value parts with low and irregular demand pattern.

In case of extremely low volume parts, alternative strategy such as cooperative stocking pool can be created among the few relatively closely located users. With this arrangement, sporadic demands of individual users are consolidated into smoother one and holding of safety stock is more justified. To be operative, such a practice needs fast and reliable means for transmitting information. For this kind of virtually centralized, but physically decentralized inventory holding, internet-based applications provide viable solution. However, for low value parts, provisioning with own safety stocks may prove more desirable as they do not have to tie capital significantly.

In the case of low criticality parts, the user's need for holding local stocks for provisioning purposes is reduced. This reverts back to the economic efficiency of replenishment operations in the supply chain. One of the options is to push the entire user's stock backward in the chain to the supplier or service provider. This strategy is based on economies of scale achieved in consolidation of low volumes in the supply chain and postponing the replenishments of high value items until needed. As when the value of parts becomes lower, the need for simple replenishment practices is emphasized. Computerized automated replenishment system is one of the highly sourced options in this situation. Likewise, a supplier may also take the responsibility of controlling the whole process of replenishments (ie. VMI –vendor managed inventory practices).

4.1 Analytical Planning Approach

To further enhance the findings, the strategic adaptive planning approach is adopted to demonstrate how AHP can be used to plan for likely and desired futures. The forward-backward process is explored in this model. In the forward process, one considers the relevant present factors, influences and objectives that lead to sensible conclusions or scenarios. Adversely, the backward process begins with the desired scenarios then examines the policies and factors that might achieve those scenarios. Iteration of the two processes narrows or converges the gap between the desired and the logical scenarios. Hence, the forward planning process provides an assessment of the state of the likely outcome, while the backward planning process provides a means for controlling and steering the forward process towards a desired state. Forward-backward planning process can effectively generate a good plan and has outperformed each method alone stemming from the fact of classical planning theory itself which clearly stated that logical or reachable goal will remain substantially unchanged, but desired goal requires a great deal of change in inputs both internally and externally.

4.2 Forward-Backward Analysis

The mechanics of carrying out the forward-backward process of the inventory policy model is summarized as follows. The forward process hierarchy is established by identifying the overall purpose of the inventory management system. At such, the current model as illustrated in Figure 1 follows the forward process. The top level consists of the overall focus which is the objective of the model. The second level includes the various characteristics of the spare parts or factors affecting the outcome of the policy. The third level consists of the sub characteristics of the spare parts, and last level is the policies / scenarios. The fourth level consists of four exploratory scenarios which best described the range of alternative futures. One more level (the fifth level), which is known as the composite scenario will be some mixture of the four scenarios identified in the fourth level. With relative weights assigned to the four scenarios, a composite scenario can then be formulated. In this case, the composite scenario is represented by four state variables which are sales revenue, volume of goods shipped, cash flow and inventory turnover. State variables specify the structure and flow of the systems in that state, and may range over different aspects of an outcome. The intensity of variations is indicated by a difference scale which ranges from -8 to 8. (Saaty, 1985), as shown in Table 4.1 below.

Firstly, the state variables are placed in the priority order according to their importance to the company (See Table 4.2). The importance index thus achieved will be used later when assessing the degree of convergence between the likely future and the desired future – convergence achieved through the addition of policies identified in the *backward process* which will be discussed later. Next step is to obtain the composite scenario (See Tables 4.3 and 4.4). The composite scale measurement for a state variable is obtained by forming the sum of the products of scenario weights by the corresponding state variable measurement. The composite scale measurement (3.56) is not a "weight" or "priority ranking"; rather, it is used merely as a global measure or benchmark against the degree of convergence between the likely and desired futures produced by the addition of policies identified in the backward process.

Table 4.1: Scale for Different Comparisons

Difference in Values	Definition
0	No change in value
2 (-2)	Slight increase (decrease) in value
4 (-4)	Important increase (decrease) in value
6 (-6)	Remarkable increase (decrease) in value
8 (-8)	Maximum increase (decrease) in value
1,3,5,7	Intermediate values between the two
-1, -3, -5, -7	Intermediate values between the two adjacent judgments

Table 4.2: Average consistencies for different order random matrices.

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4.3: Pairwise comparison of state variables

State variables	Sales revenue	Volume shipped	Inventory turnover	Cash flow	Lambda	Vector weights
Sales revenue	1.00	0.33	4.00	6.00	4.18	0.290
Volume shipped	3.00	1.00	5.00	7.00	4.20	0.552
Inventory turnover	0.25	0.20	1.00	3.00	4.14	0.107
Cash flow	0.17	0.14	0.33	1.00	4.17	0.051
					Lambda max:	4.17
					C.I.	0.057
					C.R.	0.064

Table 4.4: Calibration of state variables with respect to scenarios (First Forward Process)

	Optimal safety stock	Decentralized safety stock	Time guaranteed supply	Outsource to supplier	First forward process
Sales	5	3	3	3	3.62
Volume shipped	5	3	4	4	4.07
Inventory turnover	5	3	3	3	3.62
Cash flow	-5	-3	-3	3	-2.34
Composite					3.56

4.3 Backward Planning Process: Desired Future of Inventory Policy for 'LED'

The backward process is critically important in AHP because it identifies policies which could produce convergence of the likely and desired futures of the company. In addition to identifying the best policies to pursue, the backward process enumerates various problems that could occur by implementing alternative policies. As shown in Figure 2, it has 5 levels: Level 1-The Focus of the Desired Future, Level 2-Desired Scenarios of that Future, Level 3-Problems and Opportunities Facing the Future, Level 4-Characteristics which control those problems and opportunities, and Level 5-Objective (or Policies) of the spare parts.

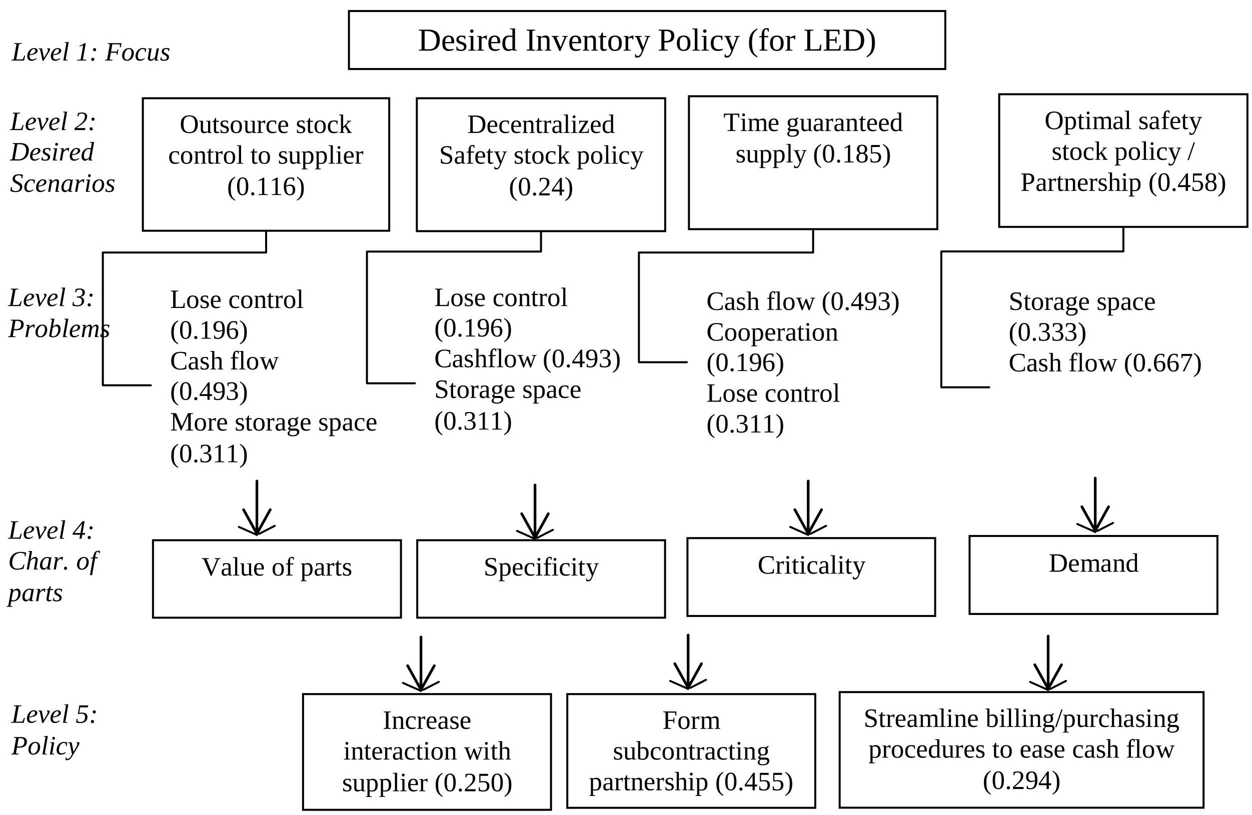

Figure 2: Backward Process Hierarchy

In the backward process, the planning executives in the company identified 'Optimal Safety Stock' as the desired scenario which is the same exploratory scenario they projected to be the most likely future in the first forward process. Hence, there will be a high probability that the policies identified in the backward process will produce some convergence of the likely and desired futures. The primary concern here is how much convergence will be produced with the addition of these policies. The detail backward model is analyzed using AHP listed in Appendix A.

4.4 Second Forward Process: Measuring Convergence

Two policies with the highest relative weights in the backward process were introduced into the second forward process to assess the amount of convergence they produce. A brief description of the two policies is provided below:

1. Form subcontracting partnership - this relationship will certainly improve the interactions and coordination of activities of the manufacturing line. Centralized management and information sharing will produce more accurate information about level of safety stock in the production line.
2. Streamlining of operations to ease cash flow – billing and purchasing operations will be streamlined to speed up the transaction time, hence shorten the cycle time for every transactions. Reduce transaction time will ease company cash flow.

The second forward hierarchy is developed and analyzed again using Expert Choice 2000. (Refer to Appendix A). The new level is added which includes the two high priority policies the weights of which have been determined with respect to the relative contribution to the objectives of the company. The composite scenario will then be assessed given the addition of the policies in the fourth level. The relevant question would be: "Given subcontracting partnership and streamlining of purchasing operations, what is the relative likelihood of each of the four scenarios?"

The true convergence cannot be assessed accurately until a new composite scenario is constructed. The composite scale measurements for the state variables are presented in Table 4.5. It is observed that all state variables will increase marginally. However, there will be a slight decrease in the cash flow given the increased likelihood of the partnership relationship. Thus, not all aspects of the composite scenario are favorable illustrating the trade-off that must be inevitably made in all planning problems.

Table 4.5: Calibration of state variables with respect to scenarios (Second Forward Process)

	Optimal safety stock	Decentralized safety stock	Time guaranteed supply	Outsource to supplier	Second forward process
Sales	5	3	3	3	3.86
Volume shipped	5	3	4	4	4.26
Inventory turnover	5	3	3	3	3.86
Cash flow	-5	-3	-3	3	-2.39
Composite					3.76

	First forward process	Second forward process
Sales	3.62	3.86
Volume shipped	4.07	4.26
Inventory turnover	3.62	3.86
Cash flow	-2.34	-2.39
Composite	3.56	3.76

The policies identified in the backward process improve the composite outcome in the second forward process. The composite score is improved by 5.62%. Generally, before pursuing a desired policy, one must determines whether their costs justify the marginal increase in global benefits. If the costs are not justified, the decision maker will have to proceed to a second backward process and reexamine their assumptions, formulating new judgments or adding new policies that would address the weaknesses of those identified in the first backward process. In the above model, it can be concluded that the costs of implementing the new policies were less than the global benefits they could be expected to produce.

V. CONCLUSION

The research shows the application of AHP in decision making of inventory management policy has several benefits as it formalizes and makes systematic subjective decision process to facilitate 'accurate' judgments and also provides management the implicit weight of the evaluated criteria. The model also serves better communication, leading to clearer understanding and consensus among the members of decision-making groups. In the second part of the paper, the analytical strategic planning is addressed and it is shown that planning can be actualized by successive iterations of the forward-backward process. Hence, the decision maker can decide on what is likely to happen, what he/she wants, what he/she must control or bring about and how effective this control is likely to be in directing the likely future towards the desired future. This approach provides logical dynamics to test for promising alternatives and must precede action. In summary, the integration of AHP into the inventory management decision making model has enabled validation and revision of inventory policy of a company for different types of inventory in a fast and easy way. It also provides insight to managers for collaborative manufacturing value chain according to the company's specific needs.

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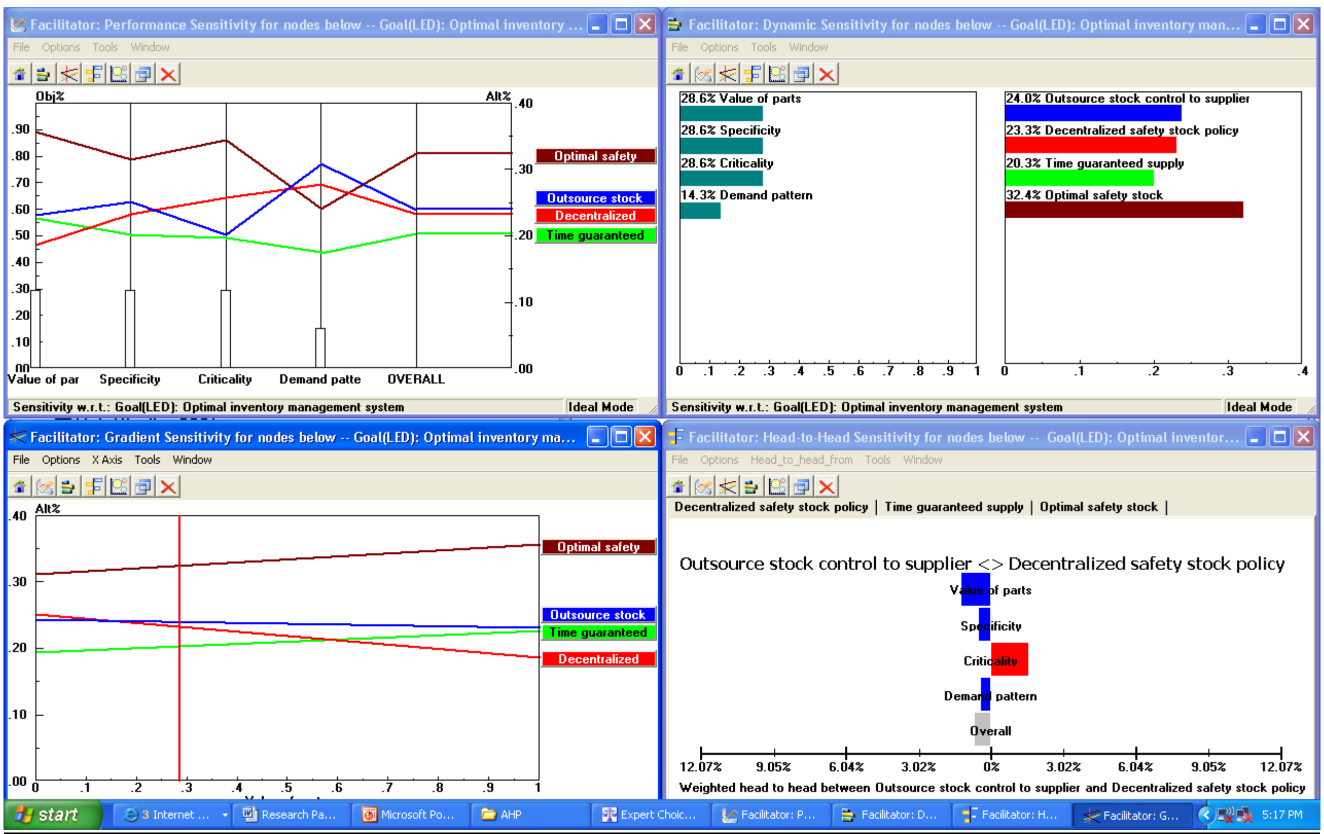
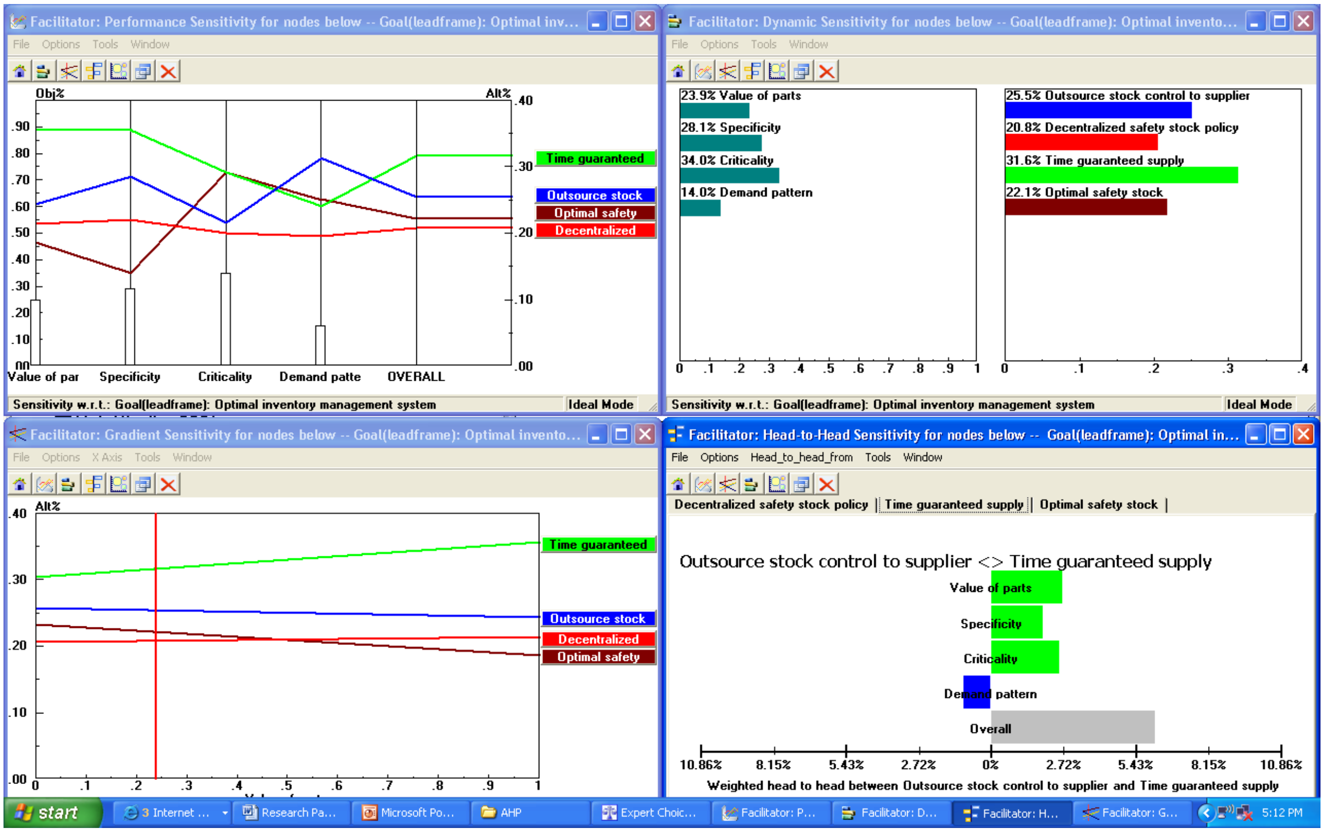
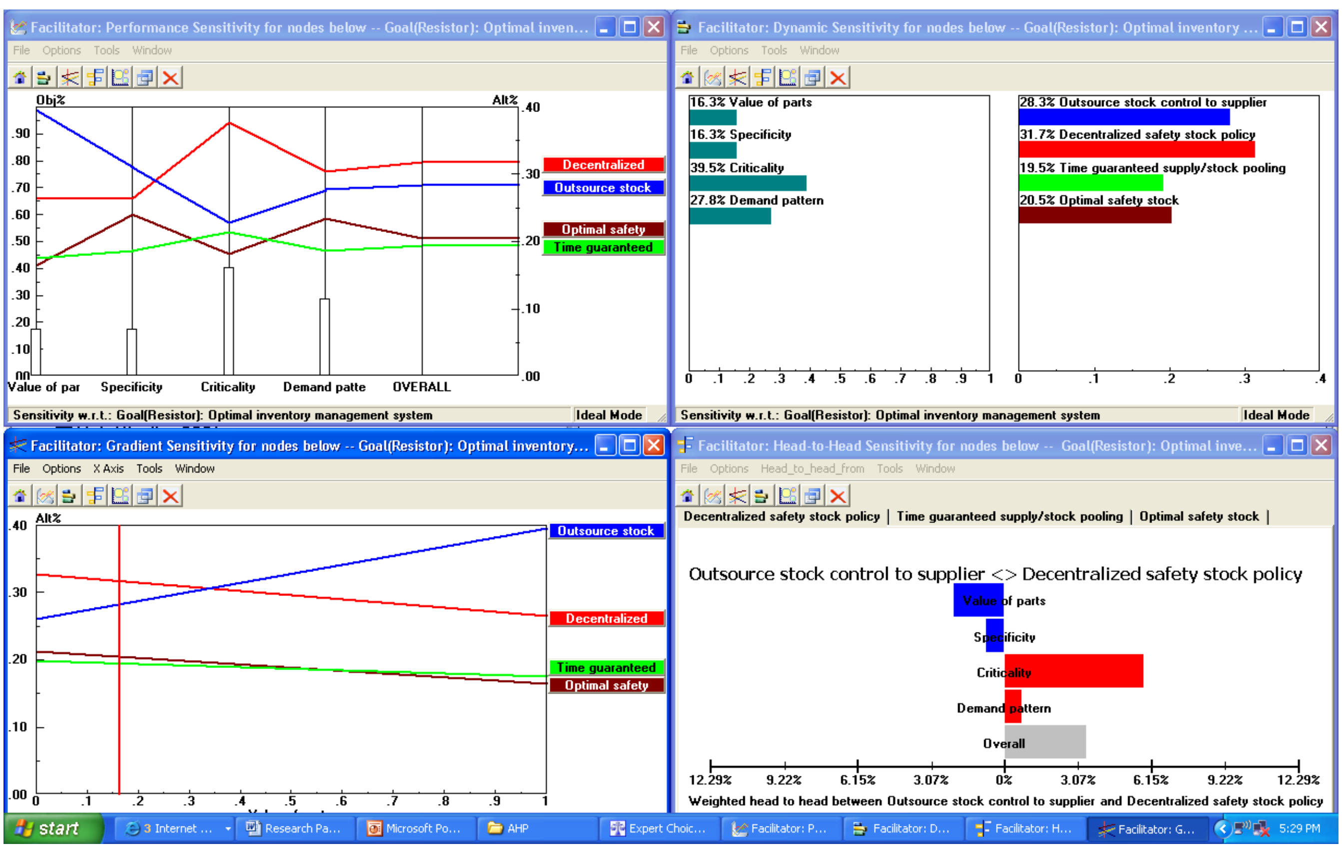
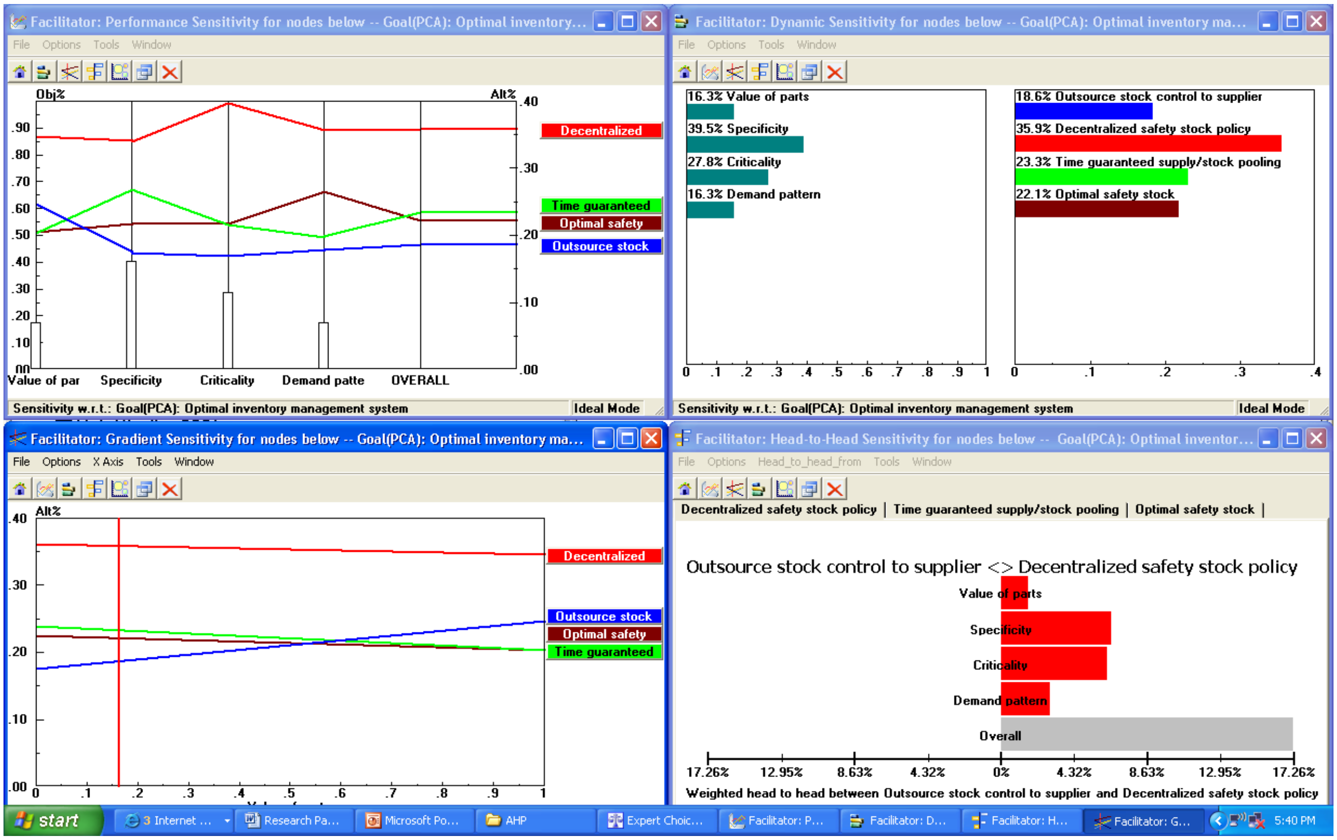
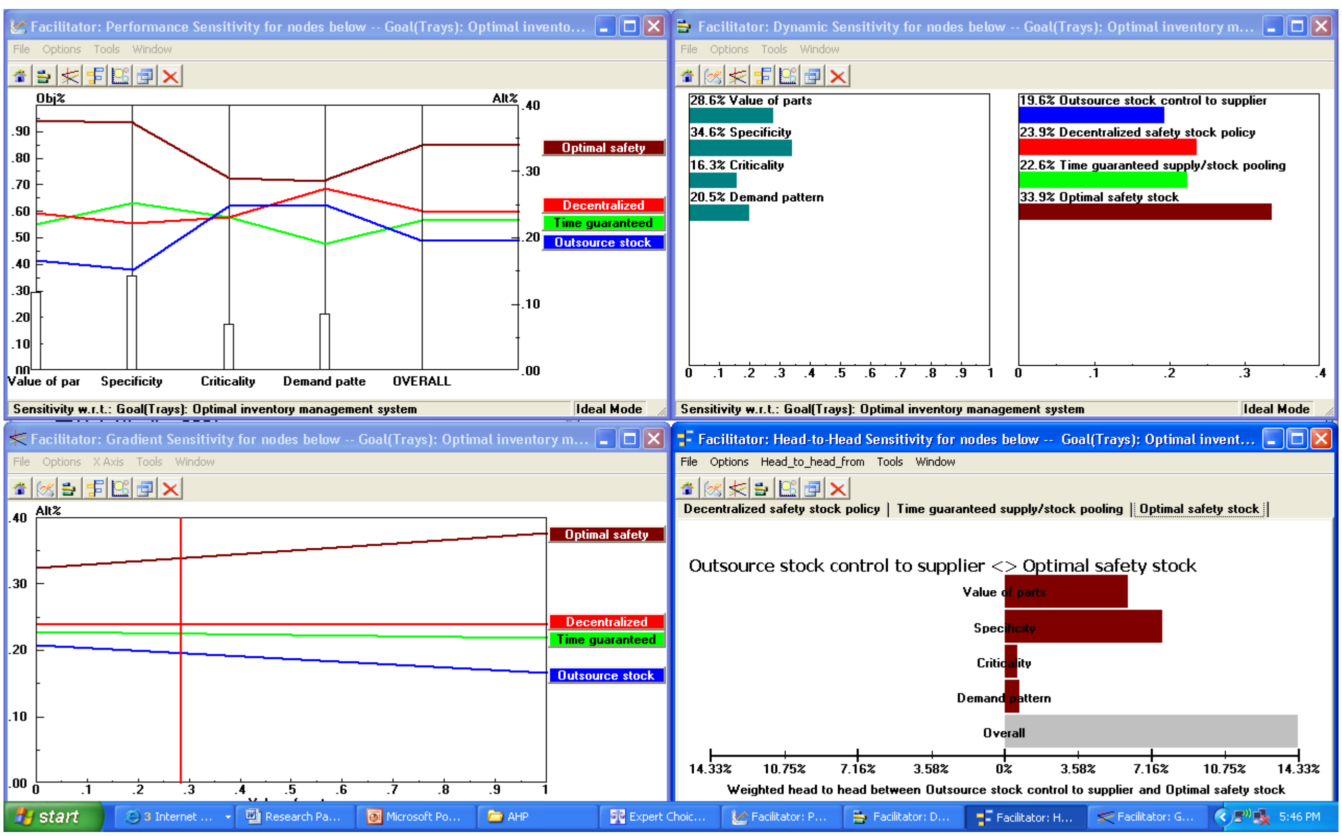
APPENDIX A: EXPERT CHOICE RESULTS

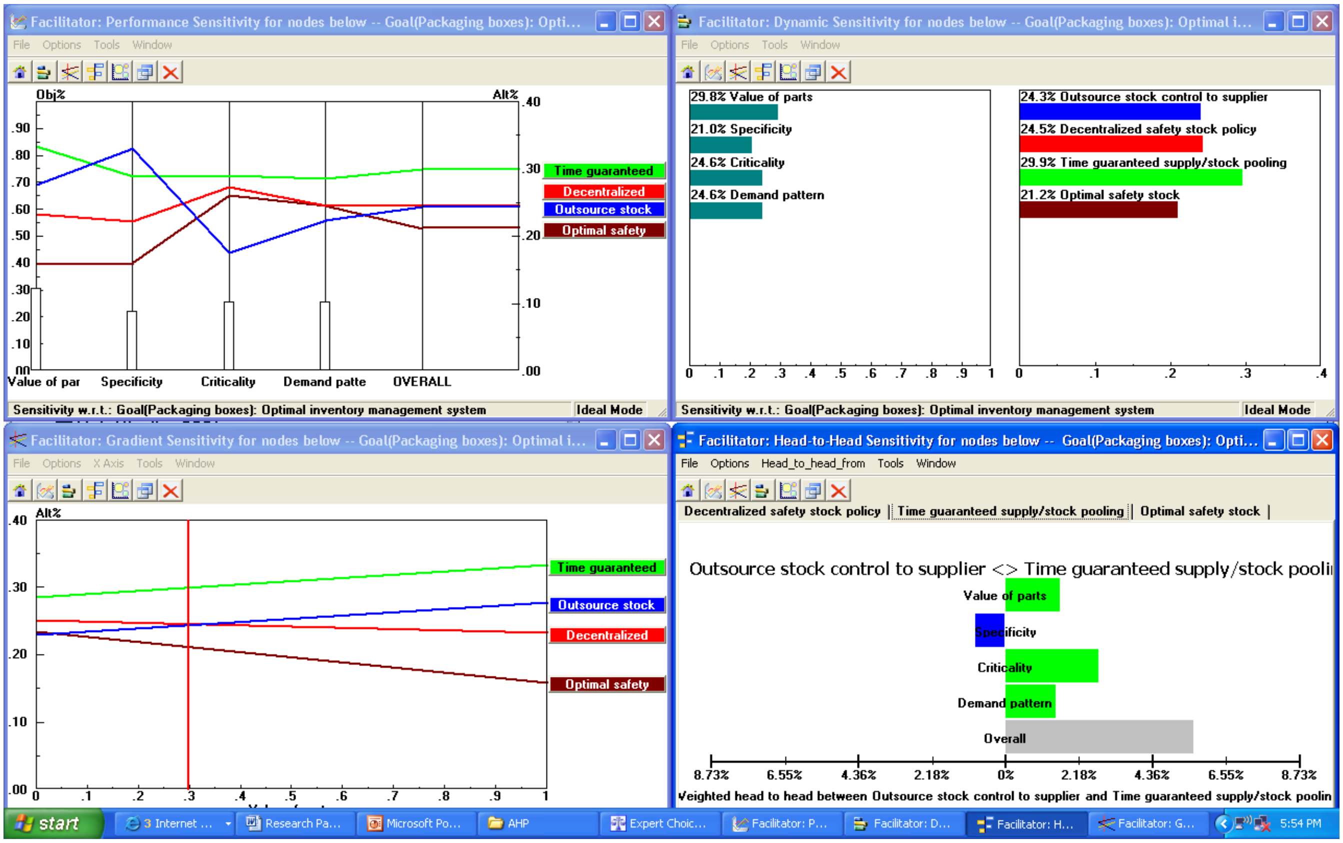



Facilitator: Performance Sensitivity for nodes below -- Goal(leadframe): Optimal inv...
Time guaranteed
Outsource stock
Optimal safety
Decentralized
Value of par
Specificity
Criticality
Demand patte
OVERALL
Sensitivity w.r.t.: Goal(leadframe): Optimal inventory management system
Ideal Mode
Facilitator: Dynamic Sensitivity for nodes below -- Goal(leadframe): Optimal invento...
23.9% Value of parts
28.1% Specificity
34.0% Criticality
14.0% Demand pattern
25.5% Outsource stock control to supplier
20.8% Decentralized safety stock policy
31.6% Time guaranteed supply
22.1% Optimal safety stock
Facilitator: Gradient Sensitivity for nodes below -- Goal(leadframe): Optimal invento...
Facilitator: Head-to-Head Sensitivity for nodes below -- Goal(leadframe): Optimal in...
Decentralized safety stock policy | Time guaranteed supply | Optimal safety stock |
Outsource stock control to supplier <> Time guaranteed supply
Value of parts
Specificity
Criticality
Demand pattern
Overall
Weighted head to head between Outsource stock control to supplier and Time guaranteed supply


Facilitator: Performance Sensitivity for nodes below -- Goal(Resistor): Optimal inven...
Decentralized
Outsource stock
Optimal safety
Time guaranteed
Value of par
Specificity
Criticality
Demand patte
OVERALL
Sensitivity w.r.t.: Goal(Resistor): Optimal inventory management system
Ideal Mode
Facilitator: Dynamic Sensitivity for nodes below -- Goal(Resistor): Optimal inventory ...
16.3% Value of parts
16.3% Specificity
39.5% Criticality
27.8% Demand pattern
28.3% Outsource stock control to supplier
31.7% Decentralized safety stock policy
19.5% Time guaranteed supply/stock pooling
20.5% Optimal safety stock
Facilitator: Gradient Sensitivity for nodes below -- Goal(Resistor): Optimal inventory...
Facilitator: Head-to-Head Sensitivity for nodes below -- Goal(Resistor): Optimal inve...
Decentralized safety stock policy | Time guaranteed supply/stock pooling | Optimal safety stock |
Outsource stock control to supplier <> Decentralized safety stock policy
Value of parts
Specificity
Criticality
Demand pattern
Overall
Weighted head to head between Outsource stock control to supplier and Decentralized safety stock policy


Facilitator: Performance Sensitivity for nodes below -- Goal(PCA): Optimal inventory...
Decentralized
Time guaranteed
Optimal safety
Outsource stock
Value of par
Specificity
Criticality
Demand patte
OVERALL
Sensitivity w.r.t.: Goal(PCA): Optimal inventory management system
Ideal Mode
Facilitator: Dynamic Sensitivity for nodes below -- Goal(PCA): Optimal inventory ma...
16.3% Value of parts
39.5% Specificity
27.8% Criticality
16.3% Demand pattern
18.6% Outsource stock control to supplier
35.9% Decentralized safety stock policy
23.3% Time guaranteed supply/stock pooling
22.1% Optimal safety stock
Facilitator: Gradient Sensitivity for nodes below -- Goal(PCA): Optimal inventory ma...
Decentralized
Outsource stock
Optimal safety
Time guaranteed
Facilitator: Head-to-Head Sensitivity for nodes below -- Goal(PCA): Optimal inventor...
Decentralized safety stock policy | Time guaranteed supply/stock pooling | Optimal safety stock |
Outsource stock control to supplier <> Decentralized safety stock policy
Value of parts
Specificity
Criticality
Demand pattern
Overall
17.26% 12.95% 8.63% 4.32% 0% 4.32% 8.63% 12.95% 17.26%
Weighted head to head between Outsource stock control to supplier and Decentralized safety stock policy


Facilitator: Performance Sensitivity for nodes below -- Goal(Trays): Optimal invento...
Optimal safety
Decentralized
Time guaranteed
Outsource stock
Value of par
Specificity
Criticality
Demand patte
OVERALL
Sensitivity w.r.t.: Goal(Trays): Optimal inventory management system
Ideal Mode
Facilitator: Dynamic Sensitivity for nodes below -- Goal(Trays): Optimal inventory m...
28.6% Value of parts
34.6% Specificity
16.3% Criticality
20.5% Demand pattern
19.6% Outsource stock control to supplier
23.9% Decentralized safety stock policy
22.6% Time guaranteed supply/stock pooling
33.9% Optimal safety stock
Facilitator: Gradient Sensitivity for nodes below -- Goal(Trays): Optimal inventory m...
Optimal safety
Decentralized
Time guaranteed
Outsource stock
Facilitator: Head-to-Head Sensitivity for nodes below -- Goal(Trays): Optimal invent...
Decentralized safety stock policy | Time guaranteed supply/stock pooling | Optimal safety stock |
Outsource stock control to supplier <> Optimal safety stock
Value of parts
Specificity
Criticality
Demand pattern
Overall
14.33% 10.75% 7.16% 3.58% 0% 3.58% 7.16% 10.75% 14.33%
Weighted head to head between Outsource stock control to supplier and Optimal safety stock


Facilitator: Performance Sensitivity for nodes below -- Goal(Packaging boxes): Opti...
Time guaranteed
Decentralized
Outsource stock
Optimal safety
Value of par
Specificity
Criticality
Demand patte
OVERALL
Sensitivity w.r.t.: Goal(Packaging boxes): Optimal inventory management system
Ideal Mode
Facilitator: Dynamic Sensitivity for nodes below -- Goal(Packaging boxes): Optimal i...
29.8% Value of parts
21.0% Specificity
24.6% Criticality
24.6% Demand pattern
24.3% Outsource stock control to supplier
24.5% Decentralized safety stock policy
29.9% Time guaranteed supply/stock pooling
21.2% Optimal safety stock
Facilitator: Gradient Sensitivity for nodes below -- Goal(Packaging boxes): Optimal i...
Time guaranteed
Outsource stock
Decentralized
Optimal safety
Facilitator: Head-to-Head Sensitivity for nodes below -- Goal(Packaging boxes): Opti...
Decentralized safety stock policy
Time guaranteed supply/stock pooling
Optimal safety stock
Outsource stock control to supplier <> Time guaranteed supply/stock pooli
Value of parts
Specificity
Criticality
Demand pattern
Overall
Weighted head to head between Outsource stock control to supplier and Time guaranteed supply/stock poolin

Service Quality and Customer Behavioral Intentions: A Study in the Hotel Industry

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The purpose of this paper is to examine the relationship among the constructs of service quality, customer satisfaction and behavior intentions in the hospitality industry. The study reviews a proposed model of service quality and its relationship with customer satisfaction and behavior intentions: service quality is positively related to satisfaction, and behavioral intentions. Similarly, customer satisfaction works as mediator between service quality and behavioral intentions of the customers. The model is tested empirically with the data from a survey among 243 Asian, European and American customers who stay in five star hotels in Nepal. The four hypotheses establish the fact that service quality and behavioral intentions of the customer in the hotel industry are positively associated. Service quality has no relationship with customer satisfaction. Customer satisfaction has direct relationship with behavior intentions of the customer, but customer satisfaction has worked as a mediator between customer service quality and behavior intentions of the customer in the hotel industry.

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I. INTRODUCTION

The causal relationship among service quality, customer satisfaction and behavioral intention is of increasingly academic and management interests (Ladhari, 2009; Lenka *et al*, 2009 & Ryu & Han, 2010). There is strong evidence in academic research that links service quality with behavioral intentions. wiithout controlling customer satisfaction. But in contrast, Ruy & Han (2010), Zeithmal *et al.* (1996) show customer satisfaction mediates between service quality and behavioral intention.

Quality management has become the prime issue in Nepalese business along with the growth of the service sectors since 1990s. The reason for growing awareness in service quality is directly related organization's short and long term financial goals, increased market share and sustainable competitive advantage (Gupta, McDanial & Herath, 2005,p.398). Terziovski (2006) also shows quality management practices have a significant and positive relationship with customer satisfaction (p:422).

Service quality permanently imprints and restores positive image on customers' perceived emotional experience of particular goods and services, and leads to behavioral intention. The expected result of application of service quality is to create emotional experience to satisfy customer by providing superior service quality and induce long lasting effects in their behavior, i.e. willingness to stay in the same hotel, recommendations by the customers' friends and acquaintances in the same hotel and readiness to pay high price (Ladhari, 2009). Superior service is required to make organization distinct from its competitors and gain a sustainable competitive advantage that enhances efficiency (Mei *et al*., 1999; Kandampully and Suhartanto, 2000).

There is still lack of sufficient research in the field of service quality, customer satisfaction and behavioral intentions. Most of the existing researches have mainly explored the link between productivity and satisfaction only, and have not yet tried to link behavior intentions with them. Therefore, this research is mainly focused to examine the direct relationship between the service quality and behavioral intentions, and also the role of customer satisfaction between service quality and behavior intention as a mediator.

The paper aims to develop and test a conceptual model of the relationships among these constructs. After a brief introduction, paper reviews theoretical and empirical review of the literature, and develops the hypothesized relationships among the proposed constructs. Descriptive and analytical design of the proposed model and its implications are presented.

II. LITERATURE REVIEW

2.1 Service quality and customer satisfaction

Service quality is the cognitive assessment in each service performance. However, satisfaction is the sum total of the customers' evaluation of the services. Ryu & Han (2010) show that service quality has a positive influence on customer satisfaction (p. 322). Service quality comprises both tangible and intangible cues. Services are mainly intangible and require the customer to be present during the process; the physical environment can have a significant impact on the perceptions of the overall quality of the service encounter, which in turn affect customer (Bitner 1990, 1992, Brady & Cronin, 2001; Kotler 1997; Parasuraman *et al.* ,1988. Perceived service quality is measured in the actual performance of quality received by the customers. The service of Gronros (1984) covers both functional and technical quality which measures respectively the tangibility and intangibility from actual service performance. Parasuraman *et al.* (1988) show the relationship between service quality and customer satisfaction by using five cues of quality i.e. tangibility, reliability, responsiveness, confidence and communication, popularly known as SERVQUAL model. Clark & Wood (1998) argue that tangible elements have greater influence in measuring customer satisfaction rather than intangible ones. Therefore both cues are equally important to measure influence of service quality toward customer satisfaction. Saha (2009) shows service quality is the significant determinant of customer satisfaction, and quality of service satisfaction affects such behavioral intentions of the customer (p.367).

Dagger & Sweeney (2006) identifies service quality cues into two dimensions which include technical service quality and functional service quality. Similarly, Mei *et al.* (1999) identifies three cues of hotel service quality which include employees, tangibles and reliability in the Australian hotel industry. This model is called as HOLSERV too. Olurunniwo *et al.* (2006) identifies four cues of service quality which includes tangibles, recovery, responsiveness and knowledge in the hotel industry. Lenka *et al* (2009) defines service quality into human, technical and tangible aspects and reveals that human aspect of service quality has more influence in customer satisfaction than in technical and tangible aspects.

Quality identifies seven cues service quality which include courtesy and competence, communication and transactions, tangibles, knowing and understanding the customer, accuracy and speed of server, solution to the problems, and accuracy of hotel reservations.

These all models of service quality comprise two or three dimensions viz. tangible (physical facilities) and intangibles (employee-customer interactions) or human, technical and tangible. Among the five cues of the service quality, three cue i.e. responsiveness, confidence and communication represent intangible or human cue. Reliability is a technical cue, and physical facilities of the hotel are referred as a tangible cue which covers the thrust of all models of service quality.

H1: Service quality has positive relationship with customer satisfaction.
H1a: Tangibility is positively correlated with customer satisfaction.
H1b: Reliability is positively correlated with customer satisfaction.
H1c: Responsiveness is positively correlated with customer satisfaction.
H1d: Confidence is positively correlated with customer satisfaction.
H1e: Communication is positively correlated with customer satisfaction.

2.2 Service quality and behavioral intentions

Several empirical studies have showed that service quality has positive relationship with customer behavioral intention. Behavioral intention includes spoken word, repurchase visit & loyalty (Ryu & Han, 2010; Zeithmal, 1996; Swonson & Davis, 2003). Zineldin's (2006) study correlates the patient's service satisfaction with service quality and explores that service quality is positively correlated with behavior intentions (willingness to recommend the hospitals to others). Behavior intentions can be measured as repurchase intentions, word of mouth, complaining behavior and price sensitivity. Low service quality leads to unfavorable behavioral intentions (Burton *et al.* (2003). Behavioral intentions can be observed from customer's decision whether he/she remains intact or gets isolated from the service providing company. The greater the customers' experience, the better the customer is willing to reuse the services.

H2: Service quality has positive relationship with behavior intentions of the customer.
H2a: Tangibility has positive relationship with behavior intentions of the customer.
H2b: Reliability has positive relationship with behavior intentions of the customer
H3c: Responsiveness has positive relationship with behavior intentions of the customer
H4d: Confidence has positive relationship with behavior intentions of the customer.
H5e: Communication has positive relationship with behavior intentions of the customer.

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2.3 Customer satisfaction and behavioral intentions

Ryu & Han (2010) show that there is significant relationship between customer satisfaction and behavioral intentions (p.323). Saha & Theingi (2009) state that behavioral intention is a customer's subjective probability of performing a certain behavior related to behavioral aspects. Positive behavior promotes organization's profitability and increases market share in the airlines industry. A behavior intention is also found different between more and less satisfied customers (Soderlund, 1998). Positive behavior reduces the cost of marketing, and it may increase revenue if new customers are attracted (Riechheld & Sesser, 1990). Kandampully & Hu (2007) argue that customer satisfaction has direct relationship with customer loyalty. Customer loyalty is the major component of behavioral intentions. Both service quality and satisfaction increase hotel's image (p.440). Olurunniwo *et al.* (2006) also show service satisfaction has a role of mediation between service quality and behavioral intention, and service quality has an indirect relationship with them.

H3: Customer satisfaction has positive relationship with behavioral intention of the customer.

III. METHODOLOGY

Descriptive ad analytical research design has been used in this research. Data are collected from five star hotels based in capital of Nepal.

To measure the service quality in hotel, lodging quality index (LQI) composed with 26 items has been used. LQI was developed by Getty & Getty (2003). LQI was categorized into five cues include tangible, reliability, responsiveness, confidence and communication. Olurunniwo *el al.*(2006) uses 4 items of customer satisfaction to measure the behavioral intentions of the customer in the hotels. 243 respondents (all were the customers) were taken to measure quality services, satisfaction and behavior intentions of customers who stayed and received their perceived experience in five star hotels in Kathmandu (capital), Nepal.

IV. RESULTS AND ANALYSES

4.1 Sample and Data Collection

An empirical study was conducted through a set of survey questionnaire to know service quality, satisfaction and behavior intentions of the customers staying at the hotels. Data were collected by 10 students who had completed their 6 month long internship from these respective hotels. From, this population, a sample for the study was selected on the basis of connection of students (convenience sampling). Questionnaire was collected over 3 weekends. The students were from Bachelor of Hotel Management Program final semester. They were familiar with hotel environment because they had stayed six month during the internship. Regarding service quality, customer satisfaction and behavioral intentions, 243 valid questions returned from customers who had stayed in the hotels.

The customer characteristics of the respondents are summarized in Table I. Table I shows, a majority (60.1 per cent) of the respondents were males. 50.6 per cent of respondents were European, 26 per cent were Asian, and 22.4 per cent were American. 65.1 per cent respondents stayed for 1-4 days, 26.3 per cent respondents for 5-8 days and reaming 8.20 per cent stayed for 9 days and more.

Table I. Profile of customers

Variables	Frequency	Percent of total
Gender		
Male	146	60.1
Female	97	39.9
Nationality		
Asian	65	26.7
European	122	50.6
American	54	22.4
Unstated	2	0.8
Days staying		
1-4 days	159	65.4
5-8 days	64	26.3
9 days above	20	8.20

Note: n=243

4.2 Measures

4.2.1 Service quality

The service quality measure is selected from lodging quality index (LQI) developed by Getty and Getty (2003). LQI is composed of 26 items of five dimensions. They are:

1. tangible (consists of eight items, such as" the front desk was visually appealing");
2. reliability (consists of four items, such as "My reservation was handle efficiently");
3. responsiveness (consists of five items, such as "employees responded promptly to my request");
4. confidence (consists of five items, such as "the hotel provided safe environment"); and
5. communication (consists of four items, such as "charges of my account were clearly explained").

4.2.2 Customer satisfaction

The customer satisfaction is measured in terms of 4 items developed by Olurunniwo *et al.* (2006). It is composed with following constructs. They are:

1. "I am satisfied with my decision to visit this hotel";
2. "my choice to stay at this hotel was a wise one",
3. "I think I did the right thing when I chose to stay in this hotel" and
4. "I feel that my experience with this hotel has been enjoyable".

4.2.3 Behavior Intentions

Getty and Getty's (2003) multidimensional constructs are used to measure the behavior intentions of the respondent, which are mentioned below:

1. "I will certainly recommend….. hotel to friends and acquaintances".
2. "I will pay a higher price then competitor charge for the benefits that I received from………. Hotel".
3. "…….. hotel is always my first choice".

A six point Likert scale (1= strongly disagree, 2= disagree, 3= slightly disagree, 4= slightly agree, 5= agree 6= strongly agree) is used.

V. RESULTS

5.1 Descriptive statistics

Means and standard deviation for all measures (26 items of service quality, 4 items of customer satisfaction and 3 items of behavior intentions) are reported in Table II. All score range from one to six. Table II shows descriptive value of each service quality, customer satisfaction and behavioral intention in hotel industry. Regarding the service quality, mean value of responsiveness is the highest (M=5.87,) and tangible is the lowest (M=5.05,). But lowest standard deviation correspondences to tangible and, is only 0.55. This indicates that consistency in tangible is higher than other service quality cues. But responsiveness is more essential for customer satisfaction and behavioral intention. The mean value of all service cues ranges between 5.02 to 5.87 in the rating of agree and strongly agree level. It means service quality in the hotel industry in Nepal is good. Mean value of service satisfaction and behavioral intentions is 4.87 and 4.90 respectively. This indicates that customer satisfaction and behavioral intentions of the customers are also responded as "agree". This shows customers' have high rate of word of mouth (recommendation to their family and friends to stay in the hotel) and that's really influential to promote the willingness to stay in the same hotels when they visit Nepal.

Table II: Descriptive Statistics (Field Survey 2010)

	Service Quality	N	Mean	S.D.	Cronbach Alpha
1.	Tangible	243	5.02	0.55	0.80
2.	Reliability	227	5.04	0.71	0.80
3.	Responsiveness	238	5.87	0.57	0.77
4.	Confidence	235	5.19	0.60	0.67
5.	Communication	235	5.05	0.90	0.69
6.	Customer Satisfaction	232	4.87	0.67	0.85
7.	Behavioral intention	227	4.90	0.59	0.65

5.2 Reliability analysis

Cronbach's alpha coefficients are used to measure the reliability of five cues of service quality, customer satisfaction and behavior intention, Cronbach alpha coefficient value of all cues are above 0.65. Table II, customer satisfaction is the highest (0.85) and behavior intentions (0.65) has lowest.

5.3 Relationship between service quality, customer satisfaction and behavior intentions

Table III shows the relationship among each cues of service quality with behavior intentions of customers' and their satisfaction. Result shows that except communication, remaining cues of service quality has the relationship with behavior intention. Tangible (r=0.50, p=0.01), reliability (r=0.43, p= 0.01), is correlated with behavior intentions of customer, i.e.(r=0.54 , p= 0.01), responsibility (r=0.50, significant at 0.01), confidence (r=0.52, p= 0.01), communication (r=0.26, p=0.01). It means H2 is accepted. Result shows that quality service has a positive relationship with behavior intentions. H1 and H3 supported the proposed hypothesis, and it indicated that there is evidence of positive relationship between service quality and customer satisfaction, and customer satisfaction and behavioral intention.

Table III: Correlation matrix among service quality and behavior intentions among the customer in hospitability industries in Nepal

	1	2	3	4	5	6	7
Tangible	1						
Reliability	.60*	1					
Responsibility	.79**	.71**	1				
Confidence	.50**	.32**	.40**	1			
Communication	.53**	.30**	.61**	.08	1		
Behavior Intention	.43**	.54**	.50**	.52**	.26**	1	
Customer Satisfaction	0.86	0.08	0.10	0.04	0.12	0.11	1

** Correlation is significant at the 0.01 level (2-tailed).

5.4 Customer satisfaction as a meditation between service quality and behavioral intentions

Table IV shows positive relationship (r=0.54 & p=000) between behavior intentions and service quality by keeping customers' satisfaction level as constant. This indicates that customer satisfaction level plays a mediation role to establish positive relationship between service quality and behavior intentions of the customer. Without controlling customer satisfaction level, the relationship between service quality and behavior intention is observed insignificant. This indicates that minimum level of customers' satisfaction is essential for recommendation to their friends and acquaintances to stay in the same hotels.

Table IV: Mediation role of customer satisfaction between service quality and behavior intentions

			1	2
Controllable customer satisfaction	Behavior Intentions			
		Correlation	1.00	.54**
		Significance (2-tailed)	.	.000
	Service quality	Correlation	.54**	1.00
		Significance (2-tailed)	.000	.
		df	191	0

** Correlation is significant at the 0.01 level (2-tailed).

VI. DISCUSSION, CONTRIBUTION AND IMPLICATIONS, AND LIMITATIONS

6.1 Discussion

The objective of this study is to examine the relationship between service quality, satisfaction and behavioral intentions of the customers' in the hotel industry in Nepal. The service quality is correlated with behavioral intention of the customers but it is directly correlated with customer satisfaction. At the same time, customer satisfaction is also directly correlated with behavioral intentions of the customer. Customer satisfaction works as a mediator between service quality and behavioral intentions since the satisfaction variable in the table is fixed.

This finding is based on the study of Ladhari (2009), Olurunniwo, *et al.* (2006), Ryu & Han (2010). Each service quality cues is positively associated with behavior intentions of customer in hotel industry. The finding also supports (Olurunniwo, *et al.* 2006; Dagger & Sweeney ;2006 and Lanka et al, 2009) that customer satisfaction has direct relationship with behavior intentions of the customer itself, and adding special features under present service can increase the customer satisfaction. In the hotel industry, all customers are aware about their schedule and program. In addition to that customers expect prompt response and involvement about other immediate activities, not included under their schedule. Therefore providing these services can increase word of mouth and increase loyalty of the customer. Most of the customers are found staying in the hotels for few days and their concentration is mainly on participating into various schedule functions. The first reason is that they cannot measure service in the cognitive perspective. Cognitive prospective evaluates each cues of service in very rational and logical way. Affective perspective measures service in the emotional and irrational way. The result of this research does not meet the expectation of highly affective perspective of the customer. The second reason, customer in Nepal arrives from different parts of the world after they successfully travel other parts of the world. Receiving perceived experience at the hotel is not their first experience. Customer compares service offered by Nepalese hotel industry to the hotels of the other countries. Service quality received in Nepalese hotel may not be same to that of other countries. To maintain the standard of service quality and to meet the customer's expectation, the hotel industry must incorporate the standard features as per the requirement. Besides, customers visit Nepal due to its glorious adventure and landmarks and they do not take the facilities provided by the hotels that much seriously. It is because they just use hotel as a stations of arrival and departure of their visit. Limited time is not adequate to travel the entire landmark in Nepal. Similarly, customers visit in a short schedule (3-4 days stay) and they seem eager to travel other neighboring countries like China and India. They are found highly influenced with Nepalese cultural, World heritage and panoramic scenario and realize the need to revisit Nepal. Because of short and busy schedule, they cannot change and compare service facilities of other hotels during their stay. Therefore, they are compelled to stay and recommend their friends and acquaintances to the same hotels.

This study result is consistent with Kandampully (2006) that is increase in customer's satisfaction increases positive behavior intentions of the customer. In present study there are other factors which could explain the satisfaction and behavioral intentions.

Meeting expectation of the service leads to satisfaction and satisfaction leads to positive behavioral intentions of the customer. This study contradicts with Ladhari (2009) and Wong (2004). They suggest that hotel industry pays higher attention to comfort, security and pleasure, and welcoming that further leads to positive behavior response of the customer like greater loyalty, positive word of mouth, and recommendation to their friends and acquaintances and show willingness to pay high price.

6.2 Managerial implications and future research

Based on research findings, the questions of which cues of service quality increase customer satisfaction and their behavior intentions in the hotel industry revel that reliability and confidence have the highest rating among five cues of quality service. Customers' opinion also reflected to increase commutation, tangibles and responsiveness in the hotel. More service quality value is required to add in present service quality in the hotel and that can lead toward satisfaction. Tourist landmark, historical visiting sites, and natural beauty of the nation can be the causes because of which the customers show positive behavioral intentions to stay in the same hotel.

Managers or entrepreneurs of the hotel need to ask cognitive aspect of feedback on the several cues of service quality by recording positive and negative perceived experienced of the customer during their stay in hotel. Increasing quality service increases customer satisfaction which increases positive word of mouth of the customers. Their recommendation of the hotels to their friends and relatives are the major factors to increase willingness to stay in hotel along with the ability to pay. The result of this study suggests that additional service quality in addition to present services is required to create the long lasting imprint in the customer's mind. Nepalese hotels need to do a lot in this regards.

Regarding the implication of the research, we agree that due to the limited number of the sample size our research provide merely an indication of some trends in the areas of service quality, satisfaction and behavior intention. This paper confirms that inference is justified by introducing additional related variables like age, sex, nationality income and occupation of the customers.

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