The current issue and full text archive of this journal is available at
www.emeraldinsight.com/0960-0035.htm

A model of supply chain and supply chain decision-making complexity

Ila Manuj
Department of Logistics and Marketing, University of North Texas, Denton, Texas, USA, and
Funda Sahin
Department of Marketing and Logistics, The University of Tennessee, Knoxville, Tennessee, USA

Received March 2009
Revised December 2009
Accepted December 2009

Abstract

Purpose – The objective of this paper is to develop a comprehensive model of supply chain and supply chain decision-making complexity that provides an understanding of the drivers of supply chain complexity and strategies to manage supply chain and supply chain decision-making complexity and outcomes.

Design/methodology/approach – Grounded theory methodology is employed to build a theory of supply chain and supply chain decision-making complexity and develop propositions related to antecedents, moderators, and outcomes of supply chain complexity. In addition, extensive literature review and informal interactions with a number of supply chain professionals have been used to validate the theory.

Findings – In addition to identifying the antecedents of supply chain complexity, the authors explore strategic, human cognitive ability, and tactical moderators for managing supply chain complexity.

Research limitations/implications – The comprehensive framework presented in the paper builds a theory of supply chain and supply chain decision-making complexity that is grounded in empirical data. The research also incorporates disparate findings, constructs from multi-disciplinary research on supply chain complexity and provides future research directions.

Practical implications – The research helps practitioners better understand the sources and outcomes of supply chain complexity and how to manage it. Various strategies to moderate the impact of supply chain complexity are presented.

Originality/value – An integrated, comprehensive theory of supply chain complexity is proposed along with definitions of supply chain complexity and supply chain decision-making complexity. The proposed model is rooted in actual practice and supported by the existing literature.

Keywords Supply chain complexity, Supply chain decision-making complexity, Qualitative study, Supply chain management

Paper type Research paper

1. Introduction

The key to successful supply chain management is attaining effective integration of the business functions and channel members such that all processes are aligned to achieve the overall system objectives (Sahin and Robinson, 2002, 2005). However, the dynamic, multi-functional, and global nature of supply chains with their multiplicity of firms, processes, and flows yield highly complex, multifaceted, and large-scale systems, which the literature refers to as supply chain complexity (Mentzer *et al.*, 2001; Choi *et al.*, 2001; Choi and Hong, 2002). The degree of complexity is derived from the structural properties

International Journal of Physical Distribution & Logistics Management
Vol. 41 No. 5, 2011
pp. 511-549

0960-0035
DOI 10.1108/09600031111138844

of the system as determined by the number and variety of elements defining the supply chain and their interactions (e.g. the number of participants, facilities, products, transportation links, information flows, etc.).

Highly complex supply chains, due to the vastness of data, decision variables, intricate interrelationships among variables and system constraints, and performance trade-offs present many challenges for management in arriving at sound business decisions. The managerial effort for effectively planning, implementing, and controlling the supply chain is known as supply chain decision-making complexity. While the two complexity measures are interrelated, it is important to note that supply chain complexity relates to the structural elements defining the supply chain, while supply chain decision-making complexity relates to human cognitive and organizational decision-making processes.

Today's supply chain managers find their roles to be evolving into managing more complex supply chains that are defined by rapidly changing, continuously expanding and often uncertain business environments. Given the dynamism and uncertainty of the environment, supply chain professionals take on responsibility for more complicated tasks and face increased challenges in supply chain decision making. Despite the fact that they realize and recognize the negative outcomes of complexity, they often have a difficult time identifying and effectively addressing the real causes of the complexity. Lack of understanding of the complexity drivers, and poorly designed and executed strategies to address complexity in supply chains make supply chain decision-making much more difficult and often lead to undesirable outcomes. One needs to understand the source of complexity (keeping in mind that not all sources of complexity are bad; see Bozarth *et al.* (2009) and Closs *et al.* (2008) for more discussion) in order to develop effective strategies to manage it and accomplish corporate goals that are not hindered by undesirable complexity outcomes.

While there is an emerging literature on supply chain complexity, it falls short in explaining the relationship between supply chain complexity and supply chain decision making. First, the literature primarily focuses on structural measures of supply chain complexity. However, due to the dynamic and large-scale nature of the supply chain, it is impractical to enumerate all of the possible alternatives, activities, information queues, transactions, linkages, and other factors proposed as drivers of supply chain complexity. Hence, the concept of objectively measuring supply chain complexity, while theoretically appealing, does little to aid management in improving supply chain management processes. Second, the majority of past research, with few exceptions (Perona and Miragliotta, 2004), does not clearly differentiate supply chain complexity and supply chain decision-making complexity. However, the cognitive decision-making literature strongly suggests that they need to be differentiated. Supply chain managers may be able to apply cognitive processes, organizational processes, and/or decision aids that may transform a highly complex supply chain into a manageable decision-making problem. However, it is not clear in the current literature which decision aids or processes, if any, mitigate supply chain complexity. A comprehensive empirical-based model of supply chain complexity and its relationship to supply chain decision making is lacking in the literature. Such a theoretical model that takes an integrated view of supply chain and supply chain decision-making complexity and that is empirically grounded in practice is well justified and required to advance supply chain complexity research in a meaningful direction. Such research, employing field study of actual industry practice would transcend prior efforts, which focus on narrowly defined tasks or anecdotal evidence.

This research takes the first steps toward filling this void in the literature. Our specific research questions address what supply chain professionals mean by supply chain complexity, how they define it, what drives complexity, and what the outcomes are. Of particular interest are also strategies that supply chain professionals use to manage supply chain complexity. Towards this end, we propose a supply chain and supply chain decision-making complexity model that is constructed using a grounded theory research methodology based on in-depth interviews with supply chain professionals Theoretical support from the literature in various disciplines is also provided. The research findings provide an understanding of supply chain and supply chain decision-making complexity, complexity drivers, outcomes, and strategies that business professionals apply to moderate the complexity outcomes.

The remainder of the paper is organized as follows: Section 2 provides a review of the relevant literature followed by a discussion of the research methodology in Section 3. Research findings are presented in Section 4. Section 5 presents the conclusions. Finally, Section 6 discusses research limitations and future research directions.

2. Literature review

This section reviews the multi-disciplinary literature that relates to supply chain and supply chain decision-making complexity.

2.1 Supply chain complexity

Organizations can be viewed as systems that show complex, adaptive and emergent behaviors in reaction to interacting agents. These organizations gather information about their environments, other organizations, and their own behavior in order to adapt to or co-evolve with their environments (Capra, 1996; Wheatley, 1992; Stacey, 1992, 1995; McDaniel, 1997; Vaill, 1989; Bergquist, 1993; Wheatley and Kellner-Rogers, 1996; McDaniel and Walls, 1997; Brown and Eisenhardt, 1997; Kauffman, 1995; Ashmos *et al.*, 2000). The larger the number of ties and connections these organizations have, the greater is the variety of behaviors they exhibit. These behaviors may eventually lead to adaptability (McDaniel and Walls, 1997; Stacey, 1995; Ashmos *et al.*, 2000).

Supply chains are complex adaptive systems (Choi *et al.*, 2001; Wycisk *et al.*, 2008) and their efficient and effective management poses many challenges for business professionals (Ellinger *et al.*, 2002). Prior research identifies supply chain complexity as a key issue confronting supply chain managers (Mentzer *et al.*, 2001; Choi and Krause, 2006). Applying systems theory, Dubois *et al.* (2004) state that in a complex system, a linear change in one part of a system may cause nonlinear and unexpected changes in other parts of the system. Given this potential for an adverse impact, Gottinger (1983) emphasizes the importance of understanding and controlling the system complexities that may otherwise lead to system sub-optimization. Therefore, system complexity should be managed internally, externally and interactively (Kohn and McGinnis, 1997). Other researchers discuss the impact of supply chain complexity on system performance and supply chain risk (Forrester, 1958; Wilding, 1998; Manuj and Mentzer, 2008; Tierney, 2004). Complexity is also argued to be a barrier to achieving supply chain agility (Christopher, 2000).

Various elements defining the structure and scope of the supply chain are proposed as complexity drivers (Rao and Young, 1994; Vachon and Klassen, 2002; Stock *et al.*, 2000; Choi *et al.*, 2001; Choi and Hong, 2002; Choi and Krause, 2006;

Perona and Miragliotta, 2004; van Donk and van Dam, 1996; Funk, 1995; Blackhurst *et al.*, 2005; Craighead *et al.*, 2007; Meepetchdee and Shah, 2007; Wycisk *et al.*, 2008). Understanding these drivers is critical when devising strategies to manage the resulting complexity. Table I summarizes the literature by the type and source of complexity studied.

2.2 Cognitive processes and supply chain decision-making complexity

The literature on cognitive and decision-making processes provides insight into the relationship between supply chain and supply chain decision-making complexity. The seminal research by Wood (1986) and Campbell (1988) on cognitive decision making defines a task's objective complexity in terms of problem attributes that can be enumerated. This is analogous to measures of supply chain complexity based on the number

Author (year)	Type of complexity	Source of complexity
Forrester (1958)	System (supply chain) complexity	Channel members' ordering decisions
Funk (1995)	Logistical complexity	Number of manufacturing steps, part numbers
Rao and Young (1994)	Global logistics complexity	Network, process, and product
van Donk and van Dam (1996)	Scheduling complexity	Number of products, production lines, machine, and labor constraints
Wilding (1998)	Supply chain complexity	Deterministic chaos, parallel interactions, demand amplification
Stock *et al.* (2000)	Logistical complexity	Globalization (geographically dispersed network of resources)
Choi *et al.* (2001) and Choi and Krause (2006)	Supply base complexity	Number of suppliers, degree of differentiation among suppliers, level of interrelationships between suppliers
Vachon and Klassen (2002)	Supply chain complexity	Technology and information processing
Choi and Hong (2002)	Network complexity	Horizontal, vertical, and spatial complexity
Faber *et al.* (2002)	Warehouse complexity	Number and variety of items handled, degree of interaction between items, and the number, nature, and variety of processes
de Koster (2002)	Distribution operations complexity	Assortment type, assortment width, and number of weekly orders
Perona and Miragliotta (2004)	Manufacturing and logistics complexity	Sales processes, inbound/outbound logistics, new product development, production process, process engineering
Blackhurst *et al.* (2005)	Supply chain complexity	Multiple levels of suppliers, large network of manufacturers/distributors, involvement with other supply chains, change/dynamic nature
Sivadasan *et al.* (2002, 2006)	Supplier-customer system complexity	Operational and structural complexity
Craighead *et al.* (2007)	Supply chain complexity	Number of nodes/flows
Meepetchdee and Shah (2007)	Logistical complexity	Degree of connectivity
Bozarth *et al.* (2009)	Supply chain complexity	Detail and dynamic complexity; downstream, manufacturing, and upstream complexity

Table I.
Types and sources of complexity described in supply chain literature

of structural elements (i.e. the number of products, facilities, channel members, etc.) that define the supply chain. The implicit assumption is that measures of objective complexity provide a surrogate measure for decision-making complexity, which is related to the volume and structure of information cues that must be considered when making a decision (Efstathiou *et al.*, 2002). Campbell (1988) introduces the concept of a task's perceived complexity as distinct from the task's objective complexity. Perceived complexity, which relates to the decision-making difficulty of arriving at a problem solution, is based on the observation that humans possess cognitive skills, which often allow them to implicitly enumerate many potential solution paths (i.e. solution candidates) while explicitly evaluating only a few promising paths when deriving a problem solution. Furthermore, there may not be a linear relationship between the task's objective and perceived complexity. Hence, a problem's objective complexity measurement may not provide an accurate portrayal of the level of perceived (decision-making) complexity experienced by the decision maker.

Mapping this research into a supply chain setting suggests that business professionals, when faced with high levels of supply chain complexity (i.e. objective task complexity) apply cognitive processes and managerial tools such as information systems to reduce the high levels of supply chain complexity into a more tractable level of perceived supply chain decision-making complexity that can be tackled by a supply chain manager. In their study of human cognitive decision-making processes, Robinson and Swink (1994) and Swink and Robinson (1997) discuss the relationship between objective task complexity and perceived task complexity within the context of designing facility networks. Their findings indicate that objective and perceived task complexity are not always positively correlated. Instead, human cognitive processes often cut through the large levels of objective complexity to arrive at decision problems of low perceived complexity. In one counter intuitive finding, managers found better solutions for the larger sized (i.e. more complex) than smaller sized network design problems. As expected, decision support systems (DSS) software (and/or other decision aids) further mitigated objective complexity (Guimaraes *et al.*, 1992) and thereby, decreased perceived complexity and enhanced decision-making performance.

The cognitive process literature takes needed steps toward a theory of supply chain decision-making complexity. However, this literature only considers the solution of well-defined problems in a laboratory setting. In contrast, supply chain management encompasses planning, implementing and controlling supply chain processes, which often requires problem definition and establishing new managerial processes across organizational boundaries. This is quite different than performing a narrowly defined task within a laboratory setting.

3. Research methodology

The research objective is to develop a comprehensive model of supply chain complexity and supply chain decision-making complexity that is grounded in actual business practice. Toward this end, we applied the grounded theory research methodology. This is a rigorous qualitative, theory-building approach that is based on field study of a multifaceted phenomenon or process through a series of structured data collection and analysis steps. It is a discovery-oriented, interpretive method similar to ethnography, which is designed to facilitate theory construction from field data (Flint and Mentzer, 2000).

3.1 Sampling

Following the guidelines of grounded theory, we conducted semi-structured, in-depth interviews with senior level supply chain managers. Initial sample (interview participants) was determined following the theoretical sampling guidelines which dictate that participants, who can provide meaningful, relevant data about the phenomenon investigated were selected (Fetterman, 1988). Initial participants were identified based on their experience with the phenomenon, job titles, job profiles, articulation skills and willingness to participate. As the study progressed, when the need for understanding of certain aspects of the emerging theory rose, participants that could provide further details on emerging questions were purposefully selected. Tables II and III provide brief descriptions of participating firms and profiles of supply chain professionals, respectively.

The supply chain managers hold positions in a wide variety of industries including home appliance, electronic component/product supply and assembly, pharmaceuticals, over-the-counter medical products, office products, heavy equipment, building products, and consumer products. The sampled firms represent a variety of major players with extensive global supply chains, have worldwide revenues ranging from $3 billion to over $50 billion (excluding a privately held company) and exist at different levels of supply chain, e.g. assembler, manufacturer, supplier, distributor, and a third-party logistics service provider. The interview participants have varying job titles including vice president of supply chain strategy, director of supply chain strategy, director of global supply chain strategy, director of operations and fulfillment, director of supply chain integration, director of worldwide customer and distribution services, and manager of supply chain solutions. Most of the interviewees had senior-level managerial experience with other firms (and industries) before taking on their current jobs. Some are long time employees of their current companies and are able to provide a historical perspective of their firm and their decision-making responsibilities. Discovering common themes and concepts among a wide variety of respondents in a given context helped get to the core of the phenomenon.

3.2 Interview process

As suggested by Morrison *et al.* (2002) and Strauss and Corbin (1998), the researchers started out by asking broad, open-ended, grand-tour questions guided by the extant literature. An interview guide laying out the topics of interest broadly was used to guide the interviews. As the interviews progressed, broad questions were followed by more focused and directed questions, both during each interview and between successive interviews. Each interview followed a unique course due to varying responses of the participants. Table IV describes the interview protocol.

Theoretical saturation (i.e. no new information or insights obtained from additional interviews) was attained after conducting 11 (six on-site, five phone) interviews. The number of interviews is consistent with the qualitative research guidelines that suggest interviewing enough participants until saturation is attained, which is usually eight or fewer informants (McCracken, 1988; Strauss and Corbin, 1998; Mentzer and Flint, 1997). The nature of the research and research design permits phone interviews without introducing any form of bias or misinterpretation. Each interview lasted 60-90 minutes.

To ensure that all aspects of the phenomenon were explored and adequately understood by the interviewer, during and at the end of each interview, the key points of the discussions were summarized and participants were asked to add anything that

Table II. Profile of participating firms

Company pseudonym	Industry	Supply chain role	Description
HomeCo	Home appliances and consumer goods	Manufacturer and distributor	Global home appliance manufacturing company; has presence in over 50 countries; revenue over $15 billion
HealthCo	Consumer health products, pharmaceuticals, biologics, and health devices and diagnostics	Manufacturer and distributor	Multinational company specializing in healthcare, medical devices, diagnostics, and consumer healthcare products; has presence in over 50 countries; revenue over $50 billion
ElectriCo	Electronic and electrical components	Manufacturer and distributor	Multinational firm providing engineered electronic components for consumer and industrial products, network solutions and telecommunication systems; has presence in over 50 countries; revenue over $15 billion
ComputerWare	Information technology and services	Manufacturer and distributor	Global company, leading provider of computer hardware, storage, servers, and IT services; revenue over $55 billion
BuildersInc	Building materials	Manufacturer and distributor	Leading manufacturer and distributor of building materials; runs several facilities in North America and South America; delivers building products to retail, wholesale, home building, and industrial customers; revenue over $3 billion
MachineCo	Machinery	Manufacturer and dealer	Global diverse, technology leader delivering products, services, and technology in machinery, engines, and financial products; revenue over $40 billion
SuppliesCo	Office supplies and equipment	Retailer	Company providing B2B services, technology products and solutions, and retail office supplies to large, medium, and small businesses through catalogues, e-sales, and hundreds of stores nationwide; revenue over $10 billion
CompuSystems	Computer hardware	Manufacturer and distributor	Global manufacturer of technology; operates in four segments: aerospace, automation and control, specialty materials, and transportation systems; revenue over $30 billion
LogisticsCo	Third-party logistics	Warehousing and transportation services	Privately held company with global clients

Table III.
Profile of participating supply chain professionals and major challenges they face

Participant pseudonym	Company name	Experience	Major challenges
Peter	HomeCo	32 years of experience; recently retired after 32 years in the most recent organization as vice president of supply chain strategy; responsible for transportation, warehousing, manufacturing engineering, forecasting, and corporate planning Previous experience in manufacturing engineering and logistics in consumer products. Former responsibilities in the areas of global logistics systems and processes, warehousing, inventory management, procurement, and manufacturing	Loss of flexibility in global sourcing versus local sourcing; longer lead times and decision-making complexity; risks of supply disruptions leading to added inventory in the system; prolonged waiting times and stock unavailability leading to lost sales; incorrect forecasting over long lead times; quality and safety concerns regarding offshore sourcing
Rob	HomeCo	Ten years of experience, five years with the current firm; vice president of technology; responsible for product development and brand management Previous industry experience includes product architecture planning and electronics. Former responsibilities in the areas of research engineering, corporate innovations, and technology development	Quality design issues; suppliers are external to the organization which in turn is creating problems
Kevin	HomeCo	34 years of experience, 32 years with the current firm; director of global sourcing strategy; responsible for procurement, supply chain, and manufacturing strategy Previous industry experience includes consumer goods, pharmaceuticals, and medical device. Former responsibilities in the areas of finance, manufacturing, material control, and global procurement	Quality problems due to engineering changes; securing availability of components
Tim	HealthCo	30 years of experience, 27 years with the current firm; director of worldwide customer and distribution services; responsible for global fulfillment and returns processing Previous industry experience includes consumer goods, medical devices, and pharmaceutical. Former responsibilities in the areas of production planning, inventory management, procurement, facilities planning, customer service, and distribution	Fast changing marketplace; rapid new product introductions; pressure to reduce costs while maintaining top-line; ensuring compliance and control in DCs
Tyler	ElectriCo	20 years of experience, all with the current firm; manager, strategic supply management; responsible for strategic sourcing and planning Previous industry experience includes consumer electronics and electrical components manufacturing. Former responsibilities in the areas of contract management, cost containment and process improvement, inventory optimization, risk management, and change management	Lack of customer interaction, global lead times, demand planning, supplier quality, and extensive supplier base

(*continued*)

Table III.

Participant pseudonym	Company name	Experience	Major challenges
Bill	ComputerWare	20 years of experience, nine years with the current firm; director of fulfillment; responsible for contract management, cost containment and process improvement, inventory optimization, risk management, and change management Previous industry experience includes information technology and services. Former responsibilities in the areas of materials management, procurement, and production control	Very little inventory throughout the whole delivery process; inaccuracies and variations in incoming material; difficult demand forecasting
Tony	MachineCo	27 years of experience, ten years with the current firm; director of global supply chain strategy; responsible for client account management, supply chain strategy for the entire organization Previous industry experience includes machinery and equipment manufacturing; former responsibilities in the areas of remanufacturing business, and product support operations	Currency and country risks; port delays and higher safety stock levels; costly transportation infrastructure; ensuring effective facility planning, machinery and equipment specifications
Matt	Builders Inc	Seven years of experience, five years with the current firm; director of supply chain; responsible for procurement, distribution, logistics, and operations planning Previous industry experience includes consumer electronics. Former responsibilities in the areas of demand planning, forecasting, and sales	Tightening of the market; capacity rate increases, rising fuel surcharges; inadequate product visibility; costly shipping problems
James	SuppliesCo	22 years of experience, three years with the current firm; executive vice president of supply chain; responsible for inventory management, transportation, warehousing, real estate strategy and, store development Previous industry experience includes consumer goods, pharmaceuticals, automotive, energy, and management consulting. Former responsibilities in worldwide supply chain management, e-business management, dealer relationship management, worldwide production, and logistics integration	Lack of understanding of cross-functional integration; achieving profit optimization with SKU forecasting, product transition, and supplier management
Charles	CompuSystems	27 years of experience, four years with the current firm; vice president of supply chain integration; responsible for global distribution management Previous industry experience includes automotive and machinery. Former responsibilities in the areas of global supplier management, worldwide logistics management	Global supply chain management due to supplier and manufacturer process discrepancies; ensuring suppliers comply with freight and logistics cost; consistent performance measurement across cultural lines/businesses
Gary	LogisticsCo	12 years of experience, three years with the current firm; president and CEO; responsible for logistics planning, warehousing operations, and transportation services Previous industry experience includes third-party logistics and transportation services. Former responsibilities in the areas of logistics planning, transportation services, IT infrastructure management, sales, and warehousing operations	Optimization issues; resistance to change; tougher competition with smaller and medium-sized enterprises penetrating the industry; implementation issues, longer processing times, and sophistication of processes making it harder to implement logistics planning

Opening	Introductions of the interviewer and the interviewee Overview – purpose of the study Confidentiality assurance Permission to audiotape
Demographic data	Title of the interview participants Job history Organizational structure Background – organization, industry
Questions	Can you tell me about a situation in which you had to make a particularly difficult decision? What was the objective of the decision? What made it difficult? How do you deal with complex problems/decisions? What makes your supply chain complex? What are the outcomes when supply chain is (or becomes more) complex? What makes it easy (or difficult) for you to deal with complexity? What may help you in dealing with complexity?
Additional unplanned/ floating prompts	Will you describe that? Could you tell me more about that? Will you explain that in more detail? Can you give me examples or tell me about a related incident? How does that work? Tell me about a time when that did not happen
Some additional actual questions from interviews	You mentioned that the Division X's supply chain has higher complexity. Could you elaborate on that? 40,000 SKU's is really a big number with so many customers and volume of transactions. It really sounds like a very complex chain. So, how do you manage it? Between those two industries (referring to the industries the interviewee used to work for and currently works for), which one is more complex? What does supply chain complexity mean to you? (This question was asked when the interviewee used the term "complex" or "complexity" with no probing

Table IV.
Interview protocol/guide

Note: The interview protocol followed recommendations by McCracken (1988)

was missed during the interviews. The participants also reviewed the transcript of their responses to determine if there was anything that was overlooked. This provided the interviewee time for reflection after the interviews and an opportunity to express additional insights about the subject matter.

3.3 Model building process

To assure data quality and reliability, all of the interviews except one were audio-taped. Since one participant did not allow audio-taping, extensive notes were taken during that interview. The audio tapes and notes were transcribed to enable detailed and repeated analysis.

Consistent with qualitative research guidelines (Strauss and Corbin, 1998), the researchers collected, coded, and analyzed interview data continuously throughout the interview process. The interview transcriptions were analyzed using the ATLAS.Ti software which enabled an objective evaluation of the transcripts. Emerging themes were identified within interviews and integrated across multiple interviews.

Corporate documents provided by the interview participants, websites and news items and literature served as secondary data sources to supplement the interview data. Secondary data sources were helpful in better understanding the role of the company within its supply chain, firm size, product information, and industry characteristics. Overall, theory building was a gradual process with emerging research findings guiding who to interview next, what questions to focus on, and continual revisions of the emerging model (Belk, 1989; Strauss and Corbin, 1998). After the analysis, the researchers reviewed the literature for theoretical support of the model.

3.4 Trustworthiness

In addition to the objective transcript analysis, the researchers assured that the appropriate criteria for the trustworthiness of the theory building research was met. Table V provides details on how the trustworthiness of the research was assured.

Additionally, several measures were taken to control for interviewer bias. First, the interviewer was well trained in the qualitative research methods and experienced in conducting and analyzing qualitative interviews. Second, to ensure that the interviewer did not force any preconceptions or prior knowledge into the interviews, she wrote down everything she knew about the phenomenon prior to the interviews. This technique, similar to bracketing (Kvale, 1983), helps minimize researcher bias. Finally, the second author also analyzed the transcripts and provided input for successive interviews. The interview participants also reviewed the transcripts and summaries and provided feedback for accuracy.

4. Research findings

This section discusses the major research findings and the resulting complexity model that includes the antecedents, elements, outcomes, and moderators related to supply chain complexity and supply chain decision-making complexity.

4.1 Defining supply chain complexity and supply chain decision-making complexity

The interviewees often used the term "complex" or "complexity" when referring to their supply chains. However, when asked to define what they meant by supply chain complexity, they had a difficult time providing a definition. Yet, it was apparent from the discussions that each manager faced difficult managerial decisions and articulated it by identifying the factors that made their supply chains complex. As illustrated by Tony:

> [. . .] (*what makes supply chain complex is the need to*) [. . .] understand the critical elements, the dependencies, and constraints of a prospective client.

This perspective is consistent with the complexity discussions in Choi *et al.* (2001), Dubois *et al.* (2004) and Gottinger (1983).

Matt's description succinctly describes supply chain complexity and the objectives and challenges encompassing supply chain management:

> I'm not exactly sure how to define supply chain complexity other than, you know, it is kind of one, kind of taking chaos and trying to put some order to it.

The term "chaos," indicating disarray, disorganization, confusion, etc. associated with a lack of rules providing structure to an overwhelming number of inputs and interactions

Criteria	Method applied in the study
Credibility	
Extent to which the results appear to be acceptable representations of the data	Summaries of the preliminary findings were provided to the participants for feedback Interviews were conducted over a three-month period The rest of the research team also reviewed the transcripts and the interpretation
Transferability	
Extent to which the findings from one study in one context will apply to other contexts	Participants were chosen based on theoretical sampling. The participants presented diversity in terms of tenure, type of industry, position type, position level, and company size
Dependability	
Extent to which the findings are unique to time and place; the stability or consistency of explanations	Participants were asked to reflect on many experiences including the recent events. Participants reflected as far back as 20 years and results indicated consistency across the industries
Confirmability	
Extent to which interpretations are the result of the participants and the phenomenon as opposed to researcher biases	Interpretations, documents and summary of the preliminary findings were reviewed by the rest of the research team Quotes from the interviews were used to support the preliminary findings
Integrity	
Extent to which interpretations are influenced by misinformation or evasions by participants	Interviews were professional, of a non-threatening nature, and anonymous
Fit	
Extent to which findings fit with the substantive area under investigation	Addressed through the methods used to insure credibility, dependability, and confirmability Concepts were described in detail, capturing the multifaceted nature of the phenomenon
Understanding	
Extent to which participants buy into results as possible representation of their world	The participants were provided a summary of the findings and they confirmed that the interpretations reflected their world
Generality	
Extent to which findings discover multiple aspects of the phenomenon	Interviews were of sufficient length and openness to elicit many facets of the phenomenon and related concepts
Control	
Extent to which organizations can influence aspects of the theory	Participants could have control over some theory variables

Table V.
Establishing research trustworthiness

among inputs, is a particularly insightful choice of words. The end results of chaos are highly unpredictable outputs containing both desired and undesired elements. This simple definition, which reflects the respondents' general perceptions, elevates the concepts of supply chain complexity and supply chain decision-making complexity beyond the mere discussion of problem inputs and the amount of effort required to find the solution. Assimilating the managers' responses, we propose the following definitions:

- Supply chain complexity is the structure, type and volume of interdependent activities, transactions, and processes in the supply chain that also includes constraints and uncertainties under which these activities, transactions and processes take place.
- Supply chain decision-making complexity is the difficulty faced by a decision-maker when managing a supply chain. It is a measure of the collective effort required for problem definition, data collection, problem analysis, solution implementation, and control.

The supply chain complexity definition is in agreement with Wood (1986) and Campbell's (1988) objective task complexity definitions. However, the definition for supply chain decision-making complexity extends the perceived complexity concepts of Campbell (1988), which are static and single-task oriented, to the broader context of supply chain management. This broader context is dynamic in nature and considers multiple and inter-related decisions, where each decision requires problem identification, data collection, solution implementation and control. The proposed definitions provide a more comprehensive, robust, and accurate depictions of supply chain complexity and supply chain decision-making complexity.

4.2 A model of supply chain and supply chain decision-making complexity

A theoretical model of supply chain and supply chain decision-making complexity emerged from the analysis and synthesis of the interview data. The model is grounded in the problem environment and directly reflects the results of the field study as dictated by qualitative research guidelines. The model extends the findings of Swink and Robinson (1997) that perceived decision-making complexity is a function of a combination of factors including objective task complexity (i.e. supply chain complexity), decision-making aids, and user factors. However, where prior research addresses isolated tasks in a laboratory setting, this research employs industry field study and considers the full range of supply chain decisions. The resulting complexity model is supply chain domain specific and provides a unique contribution to the literature by laying the foundation for building a theory of supply chain and supply chain decision-making complexity. The fact that it is strongly supported by the literature strengthens its external validity and provides unique contributions to both the complexity and supply chain management literature.

Figure 1 shows a model of supply chain and supply chain decision-making complexity. It is composed of the antecedents to supply chain complexity, supply chain complexity, supply chain decision-making complexity, moderators to the link between supply chain complexity and supply chain decision-making complexity, moderators to the link between supply chain decision-making complexity and outcomes, and the performance outputs. A summary of the model elements as discussed by the interviewees are provided in Table VI. The table also shows that all participants focused on almost all elements with varying levels of importance. The remainder of this section discusses each component of the model.

4.2.1 Supply chain complexity antecedents. Supply chain antecedents include factors relating to supply chain structure and size, customer expectations, environmental conditions, globalization and organizational restructuring (e.g. mergers, acquisitions, and consolidations). These are the drivers that increase supply chain complexity by increasing

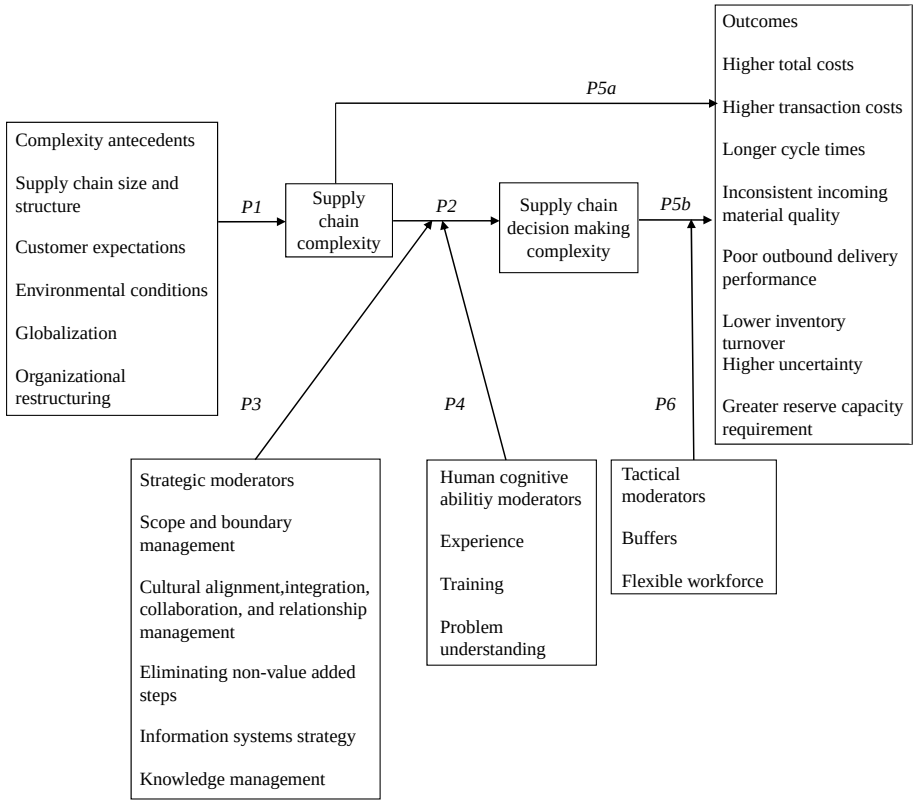

Figure 1.
Supply chain and supply chain decision-making complexity model

the structure, type and volume of interdependent activities, transactions, and processes in the supply chain or increasing the number of constraints and uncertainties under which these activities, transactions and processes take place. We discuss each antecedent and develop propositions for theory-testing in subsequent research efforts.

Supply chain size and structure. All respondents associated supply chain size and structure components with supply chain complexity. Supply chain size and structure refers to the number and types of connections, and linkages. Of particular concern are the number of stock keeping units (SKUs), parts and components in the bill-of-materials, extent of custom product design, and inbound and outbound shipping locations. As James illustrates:

> (*At this company*) [. . .] for all the inbound and the production scheduling, I had to get 150 end items to come together to build a [*product X*]. At another company I got 15,000 end items coming together to build [*product Y*]. So I think it is just more complex.

And Bill quotes:

> [. . .] complexity, being made up of, how many SKUs were involved. How many different types of order entry processes or inputs to (order entry) are there. If it was one SKU and you sold it to one customer, it would have been a very low complexity and in the environment we were in, we had thousands and thousands of orders per day and thousands of SKUs.

Table VI. Cross company comparison

Antecedents *Participant*	*Supply chain size and structure*	*Customer expectations*	*Environmental conditions*	*Globalization*	*Organizational restructuring*
Peter	Number of SKUs, new product introductions, number of components, customers, DCs	Continuously improving availability of products, changing customer requirements, customer bargaining power	Changing economy, marketplace and competition affect degrees of freedom	Huge factor, higher lead times, language barriers, cultural differences, bigger time commitment	Major restructuring based on implementation of an ERP package
Rob	Number of manufacturing plants, DCs, SKUs, customers	Changing customer requirements, customized products	Rapidly changing technologies	Supplier quality control issues, product manufacturing dispersion across multiple countries, customers in different countries like different product looks	Not mentioned
Kevin	Number of tiers of suppliers, DCs, products, sourcing locations	Customers need new products, new innovations	Global political and economic changes, competition	Capital requirements for global distribution, global supply base risks, global competition	Continual changing in off-shoring in terms of products outsourced as well as suppliers and supplier locations
Tim	Number of customers, customer locations, manufacturing locations, DCs, SKUs, transactions, more frequent new product introductions, specific requirements such as refrigeration for products	Customer demanding single point of contact for multiple companies within an organization, different channels of trade have different requirements	Matching services provided by the competition, changing marketplace	DCs in over 50 countries serviced from USA, customs clearance	Internal consolidation of companies within the organization, internal consolidation of DCs
Tyler	Number of processes, products, suppliers, ports, carriers, customer	Frequently changing and increasingly demanding customer requirements	Competition	Security, global supply chain risks, lead times, and customs	Acquisitions
Bill	Number of distribution tiers, SKUs, order entry processes, customers channels of distribution, volume	Speed of introduction of new products	Changing technology roadmap, supply constraints, fuel costs	Global supply chain susceptible to weather, less visibility, less insight into supply market, global competition	Not mentioned
Tony	Number of distribution sites, dealers, SKUs	Limited amount of time to understand customer expectations	Currency risk, country risk, transportation capacity, port congestion	International distribution network, dealing with 35-40 countries	Series of acquisitions

(*continued*)

Table VI.

Matt	Distribution steps, number of supplier, number of customers	Product life cycle, different types of customers with different expectations	Tight capacity, fuel pressures	Competition, getting product overseas	Industry-wide consolidation
James	Different supply chain structures for different customers, number of retail outlets, DCs, SKUs	Having the stuff that customer wants	Not mentioned	Global cultures	Multiple mergers and spin-offs, fully owned subsidiaries to integrated units
Charles	Number global distribution locations, manufacturing centers (Asia, Mexico, Eastern Europe), SKUs, ship-to points	Poor customer service is expensive	Not mentioned	Infrastructure, government regulations, cultural clashes between receiving and shipping plant	Not mentioned
Gary	Number carriers, lanes, ship-to locations, DCs, types of commodities handled	Understanding customer requirements is difficult	Changes in domestic economy, risks, market uncertainties, competition	Transitioning from import-heavy to export-heavy business	Not mentioned
Strategic moderators					
Participant	*Scope and boundary management*	*Cultural alignment, integration, and relationship management*	*Eliminating non-value-added steps*	*Information systems strategy*	*Knowledge management*
Peter	Outsourcing, limiting the scope of a person's responsibility	Cross-functional and cross-organizational integration	Process change and process re-engineering, streamlined internal processes	Poor information system integration, too many systems, no one person understands the complete system	Formal documentation
Rob	Whether to locate assets within or outside the company	Suppliers bring expertise, they are closely integrated, committed to each-other's success	Invent newer efficient processes	Move from local to system optimization using information	Formal documentation for processes such as supplier approval, product audit, changes to product
Kevin	Not mentioned	Integration with suppliers such that they move globally with the company	New processes within existing factories, replacement of processes in existing factories, excessive fear about risks introduces redundant processes	Coordination of capital spend	Institution knowledge of a supplier and their technical capabilities needs to be documented; documents product and site audit processes exist
Tim	Do not perform all activities at the central US DC-perform some at the specific country DC	Not mentioned	Solid processes, automated DCs	Robust information systems, technologies such as telecommunication systems, internet, EDI, optical character recognition	Process excellence tools require data and expert opinions to make decisions

(*continued*)

Table VI.

Tyler	Fixing the number of supply countries	Developing relationships outside the boardroom	Agile and efficient processes	Linked suppliers and customers	Not mentioned
Bill	Not mentioned	Not mentioned	Automating order entry, reducing human intervention	Using web-interface for customer self-service, reliability of systems, spend a lot of time flushing our inaccuracies	Not mentioned
Tony	Decide on most important performance metrics	Work collaboratively	Six sigma, process discipline, process mapping	Availability of modeling tools	Not mentioned
Matt	Not mentioned	Supply chain software provider culturally aligned with the company, developing strategic relationships	Process management	Using available information, optimization techniques, selection of software provider, need for more sophisticated demand management and inventory planning	Not mentioned
James	Focus on core SKUs that generate maximum profitability, driving commonality between SKUs for different customers, number of supply chain roles performed, number of components	Cross-functional integration, supplier relationship management, work collaboratively with suppliers, customers, operations, and finance	Finding the most efficient and effective process and structure to get the outputs, discipline for process execution	Create a foundation of information, have complete information, enable integration	Key process documentation, documenting the best process to get a key output, well-defined processes
Charles	Within company structure-decentralized versus centralized, reporting matrix (accountability and responsibility), DC consolidation	Alignment and integration with suppliers	Broken processes, inconsistent processes, variability in processes	Lack of data, no information, better measurement systems, IT team important for success	Building and documenting sustainable, repeatable processes
Gary	Outsource personnel/HR management	Working closely with customers, continually transitioning customer base	Make supply chain leaner and faster	Data critical for decision making, information systems create competitive advantage, replace inventory with information	Not mentioned
Human cognitive abilities and tactical moderators					
Participant	*Experience*	*Training*	*Problem understanding*	*Buffers*	*Flexible workforce*
Peter	Experience in managing changes over and above functional knowledge	Training in cultural, emerging economic issues, training in latest tools and processes	Handful of key people who understand the critical problem	Inventory	Multi-skilled, multi-trained people

(*continued*)

Table VI.

Rob	Operationally excellent people with experience	Technical capability, train customers' employees to assemble products	Understand root cause of the problem, hire the right people	Multiple suppliers	Need for people who can serve in different functions
Kevin	Not mentioned	Training new operators to run processes is a monumental but need tasks	Engineers and procurement have to work together to understand the complete problem	Manufacturing capacity, important to redistribute buffer capacity periodically, lack of buffers leads to inability to handle interruptions or uncertainties	Not mentioned
Tim	Job getting easier because of experience	Not mentioned	Having good people with process knowledge, people who understand the bigger picture	Inventory between the company and end customer	Multi-tasking
Tyler	Experience enables better decisions	Not mentioned	Having people with good understanding of the problems	Capacity, inventory	People who can work in and understand multiple functions
Bill	Experience needed to make decisions with incomplete data, experience leads to risk-taking	Training to impart new skills, multi-trained employees	Go to people who understand the problem	Inventory	Extremely flexible workforce
Tony	Important for modeling logistics problems	Not mentioned	Capable people, intellectual capability, problem solvers, need a savvy logistician to ask the right questions	Not mentioned	Not mentioned
Matt	Fill some positions in-house as they are more company specific	Training people with capability to learn skills, take human resource to next level of sophistication	Analytical people	Lot of inventory because of lack of visibility	Not mentioned
James	Learn from experience	Not mentioned	Bringing right people for the job	Inventory	Multi-skilled people
Charles	Understand very quickly	Send young "foot soldiers" along with experienced teams to field to train on-the job	Quickly conduct baseline analysis, right people who can be in-charge, people who understand a function very well	Inventory	Regional leaders who understand different functional processes

(*continued*)

Table VI.

Gary	Quicker, efficient, and better problem solving	Training for DC staff important for efficient functioning, training staff on new technologies	Matching personality types to problems		Labor, material handling equipment		Flexible workforce in DC	
Outcomes								
Participant	*Total cost*	*Transaction costs*	*Cycle time*	*Quality*	*Outbound delivery*	*Inventory turnover*	*Internal uncertainty*	*Reserve capacity requirement*
Peter	X	X	X	X	X	X	X	X
Rob	X	X	Not mentioned	X	Not mentioned	X	Not mentioned	Not mentioned
Kevin	X	Not mentioned	X	X	Not mentioned	Not mentioned	Not mentioned	Not mentioned
Tim	X	X	X	Not mentioned	X	X	X	X
Tyler	X	X	X	X	X	X	X	Not mentioned
Bill	X	Not mentioned	X	X	X	X	X	X
Tony	X	Not mentioned	X	X	X	X	X	X
Matt	X	X	Not mentioned	X	X	Not mentioned	X	X
James	X	X	Not mentioned	Not mentioned	Not mentioned	X	X	Not mentioned
Charles	X	Not mentioned	X	X	X	X	X	X
Gary	X	X	Not mentioned	Not mentioned	Not mentioned	X	X	Not mentioned

Notes: DC, Distribution center; SKU, stock keeping unit

Respondents also identified network structure and size (number and type of interconnected facilities, technology and process interfaces, transportation modes and shipping lanes, and the geographical dispersion of facilities) as related to size and structure. This is in agreement with the objective complexity measures suggested in the literature and concurs with mathematical complexity theory, where in the worst case, computational requirements for solving network design problems increase exponentially with the number of potential facility locations, echelons and product types (Garey and Johnson, 1979). Respondents also referred to the disproportionate increase in complexity as the supply chain size increased. One respondent, Matt, describes the impact of network size as follows:

> Many points of origin, points of manufacture and ultimately those products have to get to a customer or consumer destination that can be a very complex problem to work out.

Another talked about SKU by location in discussing supply chain size and structure:

> Well, I would say that the biggest element of complexity would be the SKU by location [. . .] If you have 10,000 SKUs at 10,000 locations, then you have 10,000 times 10,000 combinations.

Based on these observations, we propose the following:

P1a. There is a positive relationship between supply chain size and structure and supply chain complexity.

Customer expectations. Customer expectations emerged as an important complexity antecedent. Managers indicate that increased customer expectations in terms of wider product offerings, shorter product life cycles, higher service levels, and reduced cost are supply chain complexity drivers. Higher customer expectations place more stringent performance standards on supply chain processes and may lead management to investigate new processes or partner relationships capable of meeting these ever-changing customer expectations. Although the literature refers to number and location of customers as a driver of complexity, "customer expectations" emerged as a new antecedent in this study. This antecedent broadens the supply chain complexity definition to consider more than supply chain size related dimensions. An interviewee, James, in discussing how customer expectations impacts job complexity, stated the following:

> The complex challenge of retail distributor is making sure you've got the stuff your customer wants.

Professionals also pointed out to those things that they do in order to make things simpler or less complex for their customers, but things that increase their supply chain complexity. Tim states:

> Less complex would be probably not consolidating (*the distribution function for several companies within an organization*); it would be more costly. I think it would be simpler to operate from an internal perspective [. . .] but externally our customers wouldn't see it as simple, they would actually see it as making their life more difficult as they will have to place separate orders with each of the 50 or so different companies.

Based on these observations, we propose the following:

P1b. There is a positive relationship between customer expectations and supply chain complexity.

Environmental conditions. Environmental conditions such as dynamism, munificence, hostility and heterogeneity (Aldrich, 1979; Dess and Beard, 1984; Miller, 1987; Ward *et al.*, 1995) surrounding a supply chain increase uncertainty due to lack of information or inability to predict future events, which consequently increases supply chain complexity. Environmental factors such as industry structure may sometimes impose additional constraints (Sohal and Perry, 2006).

The types of environmental conditions most often identified by the respondents include technology changes, natural disasters, and business risks. Specific examples are unexpected increases in fuel prices, cost pressures, capacity limitations in transportation, and supply shortages. Bill described an unforeseen industry-wide supply shortage as a complexity driver:

> So, to give you an example, the explosion of phones. Most of the phones today have some sort of LCD crystal on it. Well that wasn't the case several years ago. And, so now when we're looking at demand and supply in the market, we found a couple of years ago, we got into some problems with the supply chain because the phone market was sucking up a lot of the technology or LCD capacity…you know, we buy the LCDs from somebody else, we didn't perceive being a shortage globally because of cell phones which we don't do anything with.

This illustration links to decision-making theory where the existence of unknown paths leading to a desired outcome increases task complexity (Campbell, 1988). However, the corollary proposed by this example suggests that removing the paths to a desired output may also increase complexity. In this particular example, the supply chain is also prone to the "shortage gaming" (Lee *et al.*, 1997a, b) among competitors competing for scarce capacity, which further amplifies supply uncertainty.

Other types of environmental conditions that respondents identified as drives of complexity include economic factors and weather related events such as hurricanes, floods, drought, or inclement winter weather as illustrated by Matt:

> […] what I think is, it's not as big of a problem from day to day logistics perspective whenever the economy is just kind of moving along okay and, not really growing substantially and not really declining substantially. But, anytime you have a major spike in terms of either economic activity or as we've seen here recently with the hurricanes, a major supply shock or capacity shock, it really hits us hard.

Based on these observations, we propose the following:

P1c. There is a positive relationship between adverse environmental conditions and supply chain complexity.

Globalization. The participants cited global supply uncertainty, import quotas, currency fluctuations, lack of standards/common terminology across firms in different regions, and long lead-times as supply chain complexity drivers. Globally intense supply chains are more difficult to manage than domestic supply chains due to different cultural norms, business and technology standards, economic and political conditions, regulations, language barriers, and other geographical issues. Tony illustrates some of the specific challenges associated with global supply chain management:

> When you are dealing with international trade, certainly it introduces currency risk and country risk issues, infrastructure constraints, much as what we've seen in the last several years across the Pacific. For example, the port of Los Angeles, Long Beach is highly congested. Costs are going up; booking ships is becoming more and more difficult. There are delays

> at the Port sometimes two or three weeks. That, in turn, is driving up safety stock, fuel surcharges are driving up transportation costs and obviously it is more of a supplier power market now, as opposed to a buyer power market. So, as you move internationally, the complexity goes up considerably.

Based on these observations, we propose the following:

P1d. There is a positive relationship between globalization and supply chain complexity.

Organizational restructuring. Participants specifically identified organizational restructuring due to mergers, acquisitions and consolidations as a leading cause of supply chain complexity. As James describes:

> [*Company M*] is the result of some acquisitions and sales in [*month, year*]. [*Corporation N*] purchased M for X billion dollars in cash and stock. And then, [*a year later*], N sold off three of the four sectors of the company to [*Company O*] for Y billion. And then [*a month later*] de-listed N from the New York Stock Exchange and became M which is now a Z billion dollar company. So, the company itself is a Z billion dollar startup with retail business and contract business. The role that I was recruited for was to put together a single supply chain that would service these two channels, almost 1,000 retail stores and contract business.

Johnsson *et al.* (2007) provide an interesting case study of a merger between multiple farmer cooperatives into one cooperative and associated complexity in advanced planning systems for the supply chain. Organizational restructuring often requires re-optimizing SKU offerings, network structure, and creating, modifying, or eliminating processes for the combined firms (Harrington, 2006). Proctor and Gamble's acquisition of Gillette provides an example, where P&G had to incorporate 100,000 customers, 50,000 SKUs and $11 billion in revenue into a single order entry system and a common distribution platform (Cooke, 2007).

Several managers also indicated the need for organizational restructuring over time as the firm or business environment evolves. For example, James says the following in discussing his team's effort during his firm's re-organization:

> SKU management, forecasting, product transition, the sophistication, supplier management, you know, each of these have a crawl, walk, and run component.

Based on these observations, we propose the following:

P1e. There is a positive relationship between organizational restructuring and supply chain complexity.

4.2.2 Impact of supply chain complexity on supply chain decision-making complexity. Increased supply chain complexity requires more effort for problem definition, data collection, problem analysis, solution implementation and control. Therefore, we propose:

P2. In the absence of moderating variables, there is a positive relationship between supply chain complexity and supply chain decision-making complexity.

Supply chain managers face an almost infinitely complex managerial task. In order to decrease the potential adverse impact of supply chain complexity on decision making, organizations employ complexity moderators (March and Shapira, 1987). For example, two supply chains facing similar objective supply chain complexity (i.e. sourcing from

a similar set and number of suppliers and serving a similar set and number of customers) may manage complexity differently. One supply chain may have better information systems or more experienced and better trained executives that can apply more effective strategies and as a result, experience reduced supply chain decision-making complexity. Similarly, one of our participants, having worked in both electronics and building products industries, found that supply chain complexity (objective complexity) was much higher in electronics than building products industry, while building products industry experienced increased levels of supply chain decision-making complexity due to lack of sophisticated systems and skilled workforce.

Two categories of moderators that moderate the impact of supply chain complexity on supply chain decision-making complexity emerged in the field research: strategic moderators and human cognitive ability moderators. Strategic moderators are strategic business initiatives that reduce decision-making complexity. Human cognitive abilities enhance managerial understanding of complex problems and facilitate decision making.

4.2.3 Strategic moderators. Literature suggests business strategies as moderators of complexity (Perona and Miragliotta, 2004). The remainder of the section discusses specific strategies that emerged in our study for moderating supply chain decision-making complexity.

Scope and boundary management. Effective supply chain management requires integrating various business functions, organizational units and channel partners such that each has a well-defined role in accomplishing system objectives. Complexity theory indicates that the greater the number of inputs associated with a decision problem, the higher its decision-making complexity is. In the supply chain domain, these inputs could include the number of suppliers, inbound raw materials and component parts required to build a product, final consumers, ship-to-locations, distribution levels, distribution mediums/channels of trade, SKUs and orders/transactions, etc. One mechanism for moderating supply chain complexity is by controlling the problem size facing each decision maker through scope and boundary management. This is accomplished by partitioning the supply chain management activities and processes among the multiple players (hopefully in a mutually agreed, aligned and coordinated way), each with a restricted decision-making scope and boundary.

A firm can also control problem scope by limiting the number of SKUs or shipping points under a decision maker's control. This is achieved through scope management by assigning a subset of SKUs to a particular manufacturing or distribution facility, and using geographic and product focused factories, among other strategies. For example, 30,000 components coming from 200 suppliers, 1,000 products distributed to 500 customers, and involving ten global manufacturing locations describes supply chain complexity antecedent of supply chain size and structure. However, a production manager when faced with a production allocation decision problem may choose to allocate manufacturing of one product to no more than two manufacturing locations worldwide, thereby reducing his supply chain decision-making complexity by using scope and boundary management strategy.

Similarly, following their acquisition of Gillette, Proctor and Gamble applied boundary and scope management by piloting system integration in Latin America prior to undergoing global integration. This limited the scope of the integration activities and associated problem complexity until they gained managerial experience with the problem (Cooke, 2007).

Based on the observations, we propose the following:

P3a. Scope and boundary management is a strategy for reducing supply chain decision-making complexity.

Cultural alignment, integration, collaboration and relationship management. James described the importance of cultural alignment among channel members as a moderator of supply chain complexity:

> When we look for business partners, what we see when we interact with them, we want, kind of what you see is what you get. And that's kind of the company that we are, pretty straight forward and honest. I think if you do a good job of aligning your company's culture and view of things, it's pretty simple, but I think it makes for at least a foundation of a strong lasting relationship.

Organizational culture plays a facilitating role in building relationships both within the firm and across firms (Stock, 1996; Anderson and Coughlan, 1987). Respondents identify business strategies promoting channel integration and collaboration as moderators of supply chain complexity. A manager with experience in both the electronics and building products industries discussed this issue by comparing channel linkages in the two industries. He indicated that many people assume that supply chain management is more difficult in the electronics industry than in the building products industry due to the complexity of the environment as the result of a larger number of parts, components required for the final product as well as the global sourcing dimensions of the industry. However, James clarified this misperception by explaining that the higher level of channel integration and collaboration in the electronics industry provides a more manageable supply chain environment:

> Customers, suppliers, manufacturers [. . .] I think it's so much more integrated and engrained in the culture in the electronics industry versus this (building products) industry [. . .] being able to integrate not only relationships but also information, the electronics industry is so much further along.

Collaboration is an interdependent relationship, where parties work closely with each other to create mutually beneficial outcomes (Sinkovics and Roath, 2004). Integration takes it a step further and brings together external (i.e. supply chain activities across firm boundaries; Stock *et al.*, 1999) and internal activities and processes (i.e. activities, processes across departments/functional areas; Kahn and Mentzer, 1996). Integration, combined with collaboration, reduces duplication and redundancy (Rodrigues *et al.*, 2004) and leads to improved firm performance (Stank *et al.*, 2001). The field study adds to the literature base by suggesting that integration leads to reduced decision-making complexity.

Realizing that not all relationships are equally important, building long-term relationships with key channel partners is viewed as an effective strategy for moderating supply chain complexity and streamlining supply chain processes. In discussing complexity and its implications, Matt emphasizes the importance of developing relationships as follows:

> (*Being more sophisticated at doing business involves*) [. . .] not only identifying where it makes the most sense to manufacture our products but also how to efficiently get them from A to B and sometimes that means, developing a new strategic relationship with a distributor, or maybe ending some relationships that we had that don't provide value.

Integration emerged as a common theme across the interviews. Charles compared relationship management and integration at his current and prior employer indicating that tighter integration simplifies supply chain processes. He described supplier relationships as an example:

> We haven't taken our suppliers with us as we've expanded into the emerging regions; so your suppliers are back in the old process. Initially when they did the modeling on the emerging regions, they failed to take into account freight compliance and logistics cost. So they took just labor rates, most of the driving force. And they didn't look at moving the rest of the supply chain with the process. At [*the participant's previous employer*] they moved the supply chain so suppliers came, as the manufacturing moved to North America, the supplier came. So, that was very complex, I had 15,000 mile- long supply chain to manage. However, it was pretty standard; we were able to, through the course of time, to standardize the process down to within 15 minute window times, on 8,000 miles of supply. And so, it was pretty interesting that we could go to 15 minutes [. . .].

Relationship management is at the forefront of successful supply chain management initiatives. Today's dynamic environment requires building close relationships among channel members, customers and other business parties (Zineldin, 1998). Changes in technology, political, social and legal environments, competition, social values and attitudes, beliefs, and changing lifestyles are all believed to add to supply chain complexity. Perona and Miragliotta (2004) argue that relationship management is a lever to reduce this complexity. Sturgeon *et al.* (2008) support Perona and Miragliotta (2004)'s findings with a similar argument. Sturgeon *et al.* (2008) argue that increased product complexity in the auto industry, as an example, has been driving the buyer-supplier relationships from a transactional relationship to a more relational form of governance.

Based on the results of the field study and literature review, we propose the following:

P3b. Cultural alignment, integration, collaboration and relationship management are strategies for reducing supply chain decision-making complexity.

Eliminating non-value-added steps. Eliminating non-value-added steps in supply and distribution channels simplifies supply chain processes, reduce costs, and lower managerial complexity. Examples of eliminating non-value-added steps that emerged in the study include direct shipment of high volume products from suppliers to customers instead of routing all products through internal distribution centers (DCs), automating order entry processes to reduce human involvement, automating DCs, and integrating information systems to facilitate single data entry for all supply chain processes. The following quote by Bill is illustrative:

> Today we sell product through the web, we sell product over the phone, we sell product three or four different ways. If everything was a web-order, and has very little human touch, that's a whole lot less complex than answering phone calls, trade shows.

Participants used terms such as "solid process" to describe the value of process management in removing redundant activities. They suggested applying continuous process improvement strategies (e.g. Six Sigma, Total Quality Management, and ISO Certification) to design robust, repeatable, and efficient processes. Inventing newer, agile, and efficient processes to achieve the desired outputs was mentioned in most of the interviews. One manager made an interesting observation that too much risk aversiveness leads to redundant processes.

Based on the interview findings, we develop the following proposition:

P3c. Eliminating non-value-added steps is a strategy for reducing supply chain decision-making complexity.

Information systems strategy. The interviewees referred to information systems strategy of a company as the collection of relevant technologies and skilled staff leading to the development of capabilities that assist a team or a manager in making better, quicker decisions, and implementing supply chain strategy. Unique information technology capabilities are argued to create or improve competitive advantage (Porter and Millar, 1985). Swink and Robinson (1997) indicate the potential role of DSS as complexity moderators for reducing decision-making complexity when designing facility networks. A similar theme emerged in this field study, where the availability of timely, accurate and relevant information is viewed as an important moderator of supply chain complexity. However, participants stressed that information systems must be integrated and aligned with global supply chain processes in order to effectively reduce decision-making complexity. Tony talks about the limitations of poorly integrated and unreliable information systems that lead to increased decision-making complexity for supply chain managers:

> It's not necessarily that we're missing the information, it's just that we're not analyzing the information, the information is too overwhelming for a person, or a piece of paper or a spreadsheet to be able to handle. In terms of production costs, logistics costs, what it costs for specific lanes, how to apply appropriate surcharges in certain lanes, certain areas. I think being able to get to the detail, we're kind of handicapped right now because we don't have the technical horsepower to get there.

Peter emphasizes it in a similar way:

> Often times the systems that we're assessing and getting involved with are legacy systems with a large number of interfaces and in many cases the processes are not well-documented; they are just understood within an organization.

Consistent with our findings, Bozarth *et al.* (2009), in their study of manufacturing firms found that increased number of suppliers, parts, products, and customers do not affect manufacturing performance and propose that information technology might be the reason. Our study provides empirical evidence for their conjecture. Participants identified technology advancements in areas such as enterprise resource planning systems, supply chain analytics, advanced planning systems, geographic positioning systems, and radio frequency identification as potential applications for reducing supply chain decision-making complexity. The interview participants also emphasized the importance of an information systems strategy as going beyond information processing and reliability issues. They indicated that higher levels of information technology investment were not always necessary and added that information systems strategy was about both appropriate strategy and technology investment. As pointed out by one of the participants, the problem is not necessarily the availability of information, but rather the overwhelming amount of information. The problem cannot be handled only by additional investment, but rather, appropriate information systems strategy and well-trained people. This discussion suggests that information systems strategy is a moderator of supply chain complexity. We propose the following:

P3d. Information systems strategy is a strategy for reducing supply chain decision-making complexity.

Knowledge management. The study participants discussed knowledge management as the documentation, organization and storage of business-process information, managerial and group experiences and sharing of those experiences within an organization with other managers and groups. Managers, with availability and easy access to organizational knowledge, can quickly identify the key considerations in making a decision, thereby reducing the number of constraints they need to actively consider. Study participants also indicated that due to improper business process understanding and documentation, a firm may lose significant knowledge when key employees depart the firm or are transferred to new positions. In addition, information transfer was virtually impossible during mergers and acquisitions when processes were not documented. The loss of business knowledge increases managerial complexity. As Peter said:

> In many cases the processes are not well documented; they are just understood within an organization.

Rob says:

> (*My strategy*) is to introduce structure and make decisions as quickly as possible, but make many small ones so you can learn and correct.

Practitioners suggested establishing formal process documentation procedures as complexity moderators.

Based on the above discussion, we propose:

P3e. Knowledge management is a strategy for reducing supply chain decision-making complexity.

4.2.4 Human cognitive abilities. Human abilities, which are anchored in human cognitive processes gained through natural intellect, experience, training, and/or consultancy, are thought to mitigate supply chain decision-making complexity. When faced with a difficult problem, cognitive processes often allow humans to effectively and efficiently discard poor alternatives and focus attention on a smaller set of alternatives that can potentially lead to a satisfactory although not necessarily optimal solution. Extant literature provides some support for this moderator. For example, Swink and Robinson (1997) identify human cognitive processes and DSS as complexity moderators, where DSS is a component of the firm's information technology strategy.

In the field study, managers frequently indicated that a clear understanding of the business, processes, and systems, both within and across the firms, helps them manage supply chain complexity. One respondent emphasized the importance of business and system knowledge that he gained through prior experience when redesigning a supply chain's network strategy. Supply chain training programs and hiring experienced consultants are other common practices for moderating the perceived complexity of the decision-making problems facing management. The following quotes from Charles and Tim, respectively, further illustrate the point:

> We just learn from experience. I have certain things I go in now and look for, a little recipe and I understand very quickly what the size or magnitude of the issue was.

> I wanna say it's (*my work is*) getting easier because we're getting better at it just through experience.

Based on the research findings and theoretical support from the literature, we present the following propositions:

P4a. Experience is a human cognitive ability moderator for reducing supply chain decision-making complexity.

P4b. Training is a human cognitive ability moderator for reducing supply chain decision-making complexity.

P4c. Problem understanding is a human cognitive ability moderator for reducing supply chain decision-making complexity.

4.2.5 Outcomes of supply chain and supply chain decision-making complexity. Supply chain and supply chain decision-making complexity yield outcomes that may be planned or unexpected and/or undesirable. The unexpected outcomes often relate to supply chain inefficiencies that result in higher costs and/or lower customer service levels. The study participants could identify the outcomes of supply chain and supply chain decision-making complexity but had difficulty quantifying the impact. The most frequently cited adverse consequences of complexity include higher total cost, higher transaction costs, longer cycle times, inconsistent incoming material quality, poor outbound delivery performance, lower inventory performance, higher internal uncertainty and greater reserve capacity requirement.

A professional from the electronics industry, Bill, indicated that his job is getting more difficult and listed the following as one of the outcomes of this increased supply chain complexity:

> Well, customers get things later than anticipated. We also have the opportunity for more missing wrong or damaged shipments.

An in-house logistics consultant, Tony, mentioned lower inventory turns as an undesired outcome of supply chain decision-making complexity:

> (*As a result of supply chain decision-making complexity*), inventory velocity is not what it should be, fill rates and service is not what it should be.

Respondents also indicated that supply chain complexity and the associated decision-making complexity increases the need to maintain reserve capacity and thereby increases costs. Overall, the suggested cost and service outcomes related to supply chain and supply chain decision-making complexity are fairly consistent across participants and receive support from the literature. Participants also identified internal uncertainty as an unexpected outcome of system complexity. Internal uncertainty arises from firm-specific factors such as labor unrest, machine failures, and confused lines of responsibility. Matt provided an example of internal uncertainty resulting from the inability to coordinate demand factors with manufacturing decisions:

> I think there is a lot that we can do in our company to be able to more efficiently know where to make products, at what mills as well as, you know how to get them most effectively from Point A to Point B." He also adds, "You know, we haven't really put order to that chaos [. . .] in many sense we don't have a central view of manufacturing capacity compared with demand. Compared with the location of where that demand ultimately ends up.

Outcomes of supply chain decision-making complexity imply the inability to effectively plan and execute supply chain processes. For instance, estimating profitability at the customer level becomes more difficult as supply chains become more complex (Niraj, 2001). The literature also argues that complexity can weaken brand image, lower brand loyalty, stagnate category management and disturb channel trade relations (Quelch and Kenny, 1994) and reduce supply chain adaptability (Masson *et al.*, 2007; Davis, 1993). Therefore, the role of the strategic and human factor moderators to reduce decision-making complexity and thereby reduce the unplanned and unwanted outcomes of supply chain complexity becomes more critical.

Based on the responses of the participants and the literature findings we propose the following:

P5a. There is a positive relationship between supply chain complexity and unexpected and/or undesirable outcomes.

P5b. There is a positive relationship between supply chain decision-making complexity and unexpected and/or undesirable outcomes.

4.2.6 Tactical moderators of supply chain complexity outcomes. While firms apply strategic moderators and human cognitive abilities to reduce supply chain decision-making complexity facing management, they also employ tactical moderators to minimize the undesirable outcomes resulting from the remaining managerial complexity. Typically, several different approaches are used to moderate outcomes and they all aim at increasing system flexibility. In order to deal with supply shortages, for example, many firms work with multiple suppliers, which increase their supply chain flexibility by providing access to a broader technological/supply base. As defined by Upton (1994), flexibility is the ability to change or react with little penalty in time, effort, cost or performance.

Building buffers (which might be in the form of keeping reserve capacity, safety stock, equipment and such) and developing a flexible workforce are the two specific strategies that the supply chain managers identified as tactical moderators for reducing undesirable outcomes.

Building buffers. Buffers, such as extra capacity (labor, space, machinery, equipment, systems, time, multi-sourcing, etc.) or inventory (raw material, semi-finished, and finished goods), provide a hedge against operational, demand, and other environmental uncertainties, and thereby reduce undesirable outcomes of supply chain decision-making complexity. The following quotes by Bill are illustrative:

> It (*not having buffer inventory*) makes it more difficult. In the traditional models, you've got all these stacks of inventory in certain places that lets you eliminate, or lets you absorb a bunch of variations.

> There is an accordion effect in inventory, then if we oversell a particular product line one day, there is a buffer inventory between us and the customer that enables us to, you know, catch up.

One manager added to this discussion by talking about how they need to rely on inventories when a customer runs a promotion and creates an unexpected surcharge without prior notice.

However, most participants identified the additional costs associated with maintaining buffer. Bill, in reference to their "zero buffer inventory" policy, made the following statement:

> It (*no inventory*) is the only way to do it because our cost structure is about 15 percentage points lower than our competition because of it. Our cost structure is inherently advantaged over our competition.

He also added that even though they did not maintain buffer inventory, his company maintained surge capacity (process flexibility) in the form of extra assembly lines that were staffed when necessary.

Sivadasan *et al.* (2002) suggested the use of excess capacity and inventory as a tactic to absorb complexity between scheduled and planned production within a firm. Our finding provides empirical evidence to Sivadasan *et al.*'s (2002) finding and extends their finding from a "firm" to a "supply chain" context. It is clear that one needs to be careful in using buffers as they can be an expensive waste of limited resources if made available in the wrong form (Horman and Thomas, 2005; Bozarth *et al.*, 2009). Based on the discussion, we propose the following:

P6a. Buffers such as extra capacity or inventory are tactical moderators for reducing undesirable outcomes of supply chain decision-making complexity.

Flexible workforce. The interviewees also believe that workforce flexibility can help mitigate the counter-productive outcome of supply chain decision-making complexity. As Bill illustrates:

> (*To manage complexity*) you have to have an extremely flexible workforce that's trained to do more than just, you know, one job.

Some managers were more specific in what kind of workforce flexibility they needed. For instance, several managers expressed the need for trained personnel that could handle the complexity of documentation and procedures since many companies today need to have a better understanding of the initiatives such as Customs Trade Partnership Against Terrorism or the strict requirements of Sarbanes Oxley. Other participants indicated that they would like their workforce to have good interpersonal and multi-tasking skills in addition to their job-related skills and knowledge. Tim described the importance of having multiple skills as follows:

> Being able to multi task is critical. I find that sometimes when we have people that come from a manufacturing or an engineering environment, to come into a distribution environment, very dynamic, but their strength is not multi tasking. They very much would like to stay in one project, but there's just too much activity and every day is a new day, and you need people to understand the bigger picture, the bigger process, have great inter-personal skills, and, you know, can understand cause and effect relationships between the front end of the process and the back end to make adjustments throughout the day.

The literature also suggests that a flexible workforce is a significant source of competitive advantage (Autry and Daugherty, 2003; Kathuria and Partovi, 1999). Similarly, Christopher (2000) finds that a well-developed human resource strategy that leads to multi-skill development and encourages cross-functional working helps mitigate supply chain complexity and enhances supply chain agility. The following proposition captures the research findings:

P6b. Flexible workforce is a tactical moderator for reducing undesirable outcomes of supply chain decision-making complexity.

4.2.7 Relationships between the elements of the model. While exploring the relationships between the antecedents, moderators, type of complexity and outcomes, we found that specific moderators were more relevant for managing the impact of certain types of antecedents. These relationships are summarized in Table VII. The first column lists the antecedents. The second column provides a list of moderators that are most relevant for managing supply chain complexity that results from the antecedent listed in the first column. The third column presents the outcomes that are most influenced by the moderators presented in the second column.

5. Conclusions

The past 20 years witnessed a broadening of managerial responsibility from a functional focus in the 1980s to an enterprise focus in the 1990s to a supply chain focus in the 2000s. At the same time, the business environment expanded globally, customers' expectations increased in terms of product variety and service, technological innovations shortened product life cycles, organizational and network structures became more dynamic, and market and logistics uncertainties increased risks. These changes increased the magnitude of problems facing supply chain managers and increased managerial efforts to "put order to chaos." The growing importance of this challenge is articulated by a VP of supply chain operations for a leading multinational company:

> If you are in supply chain management today, complexity is like a cancer that destroys supply chain efficiency and one that you have to fight (Gilmore, 2008).

Antecedent	Most relevant moderator	Most relevant outcome
Supply chain size and structure	Scope and boundary management	Total costs
	Cultural alignment, integration, collaboration and relationship management	Cycle time
		Incoming material quality
	Information systems strategy	Transaction costs
		Internal uncertainty
		Reserve capacity requirement
Customer expectations	Eliminating non-value-added steps	Outbound delivery performance
		Reserve capacity requirement
	Information systems strategy	Internal uncertainty
Environmental conditions	Scope and boundary management	Reserve capacity requirement
	Knowledge management	Internal uncertainty
	Building buffers	Reserve capacity
	Flexible workforce	
	Information systems strategy	
Globalization	Scope and boundary management	Outbound delivery performance
	Building buffers	Reserve capacity requirement
	Flexible workforce	Internal uncertainty
	Reserve capacity	
Organizational restructuring	Scope and boundary management	Total costs
	Cultural alignment, integration, collaboration and relationship management	Cycle time
		Incoming material quality
		Transaction costs
	Knowledge management	Inventory turnover
	Information systems strategy	Reserve capacity requirement
		Internal uncertainty

Table VII.
Relationships between the elements of the model

This research study has several implications for both theory and practice, and provides several future research directions.

5.1 Theoretical implications

While there is an emerging literature on supply chain complexity, it is highly fragmented, investigates only a small subset of the complexity drivers identified in this research, and has a predominant focus on task complexity while ignoring decision-making complexity. It is only in the network design laboratory studies by Robinson and Swink (1994) that the relationship between task complexity, complexity moderators, and decision-making complexity begin to emerge. The literature lacks a comprehensive, agreed-upon model describing supply chain complexity and its relationship to supply chain decision-making complexity. Such a model would embrace a panoramic view of the multitude of decisions facing today's supply chain manager. This research begins to fill this void by applying grounded theory research methodology to capture the perceptions of senior supply chain managers and synthesize them into an integrated model of supply chain and supply chain decision-making complexity. The model is rooted in industry practice and corroborated by theoretical models in the supply chain, complexity theory, and cognitive process literature. The model identifies and ties together the concepts that exist in the literature in a disparate form.

The theoretical model emerging from this research provides the antecedents of supply chain complexity, business strategies and human cognitive abilities for moderating the degree of decision-making complexity experienced by managers, the undesirable outcomes resulting from immitigable complexity, and tactical moderators for mitigating the unexpected/undesirable outcomes. The research identifies new concepts that have not been explicitly linked to supply chain complexity (e.g. customer expectations as a supply chain complexity driver; scope and boundary management as a strategy), further elaborates those already discussed in the literature in various contexts (e.g. information systems strategy and knowledge management), and provides meaningful ways of managing complexity that go beyond the generic prescriptions of the literature. The research also provides clear and succinct definitions of supply chain complexity and supply chain decision-making complexity, and links complexity drivers to the most relevant moderators and the outcomes that are highly influenced (as presented in Table VII). Overall, the model provides an integrated and fresh approach for viewing supply chain complexity and understanding its impact on supply chain decision-making and supply chain performance. As such, the model provides a platform for additional research and a paradigm for improving supply chain management.

5.2 Managerial implications

The research findings redefine the supply chain managers' role as one of managing complexity. That is, how to best "put order to chaos." Many supply chain professionals realize and experience the negative outcomes of complexity, but are unable to always see the true cause. Often times, they blame poor execution of strategies as the driver of complexity, when in fact, it is the lack of understanding of the drivers and sometimes the poorly designed strategies that result in complexity and unwanted outcomes (Gilmore, 2008). The supply chain complexity model puts the components of the problem into focus.

Managing the supply chain complexity antecedents provides the starting point for complexity management. Not all the sources of complexity are necessarily bad and

therefore, need not always be eliminated (Bozarth *et al.*, 2009). Companies often accept increased supply chain complexity in an attempt to achieve corporate profitability goals. One needs to understand the source of complexity that is usually tied to corporate goals and manage it so that unintended outcomes do not materialize and stand in the way of accomplishing the corporate goals. For example, consider product line management. New products are often launched in an attempt to remain competitive and gain market share but adequate consideration is not given for discontinuing slow sellers. Hence, the anticipated profitability gains may not materialize due to SKU proliferation which places an undue burden on supply chain management effectiveness. Simplifying product design and standardizing product components, taking advantage of a platform product strategy and following a stage-gate process to systematically eliminate slow-movers from the product line are other avenues for managing product related supply chain complexity. Therefore, new products can be a good source of complexity if the appropriate strategies are in place to mitigate the negative consequences of complexity. Similarly, strategies for simplifying network structure, global expansion, organizational restructuring and other complexity antecedents are early control points for managing supply chain complexity.

While effective complexity antecedent management can reduce supply chain complexity, it can never eliminate it. Hence, managers must use strategic moderators to mitigate the adverse impact of complexity on decision making and system performance. Technology advancements in areas such as enterprise resource planning, supply chain analytics, advanced planning systems, geographic positioning systems, and radio frequency identification, among others, are enabling novel applications of information technology to reduce supply chain complexity. Similarly, active management of other strategic moderators provides an avenue for improved supply chain performance.

Complexity must be managed internally as well as externally and interactively. However, the majority of the emerging model factors relate to external or inter-organizational factors. This finding is not completely surprising considering that there is a propensity to think in terms of multiple organizations or inter-organizational relationships when considering supply chain management. Several intra-organizational factors such as scope and boundary management, and knowledge management provide two examples of intra-organizational factors that emerged in the theoretical model. Yet, majority of factors are inter-organizational implying that managers may be overlooking intra-organizational factors as they attempt to deal with supply chain and supply chain decision-making complexity indicating that one needs to take an integrated approach that accounts both for inter- and intra-organizational factors.

Managing human cognitive abilities provides another avenue for improved supply chain performance. The broadening scope and complexity of the supply chain places new requirements for improved problem solving skills on management. While in the past, managers might spend their career working in a single component of the supply chain such as procurement, such a narrow career focus is not in the best interest of the firm. Emerging trends in employee development are stressing depth in a functional area plus a broad understanding of the supply chain. As implied by the model, today's true supply chain professionals are those that can grasp the big picture, know how the parts are interrelated to each other and have knowledge and skills in multiple functional areas. This can be accomplished by establishing rotational work programs to provide a variety of work experiences for high-performing managers, hiring and retaining talented, experienced,

well-trained employees and such. The end result is a more system-oriented management team that is better prepared to handle the multidisciplinary issues associated with increased complexity. Leading firms such as Intel and IBM are pioneering this trend by establishing internal company recognition programs to encourage and reward career development in supply chain management. Similarly, pursuing life-long learning through industry seminars, self study, or academic training is necessary for the supply chain management team. Academic institutions, in order to support these efforts, must broaden their supply chain management curriculum and teaching pedagogies to prepare future managers to handle complex decision problems.

Managing unexpected/undesirable outcomes is of critical importance. This would include identifying key performance indicators, setting appropriate metrics, monitoring performance, cause identification, and taking corrective action. The prime objective is to identify the root cause of the undesirable outcome and eliminate it if possible. Otherwise, tactical moderators could be used to lessen the adverse impact on performance.

6. Research limitations and future research directions

The model presented in this paper is the first attempt to build a comprehensive theory of supply chain and supply chain decision-making complexity. As a result, it provides a platform for additional research.

This research was limited primarily to large manufacturing and distribution firms, and two-third party logistics companies that support the operations of these manufacturing firms. While our theoretical sampling approach allows for generalizability in this domain, our findings may not be applicable in all contexts. Therefore, exploring supply chain and supply chain decision-making complexity in various other settings is worthwhile.

The next natural phase of this research is empirically testing the proposed model or a subset of its components. Theory testing requires developing measures and scales and testing the model using research methods such as surveys, structural equation modeling, etc. Theory testing research will also identify whether any of the constructs (or the elements of the constructs) are correlated and need to be re-defined. Additionally, it should determine if the constructs that emerged from the interviews are the right ones and whether there are others that did not emerge in the field interviews, should be included.

Research could also be directed at specific complexity antecedents, strategic moderators, human cognitive ability moderators, tactical moderators or outcomes. A better understanding of each construct's role and potential for improving supply chain performance is important. For instance, information systems and knowledge management emerged as strategic moderators to supply chain decision making. However, it should be recognized that these are broad, multi-dimensional constructs that need further investigation and were not fully investigated due to the scope of this research study. Similarly, this research identified three human cognitive ability moderators. Yet, there is a substantial literature on human factors that impact decision making that needs to be tapped into. Overall, while this research discovered relationships between various constructs shown in Figure 1, the nature of several of these relationships warrants further exploration. Such focused studies may help gain deeper insights about the phenomenon and develop more specific approaches for managing complexity. It is also important to look at the interaction effects of various antecedents on supply chain complexity and interaction effects of a set of moderators on supply chain decision-making complexity.

References

Aldrich, H.E. (1979), *Organizations and Environments*, 1st ed., Prentice-Hall, Englewood Cliffs, NJ.

Anderson, E. and Coughlan, A.T. (1987), "International market entry and expansion via independent or integrated channels of distribution", *Journal of Marketing*, Vol. 51 No. 1, pp. 71-82.

Ashmos, D.P., Duchon, D. and McDaniel, R.R. Jr (2000), "Organizational responses to complexity: the effect on organizational performance", *Journal of Organizational Change Management*, Vol. 13 No. 6, pp. 577-95.

Autry, C.W. and Daugherty, P.J. (2003), "Warehouse operations employees: linking person-organization fit, job satisfaction, and coping responses", *Journal of Business Logistics*, Vol. 24 No. 1, pp. 171-97.

Belk, R.W. (1989), "Extended self and extending paradigmatic perspective", *Journal of Consumer Research*, Vol. 16 No. 1, pp. 129-33.

Bergquist, W. (1993), *The Postmodern Organization: Mastering the Art of Irreversible Change*, Jossey-Bass, San Fransico, CA.

Blackhurst, J., Wu, T. and O'Grady, P. (2005), "PCDM: a decision support modeling methodology for supply chain, product and process design decisions", *Journal of Operations Management*, Vol. 23 Nos 3/4, pp. 325-43.

Bozarth, C.C., Warsing, D.P., Flynn, B.B. and Flynn, E.J. (2009), "The impact of supply chain complexity on manufacturing plant performance", *Journal of Operations Management*, Vol. 27 No. 1, pp. 78-93.

Brown, S.L. and Eisenhardt, K.M. (1997), "The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations", *Administrative Science Quarterly*, Vol. 42 No. 1, pp. 1-34.

Campbell, D.J. (1988), "Task complexity: a review and analysis", *Academy of Management Review*, Vol. 13 No. 1, pp. 40-52.

Capra, F. (1996), *The Web of Life*, Doubleday, New York, NY.

Choi, T.Y. and Hong, Y. (2002), "Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler", *Journal of Operations Management*, Vol. 20 No. 5, pp. 469-93.

Choi, T.Y. and Krause, D.R. (2006), "The supply base and its complexity: implications for transaction costs, risks, responsiveness, and innovation", *Journal of Operations Management*, Vol. 24 No. 5, pp. 637-52.

Choi, T.Y., Dooley, K.J. and Rungtusanatham, M. (2001), "Supply networks and complex adaptive systems: control versus emergence", *Journal of Operations Management*, Vol. 19 No. 3, pp. 351-66.

Christopher, M. (2000), "The agile supply chain", *Industrial Marketing Management*, Vol. 29 No. 1, pp. 37-44.

Closs, D.J., Jacobs, M.A., Swink, M. and Webb, G.S. (2008), "Toward a theory of competencies for the management of product complexity: six case studies", *Journal of Operations Management*, Vol. 26 No. 5, pp. 590-610.

Cooke, J.A. (2007), "Weaving 2 supply chains together", *CSCMP's Supply Chain Quarterly*, available at: www.supplychainquarterly.com/print/scq200703case/ (accessed October 3, 2007).

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J. and Handfield, R.B. (2007), "The severity of supply chain disruptions: design characteristics and mitigation capabilities", *Decision Sciences*, Vol. 38 No. 1, pp. 131-56.

Davis, T. (1993), "Effective supply chain management", *Sloan Management Review*, Vol. 34 No. 4, pp. 35-46.

de Koster, R.B.M. (2002), "Distribution structures for food home shopping", *International Journal of Physical Distribution & Logistics Management*, Vol. 32 No. 5, pp. 362-80.

Dess, G.G. and Beard, D.W. (1984), "Dimensions of organizational task environments", *Administrative Science Quarterly*, Vol. 29 No. 1, pp. 52-63.

Dubois, A., Hulthén, K. and Pedersen, A. (2004), "Supply chains and interdependence: a theoretical analysis", *Journal of Purchasing & Supply Management*, Vol. 10 No. 1, pp. 3-9.

Efstathiou, J., Calinescu, A. and Blackburn, G. (2002), "A web-based expert system to assess the complexity of manufacturing organizations", *Robotics & Computer-Integrated Manufacturing*, Vol. 18 Nos 3/4, pp. 305-11.

Ellinger, A.E., Ellinger, A.D. and Keller, S.B. (2002), "Logistics managers' learning environments and firm performance", *Journal of Business Logistics*, Vol. 23 No. 1, pp. 19-37.

Faber, N., de Koster, R.B.M. and van de Velde, S.L. (2002), "Linking warehouse complexity to warehouse planning and control structure", *International Journal of Physical Distribution & Logistics Management*, Vol. 32 No. 5, pp. 381-95.

Fetterman, D.M. (1988), *Ethnography*, 2nd ed., Sage, Thousand Oaks, CA.

Flint, D.J. and Mentzer, J.T. (2000), "Logisticians as marketers: their role when customers' desired value changes", *Journal of Business Logistics*, Vol. 21 No. 2, pp. 19-45.

Forrester, J.W. (1958), "Industrial dynamics", *Harvard Business Review*, Vol. 36 No. 4, pp. 37-66.

Funk, J.L. (1995), "Just-in-time manufacturing and logistical complexity: a contingency model", *International Journal of Operations & Production Management*, Vol. 15 No. 5, pp. 60-71.

Garey, M.R. and Johnson, D.S. (1979), *Computers and Intractability: A Guide to the Theory of NP-Completeness*, W.H. Freeman, New York, NY.

Gilmore, D. (2008), "Supply chain complexity crisis", *Supply Chain Digest*, June 12, available at: www.scdigest.com/assets/FirstThoughts/08-06-12.php?cid=1750&mode=print (accessed August 2008).

Gottinger, H.W. (1983), *Coping with Complexity: Perspectives for Economics, Management and Social Sciences*, D. Reidel, Dordrecht.

Guimaraes, T., Igbaria, M. and Ming-te, L. (1992), "The determinants of DSS success: an integrated model", *Decision Sciences*, Vol. 23 No. 2, pp. 409-30.

Harrington, L.H. (2006), "Reducing complexity", *Inbound Logistics*, Vol. 26 No. 2, pp. 41-4.

Horman, M.J. and Thomas, H.R. (2005), "Role of inventory buffers in construction labor performance", *Journal of Construction Engineering & Management*, Vol. 131 No. 7, pp. 834-43.

Johnsson, P., Kjellsdotter, L. and Rudberg, M. (2007), "Applying advanced planning systems for supply chain planning: three case studies", *International Journal of Physical Distribution & Logistics Management*, Vol. 37 No. 10, pp. 816-34.

Kahn, K.B. and Mentzer, J.T. (1996), "Logistics and interdepartmental integration", *International Journal of Physical Distribution & Logistics Management*, Vol. 26 No. 8, pp. 6-14.

Kathuria, R. and Partovi, F.Y. (1999), "Work force management practices for manufacturing flexibility", *Journal of Operations Management*, Vol. 18 No. 1, pp. 21-39.

Kauffman, S. (1995), *At Home in the Universe*, Oxford University Press, New York, NY.

Kohn, J.W. and McGinnis, M.A. (1997), "Advanced logistics organization structures: revisited", *Journal of Business Logistics*, Vol. 18 No. 2, pp. 147-62.

Kvale, S. (1983), "The qualitative research interview", *Journal of Phenomenological Psychology*, Vol. 14 No. 2, pp. 171-96.

Lee, H.L., Padmanabhan, V. and Whang, S. (1997a), "Information distortion in a supply chain: the bullwhip effect", *Management Science*, Vol. 43 No. 4, pp. 546-58.

Lee, H.L., Padmanabhan, V. and Whang, S. (1997b), "The bullwhip effect in supply chains", *Sloan Management Review*, Vol. 38 No. 3, pp. 93-112.

McCracken, G. (1988), *The Long Interview*, Sage, Newbury Park, CA.

McDaniel, R.R. (1997), "Strategic leadership: a view from quantum and chaos theories", *Health Care Management Review*, Vol. 22 No. 1, pp. 21-37.

McDaniel, R.R. and Walls, M.E. (1997), "Diversity as a management strategy for organizations: a view through the lenses of chaos and quantum theories", *Journal of Management Inquiry*, Vol. 6 No. 4, pp. 371-83.

Manuj, I. and Mentzer, J.T. (2008), "Global supply chain risk management", *Journal of Business Logistics*, Vol. 29 No. 1, pp. 133-55.

March, J.G. and Shapira, Z. (1987), "Managerial perspectives on risk and risk taking", *Management Science*, Vol. 33 No. 11, pp. 1404-18.

Masson, R., Iosif, L., MacKerron, G. and Fernie, J. (2007), "Managing complexity in agile global fashion industry supply chains", *International Journal of Logistics Management*, Vol. 18 No. 2, pp. 238-54.

Meepetchdee, Y. and Shah, N. (2007), "Logistical network design with robustness and complexity considerations", *International Journal of Physical Distribution & Logistics Management*, Vol. 37 No. 3, pp. 201-22.

Mentzer, J.T. and Flint, D.J. (1997), "Validity in logistics research", *Journal of Business Logistics*, Vol. 18 No. 1, pp. 199-216.

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Zacharia, Z.G. (2001), "Defining supply chain management", *Journal of Business Logistics*, Vol. 22 No. 2, pp. 1-25.

Miller, D. (1987), "The structural and environmental correlates of business strategy", *Strategic Management Journal*, Vol. 8 No. 1, pp. 55-76.

Morrison, M.A., Haley, E., Sheehan, K.B. and Taylor, R.E. (2002), *Using Qualitative Research in Advertising*, Sage, Thousand Oaks, CA.

Niraj, R. (2001), "Customer profitability in a supply chain", *Journal of Marketing*, Vol. 65 No. 3, pp. 1-16.

Perona, M. and Miragliotta, G. (2004), "Complexity management and supply chain performance assessment. A field study and a conceptual framework", *International Journal of Production Economics*, Vol. 90 No. 1, pp. 103-15.

Porter, M.E. and Millar, V.E. (1985), "How information gives you competitive advantage", *Harvard Business Review*, Vol. 63 No. 4, pp. 149-60.

Quelch, J.A. and Kenny, D. (1994), "Extend profits, not product lines", *Harvard Business Review*, Vol. 72 No. 5, pp. 153-60.

Rao, K. and Young, R.R. (1994), "Global supply chains: factors influencing outsourcing of logistics functions", *International Journal of Physical Distribution & Logistics Management*, Vol. 24 No. 6, pp. 11-19.

Robinson, P.E. Jr and Swink, M. (1994), "Reason based solutions and the complexity of distribution network design problems", *European Journal of Operational Research*, Vol. 76 No. 3, pp. 393-409.

Rodrigues, A., Stank, T.P. and Lynch, D. (2004), "Linking strategy, structure, process and performance in integrated logistics", *Journal of Business Logistics*, Vol. 25 No. 1, pp. 65-94.

Sahin, F. and Robinson, E.P. Jr (2002), "Flow coordination and information sharing in supply chains: review, implications, and directions for future research", *Decision Sciences*, Vol. 33 No. 4, pp. 505-36.

Sahin, F. and Robinson, E.P. Jr (2005), "Information sharing and coordination in make-to-order supply chains", *Journal of Operations Management*, Vol. 23 No. 6, pp. 579-98.

Sinkovics, R.R. and Roath, A.S. (2004), "Strategic orientation, capabilities, and performance in manufacturer – 3PL relationships", *Journal of Business Logistics*, Vol. 25 No. 2, pp. 43-64.

Sivadasan, S., Efstathiou, J., Calinescu, A. and Huaccho, H.L. (2006), "Advances on measuring the operational complexity of supplier-customer systems", *European Journal of Operational Research*, Vol. 171 No. 1, pp. 208-26.

Sivadasan, S., Efstathiou, J., Frizelle, G., Shirazi, R. and Calinescu, A. (2002), "An information-theoretic methodology for measuring the operational complexity of supplier-customer systems", *International Journal of Operations & Production Management*, Vol. 22 No. 1, pp. 80-102.

Sohal, A.S. and Perry, M. (2006), "Major business – environment influences on the cereal products industry supply chain an Australian study", *International Journal of Physical Distribution & Logistics Management*, Vol. 36 No. 1, pp. 36-50.

Stacey, R.D. (1992), *Administrative Behavior*, 3rd ed., The Free Press, New York, NY.

Stacey, R.D. (1995), "The science of complexity: an alternative perspective for strategic change processes", *Strategic Management Journal*, Vol. 16 No. 6, pp. 477-95.

Stank, T.P., Keller, S.B. and Daugherty, P.J. (2001), "Supply chain collaboration and logistical service performance", *Journal of Business Logistics*, Vol. 22 No. 1, pp. 29-48.

Stock, G.N., Greis, N.P. and Kasarda, J.D. (1999), "Logistics, strategy and structure", *International Journal of Physical Distribution & Logistics Management*, Vol. 29 Nos 3/4, pp. 37-52.

Stock, G.N., Greis, N.P. and Kasarda, J.D. (2000), "Enterprise logistics and supply chain structure: the role of fit", *Journal of Operations Management*, Vol. 18 No. 5, pp. 531-47.

Stock, J.R. (1996), "The social sciences and logistics: some suggestions for future exploration", *Journal of Marketing Theory & Practice*, Vol. 4 No. 2, pp. 1-26.

Strauss, A. and Corbin, J. (1998), *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, Sage, Thousand Oaks, CA.

Sturgeon, T., van Biesebroeck, J. and Gereffi, G. (2008), "Value chains, networks and clusters: reframing the global automotive industry", *Journal of Economic Geography*, Vol. 8 No. 3, pp. 297-321.

Swink, M. and Robinson, E.P. Jr (1997), "Complexity factors and intuition-based methods for facility network design", *Decision Sciences*, Vol. 28 No. 3, pp. 583-614.

Tierney, S. (2004), "Further reflections on the supply chain complexity gap", *Supply Chain Europe*, Vol. 13 No. 4, p. 38.

Upton, D.M. (1994), "The management of manufacturing flexibility", *California Management Review*, Vol. 36 No. 2, pp. 72-89.

Vachon, S. and Klassen, R.D. (2002), "An exploratory investigation of the effects of supply chain complexity on delivery performance", *IEEE Transactions on Engineering Management*, Vol. 49 No. 3, pp. 218-30.

Vaill, P.B. (1989), *Managing as a Performing Art: New Ideas for a World of Chaotic Change*, Jossey-Bass, San Francisco, CA.

van Donk, D.P. and van Dam, P. (1996), "Structuring complexity in scheduling: a study in a food processing industry", *International Journal of Operations & Production Management*, Vol. 16 No. 5, pp. 54-63.

Ward, P.T., Duray, R., Keong Leong, R.G. and Sum, C. (1995), "Business environment, operations strategy, and performance: an empirical study of Singapore manufacturers", *Journal of Operations Management*, Vol. 13 No. 2, pp. 99-115.

Wheatley, M.J. (1992), *Leadership and the New Science*, Berrett-Koehler, San Francisco, CA.

Wheatley, M.J. and Kellner-Rogers, M. (1996), *A Simpler Way*, Berrett-Koehler, San Francisco, CA.

Wilding, R. (1998), "The supply chain complexity triangle", *International Journal of Physical Distribution & Logistics Management*, Vol. 28 No. 8, pp. 599-616.

Wood, R.E. (1986), "Task complexity: definition of the construct", *Organizational Behavior & Human Decision Processes*, Vol. 37 No. 1, pp. 60-82.

Wycisk, C., McKelvey, B. and Hülsmann, M. (2008), "Smart parts, supply networks as complex adaptive systems: analysis and implications", *International Journal of Physical Distribution & Logistics Management*, Vol. 38 No. 2, pp. 108-25.

Zineldin, M.A. (1998), "Towards an ecological collaborative relationship management", *European Journal of Marketing*, Vol. 32 Nos 11/12, pp. 1138-64.

About the authors

Ila Manuj, PhD, is an Assistant Professor in the Department of Logistics and Marketing, University of North Texas, Denton, Texas, USA. Ila Manuj is the corresponding author and can be contacted at: ila.manuj@unt.edu

Funda Sahin, PhD, is an Associate Professor of Logistics in the Department of Marketing and Logistics, The University of Tennessee, Knoxville, Tennessee, USA.