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Literature Review Supporting Development of a Resilience-Oriented Supplier Segmentation Method

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ABSTRACT: *Supply chain exposure to major disruptions has increased following trends of globalization, reduced inventory, and increased reliance on strong relationships with fewer suppliers. Many management strategies for increasing resilience are discussed in literature, but these often require trade-offs in other performance areas, such as cost. A structured method is needed to ensure selection of the best strategy for any given sourcing scenario. Supplier segmentation is a method that has been used to identify appropriate procurement strategies for groups of suppliers with similar needs. However, existing segmentation methods have not focused on the goal of choosing strategies that support increased supply chain resilience. Through systematic literature review, this work identifies and categorizes a set of management strategies and supply chain characteristics that can increase resilience. By identifying factors to enable resilience and relating them to existing dimensions of supplier segmentation, this research introduces an approach to supplier segmentation for increased resilience.*

KEYWORDS: Supply Chain Management, Supplier Segmentation, Buyer, Supplier Relationships, Risk Management, Systematic Literature Review

INTRODUCTION

A supply chain can be defined as a 'linkage of stages in a process from the initial raw material or commodity sourcing through various stages of manufacture, processing, storage, and transportation to the eventual delivery and consumption by the end consumer' (G.A. Zsidisin & Ritchie, 2009). Furthermore, stages between raw material and end consumer are not connected linearly, but form a complex network (Lambert, 2006). Because the parts of a system must work together as a whole, the overall capability of any single company must be measured as a function of the performance of every other partner in the supply chain network (Fine, 1999). A failure or weakness at any node or linkage in the network will have a negative effect on the entire system. For this reason, it is important to manage the supply chain network at all levels to ensure its favorable performance. However, because of the extensiveness of the supply chain and the limited nature of management resources, it is important to distribute the available resources carefully to the areas of greatest need and to avoid their expenditure in areas where they will be of lesser influence. Furthermore, the idea of favorable performance must be defined carefully. Strategies implemented to improve one performance area may negatively affect other areas. It becomes necessary to analyze any trade-offs that may occur due to implementation of a certain strategy. Detailed studies can be performed using simulation techniques, but a complete analysis of the supply chain is difficult to achieve due the extensiveness of the problem and the limited nature of data and resources. A resource-efficient method that could provide an initial assessment and suggest appropriate strategies for any given supply chain member would be an invaluable asset to supply chain managers.

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The focus of the following research is the identification and selection of management strategies for the specific purpose of enabling supply chain resilience. The method of strategy selection is based on the concept of supplier segmentation, which is a key sub-process of Supplier Relationship Management (SRM). SRM is one of the eight key business processes in the framework for implementation of supply chain management outlined by the Global Supply Chain Forum (Croxton, Garcia-Dastugue, & Lambert, 2001). The role of SRM is to provide structure and planning to the development and maintenance of supplier relationships. The method provides a solid basis for strategy selection. However, segmentation has not heretofore been focused on the enablement of resilience. This work explores through an analysis of literature the necessary adjustments needed to tailor supplier segmentation to this purpose.

Resilience has been defined by Ponomarov and Holcomb (2009) as ‘the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.’ As summarized from Wagner and Bode (2009) a disruption is an unintended and anomalous event resulting in an exceptional situation that significantly threatens the course of normal business operations. The study of methods to increase supply chain resilience against disruptions has emerged as an important topic due in part to the continuation of such trends as increasing globalization, decreasing length of product life-cycles, and increasing demand for efficient, low-inventory supply chains (Hohenstein, Feisel, Hartmann, & Giunipero, 2015; Ponomarov & Holcomb, 2009; G. A. Zsidisin, Melnyk, & Ragatz, 2005). While these trends are brought about by the efforts of organizations to gain competitive advantage, they may at the same time increase the supply chain’s vulnerability to disruptions. Increasing supply chain complexity, increasing reliance on outsourcing and partnership, using single source procurement strategies, and reducing levels of redundancy can all have the unintended consequence of diminished resilience (Hendricks & Singhal, 2005).

Evidence supports the continued relevance of resilience as a topic in supply chain management. Each year, the Business Continuity Institute (BCI) conducts a survey on supply chain resilience. The report from 2014 indicates both an increasing frequency and severity of disruption incidents among respondents (Alcantara, 2014). Despite the trend of increasing disruptions, the survey indicates that management commitment to supply chain resilience has not risen to meet the need. This lack of commitment may be due in part to the presence of multiple conflicting requirements faced by supply chain management. In addition to major disruptions, supply chains are constantly exposed to operational risk events that affect the day-to-day organizational operations within the supply chain. These operational risks typically have a low impact on performance, but have a high probability of occurrence. Due to their frequent occurrence, these events are associated with much more historical data than disruption events. A larger body of research has been dedicated to identification and mitigation of operational risks because of the availability of data and the more-observable impact of their occurrence. Because of the comparatively rare occurrence of disruptions, it is difficult to formulate traditional measures such as return-on-investment for disruption management efforts. With continued pressure for companies to drive down operating costs, investments to increase resilience will need strong justification requiring increased understanding of trade-offs between different management strategies. It becomes pertinent to reveal strategies capable of adding resilience against disruption without increasing the cost of day-to-day operations.

The process of supplier segmentation groups suppliers with similar characteristics and needs in order to streamline the management of suppliers within each group. The result of supplier segmentation is the specification of an effective procurement strategy, including both technical and social aspects, for each supplier in the network. Effectiveness is most often represented by cost or profitability during normal operating conditions. The segmentation process takes into account a number of external variables when characterizing the supply chain scenario, and determines the best procurement strategy for each supplier. As stated, this work examines the possibility for re-purposing supplier segmentation to the specific purpose of increasing resilience. It is hypothesized that supplier segmentation can be used as a tool by supply chain managers when selecting supplier relationship strategies that both enable resilience and support operational efficiency during day-to-day operating conditions. This work explores what additional external variables may be necessary to reflect the probability and severity of disruptions in the supply chain, including both social and technical aspects.

The supply chain is a complex socio-technical system. There is a technical network of facilities, where materials move across them, and an overarching social network that governs formal and informal exchanges of information (Behdani, 2012). For example, technical aspects of the relationship might specify order volumes and whether to use single or dual suppliers. On the other hand, social aspects might dictate the level of collaboration with each supplier. As stated by Yossi Sheffi and Rice Jr (2005) regarding the enablement of resilience, 'the issue is not whether to use a single supplier or multiple ones; the issue is the correct alignment of the corporate-supplier relationship with the procurement strategy.' For instance, the choice of the single-sourcing approach may be more resilient when paired with a highly collaborative relationship. When using dual suppliers, a more distant relationship may be preferable for maintaining switching flexibility between the two suppliers. This work looks specifically at supplier segmentation, a key sub-process of SRM, because it is well-suited to support the comparison of different socio-technical elements of procurement strategy.

The remainder of the article is as follows. First, the research question and theoretical framework are formally presented regarding the possible link between supplier segmentation and resilience. Next, the systematic review methodology is described which is used to examine the literature on resilience-enabling strategies and characteristics. The next section synthesizes from the literature a list of resilience-enabling factors and elements. Presented next are the most common methods used for supplier segmentation and their associated input variables. The discussion section offers insight into the method of including resilience-oriented variables in the segmentation process. Finally, the conclusions section summarizes the research implications of the work and possibilities for future work are provided.

THEORETICAL FRAMEWORK

The goal of supplier segmentation is to group suppliers with similar needs in such a way that procurement strategies can be formulated and applied to these groups, thereby removing the need to develop a fully-tailored procurement strategy for each individual supplier. In this way, management resources are efficiently allocated throughout the supply chain. First, a set of external variables are selected and assessed to provide a good representation of the current state of the sourcing environment. Based on the information gained through this assessment, suppliers with similar needs are identified. Then, based on the needs of each differentiated supplier segment, an appropriate procurement strategy is suggested for each group of similar suppliers.

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Existing segmentation methods have failed to fully consider the potential implication that procurement strategy may have on disruption preparedness. Because segmentation specifies the day-to-day procurement strategy, it in turn specifies the pre-disruption supply chain capabilities. When a disruption occurs, a recovery strategy must be selected and implemented. The success of the implementation of the recovery strategy partially depends on the initial supply chain capabilities. Pre-disruption procurement strategy and post-disruption recovery strategy combine to determine the effectiveness of disruption preparation and response. Therefore, strategic options should be compared based on their expected effects on performance both before and after a disruption.

The disruption response profile is an effective tool for visualizing the effectiveness of a supply chain's preparation for and recovery from disruptions by tracking a Key Performance Indicator (KPI) over time (Y. Sheffi & Rice, 2005). As described by Brown and Badurdeen (2015), the response profile can be used to demonstrate supply chain resilience, measured by Time-To-Recovery (TTR), as well as robustness, measured by the maximum decrease in the KPI. TTR represents the time between a disruption and the point at which operations return to a pre-disruption level. Robustness is a related but distinct concept from resilience and is defined as the ability of the supply chain to remain effective under all possible future scenarios (Klibi, Martel, & Guitouni, 2010). While robustness is the ability to avoid or lessen severity of disruption impact, resilience is the ability of an impacted supply chain to return to normal operating conditions. An example of the disruption profile is shown in Figure 1.

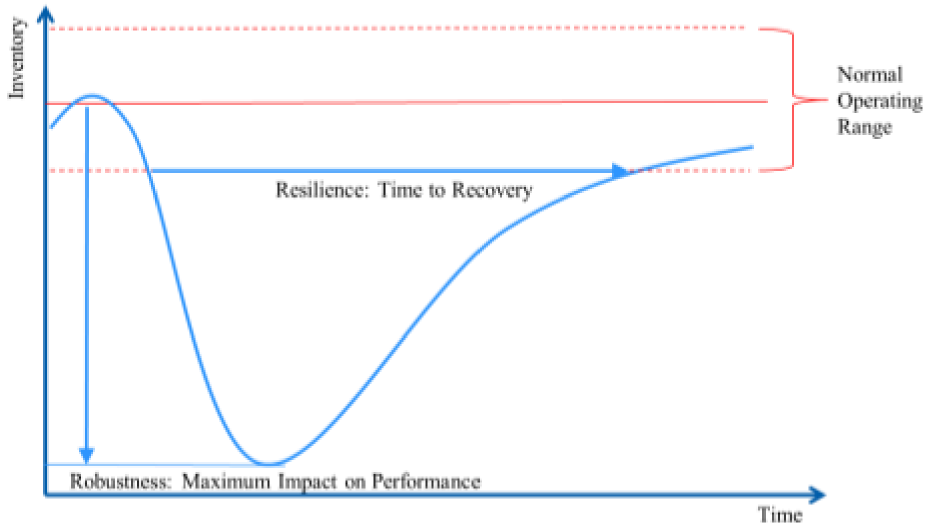

Figure 1. Disruption response profile

Figure 1 shows the response of a KPI plotted over time. The normal operating level of the KPI varies within a set of upper and lower control limits that are established through historical observation. The width of the normal operating range reflects the degree of random variability on the KPI. The beginning of a disruption is indicated by the moment the KPI level falls below its normal operating range. TTR is the amount of time the KPI spends below the lower control limit. The disruption response profile is useful because it can be used to compare the resilience offered by different management strategies, while simultaneously demonstrating any trade-offs that may occur with regard to the normal KPI operating level, its normal operating range, and its robustness.

The first objective of this research is to identify and categorize a comprehensive set of supply chain resilience-enabling factors by conducting a systematic literature review. Developing a comprehensive list of all resilience-enabling factors is important so their consideration in existing segmentation methods can be recognized. Also, aspects of resilience which are not considered by existing procurement strategies can be identified. Throughout the review, the term *factors* will be used to distinguish the most frequently cited management strategies and supply chain characteristics relating to resilience. Each factor is then further specified by a set of *elements.*

The second objective of the article is to identify existing supplier segmentation methods. The variables used to characterize the suppliers are extracted from the different segmentation methods, and the segmentation variables are examined for any plausible association with the previously identified resilience-enabling factors. In this way, aspects of resilience which are not effectively assessed by existing segmentation variables can be revealed.

Finally, modifications to existing supplier segmentation methods are suggested. The modifications should facilitate selection of the best procurement strategies for resilience. In Figure 2, a theoretical framework is proposed linking resilience-enabling factors to supplier segmentation. The steps shown in the framework in solid outline demonstrate a proposed resilience-oriented segmentation process, and the steps shown in dashed outline demonstrate a traditional approach. In the traditional approach, there is some overlap between the set of segmentation variables used and the exhaustive set of resilience-enabling factors and elements. In the revised approach, the set of segmentation variables has been expanded so that all resilience-enabling factors are assessed in some way and included as inputs to the segmentation process. The expected result of the revised method is an improved disruption response profile compared to the same supply chain when segmented according to the original method.

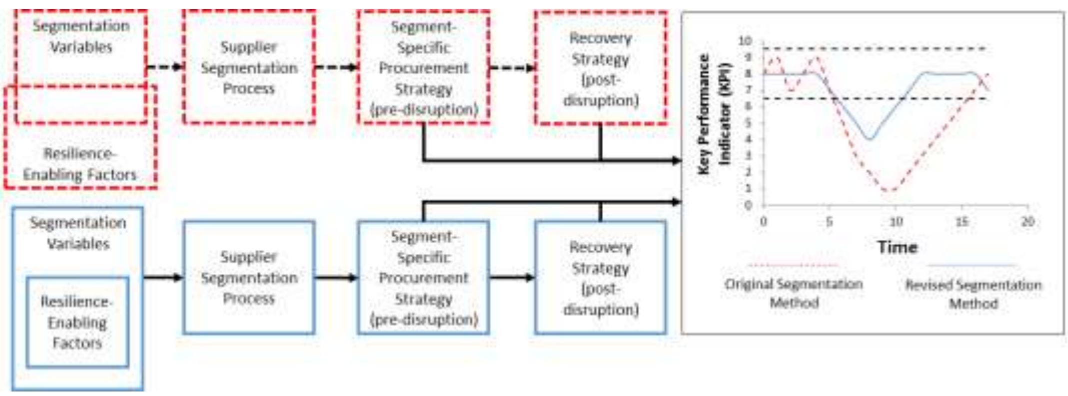

Figure 2. Theoretical framework

Systematic Review Method

The systematic review is modeled after that by Denyer and Tranfield (2009). The method includes five steps: question formulation, study location, study selection and evaluation, analysis and synthesis, and report and use of results. The merits of the systematic review process have been demonstrated in several recent publications (Hallikas, Puumalainen, Vesterinen, & Virolainen, 2005; Hohenstein et al., 2015; Rezaei & Ortt, 2012). Among the merits are increased transparencies of paper inclusion and exclusion criteria, which allow replication of information analysis and add a level of control to the comprehensiveness of the review.

The systematic literature review process begins with the development of a primary research question and the definition of search terms. The primary research question can be stated as 'What management strategies exist to enable supply chain resilience against disruptions?*'* The research question is deconstructed to formulate search criteria based on a combination of key words from two groups: the first pertaining to supply chain management and the second to disruptions. A Boolean search criteria was used requiring terms from each group of related terms, stated as:

('supply chain' OR 'supply chain management' OR 'industrial management' OR 'management practice' OR 'management policy' OR 'management strategy' OR 'business continuity planning')

AND

('disruption' OR 'disaster plan*' OR 'disaster management' OR 'disaster preparedness' OR 'disaster relief' OR 'disaster prevention' OR 'emergency plan' OR 'emergency management' OR 'emergency preparedness' OR 'emergency relief' OR 'emergency prevention' OR 'catastrophe modeling' OR 'risk modeling' OR 'grey swan' OR 'black swan' OR 'resilience')

The databases Compendex and Business Source Complete were used to find publications in business and engineering. The search results in articles that contain some combination of terms listed above. The initial search returned 938 references between the years 1967 and 2015. From this population of references, a secondary search was conducted to identify the sub-set of empirical studies that focused on identification of factors for increased resilience. The secondary search resulted in 43 articles, which were individually checked for relevancy. An article was deemed to be relevant if it met the following criteria:

(1) Relates directly to the effects of major disruptions

(2) Discusses strategies for managing supplier relationship

(3) Includes supply chain context, pertaining to at least one buyer-supplier exchange

Articles that primarily focused on the effects of operational risk were excluded, since this work is concerned with low-probability, high-impact disruptions. In addition, articles that solely focused on the modeling of technical aspects of supply chain management were excluded, since this work studies factors influencing specification of socio-technical supplier relationship strategies. Finally, articles that do not show a direct connection to supply chains were removed from the study. The final set contained 34 articles and formed the basis of the review.

The goal of the synthesis stage is to provide insight that would not be discernible solely through individual analysis of the collected articles. The synthesis of information from the remaining articles is supported by the development and examination of sub-questions. The sub-questions

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can be stated as 'What major resilience-enabling factors can be extracted from the identified management strategies?' and 'How are the identified resilience-enabling factors assessed?'

REVIEW RESULTS: RESILIENCE-ENABLING FACTORS

As evidenced by the large number of articles returned by the initial search terms, significant interest surrounds the field of supply chain resilience. Some of the works center around the goal of identifying and classifying key factors influencing supply chain resilience. The article by Hohenstein et al. (2015) aggregates several studies to reveal 36 resilience-enabling 'elements'. Of the elements identified, the most frequently mentioned were flexibility, redundancy, collaboration, visibility, agility, multiple sourcing, capacity, culture, inventory, and information sharing.

Other works demonstrate the importance of supply chain network-related factors such as network density, complexity, and node criticality (Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007; Greening & Rutherford, 2011), and examine the application of supply chain 'capabilities' to the reduction of 'vulnerabilities' (Jüttner & Maklan, 2011). Capabilities examined by the authors included flexibility, velocity, visibility, and collaboration.

The existing research in the field of supply chain resilience provides an important foundation and guide for the work presented in this article, which has the goal of synthesizing information from the identified sources. The purpose of the following examination is to organize existing information regarding management strategies for resilience, and to combine related strategies into major groups of resilience-enabling factors. Figure 3 presents a summary of the frequency of mention of distinct management strategies and supply chain characteristics. Starting from this list of strategies and characteristics, distinguishable groups of resilience-enabling factors were identified. Details explaining the justification behind grouping of certain strategies and elaboration of the different factor elements are provided in the following sub-sections.

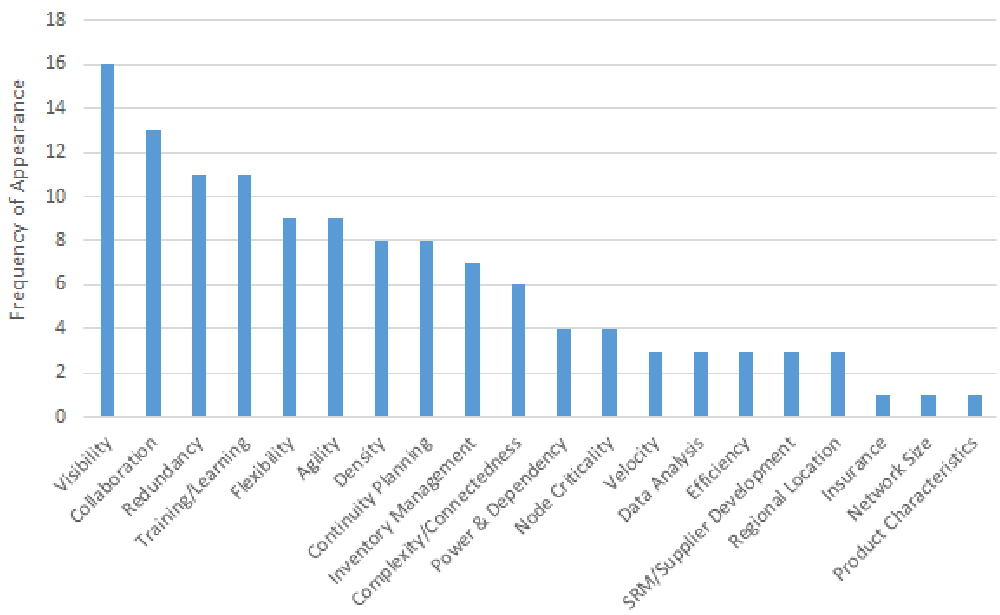

Figure 3: Frequently Mentioned Strategies and Characteristics for Resilience

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Supply Chain Visibility and Data Analysis

Based on the reviewed literature it is surmised that visibility is a multi-faceted concept centered on communication with suppliers through sharing of information. The factors of visibility and data analysis act together to allow a company to collect, interpret, and exchange information. The various assessments and descriptions of the concept relate to the type of information collected, the extent or timeliness of information shared, the capability of a company to convert the shared information into useful knowledge, the information uncertainty, and the types of tools used to enable information sharing.

Regarding the type of information collected, knowledge of the status of inventory and material flow throughout the supply chain are of key importance (Shao, 2013). Brandon-Jones, Squire, Autry, and Petersen (2014) describe visibility as access to information regarding inventory and demand levels throughout the supply chain. Monitoring and detectability create visibility into events occurring in the surrounding environment concerning end-to-end orders, transportation, and distribution (Jüttner & Maklan, 2011). Scholten, Scott, and Fynes (2014) indicate relevance of monitoring events that occur within the supply chain and noting any deviation from planned and actual outcomes.

The extent of information that is shared or the timeliness of information sharing can be descried in a number of ways. J. Blackhurst, Craighead, Elkins, and Handfield (2005) emphasize real-time information sharing from all supply chain nodes. Hohenstein et al. (2015) note the importance of early warning indication achieved through real time monitoring. Relational competencies such as communication and cooperative relationships have been examined for their potential importance to the enabling of resilience (Wieland & Wallenburg, 2013). The development of relational competency reflects visibility in that it implies a supplier's openness to regular screening a willingness to take sensitive information regarding disruptions and make it available. Olcott and Oliver (2014) examine the relevance of social capital to disruption recovery, where social capital refers to the goodwill and sense of obligation that exists between organizations, as well as to trust between firms and the development of a common knowledge base. Organizations that share a higher degree of social capital are likely to experience greater degrees of information sharing and reduced monitoring costs.

The presence and exchange of data cannot lead to increased resilience unless it is converted into useful information, such as an improved warning capability. Craighead et al. (2007) describe warning capability as the interaction and coordination of resources to detect a pending or realized disruption and to disseminate pertinent information about the event throughout the supply chain. In this way, visibility relates directly to data analysis capability. In addition to the collection of information from suppliers, data analysis is needed to process the data through such means as predictive analysis (J. Blackhurst et al., 2005) as well as forecasting and development of early warning signals (Pettit, Croxton, & Fiksel, 2013). Data analysis capability is important after a disruption for determining accuracy and relevance of the available information. Ojha, Gianiodis, and Manuj (2013) note the importance of developing an awareness of risk levels and improving understanding of optimal operating performance levels. This awareness can improve detection of deviations. Using the term disruption orientation, Ambulkar, Blackhurst, and Grawe (2015) also examine the significance of a firm's focus on developing awareness of pending disruptions.

When assessing strength of visibility it is important to recognize the potential effect of uncertainty in the shared information. J. Blackhurst et al. (2005) stress the importance of

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information accuracy. Inaccuracies in data may result from changing requirements for quality and price or from forecasting uncertainties (Ellis, Henry, & Shockley, 2010).

The collection, analysis, and sharing of information can be streamlined though the use of standard tools, methods, and procedures. Tangible systems to support visibility include connectivity infrastructure, such as Information Technology (IT) systems (Olcott & Oliver, 2014), and visualization tools that can be used to communicate information about the status of the supply chain (Basole & Bellamy, 2014). For example, in one empirical study of the electronics industry, a network visualization was used to represent collaborations between organizations as well as the risk level and strategic importance of each partner based on network position (Basole & Bellamy, 2014). Yossi Sheffi and Rice Jr (2005) discuss visibility in terms of disruption detection through use of technical capabilities such as shipment visibility systems. Development and use of formal knowledge management systems may be crucial to the orchestration of effective disruption preparation and recovery (Ponis & Koronis, 2012). Kleindorfer and Saad (2005) discuss the practice of sharing of information and best practices through compatible communication and information technologies.

The elements of visibility are summarized in Table A1 in the appendix.

Collaboration and Suppliers Development

Many authors cited the importance of collaborating with supply chain partners to ensure resilience. Supplier development is also included in this factor as the efforts to develop supplier capability are dependent upon resources owned and shared by both the buyer and supplier. When examining the various assessments for level of collaboration, the individual elements were found to relate to the types of mutual efforts made, the use of shared information for synchronous decision making, supplier openness to meeting buyer requirements, the presence of shared incentives or risk, the types of efforts made to organize and unify employee efforts, and cultural compatibility.

Collaboration can be conceptualized as the establishment of joint efforts by organizations to achieve a common objective (Hohenstein et al., 2015). Integration between organizations can serve to improve warning capability through the interaction and coordination of resources, which in turn positions the firm for faster recovery after a disruption (Shao, 2013). Collaboration may exist between organizations not necessarily in direct partnership in the form of contributions to and participation in development of information databases and exchanges, or through development of trade partnerships (Jennifer Blackhurst, Dunn, & Craighead, 2011). Examples of collaborative supply chain activities include development of a business continuity plan (Hohenstein et al., 2015), joint training efforts (Kovács, 2009), and improvement of supplier performance (Chiang, Kocabasoglu-Hillmer, & Suresh, 2012).

Although collaboration relates heavily to information exchange, an aspect already discussed under visibility, a distinction can be made in the context of collaboration in that the information is used mutually in an effort to build new knowledge that is beneficial to each party. The information is used for the enablement of synchronous decision making (Jüttner & Maklan, 2011). For example, decisions can be made jointly between buyer and supplier regarding optimal order quantities and timing of promotional events (Mandal, 2012). Mutual use of information is needed to perform collaborative planning and forecasting (Kleindorfer & Saad, 2005; Peck, 2005).

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Collaboration often requires an openness of the supplier towards meeting the buyer requirements. The willingness of the supplier to collaborate may be related to relative power position. A dominant organization in a supply network has the opportunity to lead and support ‘extended enterprises’ wherein information and risk are shared in a way that is beneficial for all the involved parties. However, the dominant organization must possess the willingness and capability to drive this form of collaboration (Peck, 2005). Wieland and Wallenburg (2013) also note the need for willingness to support sharing of sensitive information during cooperative efforts.

The strength of collaboration in the supply chain can also be indicated by the alignment of incentives (Jüttner & Maklan, 2011; Mandal, 2012). The presence of a sense of mutual obligation, or a shared stake in both the success and risk of an endeavor can reflect the nature of cooperative behavior between firms (Olcott & Oliver, 2014).

An important pre-requisite to collaboration is the identification of personnel and their roles and responsibilities. It is advantageous to maintain a good understanding of the presence and location of expertise within the collaborate network (Scholten et al., 2014). Developing a formal specification of roles through planning can be helpful in facilitating efficient collaboration between parties of multiple affiliation. It is important to develop a good understanding of the capabilities and restrictions that may be in place at any potential collaborator (Kovács, 2009). Venkateswaran, Simon-Agolory, and Watkins (2014) studied factors influencing business continuity and economic recovery, including the formal assignment of roles and responsibilities during recovery efforts.

Finally, the degree of cultural compatibility between firms can reflect the strength of collaboration. Kleindorfer and Saad (2005) make the point that contractual agreements and incentive schemes can be used to encourage and solidify collaborative efforts, but that a level of trust is needed between the participating parties to reach these agreements. Management of extreme events necessitates an increase from the typical levels of coordination and goodwill between responding agencies (Kapucu & Van Wart, 2006). For collaboration to exist, a level of visibility is needed between firms which includes access to sensitive risk-event information (Jüttner & Maklan, 2011). However, through a collaborative arrangement involving cultural alignment companies can safeguard themselves against opportunistic behavior (Chiang et al., 2012).

The elements of collaboration and supplier development are included in Table A2 in the appendix.

Training, Learning, and Business Continuity Planning

Many management strategies for increasing resilience relate to the actions taken to increase the experience and skill level of employees in disruption preparedness and recovery. Such actions include training employees in recovery procedure after a disruption using simulations and discussions of previous events. The presence of a risk-oriented culture can also indicate greater disruption preparedness at a supplier. The process of learning from the past and training for future events can be formalized though development of Business Continuity Plans. The effectiveness of such plans can be measured using a pre-established system of metrics and performance indicators. Together these elements help to establish an organized plan of action for suppliers both before and after a disruption.

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Study and awareness of previous disruptions can increase the level of preparedness in the pre-disruption phase (Ponis & Koronis, 2012). Learning capability is indicated by an openness and receptivity to change. The level of innovation exhibited during and after a disruption may be proportional to the magnitude of the event (Golgeci & Ponomarov, 2013). Learning can then result in ideas for process improvement (Revilla & Sáenz, 2014). Organizations that learn from disruptions hold post-disruption discussion sessions and commit to implementation of improvements based on the generated ideas (Pettit et al., 2013).

In addition to learning from past events, organizations can learn by taking part in simulations and training exercises (Revilla & Sáenz, 2014; Scholten et al., 2014; Venkateswaran et al., 2014). This type of preparation can help employees to practice implementation of their response actions when faced with different disruption scenarios (Hohenstein et al., 2015).

Development of employee skills for resilience can be achieved in part by means of effective human resource management (Hohenstein et al., 2015). Employee skills that should be developed include their ability to maintain a risk-sensitive mindset and to function in cross-functional teams. Innovation was shown to be a relevant skill in the form of motivation and capability to devise creative business solutions (Golgeci & Ponomarov, 2013). The findings indicate that firms with greater levels of innovation were more likely to establish desired levels of resilience.

By fostering a culture that encourages learning, organizations can increase resilience (Yossi Sheffi & Rice Jr, 2005). This includes making risk assessment a formal part of regular decision making (Scholten et al., 2014). A cultural commitment is required for effective continuity planning to take place, and this commitment can be realized through the provision and maintenance of the necessary infrastructure such as a dedicated risk or disruption department and information system (Ambulkar et al., 2015).

Through development of business continuity plans, organizations can improve communication by reducing the focus on managerial hierarchy and allowing the most knowledgeable employees to act in positions of responsibility (Ojha et al., 2013). The reduction of decision hierarchy reduces reliance on centralized authority which may not be immediately available (Kapucu & Van Wart, 2006). The planning process equips decision makers with information regarding potential challenges that may arise during the stages of disruption recovery (Kovács, 2009). Planning programs can help in the establishment of trust with key suppliers, and can increase a firm's understanding of its supplier's capacity and alternative options (Jennifer Blackhurst et al., 2011). Requiring suppliers to create formal business continuity plans can be an important step in supplier development, as the plan outlines in detail the steps the supplier will take, including schedules for periodic testing, to ensure survival of the business (Venkateswaran et al., 2014).

Finally, commitment to training and learning can be exhibited though the use of a consistent set of performance indicators to manage risk (Kleindorfer & Saad, 2005). Periodic review of the performance metrics can help to establish a baseline and facilitate benchmark comparisons (Pettit et al., 2013).

Table A3 in the appendix summarizes the elements of training, learning, and business continuity planning.

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Redundancy and Inventory Management

Adding redundancy of resources in the supply chain is a straightforward means of increasing disruption preparedness. The level of redundancy can be indicated by the amount of buffer inventory kept on hand, the amount of unused production capacity, the number of suppliers used, and the availability of surplus labor. However, redundancy can lead the supply chain to incur excess cost and it is important in the design process to balance cost and vulnerability (Yossi Sheffi & Rice Jr, 2005). The effectiveness of buffer stock in adding resilience is often dependent on a larger strategy of inventory management. Inventory management is characterized by strategic placement of inventory and careful placement of controls on inventory levels and reordering practices.

Redundancy can be achieved through the practices of keeping excess resources in reserve, often referred to as safety stock, buffer inventory, or insurance inventory (Jennifer Blackhurst et al., 2011; Klibi et al., 2010; George A. Zsidisin & Wagner, 2010). The inventory may be held by the focal company, or in some cases by its suppliers who are required to hold a certain number of days' worth of material (Jennifer Blackhurst et al., 2011; George A. Zsidisin & Wagner, 2010). An important insight is made by Suzuki (2012) that consumable products, particularly fuel for transportation, should also be considered as an important resource when conducting material management after a disruption.

Keeping extra production capacity is another element of redundancy (George A. Zsidisin & Wagner, 2010). Similarly, Klibi et al. (2010) discuss insurance capacity as an enabler of resilience. Decisions regarding specification of capacity and inventory planning are a large component of supply chain design (Mandal, 2012). Capacity considerations can also be extended beyond production to include transportation requirements (Hohenstein et al., 2015).

The practice of employing more than one supplier for a given component is another frequently-cited form of redundancy (Hohenstein et al., 2015; Yossi Sheffi & Rice Jr, 2005; George A. Zsidisin & Wagner, 2010). While multiple suppliers can increase redundancy, it can also be shown that the number of nodes in a network is inversely related to resilience (Jennifer Blackhurst et al., 2011). When designing in redundancy to increase resiliency, diversification in facility locations is an important consideration, as this may affect the likelihood of multiple sites being affected simultaneously (Hohenstein et al., 2015; Kleindorfer & Saad, 2005).

The choice of positioning of buffer inventory throughout the supply chain can be an important factor in determining its benefit. The location of inventory relative to the location of the disruption, as well as the number of routing options available for the existing buffer each affect the realized level of redundancy (Jennifer Blackhurst et al., 2011; Klibi et al., 2010).

Boone, Craighead, Hanna, and Nair (2013) examine different approaches to inventory management, including the item approach and the system approach. The item approach seeks to maintain pre-specified service levels for each item, while the system approach considers all items in the system simultaneously with the goal of attaining system-level objectives. The choice of inventory management system should be aligned with the operating environment, and can be important to enabling improved continuity and resiliency. Furthermore, inventory management systems can implement controls on the process of ordering materials, such as requiring a special authority to release inventory (Yossi Sheffi & Rice Jr, 2005). The re-ordering rules can be used to add redundancy by allowing for a safety factor in the expected order lead time (Peck, 2005), or planning for operational delays (Kleindorfer & Saad, 2005).

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Finally, redundancy can be developed by maintaining plentiful human resources and expertise (Peck, 2005). Labor availability can be a key factor in ensuring sufficient levels of operating capacity (Jennifer Blackhurst et al., 2011).

Table A4 in the appendix includes the identified elements of redundancy and inventory management.

Flexibility, Velocity, and Agility

The terms flexibility, agility, and velocity have been used in the literature to describe a related set of capabilities for enabling resilience, all of which relate to the supply chain's ability and speed in reaction to changing conditions. Agility as a concept has varying interpretations in literature, so it is important to be clear when establishing the context and use of the term. Different authors may use varying levels of specificity when using the term. Agility has been defined simply as the ability to respond rapidly to change through adaptation of an initial stable configuration (Wieland & Wallenburg, 2013). In the context of supply chain reconfiguration, agility can imply a combination of the related capabilities flexibility, velocity, and visibility. A supply chain that has good visibility into upcoming supply and demand fluctuations, and is able to quickly reconfigure to accommodate these fluctuations would thus be referred to as agile. The different elements that emerge describing this concept include the ability to adjust production rate according to demand, to reroute logistics, to reconfigure the supply chain, to perform rapid reconfiguration, to interchange labor and processes, and to replace or redesign components.

The term velocity can be used in the supply chain context to refer to the time it takes between order placement at the first stage of production and receipt of the final product by the customer (Christopher & Peck, 2004). To respond quickly to changes in demand, the supply chain should be able to adjust its velocity up and down, an ability that Christopher and Peck (2004) call acceleration. Acceleration may depend on the speed with which reconfiguration can take place (Scholten et al., 2014; Shao, 2013). The change in production rate should be responsive to sudden changes in supply and demand. In many cases this capability is achieved by maintaining extra production capacity with flexible utilization (Jüttner & Maklan, 2011; Shao, 2013).

Jüttner and Maklan (2011) refer to flexibility in terms of re-configurability, or the number of possible states a supply chain can take. The number of configurations possible is directly related to the number of sourcing options available, which is increased by the use of dual or multi-sourcing strategies (Pettit et al., 2013; Yossi Sheffi & Rice Jr, 2005). Although many suppliers may be available, re-configuration requires a contract flexibility or otherwise-enabled ease of switching between different sourcing options (Hohenstein et al., 2015). The presence of highly-dependent relationships and rigid formalization of management processes may be indicative of a lack of flexibility for reconfiguration (Ambulkar et al., 2015; Wieland & Wallenburg, 2013).

In addition to the number of possible supply chain configurations, the speed with which reconfiguration can occur is also of relevance to resilience (Mandal, 2012). Being in a position of strong social capital and having strong supplier relationships can facilitate collaboration and have a positive effect on the rapid mobilization of resources (Olcott & Oliver, 2014; George A. Zsidisin & Wagner, 2010). The overall speed of reconfiguration depends on the ability to quickly identify changes in the marketplace (Shao, 2013) and to respond to them with quick ramp-up of alternative manufacturing plants (Hohenstein et al., 2015). Use of supplier certification programs can be associated with resilience (George A. Zsidisin & Wagner, 2010), due to the increase in efficiency in ramping up certified versus uncertified alternative suppliers.

Logistical rerouting can be seen as an independent issue from supply chain reconfiguration. The rerouting capability refers to the flexibility of distribution of materials, and it is often reflected by the usage of multiple supply channels (Hohenstein et al., 2015; Mandal, 2012). This element of flexibility also pertains to the ability to adjust delivery quantities (Yusuf et al., 2014).

Flexibility involves the ability to respond to disruptions by developing interoperable processes and systems (Yossi Sheffi & Rice Jr, 2005). This interoperability allows a disrupted process to be moved to another location quickly with little requirement for modification and validation (Shao, 2013). In a similar way, employing a cross-trained workforce can be useful in preventing disruption due to unavailability of labor. Clustering, or geographic co-location was shown to have a positive influence on agility in the oil and gas industry because of the increased skilled-labor pool in the industrial cluster (Yusuf et al., 2014).

Kleindorfer and Saad (2005) note that modular product design can be a key aspect in achieving flexibility. If a component becomes temporarily or permanently unavailable, the modular design may allow it to be easily replaced with a similar replacement component, or to simply shift to production of parts with a slightly different end configuration. Agility may be developed by use of postponement, a production strategy which delays final customization of a product to the finishing processes, thereby affording the manufacturer the ability to respond quickly to changes in demand for specific configurations (Durach, Wieland, & Machuca, 2015; Pettit et al., 2013). Similarly, the concept of product design flexibility entails the use of new product introduction, slight design changes, and product mix adjustment to meet the changing needs of the customer (Chiang et al., 2012).

Table A5 in the appendix summarizes elements of flexibility, velocity, and agility.

Network Structure

The physical layout and characteristics of a supply chain network can have significant effects on its resilience against disruptions. The descriptive elements of network structure are closely tied to aspects of redundancy and flexibility, but are unique in their consideration of the specific configuration of the nodes in the network. Elements that can be used to differentiate different network structures include size, density, connectedness, stability, and the criticality of individual nodes.

The element of network size generally refers to the number of suppliers or the supply chain length (Jennifer Blackhurst et al., 2011). The number of nodes in the network has also been referred to as node complexity (Adenso-Diaz, Mena, García-Carbajal, & Liechty, 2012) or network scale (Brandon-Jones et al., 2014). Increasing numbers of suppliers can increase risk exposure if not mitigated by other resilience-enabling factors.

Other network-related measures include density, or the number of connections that exist in the network compared to the maximum number of connections it could possibly sustain (Greening & Rutherford, 2011). The geographic dispersion of the network represents the spread of the network across different geographical regions. This spread can be useful in terms of offering decentralization of key assets (Pettit et al., 2013). However, certain advantages may be available to organizations operating in geographical clusters such as ease of communication, reduced transportation delay, and co-location of skilled labor (Jennifer Blackhurst et al., 2011; Shao, 2013; Yusuf et al., 2014).

The network can be described in terms of its flow complexity, measured by the number of interconnections between nodes (Adenso-Diaz et al., 2012). Connectivity distribution, a concept from complex network theory, describes the average number of connections possessed by each node in a network and can be used to represent supply chain connectedness (Hearnshaw & Wilson, 2013). For example, a 'scale free' network implies a system in which a small number of hub firms possess many connections while a much larger number of peripheral firms possess few connections. An increase in connectedness has a positive effect on resilience as this implies greater flexibility and collaboration among firms.

Node criticality is an important measure which takes into account a variety of information, and can be described as the importance of the node within a supply chain due to what it does and what its relative contribution is to the overall realized value of the end product (Craighead et al., 2007). The replicability of the affected product, and the degree of connectedness of the affected node all influence node criticality. Furthermore, if a supplier with a high-power position is affected by disruption, the realized effects may be greater implying greater criticality. Although the criticality of the node may be derived mainly from non-network related variables, the position of a critical node within the network can be of great significance if and when it is affected. The importance of a node based on its network position can also be reflected by the metric 'betweenness centrality' which represents the node's use as an intermediate connection (Basole & Bellamy, 2014).

Geographic location of a node can also affect its strategic nature and therefore it can be an important factor in supply chain resilience (Kovács, 2009; Revilla & Sáenz, 2014). Revilla and Sáenz (2014) found though survey analysis that risk sources from natural hazards, market, and socio-economic sources vary by region/country. For instance, the sub-Saharan Africa region suffered more political and economic instability than other regions, and natural hazard exposure varied by region depending on the type of hazard considered. In contrast, the survey showed that the level of implementation of supply chain disruption management practices was not dependent upon the region considered.

The overall network stability relates directly to the amount of time over which the network has been established. As time progresses the supply chain network tends to evolve and become more stable as buyer-supplier relationships are established and verified (Greening & Rutherford, 2011). The less volatile network is generally favorable for enabling resilience.

Table A6 in the appendix includes the elements of network structure extracted from literature.

Power and Dependency

Being in a low power position or a position of dependency can present difficulties for an organization in the event of a disruption. Whatever the reason, this positioning inhibits the ability of the supply chain to respond effectively after a disruption because of the reliance on the affected node (Adenso-Diaz et al., 2012). A buyer may depend on its supplier because the supplier controls an important resource that the buyer needs, because the supplier is simply in a superior market position, or because the component being supplied is strategically important.

In some cases, a supply chain member can exhibit high levels of control over a desirable resource. The resource may be a highly specialized component, requiring significant

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investment of time and resources for development of any alternate source (Ellis et al., 2010; Pettit et al., 2013). There may be few options for switching suppliers, diminishing the negotiating power of the buyer (Greening & Rutherford, 2011). In such cases, it is common for a buyer to be forced to rely on a single-sourcing strategy (Adenso-Diaz et al., 2012). Resource constraints should be identified through examination of the supply chain network, including areas of typically low visibility such as 2nd and 3rd tier suppliers.

If one company has a significantly higher market share or organizational strength, the less powerful firm may be subject to the other's demands (Peck, 2005; Yossi Sheffi & Rice Jr, 2005). Determining the presence of such power dependencies requires examination of the relative strengths of the buyer and supplier. Examples of ways in which these strengths may be exhibited include customer loyalty, market share, and brand recognition.

In some cases, a buyer may be dependent upon a specific resource, simply because of its strategic importance (Ellis et al., 2010). For example, the resource may represent a large portion of the value realized in the end product. In this situation, a dependency may result regardless of market conditions or the level of supplier control over the resource supply.

Table A7 in the appendix summarizes the elements of power and dependency.

Supplier Segmentation Methods

The procedure for supplier segmentation requires collection of information beginning with the assessment of a pre-specified set of variables. These segmentation variables contain specific information about the current state sourcing environment. Information from the variables is then aggregated into a dimension with some qualitative significance. Examples of dimensions include complexity of the supply market (Kraljic, 1983), product complexity (Hadeler & Evans, 1994), and supplier dependency risk (Hallikas et al., 2005). Each supplier is scored on the dimensions based on the information available within in the chosen set of variables. Both the choice of variables and the choice of dimensions depend on the segmentation method used. Based on the procedure of the chosen method, suppliers with similar dimensional rankings are grouped. Each group becomes a supplier segment, and the segment is associated with a procurement strategy that should achieve the desired result for suppliers in that segment. The procurement strategy for that segment is operationalized through a set of decision rules for buyer-supplier interaction.

Supplier segmentation is a relatively mature topic and many informative literature reviews describe the developments in the field (Carter & Narasimhan, 1996; Gelderman & Weele, 2005; Rezaei & Ortt, 2012; Turnbull, 1990). Historically, segmentation methods have not focused on the objective of improving supply chain resilience, but rather those of sustained profitability, innovation, and risk reduction with respect to operational risk. However, this work proposes that segmentation can be tailored to the purpose of increasing resilience. The choice of variables and dimensions used in segmentation affects the ultimate choice of procurement strategy. The following descriptions summarize existing supplier segmentation methods and extract segmentation variables and dimensions from each of the studied methods. The inputs used in segmentation are then compared to the inputs required to assess resilience.

The methods of segmentation can be divided into three types: portfolio method, partnership model, and involvement method. The methods are described according to type in the following sub-sections.

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Portfolio Method

One of the most popular methods of supplier segmentation is the portfolio method. This method originated from the field of financial investments (Markowitz, 1952), and seeks to either maximize return at a given level of risk, or to minimize the risk for a given return. In the context of supplier segmentation, the portfolio method focuses on reducing risk exposure that results from supplier transactions (Day, Magnan, & Moeller, 2010).

The most common variations of the portfolio method use a two-dimensional ranking method. Two dimensions are placed along the row and column, and divided into high and low values, resulting in a 2 x 2 table. The numbers in the table are characterized as a matrix. One commonly cited portfolio model, created by Kraljic (1983), bases supplier segmentation on the two dimensions: complexity of supply market and importance of purchasing. The resulting matrix is shown in Figure 4. Complexity of supply market can be based on variables such as availability, number of suppliers, competitive demand, make-or-buy opportunities, storage risks, and substitution possibilities. These variables represent the risk of potential supply shortages. Meanwhile, importance of purchasing is described by variables such as volume purchased, percentage of total purchase cost, impact on product quality, or business growth (Kraljic, 1983). Suppliers are described as non-critical, bottleneck, strategic, or leverage, and procurement strategies are associated with each type (Gelderman & Weele, 2005; Rijt & Santerna, 2010).

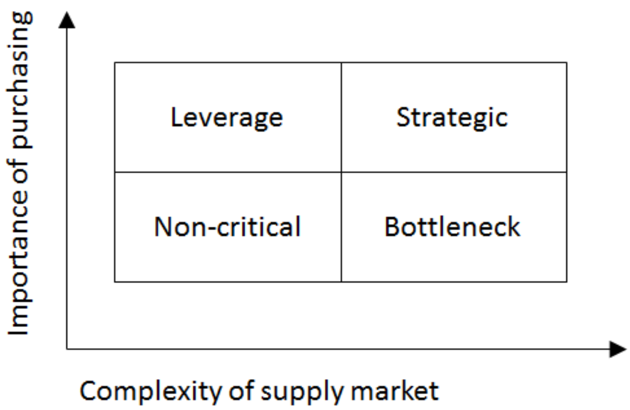

Figure 4. Supplier Segmentation Matrix, Adapted from (Kraljic 1983)

In addition to the segmentation matrix introduced by Kraljic (1983), a number of other portfolio methods were reviewed. Hadeler and Evans (1994) focused on product characteristics using the dimensions product complexity and product value potential. Olsen and Ellram (1997) use a method designed to allocate resources based on relative supplier attractiveness and corresponding relationship strength. Bensaou (1999) reflects buyer-supplier power and dependency by measuring specific investments made by each entity.

Partnership Model

Lambert, Emmelhainz, and Gardner (1996) describe the partnership model, which has the purpose of assessing suppliers and buyers for compatibility. Compatible suppliers may then be

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suited for strategic partnerships. The authors note that supply chain partnerships can be beneficial but are not appropriate for all situations. Business success is possible through more traditional arms-length relationships. Here the arms-length relationship is defined as a standard product offering for a range of customers with standard terms and conditions. The relationship lasts essentially as long as the exchange takes place, but can be renewed over many exchanges. A partnership, on the other hand is 'a tailored business relationship based on mutual trust, openness, shared risk and shared rewards that yields a competitive advantage, resulting in business performance greater than would be achieved by the firms individually' (Lambert et al., 1996).

Drivers for partnership include asset and cost efficiencies, customer service improvements, marketing advantage, and profit stability and growth. Drivers must be sufficient for both buyer and supplier to enter the partnership. In addition to drivers for the partnership, facilitators are needed which create a supportive environment for partnership. Facilitators include corporate compatibility, managerial philosophy and techniques, mutuality, and symmetry. Finally, in each partnership components must be defined that represent the set of activities and processes controlled in the partnership. Distinguishable components include planning, joint operating controls, communications, risk and reward sharing, trust and commitment, contract style, scope and financial investment. Stronger levels of partnership are associated with a greater number of jointly managed components.

Other approaches may not follow the exact partnership model outlined by (Lambert et al., 1996), but are differentiated by their focus on analyzing drivers for partnership. For example, Akman (2015) used a statistical clustering technique to group suppliers with similar performance ratings to determine which suppliers should be prioritized for long-term relationships, placed in supplier development programs, or removed from the supply chain. The performance was considered in two stages. First, traditional performance metrics were analyzed, and then the higher performing suppliers were assessed on their green performance capability.

Partnership models are less focused on the specific task of risk reduction and more so on the clarification and strengthening of existing relationships. Both the portfolio method and partnership model are however aimed at streamlining the process of managing suppliers.

Involvement Method

The final segmentation method to be discussed has been called the involvement method (Rezaei & Ortt, 2012) or the continuum approach (Hallikas et al., 2005). The involvement method is distinguished from portfolio methods due to its more specific focus on determining when and to what degree a supplier should be involved in product development. It has the similar objective to the partnership model in determining the best role for specific suppliers, and in this way might be considered as a specific type of partnership model. In the involvement method an organization focuses on separating the products and services it provides into core competencies, relevant core activities and non-core activities. Strategic partnerships should be formed for suppliers offering products closely related to the organization's core competencies. On the other hand, a transactional-based 'durable-arm's length' relationship is suggested for suppliers that offer non-core products and services (Dyer, Cho, & Chu, 1998). Arms-length suppliers interface only through purchasing and sales, prices are benchmarked across different suppliers, and inter-firm investments are minimal. In contrast, strategic partnership practices include the interfacing of many departments and functions.

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Core Variables for Suppllier Segmentation

Based on an analysis of a representative sample of 10 different segmentation methods, 161 segmentation variables were identified along with 24 associated dimensions. The extracted information is summarized in Table A8. Examination of the set of assessment variables and dimensions from all reviewed segmentation methods reveals that each of the observed variables can be categorized into one of five types. Each of these categories is described below including example variables that belong to each category.

Product Characteristics refer to descriptive variables regarding the type of product being sourced. Different relationship strategies may be required due to the differences in the products. For example, if a product is highly specialized it may be managed with greater scrutiny than a commodity product. *Example variables: unit production cost; volume or percent of total cost; substitution possibilities (with a similar product); uniqueness of product, and technicality.*

Supplier Capabilities are assessed for each individual supplier. Suppliers producing the same or similar components may be characterized differently based on their assessed capabilities. Capabilities may serve as an indication of the appropriate relationship strategy. For example, a supplier with historically excellent performance capability may be well-suited for strategic partnership. *Example variables: reserve capacity; demand growth versus capacity growth; certifications; technological know-how; specialized equipment; historical cost, quality, and delivery performance.*

Buyer Capabilities assesses the buyer, which in most cases is the focal company performing the segmentation. It may be important to compare the relative capabilities of the buyer and its suppliers. There is an inherent connection between buyer capabilities, supplier capabilities, and the buyer-supplier relationship. *Example variables: profitability of the main end products; own production capability or integration depth; and market share vis-à-vis main competition.*

Network Structure refers to variables relating to the physical connections between supply chain entities. These aspects affect the risk exposure, and may influence the ability of the network to respond after an event. *Example variables: availability of alternate suppliers; distance between facilities; and network density.*

Current Relationship variables provide an assessment of the nature of the present structure of interactions with suppliers. The current state of relationships can be an indication of how relationships will proceed to develop in the long term. *Example variables: communication system; communication openness; presence of risk & reward sharing; power and dependency; mutual investments; and cooperation.*

The classification of assessment variables is useful in the examination of their interdependencies. For instance, a supplier with strong capabilities may often be associated with a close buyer-supplier relationship. Different network structures may be associated with different buyer and supplier capabilities. Most of the segmentation dimensions used in the studied methods align with the above variable categories. For example, the dimension 'collaboration' (Kaufman, Wood, & Theyel, 2000) is similar to the category 'current relationship' and 'performance capability' (Rezaei & Ortt, 2012) is similar to 'supplier capabilities'. Exceptions include 'supply risk' or 'difficulty in managing the purchase situation' (Kraljic, 1983; Olsen & Ellram, 1997) which could depend on variables from multiple categories.

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DISCUSSION: INSIGHTS FOR DEVELOPMENT OF RESILIENCE-ORIENTED SEGMENTATION

From the systematic literature review a variety of resilience-enabling factors that influence supply chain performance were identified. The commonly used segmentation methods were also reviewed to identify variables that are frequently used to group suppliers. A closer review of the findings from these two studies reveals that many individual segmentation methods may neglect resilience-enabling factors when assessing dimensions used to group suppliers. For example, the portfolio method presented by Kraljic (1983) uses two dimensions: complexity of supply market and importance of purchasing. It can be argued that Kraljic's two dimensions would also be influenced by a number of resilience-enabling factors as shown in Figure 5.

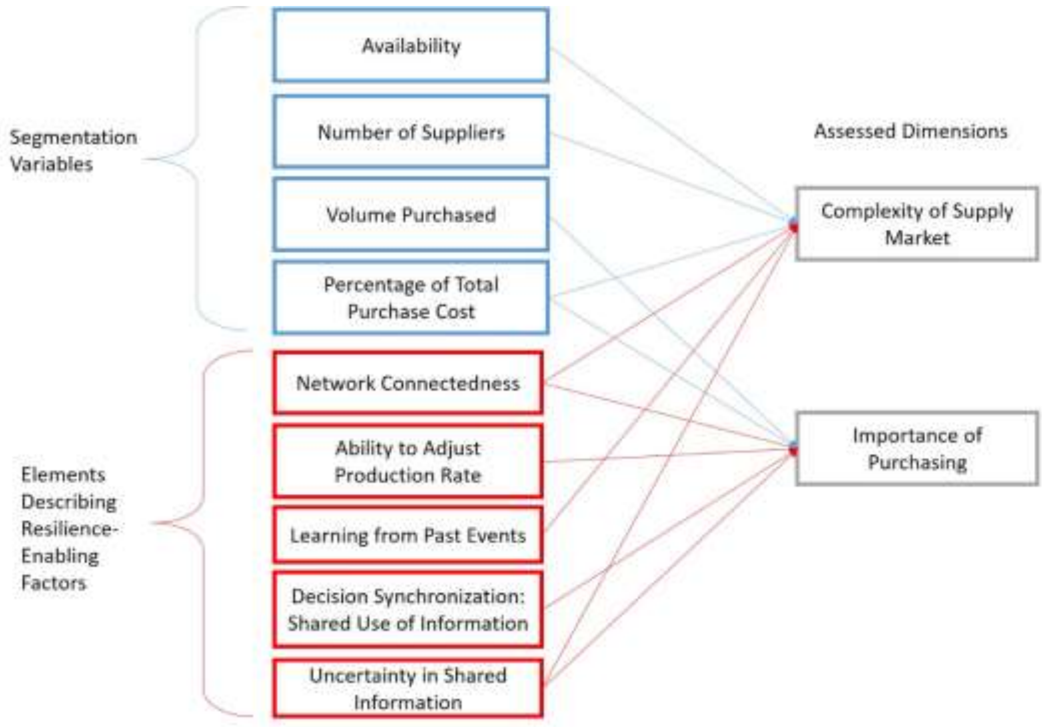

Figure 5. Resilience inputs into segmentation

Thus, we postulate that by including a new set of resilience-oriented information, a different perception of supply market complexity and purchasing importance may arise. For example, the suggested factor 'network connectedness' may shed light on a dependency in the network that exists with a certain supplier. Because this dependence is made evident by the inclusion of the variable, the overall assessment of purchasing importance may be higher than if the dependency had not been considered. Any of the resilience-enabling factors could be potentially influential in the overall characterization of the supply base. It is thus proposed that

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any resilience-oriented segmentation method should consider some descriptive element of each of these main factors.

For further insight, the 161 segmentation variables from the studied segmentation methods were examined in terms of their ability to reflect the resilience-enabling factors. Any variables that could be used as an assessment of one of the resilience-enabling factors were noted along with their category. In this way it was possible to demonstrate which resilience-enabling factors were best represented by the studied segmentation methods and by which segmentation variable categories.

From this examination it is shown that the resilience-enabling factors 'visibility and data analysis' are fairly-well represented and are assessed primarily by the segmentation variables for 'supplier capability'. Visibility depends largely on the capability of the supplier to collect data and convert it into usable information. The variables in the category of 'current relationship' also relate to visibility, indicating a need for developing a relationship with suppliers that fosters exchange of information.

Understandably, collaboration is reflected primarily by the 'current relationship' variables. Although the segmentation literature reviewed does not represent an exhaustive list, it is interesting to note that of the 161 examined variables there is no representation for the specific collaboration elements 'decision synchronization' or 'planning of employee efforts.' These elements of collaboration may be overlooked in existing segmentation methods.

The resilience-enabling factor 'training, learning, and business continuity planning' is overall poorly measured by the 161 segmentation variables. The variables that did represent this factor centered on technical know-how at the supplier. Specific elements relating to skills for recognizing risk, learning from past events and training simulations, and developing and testing continuity plans are largely overlooked by segmentation variables. The observations for this factor highlight the need for buyers to develop and include variables for self-assessment regarding these skills.

The resilience factors for redundancy and flexibility have greater implications on day-to-day operations, and thus are better represented by segmentation variables than other factors. These factors are dependent on segmentation variables from all categories, with redundancy being slightly more dependent on variables in the category 'supplier capabilities.'

Network structure is unique in that it appears as both a resilience-enabling factor and a category of segmentation variables. The network represents the system in which all other capabilities must be developed. Although both resilience and segmentation literature focus on the size and dispersion of the network, the resilience literature introduces an additional concept in the connectedness of the network. The number of connections in the network may be more relevant after a disruption occurs and alternate production routes must be established. A resilience-oriented segmentation should therefor include some assessment for network connectedness.

The final resilience-enabling factor, power and dependency, is determined mainly by the relative market strengths of the buyer and supplier. Notably, the nature of the product is more relevant to power and dependency than any other resilience-enabling factor because it is the importance and value of the product that gives significance to the control of its production.

Development of a resilience-oriented supplier segmentation method will require a resilience-assessment of buyer and supplier capabilities, buyer-supplier relationship, product, and

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network. Current segmentation methods do not consider all factors of resilience, but the examination of existing methods provides insight into the development of a more exhaustive approach.

Before a focal company undergoes the process of segmenting its supply base, it should conduct a preliminary assessment of corporate, marketing, manufacturing, and sourcing strategies (Lambert, 2006). The company should review its long-term objectives and determine whether its strategies are conducive to the stated goals. At this point, a company should have a clear idea of what types of relationships it needs to build with its supply chain to meet its objectives. For example, if a company wants to differentiate itself based on innovation and speed to market, it may want to focus on building strong relationships with suppliers exhibiting innovativeness and openness to change. Choosing a segmentation method based on the right variables and dimensions enables a company to identify opportunities for relationship development.

Implications to Research and Practice

From the practical perspective, this work offers a unique approach to the selection of strategies for increased supply chain resilience. The approach has the benefit of being based on a familiar and highly accessible process in supplier segmentation. However, for segmentation methods to provide best results in terms of resilience, a revised set of input variables should be considered. This work offers guidance for supply chain managers in the process of selecting a set of variables for supplier characterization relevant to the resilience objective.

The research presented by this review and framework takes a step forward in meeting the research objective of improving understanding of unintentional consequences of strategic decisions. The work outlines a heretofore undocumented linkage between the areas of supplier segmentation and supply chain resilience, and offers suggested approaches to further examination of the linkage. This work takes a step forward in assessing the interrelationships that exist between the many variables affecting supply chain resilience.

CONCLUSIONS AND FUTURE WORK

Through the examination of literature, many potential avenues through which resilience-enabling factors can affect segmentation results were identified. The identification of segmentation variables and dimensions, and resilience-enabling factors offers a preliminary basis on which to begin considering resilience in structured decision making processes.

The literature presented in this review indicates increasing interest in and importance of resilience in the field of supply chain management. Many opportunities remain open for the development of tools and methods for specifying strategies to increase supply chain resilience. Continued research is needed to improve understanding of the effects of social relationship aspects on supply chain performance.

In future work, it may be possible through simulation and statistical analysis to identify a set of variables with the most significant impact on TTR in various supply chain scenarios. Furthermore, simulation of a wide variety of disruption scenarios would allow comparison of the effectiveness of procurement strategies suggested by different segmentation methods.

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Given a fixed set of options for procurement strategy, the best segmentation method should be select the procurement strategy that provides most desirable TTR.

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APPENDIX

Table A1. Elements of visibility and data analysis

Reference	Extent or timeliness of information collection and/or exchange	Uncertainty in the shared information	Ability to convert information into useful knowledge	Types of information collected and/or shared	Use of tools, methods, and procedures
(J. Blackhurst et al., 2005)	real-time information sharing	correctness of shared information	predictive analysis to foresee problems	dynamic risk indices at each node	
(Brandon-Jones et al., 2014)				sharing inventory and demand levels	Information Technology and support technology
(Basole & Bellamy, 2014)					visualization tools
(Craighead et al., 2007)	dissemination of pertinent disruption information		detection of pending or realized disruptions		
(Pettit et al., 2013)	information exchange			business intelligence gathering knowledge of status of product, equipment, and people	Information Technology
(Shao, 2013)	information accessibility frequency of information sharing real-time information sharing/timely sharing of supply information	correctness of shared information		knowledge on status of material flow	
(Jüttner & Maklan, 2011)				event monitoring (environment) event monitoring (internal to the supply chain) knowledge on status of material flow	
(Yossi Sheffi & Rice Jr, 2005)			Statistical Process Control/anomaly detection		shipment visibility systems/RFID

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Table A1. continued

Reference	Extent or timeliness of information collection and/or exchange	Uncertainty in the shared information	Ability to convert information into useful knowledge	Types of information collected and/or shared	Use of tools, methods, and procedures
(Ojha et al., 2013)			awareness of optimal operating performance levels		
(Hohenstein et al., 2015)	real-time monitoring		early warning indicators		
(Scholten et al., 2014)				event monitoring (internal to the supply chain) knowledge on status of material flow	
(Wieland & Wallenburg, 2013)	screening and signaling timeliness of sharing disruption data			knowledge of changes currently occurring	
(Olcott & Oliver, 2014)	common knowledge base				integrated knowledge sharing routines/Information Technology infrastructure
(Ambulkar et al., 2015)			awareness of pending disruptions		
(Kleindorfer & Saad, 2005)					use of compatible communication and information technologies
(Ponis & Koronis, 2012)					knowledge management systems
(Ellis et al., 2010)		difficulty forecasting future developments due to technological uncertainty volatility of standards for product price			

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and quality performance

Table A2. Elements of collaboration and supplier development

Reference	Mutual efforts: working towards a common objective	Decision Synchronization: shared use of information for mutual benefit	Supplier openness and efforts to meet buyer requirements	Presence of incentive alignment and risk sharing	Planning, organization and unification of employee efforts	Compatibility: cultural alignment
(Hohenstein et al., 2015)	supplier development joint development of business continuity plan joint efforts	information sharing joint decision making	supplier certification			
(Mandal, 2012)		joint decision making on optimal order quantity and inventory requirements joint planning on promotional events and product assortment information sharing on price changes and supply disruptions		availability of incentives to both suppliers and customers		
(Shao, 2013)	joint planning for potential problems				on-site location of employees cross-function and cross-company teams	
(Peck, 2005)	mergers and other high-level consolidation	collaborative forecasting	forced reconfiguration or operational changes due to			

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			power/dependency relationship			
(Olcott & Oliver, 2014)			social capital - sense of obligation	heedfulness of needs and roles of those interacting	shared mental models - common way of thinking	
(Kleindorfer & Saad, 2005)		collaborative planning and forecasting		incentive alignment - seek ‘win-win’ outcomes risk avoidance or reduction by all partners		

Table A2. Continued

Reference	Mutual efforts: working towards a common objective	Decision Synchronization: shared use of information for mutual benefit	Supplier openness and efforts to meet buyer requirements	Presence of incentive alignment and risk sharing	Planning, organization and unification of employee efforts	Compatibility: cultural alignment
(Jüttner & Maklan, 2011)		aversion to opportunistic decision making decision synchronization	willingness to share sensitive information	incentive alignment		
(Venkateswaran et al., 2014)					establish role and responsibility assignments	
(Jennifer Blackhurst et al., 2011)	partnering with customs programs coordination of available resources				cross-functional risk management teams	
(Scholten et al., 2014)					knowledge of available expertise within the collaborative network	

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	sharing of resources	joint decision making/application of shared knowledge			cross-functional teams	
(Kapucu & Van Wart, 2006)	effectiveness of resource coordination	interagency (emergency response agency) communication				knowledge of consistent motives and integrity

Table A2. Continued

Reference	Mutual efforts: working towards a common objective	Decision Synchronization: shared use of information for mutual benefit	Supplier openness and efforts to meet buyer requirements	Presence of incentive alignment and risk sharing	Planning, organization and unification of employee efforts	Compatibility: cultural alignment
(Wieland & Wallenburg, 2013)		integration of supplier and customer information for internal planning formal and informal sharing of meaningful and timely information	willingness to make sensitive information available	shared sense of responsibility		psychological connections formed for mutual gain
(Kovács, 2009)	develop common knowledge base regarding mandates and capabilities of each organization division and coordination of activities joint training efforts				specification of potential collaboration partners	

(Chiang et al., 2012)	activities undertaken by the buyer to improve supplier's performance or capabilities					strengthening of relationship to reduce risk of opportunistic behavior

Table A3. Elements of training, learning, and business continuity planning

Reference	Learning from past events	Learning from training exercises and simulations	Employee skills for preparation and recovery	Risk-oriented culture	Continuity or Contingency Planning	Use of metrics
(Yossi Sheffi & Rice Jr, 2005)	culture of learning from errors and "near miss" disruptions	disruption training simulations	empowerment of front-line employees to take initiative			
(Scholten et al., 2014)	capacity for learning from past disruptions	learning exercises and simulations		training to raise risk/resilience awareness	establish role assignments/restrictions during recovery develop disruption response plan and training for execution of the plan	
(Hohenstein et al., 2015)		train/educate employees in how to deal with risk events		risk sensitive culture and mindset	business continuity plans for detecting critical suppliers and assessing recovery time establish cross-functional teams predefine contingency plans and communication protocols	
(Golgeci & Ponomarov, 2013)	openness to change		innovation capability			

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(Ponis & Koronis, 2012)	study and learning from past disruptions

Table A3. Continued

Reference	Learning from past events	Learning from training exercises and simulations	Employee skills for preparation and recovery	Risk-oriented culture	Continuity or Contingency Planning	Use of metrics
(Kapucu & Van Wart, 2006)	lessons learned from past events	intra/inter sector training exercises	technical competence to conduct response decreases reliance on central authority			
(Ambulkar et al., 2015)	learning from prior disruptions			dedicated risk/disruption department dedicated information systems for risk & disruption management awareness of environment/situational awareness		consistent set of performance indicators to monitor risk & disruption management process

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				develop Supplier Relationship Management programs to mitigate risk and increase trust	developing self-executing plans port diversification planning	
(Jennifer Blackhurst et al., 2011)	effective post-disruption analysis		understanding of cost/benefit trade-off of recovery decisions		predefined and practiced contingency plans	
(Venkateswaran et al., 2014)		simulated practice exercises	education on disaster prevention, preparedness, mitigation, and recovery training for recovery of critical business processes and operations		vulnerability study periodic testing of continuity plan	

Table A3. Continued

Reference	Learning from past events	Learning from training exercises and simulations	Employee skills for preparation and recovery	Risk-oriented culture	Continuity or Contingency Planning	Use of metrics
(Ojha et al., 2013)			training to improve communication and interpersonal skills technical skills to formulate prevention and recovery plans			

	learning from past failures		training to respond as a team to system failures empowerment of knowledgeable employees		training for creation and management of BCP	
(Kleindorfer & Saad, 2005)					prioritization of mitigation strategies design and rehearsal of organizational and communications architecture periodic review of implementation plans	
(Pettit et al., 2013)	post-disruption discussion and reporting implementation of improvements after a disruption learning from experience/ past disruptions		cross-training of workforce in multiple skills			regular use of feedback and benchmarking tools
(Revilla & Sáenz, 2014)	analysis of past incidents to identify process improvements	simulation of various supply chain risks and disruptions				

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Table A4. Elements of redundancy and inventory management

Reference	Maintenance of buffer inventory	Maintenance of extra capacity	Use of multiple suppliers	Strategic positioning and routing of inventory	Control of inventory levels: strategic inventory management	Labor availability
(George A. Zsidisin & Wagner, 2010)	safety stock; inventory help at suppliers to prevent stakeouts	low capacity utilization rates extra production capacity	maintaining dual or multiple suppliers			
(Klibi et al., 2010)	insurance inventory	insurance capacity		inventory location and routing		
(Mandal, 2012)	optimal investment in inventory to meet demand forecast and prevent stockouts	optimum capacity to meet demand forecasts and prevent stockouts				
(Yossi Sheffi & Rice Jr, 2005)	safety stock	low capacity utilization rates	use of multiple suppliers despite higher costs		strategic inventory management systems, special authority is necessary to release inventory	
(Peck, 2005)	inventory buffer	redundant production capacity			safety lead-time	redundant expertise capability; maintenance of human resources
(Jennifer Blackhurst et al., 2011)	buffer inventory kept on hand to last X number of days	implementation of employee overtime		strategic location of inventory		labor availability
(Kleindorfer & Saad, 2005)		slack in production			slack in operations planning	

		slack transportation capacity			
(Hohenstein et al., 2015)	suppliers holding excess inventory	slack resources in production	dual or multiple suppliers		
(Boone et al., 2013)					inventory management approach; system or item level objectives
(Suzuki, 2012)	extra fuel inventory for transportation				

Table A5. Elements of flexibility, velocity, and agility

Reference	Ability to adjust production rate	Logistics rerouting capability	Speed of supply chain reconfiguration	Number of possible supply chain configurations	Labor and process inter-changeability	Ability to replace or redesign parts and/or components
(Hohenstein et al., 2015)	flexible production systems acceleration of production speed in response to customer	multiple distribution channels; material rerouting	ramping up of other manufacturing plants speed of supply chain redesign	ease of switching between alternate suppliers	multi-skilled workforce	
(Jüttner & Maklan, 2011)	flexible capacity utilization		speed of reaction to market changes or events speed of flexible adaptations	number of possible states a supply chain can take; possible through dual and multiple sourcing		

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(Kleindorfer & Saad, 2005)						delayed differentiation; postponement of product specialization modularity of product and process design
(Yossi Sheffi & Rice Jr, 2005)				alignment of supplier relationship with procurement strategy; use of multiple sources or single source with close relationship	cross-trained workforce interoperable processes and systems	demand shifting; ability to influence customer to available product
(Christopher & Peck, 2004)	ability to change production velocity quickly in response to unpredicted changes in demand or supply		speed of reconfiguration			
(Wieland & Wallenburg, 2013)			speed of adaptation to marketplace uncertainty speed of system reconfiguration	supplier relationship dependence		

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Table A5. Continued

Reference	Ability to adjust production rate	Logistics rerouting capability	Speed of supply chain reconfiguration	Number of possible supply chain configurations	Labor and process inter-changeability	Ability to replace or redesign parts and/or components
(Mandal, 2012)		use of many supply channels	logistical response to unforeseen events; timeliness of reconfiguration of supply chain resources in response to supply and demand changes timeliness of reconfiguration of supply chain resources in response to changes in daily supply chain execution			
(Chiang et al., 2012)	supply flexibility: supplier's ability to satisfy buyer's dynamically changing specifications in terms of quality, time, and product mix process flexibility: competence to adjust production processes and volumes based on the changing needs of the marketplace		organizations ability to change or react with little penalty in time, cost, or performance capability to respond quickly to a change in marketplace			product design flexibility: competence of the system to develop new products, make minor design changes, and adjust product mix to satisfy dynamic market demand in timely and cost-effective manner
(Yusuf et al., 2014)		ability to adjust			flexible workforce	

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	delivery quantities		
(Ambulkar et al., 2015)		formalization of risk management processes	
(Pettit et al., 2013)	alternative logistics distributio n channels; rerouting capability	flexible supplier contracts multiple suppliers	part commonality modular product design postponemen t

Table A5. Continued

Reference	Ability to adjust production rate	Logistics rerouting capability	Speed of supply chain reconfiguration	Number of possible supply chain configurations	Labor and process inter-changeability	Ability to replace or redesign parts and/or components
(Shao, 2013)	adjustable production capacity		ability to complete an activity as quickly as possible ability to identify changes and respond quickly		ability to implement different processes at different facilities to achieve goals	
(Scholten et al., 2014)			speed of supply chain reaction to changes in demand speed of adaptation of initial supply chain configuration			
(George A. Zsidisin & Wagner, 2010)			supplier certification programs	closeness of buyer-supplier relationship		

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Table A6. Elements of network structure

Reference	Network size	Density or geographic dispersion	Connectedness and/or flow complexity	Network stability	Node risk and criticality relative to the rest of the network
(Adenso-Diaz et al., 2012)	total number of nodes in the network number of distinctive raw materials suppliers required for the final product average number of nodes in a regional cluster	variance in density of different regional clusters	total number of forward, backward, and within tier material flows		
(Hearnshaw & Wilson, 2013)			clustering coefficient: probability that two neighboring nodes connected to a local node are also connected to each other connectivity distribution: the average number of connections possessed by each node in the network characteristic path length: the average number of firms or tiers that must be traversed between any two randomly chosen nodes		

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(Brandon-Jones et al., 2014)	number of suppliers	geographic dispersion			
(Greening & Rutherford, 2011)			network density: how many connections exist compared to the number of connections the network could sustain	structural stability or evolution of the network	shortest connecting path to the disruptive event

Table A6. Continued

Reference	**Network size**	**Density or geographic dispersion**	**Connectedness and/or flow complexity**	**Network stability**	**Node risk and criticality relative to the rest of the network**
(Craighead et al., 2007)	total number of nodes in the network	supply chain density: inversely related to geographical spacing; average inter-node distance	total number of forward, backward, and within-tier material flows		node criticality: value-added by or flowing through the node
(Basole & Bellamy, 2014)	network size; number of nodes that can be reached in each tier				betweenness centrality: amount of control node exerts over the interactions of other; node's use as an intermediate connection
(Revilla & Sáenz, 2014)					geographic location; required interaction across national cultures
(Kovács, 2009)					geographic location; challenges specific to certain regions such as available infrastructure, risk exposures common to the region

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		decentralization of customer base degree of outsourcing; global distribution of supply chain distributed capacity and assets distributed decision making		
(Pettit et al., 2013)	number of members in the supply chain	decentralized sourcing of key inputs		
(Jennifer Blackhurst et al., 2011)	number of nodes in the supply chain; supply chain length	geographic clustering		volatility of supplier's location
(Yusuf et al., 2014)Yusuf et al. 2014		geographic clustering; involvement in industrial cluster		
(Shao, 2013)		geographic dispersion of suppliers, production facilities, distributors, and customers		

Table A7. Elements of power and dependency

Reference	Resource control	Strength in market	Importance of the component
(Greening & Rutherford, 2011)	power of affected node; determined by its preferential access to resources or information prevalence of high-dependency ties; cases where few options exist to renegotiate for access to scarce resources		

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(Peck, 2005)	availability of switching options	relative strength of organizations	
(Pettit et al., 2013)	product differentiation	customer loyalty to products	
		strength and duration of customer relationships	
		effective communication with customers	
		market share	
		financial strength: ability to absorb fluctuations in cash flow	
	reliance upon specialty sourced components	strength of brand recognition	
(Yossi Sheffi & Rice Jr, 2005)		market share; competitive position	
(Adenso-Diaz et al., 2012)	reliance on single-source supplier		
(Ellis et al., 2010)	switching costs due to customer-specialization		
	concentration of resource control; few alternative suppliers for the resource		importance of the resource; strategic importance of the sourced component

Table A8. Segmentation variables and dimensions

Model Type	Dimensions	Associated variables/criteria	Differentiated Segments	Reference
Partnership	Potential Benefit of Partnership	asset/cost efficiencies; customer service; marketing advantage; profit stability/growth	Arm's length; Type I, II, and III partnerships; joint ventures; vertical integration	(Lambert et al., 1996)
	Corporate Environment - Support	corporate compatibility; managerial philosophy and techniques; symmetry; exclusivity; shared competitors; physical proximity; prior history of working with the		

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		partner; shared high value end user		
Portfolio	Profit Impact	volume purchased; percentage of total purchase cost; impact on quality or bustiness growth	Strategic; bottleneck; leverage; noncritical	(Kraljic, 1983)
	Supply Risk	availability; number of suppliers; competitive demand; make-or-buy opportunities; storage risk; substitution possibilities		
	Supplier strength	market size vs. supplier capacity; market growth vs. capacity growth; capacity utilization or bottleneck risk; competitive structure; ROI and/or ROC; cost and price structure; break-even stability; uniqueness of product and technological stability; entry barrier (capital and know-how requirement); logistics situation	Action Plans: exploit; balance; diversify	
	Company strength	purchasing volume vs. capacity of main units; demand growth vs. capacity growth; capacity utilization of main units; market share vis-à-vis main competition; profitability of main end products; cost and price structure; cost of nondelivery; own production capability or integration depth; entry cost for new sources versus cost for own production; logistic		

Table A8. Continued

Model Type	Dimensions	Associated variables/criteria	Differentiated Segments	Reference
Involvement	Nature of Products	interface complexity; rate of technological change; end consumer perception influence	Critical systems (high cost, OEM provides supplier with performance specifications); hidden components (low cost simple components defined by physical specifications); invisible subassemblies	(Laseter and Ramdas, 2002)
	Cost Structures	unit product cost; amortized development cost; manufacturing scale		

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	Nature of OEM-Supplier Interaction	type of specifications passed to the supplier	(moderate cost, suppliers are provided with performance specification and detailed physical dimensions); simple differentiators (moderate cost simple assemblies; suppliers are provided with detailed physical specifications)	
Portfolio	Product Complexity	technicality of product; need for user input in making a sound purchase; importance of tight product specifications; criticality of product performance with high differentiation between various suppliers' products	close relationships; strategic partnerships; simple contracts; global trading	(Hadeler and Evans, 1994)
	Product Value Potential	dollar volume; potential for significant price reduction; potential for getting significant value-added benefits from suppliers; risk to profit or safety in case of supply shortage or quality problems		
Partnership	Collaboration	26 variables from NIST 'Quickview' manufacturing survey; 5 most influential: early supplier involvement in product development; strategic vision; customer/material supplier certification; insufficient	commodity supplier; collaboration specialist; technology specialist; problem-solving supplier	(Kaufman et al., 2000)

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		employee training; equipment supplier certification		
	Technology	22 variables from NIST 'Quickview' manufacturing survey; 5 most influential: expert machine utilization; quality function deployment; process manufacturing know-how; inexpert machine utilization; advanced process technology management		

Table A8. Continued

Model Type	Dimensions	Associated variables/criteria	Differentiated Segments	Reference
Portfolio	Strategic Importance of the Purchase	competence (of buyer), economic, and image factors	bottleneck; strategic; non-critical; leverage	(Olsen and Ellram, 1997)
	Difficulty of Managing the Purchase Situation	product, supply market, and environmental characteristics		
	Relative supplier attractiveness	financial and economic, performance, technological, organizational/cultural/strategic, flexibility to environmental changes, and safety factors	action plans: strengthen supplier relationship; improve supplier attractiveness or relationship performance; reduce resources allocated to the relationship	
	Strength of Relationship	economic factors, character of the exchange relationship, cooperation between buyer and supplier, distance between buyer and supplier		
Portfolio	Buyer's Specific Investments	tangible: buildings, tooling, equipment; intangible: people, time, knowledge	captive buyer; strategic partnership; market exchange; captive supplier	(Bensaou, 1999)
	Supplier's Specific Investments	tangible: plant location/layout, specialized facilities/dies; intangible: guest engineers, information system development		
Portfolio	Buyer Dependency Risk	value added to the customer; irreplaceability of the supplier	non-strategic; strategic; asymmetric	(Hallikas et al., 2005)
	Supplier Dependency Risk	value added to the supplier; irreplaceability of the customer		

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Portfolio	Willingness to Maintain Relationship	21 variables identified	described by quadrant, not otherwise characterized	(Rezaei and Ortt, 2012)
	Performance Capability	46 variables identified		
Involvement	Strategic Nature of Inputs	necessary but non-strategic; strategic	durable arm's-length relationship; strategic partnerships	(Dyer et al., 1998)