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# Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool

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In today's tightly connected global economy, traditional management practices that rely on "steady-state" conditions are challenged by chaotic external pressures and turbulent change. Just in the last few years, the world has experienced a string of catastrophic events, including a global economic meltdown, a volcanic eruption in Iceland, an oil spill in the Gulf of Mexico, a disastrous tsunami and power blackout in Japan, and political upheavals in Africa and the Middle East. Managing the risk of an uncertain future is a challenge that requires *resilience*—the ability to survive, adapt, and grow in the face of turbulent change. This research develops a measurement tool titled the Supply Chain Resilience Assessment and Management (SCRAM™). Data gathered from seven global manufacturing and service firms are used to validate SCRAM™, using qualitative methodology with 1,369 empirical items from focus groups reviewing 14 recent disruptions. Critical linkages are uncovered between the inherent vulnerability factors and controllable capability factors. Through mixed-method triangulation, this research identified 311 specific linkages that can be used to guide a resilience improvement process. Pilot testing suggests a correlation between increased resilience and improved supply chain performance.

*Keywords*: resilience; disruptions; risk management; supply chain management; vulnerabilities

## INTRODUCTION

Global supply chains are growing in both length and complexity (Blackhurst et al. 2005) and the turbulence that they experience is increasing. In fact, a worldwide survey of international businesses reported that 85% of firms experienced at least one major disruption in the previous year (Business Continuity Institute 2011). Business leaders need a method to manage change in their complex supply chains. For example, the March 11, 2011 earthquake and tsunami that occurred in Japan and the subsequent nuclear crisis caused physical damage estimated from $195 billion to $305 billion (Nato et al. 2011). The physical devastation and loss of 20% of the nation's electrical grid due to nuclear power shut-downs caused Toyota production to drop by 40,000 vehicles, costing $72 million in profits daily (Kachi and Takahashi 2011). Stock prices for Japanese auto manufacturers declined up to 9.5% within the first few days, and during the following month, Toyota stock lost over 17% of its value and overall auto sales in Japan fell to a 34-year low (Takahashi 2011). The immediate and lingering effects of this natural disaster, and the subsequent supply chain disruptions, have spurred renewed concerns about supply chain resilience; however, "the development of practical methods to implement resilience in an engineering context is still in an incipient stage" (Park et al. 2011, 396). Therefore, this research develops a tool that will help supply chain leaders to assess their current level of resilience and to guide purposeful change so that their supply chain can survive, adapt, and grow in the face of turbulent change (Fiksel 2006).

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Complexity is difficult to manage (Mason 2006) and systems with a large number of elements can be vulnerable to nonlinear interactions, with small perturbations causing severe impacts. Knowing the history of a dynamic, complex system does not necessarily lead to foresight because the system behavior and the external conditions constantly change (Snowden and Boone 2007). Compounding the complexity of today's supply chains is the severe impact of disruptions. Hendricks and Singhal (2005) find that over the period from one year before through two years after a disruption is announced, stock prices declined nearly 40%.

Conventional risk management approaches designed to deal with traditional incidents such as floods or management crises, are not always effective when a company is confronted with unexpected disruptions. The predominant approach to enterprise risk management requires risk identification and quantification, which are not always possible in the absence of empirical data. Moreover, strategies to deal with change need to be purposely aligned with a company's earning drivers (Ahlquist et al. 2003), and firms need to balance revenue streams with preparation and recovery costs, short-term customer service, and long-term supply chain value in terms of return on assets (Slone et al. 2007). The Council on Competitiveness (2007, 5) argues that "managing this rapidly changing risk landscape is an emerging competitive challenge" and meeting that challenge demands resilience.

The Supply Chain Resilience Framework (Pettit et al. 2010) identifies the sources of change in seven categories of vulnerabilities: Turbulence, Deliberate Threats, External Pressures, Resource Limits, Sensitivity, Connectivity, and Supplier/Customer Disruptions. These vulnerabilities must be counterbalanced with managerial controls that create supply chain capabilities: Flexibility in Sourcing, Flexibility in Order Fulfillment, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Organization, Market Position, Security, and Financial Strength. The balance between vulnerabilities and capabilities must be measured to assess the current level of resilience.

This research follows the conceptual foundations of Pettit et al. (2010) to create a measurement instrument that helps managers implement the Supply Chain Resilience Framework, thus providing direction for a supply chain to improve its resilience. This article begins with a literature review, describes the methodology used to create and validate the assessment, presents results and recommendations from initial application of the instrument with seven global manufacturing supply chains, reports empirically derived linkages between vulnerabilities and capabilities, and concludes with a summary of a pilot implementation with a global manufacturing firm.

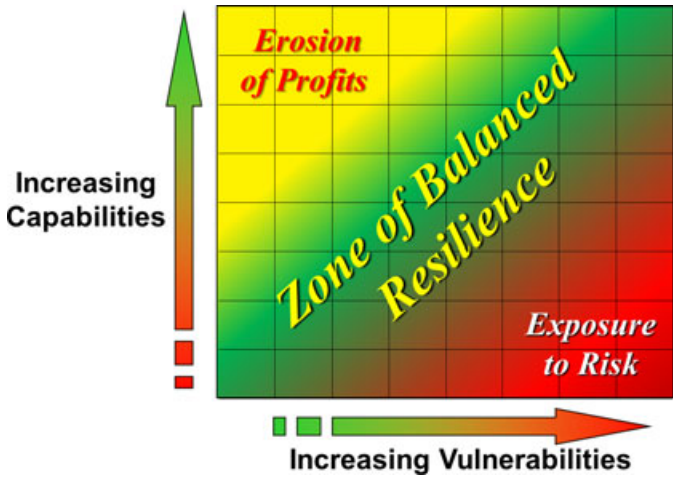
## LITERATURE REVIEW

Supply chain resilience draws from the foundations of many disciplines, including ecology (Folke et al. 2002, 2004; Perrings 2006), psychology (Bonanno 2004; Gorman et al. 2005), sociology (Adger 2000), risk management (Starr et al. 2003; Wagner and Bode 2008), and network theory (Callaway et al. 2000). Following a series of major disruptive events in global economies, several in-depth studies were conducted to better understand how supply chains can more effectively adapt to change (Cranfield University 2002, 2003; Sheffi 2005). As the term resilience entered the business vocabulary, researchers investigated enterprise attributes that contribute to supply chain disruptions and attributes that assist enterprises in preventing and coping with those disruptions (Hamel and Välikangas 2003; Rice and Caniato 2003; Christopher and Peck 2004; Kleindorfer and Saad 2005; Tang 2006b; Blackhurst et al. 2011). Flynn (2008) defines resilience with the "four Rs"—robustness, resourcefulness, recovery, and review. Rice and Caniato (2003) and Sheffi (2005, 2008) focus resilience on redundancy and flexibility, recommending leaders to develop a "flexibility DNA" through communications, distributed authority, passion for the mission, deferring to experience, and conditioning for disruptions.

Although these viewpoints vary, they all differentiate resilience from traditional risk management (Committee of Sponsoring Organizations [COSO] of the Treadway Commission 2004; Tang 2006a; Manuj and Mentzer 2008). The concept of resilience, unlike conventional risk analysis, utilizes strategies that do not require exact quantification, complete enumeration of possibilities, or assumptions of a representative future (Pettit et al. 2010). Strategic resilience imperatives call for supply chains to be less brittle and more adaptive to change through (1) supply chain design, (2) focus on business process management to enhance capabilities across the supply chain, (3) visibility to demand and supply throughout the supply chain, (4) supplier and customer relationship management, and (5) infusing a culture of resilience (Wisdomnet 2006).

However, Pettit et al. (2010) identify a research gap in linking vulnerabilities and threats to the strategies to overcome them. Based on the foundations in life and social sciences, resilience was defined by Fiksel (2006) and adapted by the Council on Competitiveness (2007) as "the capacity for an enterprise to survive, adapt and grow in the face of turbulent change." Resilience was proposed to consist of two constructs: Vulnerabilities—*fundamental factors that make an enterprise susceptible to disruptions* and Capabilities—*attributes that enable an enterprise to anticipate and overcome disruptions* (Pettit et al. 2010). These authors present Figure 1 to illustrate the resilience fitness space, and suggest that firms should strive to be in the Zone of Balanced Resilience. Not having sufficient capabilities given the vulnerabilities the firm faces (i.e., being in the bottom right corner of Figure 1) leaves the firm exposed to risks, but investing in capabilities that are not required (i.e., being in the top left corner of Figure 1) might be eroding profits. Although managing risks is critical, "perhaps the biggest challenge companies face is mitigating supply-chain risks without eroding profits" (Chopra and Sodhi 2004, 56). Tomlin (2006) creates a methodology for developing an optimal disruption management strategy under several levels of flexibility, based on the fact that mitigation and contingency actions are not free. Pettit et al. (2010) further develop the vulnerability and capability constructs to include 21 factors comprised of 111 subfactors (see Tables 1 and 2). The authors proposed that assessment of these 21 factors can be used to evaluate a supply chain's current state of resilience, and recommendations for resilience improvements can be prioritized by adjusting their portfolio of capabilities to match the pattern of vulnerabilities to remain in the Zone of Balanced Resilience.

**Figure 1:** Resilience fitness space. Pettit et al. (2010).




The responses to a vulnerability are varied and encompass the capabilities of the entire enterprise, as well as the conflicting or synergistic capabilities of the supply chain members (Hamel and Välikangas 2003; Hendricks et al. 2008; Institute of Management and Administration [IOMA] 2008; Blackhurst et al. 2011). The goal for managers is to create a portfolio of capabilities that can balance the inherent vulnerabilities in the supply chain resulting in balanced resilience, which is hypothesized to improve firm performance. The goals of this study were to first develop a useful tool to measure the current state of a supply chain's resilience, to identify links between vulnerabilities and capabilities to achieve balanced resilience, and finally, to examine the relationship between resilience and performance.

## METHODOLOGY FOR DEVELOPING THE MEASUREMENT TOOL

In accordance with Grounded Theory development (Glaser and Strauss 1967), the categories developed in the Supply Chain

**Table 1:** Vulnerability factors

| Vulnerability factor | Definition | Subfactors |
|---|---|---|
| Turbulence | Environment characterized by frequent changes in external factors beyond your control | Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic |
| Deliberate Threats | Intentional attacks aimed at disrupting operations or causing human or financial harm | Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability |
| External Pressures | Influences, not specifically targeting the firm, that create business constraints or barriers | Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change |
| Resource Limits | Constraints on output based on availability of the factors of production | Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources |
| Sensitivity | Importance of carefully controlled conditions for product and process integrity | Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity |
| Connectivity | Degree of interdependence and reliance on outside entities | Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources |
| Supplier/Customer Disruptions | Susceptibility of suppliers and customers to external forces or disruptions | Supplier reliability, Customer disruptions |

*Note*: *Pettit et al. (2010).

Resilience Framework (Pettit et al. 2010) were derived through empirical evidence; however, additional evidence is necessary to validate these concepts. Using systems theory to view supply chains as open systems that are influenced by, and interact with, their environment (Katz and Kahn 1978), this study uses the concept of vulnerabilities as influences and capabilities as continuous interactions. A two-step process was selected to measure and then validate, using case study methodology (Eisenhardt 1989; Meredith 1998; Yin 2003; Esper et al. 2007; Blackhurst et al. 2011) with qualitative analysis (Miles and Huberman 1984).

First, an assessment tool was created to measure each element of the Supply Chain Resilience Framework. Seven firms each selected one of their product-lines or product-families for evaluation. Second, to validate the assessment tool, a series of focus groups was conducted with each participating firm using a multiple case study methodology to evaluate several recent disruptions. The goal of these focus groups was not to promote consensus building or decision making, but to gather a broad base of information on complex issues (Morgan 1996). In this way, a complete evaluation of the assessment tool and its ability to accurately measure the construct of resilience was accomplished. Therefore, this research combines seven assessments from a variety of heterogeneous firms followed by multiple disruption case studies at each firm to justify previous theory building (Eisenhardt and Graebner 2007).

## THE ASSESSMENT TOOL, SCRAM™

### Instrument development

Based on the Supply Chain Resilience Framework (Pettit et al. 2010), a survey-based assessment tool—the Supply Chain Resilience Assessment and Management (SCRAM™)—was created to subjectively measure each factor and subfactor. Due to the vast scope of supply chain resilience, employing multiple items per subfactor was not practical to maintain a reasonable survey length (Dillman 2000). To determine internal priorities and compare results between heterogeneous companies, the survey concluded with questions rating the relative importance of the factors (Lambert 2006). Survey responses were designed in ordinal form using the 5-point Likert scale "Agree/Disagree." Considerable care was made to word each question and response in a parallel manner to assist participants in responding both quickly and accurately.

### Instrument refinement

Following a pretest and refinement by four academics and five practitioners, a pilot test was implemented at a global fashion retailer in a continued effort to refine the tool prior to implementation ($n = 15$, response rate of 75%). As multiple measures were categorized to represent resilience factors, the refinement process checked for unidimensionality of factor measures and internal consistency, removing inconsistent items.

### Sampling methodology

Theoretical sampling was chosen to identify firms with supply chains that were compelling examples of the target population of global manufacturing and service firms while also providing the necessary research access (Yin 2003). A total of 83 manufacturing and service firms, primarily headquartered in the Midwest to facilitate on-site interviews, were solicited with 15 candidates responding based on their interest in risk management and resilience, for an 18% response rate. Final screening of companies

**Table 2:** Capability factors

| Capability factor | Definition | Subfactors |
|---|---|---|
| Flexibility in Sourcing | Ability to quickly change inputs or the mode of receiving inputs | Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources |
| Flexibility in Order Fulfillment | Ability to quickly change outputs or the mode of delivering outputs | Alternate distribution channels, Risk pooling/sharing, Multisourcing, Delayed commitment/Production postponement, Inventory management, Rerouting of requirements |
| Capacity | Availability of assets to enable sustained production levels | Reserve capacity, Redundancy, Backup energy sources and communications |
| Efficiency | Capability to produce outputs with minimum resource requirements | Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention |
| Visibility | Knowledge of the status of operating assets and the environment | Business intelligence gathering, Information technology, Product, equipment and people visibility, Information exchange |
| Adaptability | Ability to modify operations in response to challenges or opportunities | Fast rerouting of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience |
| Anticipation | Ability to discern potential future events or situations | Monitoring early warning signals, Forecasting, Deviation and near-miss analysis, Risk management, Business continuity/preparedness planning, Recognition of opportunities |
| Recovery | Ability to return to normal operational state rapidly | Crisis management, Resource mobilization, Communications strategy, Consequence mitigation |
| Dispersion | Broad distribution or decentralization of assets | Distributed decision making, Distributed capacity and assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets |
| Collaboration | Ability to work effectively with other entities for mutual benefit | Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners |
| Organization | Human resource structures, policies, skills, and culture | Accountability, Creative problem solving, Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring |
| Market Position | Status of a company or its products in specific markets | Product differentiation, Customer loyalty/retention, Market share, Brand equity, Customer relationships, Customer communications |
| Security | Defense against deliberate intrusion or attack | Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security |
| Financial Strength | Capacity to absorb fluctuations in cash flow | Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin |

*Note*: *Pettit et al. (2010)

based on the project scope resulted in the final selection of seven firms representing a broad industry comparison (Yin 2003). Based on the enterprise view of supply chain resilience, each sponsor was requested to appoint "thought leaders" or "key informants" (Voss et al. 2002) from various functions to participate: research and development, marketing, procurement, production, logistics, finance, sales, risk management, security, information technology, and others as necessary. A total of 170 participants participated in the seven assessments, as described in Table 3 and quantified in Figure 2. It should be noted that Company F chose to use a reduced team size, identifying only senior-level managers from each functional specialty to capture the complete enterprise view.

To test for generalizability, the sample was tested for variance in demand volatility to ensure a wide spread of market influences. Demand volatility was chosen as a primary indicator of Turbulence, and as theorized by the resilience concept, a supply chain facing higher levels of change must be more resilient to survive. Volatility spread, shown in Figure 3, is calculated by each firm's primary measure of demand for the products evaluated. In a comparison with the target population, the sample firms have average quarterly revenue volatility over the past five quarters of .13 (coefficient of variation [CV]), as compared with the 18 manufacturing

**Table 3:** Description of sample

| | |
|---|---|
| Company A | Global retailer of personal care, beauty, and apparel products |
| Company B | Regional division of a multinational consumer electronics corporation |
| Company C | State-wide medical transportation firm operating as a nonprofit firm |
| Company D | Major division of a global chemical company |
| Company E | Global manufacturer of personal care items |
| Company F | Global manufacturing firm in the building materials industry |
| Company G | Division of a multinational chemical company |

**Figure 2:** SCRAM™ participants.

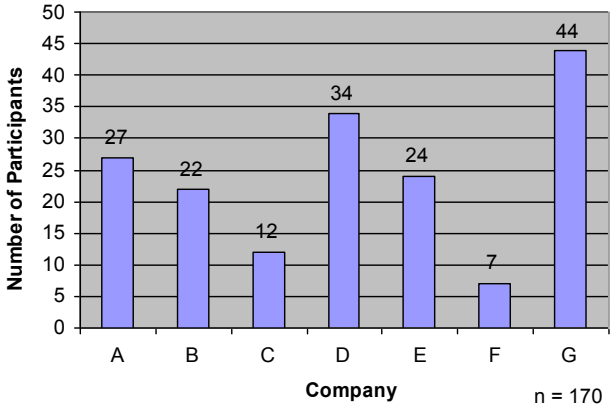
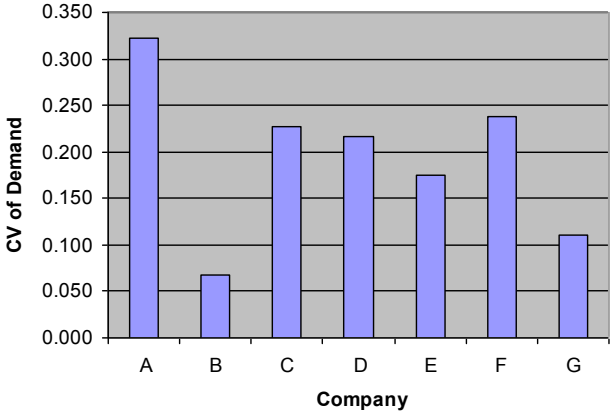



**Figure 3:** Demand volatility in sample.




firms in the Dow Jones Industrial Average with revenue volatility of .09. Thus, this limited sample represents a relatively wide range of volatility with a combined average near market means. Each firm in the sample was well established having operated from 25 to 128 years (averaging 76 years).

## Data collection

A secure, online survey was used to distribute the assessment in a user-friendly, cost-effective manner (Griffis et al. 2003). Format and design of the instrument used tenets of effective web-based surveys from Dillman (2000; e.g., clear introductions, detailed instructions, parallel questions, consistent page layout, limited length, and back paging). Participation in assessments was excellent due to the methodology of selecting a corporate sponsor to lead the project within each firm. Final response rates for each firm ranged between 76% and 100%, with an overall response rate of 82%. Techniques employed to increase response rates included preliminary messages, follow-up reminders, survey sponsorship, personalization of requests, cover letters, assurance of anonymity, and deadline dates (Kanuk and Berenson 1975; Lambert and Harrington 1990). Response rates were high enough that the effect of any nonresponse bias, if it existed, would be minimal on the larger set of respondents (Groves and Peytcheva 2008).

A minimal number of blank entries, 1%, and a minor but expected number of "Don't Know" responses, 10%, were recorded. Allowing respondents to select "Don't Know" was critical in this assessment due to the breadth of the enterprise view of the Supply Chain Resilience Framework. Subjects also rated the relative level of importance of each factor on a similar 5-point Likert scale for consistency, using endpoints of "Minor Importance" and "Critical," with the central point as "Important." Average time to complete the assessment was 30.1 minutes.

Instrument testing used Cronbach's alpha as an unbiased estimator of internal consistency of responses based on the average interitem correlation (Cronbach 1951; Malhotra 1993). Well-developed scales will have a Cronbach's alpha of .7 or greater; however, others propose lesser values as acceptable in exploratory research (Hair et al. 1998; Loehlin 1998; Min and Mentzer 2004). As shown in Table 4, results for all items except one (C1—Flexibility in Sourcing) were acceptable. Flexibility in Sourcing's lack of internal consistency (.288 in Main sample) stems from a significant negative correlation of C1.1—Supply commonality with both C1.4—Supply contract flexibility and C1.5—Alternate sources. This appears acceptable because, for example, as the commonality of supplies increases, the number of parts required decreases and then demand pooling would dictate fewer contract changes and a more limited supplier base. Additionally, the correlation between the five C1 items and the original C1 ("Our organization is flexible in sourcing supplies and services") was significant ($p = .05$), which supports the concept that multiple pathways can provide Flexibility in Sourcing, and not all are necessarily required simultaneously.

### *Focus groups*

Disruptions can be classified as accidents, intentional actions, or simply random events (Sheffi and Rice 2005), and a significant amount of insight on the cause of successful and unsuccessful reactions can be garnered from the organizational memory of recent, important events. "Qualitative interviewing helps reconstruct events the researchers have never experienced" (Rubin and Rubin 2012, 3). Focus groups were guided by a semistructured interview protocol to collect necessary data, while maintaining the highest level of reliability possible (see Appendix A). This protocol uses probes, as applicable, to prompt the group for further explanation or more depth (Crabtree and Miller 1999). The protocol was essential for gathering a consistent set of data, which was especially important with "heterogeneous groups, reflecting a maximum variation sample to effectively gather multiple perspectives on the topic under inquiry" (Patton 1990, 172). And finally, Crabtree and Miller (1999) recommend designing the focus group protocol to generate discussion by subjects from multiple functions within the firm who may have different motivations, skills, experiences, and outcomes; this was crucial to gain insight from the various perspectives required to assess Supply Chain Resilience.

## Sample

Five of the seven firms participating in the SCRAM™ assessment continued with follow-on disruption analyses for qualitative validation. The minimum group size was two, avoiding a single

**Table 4:** Internal reliability of factor measures

| | V1 | V2 | V3 | V4 | V5 | V6 | V7 |
|---|---|---|---|---|---|---|---|
| Number of items | 6 | 6 | 6 | 6 | 9 | 5 | 2 |
| Cronbach's Alpha | .651 | .756 | .746 | .730 | .704 | .745 | .756 |
| Sample size* | 138 | 134 | 142 | 105 | 102 | 130 | 142 |
| | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** |
| Number of items | 5 | 6 | 3 | 5 | 4 | 6 | 6 |
| Cronbach's Alpha | .288 | .677 | .515 | .701 | .813 | .708 | .803 |
| Sample size* | 75 | 90 | 96 | 108 | 123 | 91 | 99 |
| | **C8** | **C9** | **C10** | **C11** | **C12** | **C13** | **C14** |
| Number of items | 4 | 5 | 5 | 6 | 6 | 6 | 4 |
| Cronbach's Alpha | .682 | .461 | .615 | .779 | .763 | .896 | .682 |
| Sample size* | 136 | 115 | 89 | 158 | 141 | 87 | 136 |

*Note*: *Sample size due to listwise deletion of missing or "Don't Know" responses, $N = 170$.

**Table 5:** Disruption case studies

| Company | Disruption title | Number of subjects | Type of disruption | Number of data items collected |
|---|---|---|---|---|
| A | ILWU Lockout 2002 | 6 | Supply-side | 55 |
| | Product Launch Overestimation | 1 | Demand-side | 53 |
| B | Contract Manufacturer Delays for New Product Launch | 2 | Supply-side | 85 |
| | Warehouse Capacity Limitations to Meet End-of-Quarter Loads | 9 | Operations | 158 |
| | Instability in Government Regulations in Venezuela | 2 | Demand-side | 131 |
| | Alignment of Revenue Forecasts with Procurement Forecasts | 3 | Other | 42 |
| D | Container and Transport Availability to Asia | 5 | Supply-side | 93 |
| | Transition of Production to New Site | 5 | Operations | 89 |
| | Multiple Changes in Delivery Date for Extremely Large Order by Major Customer | 3 | Demand-side | 87 |
| E | Instability of Product Formulation from Supplier | 3 | Supply-side | 125 |
| | Major Demand Changes for Promotional Item | 3 | Demand-side | 97 |
| G | Single-Sources Supply Failure | 5 | Supply-side | 103 |
| | Product Shortage | 4 | Operations | 83 |
| | Outbound 3PL Provider Causes Delivery and Customs Delays | 5 | Demand-side | 168 |

biased response while encouraging more depth in responses (Goldman 1962; Morgan 1996). Selection criterion for topics was the type of disruption based on the failure mode. By studying various types of disruptions, each data set revealed new information in addition to many overlapping concepts. Despite the recognition that an infinite number of disruptive causes exist (Sheffi 2005), several authors have divided the spectrum of disruptions into categories (Rice and Caniato 2003; Kleindorfer and Saad 2005; Manuj and Mentzer 2008). This study therefore categorizes disruptions into the set of:

- Supply-side disruptions: relating to the creation, delivery, and availability of supplies when and where needed
- Production disruptions: the process of creation of products or services by the focal firm
- Demand-side disruptions: relating to distribution and sale of products to customers through to the end consumer, including additional manufacturing downstream of the focal firm

By including multiple disruptions from each category, a more thorough data set was gathered relative to the enterprise characteristics of the Supply Chain Resilience Framework for validation. Fifty-six participants from 14 focus groups were involved, as listed in Table 5.

### Instrument validation and reliability

"Validity is not a commodity that can be purchased with techniques" (Brinberg and McGrath 1985, 13). However, the ideal state is to be pursued through research techniques designed into

**Table 6:** Validation data summary

| | Firms | Focus groups | Subjects | Number of data line items | Number of positive coded items | Number of negative coded items |
|---|---|---|---|---|---|---|
| Total | 5 | 14 | 56 | 1,369 | 808 | 344 |
| Average per focus group | | | 4.0 | 97.8 | 57.7 | 24.6 |
| Vulnerabilities | | | | | 459 | 11 |
| Capabilities | | | | | 349 | 333 |

each stage of the process. Construct validity, ensuring that operational measures are proper for the concepts being studied (Miles and Huberman 1984; Ellram 1996; Yin 2003), was controlled using multiple respondents from each of several functional areas in the firm and multiple levels of management to measure the overall level of resilience. Results were also presented to corporate leaders for final testing of construct validity. External validity, the extent to which the results accurately represent the phenomenon studied, thus establishing generalizability (Ellram 1996; Yin 2003), was designed into the study through a sample that includes multiple firms from the spectrum of markets. Reliability, demonstrating that the operations of a study can be repeated with the same results (Yin 2003), was controlled through a pretest and pilot test of the assessment tool and, for the case studies, evaluated using a hold-out sample. These postfocus group responses recorded 119 reliability items, yielding 95% of common information with the focus groups and only 5 new pieces of information and no contradictions. Results of blind coding by two separate researchers found that 83% of vulnerabilities were like-coded while only 66% of capabilities were similarly coded. Although initial blind-coding reliability of 60% is considered good (Miles and Huberman 1984), a consensus session was conducted on the capabilities and all issues were resolved (Krueger 1988). Consensus results were used for analysis.

### Validation results

Data from these 14 disruption focus groups was used to validate the SCRAM™ tool. See Table 6 for summary statistics of the focus group data.

The chosen methodology was successful in exploring these complex issues through a combination of detailed and open-ended questioning. As the focus groups investigated actual disruptions, very few low-vulnerability issues were discussed. However, a good variety of capabilities were coded implying that the focus groups conveyed their supply chain's strengths as well as their weaknesses. Qualitative evaluation of the assessment tool's construct validity was evaluated using these interpretive codes. The factor scores from the SCRAM ™ assessment were used for comparison. Using the number of firms that validated each capability score, a 92.9% validation rate was computed. As the focus groups reported very few low vulnerabilities, a similar computation was not possible. Therefore, each vulnerability category was reviewed for each focus group in relation to their SCRAM™ results. In all 14 cases, the reports from these recent disruptions validated the subjective survey data.

## RESULTS AND ANALYSIS

### Assessment results

The exploratory methodology dictated review and analysis of each assessment individually and later as a whole. Following the administration of each SCRAM™ instrument, data and preliminary recommendations were presented in an open forum with the sponsor and key functional leaders from their firm. These discussions provided validation of the measurement abilities of the tool.

Despite literature being dominated by case studies of weather- and supplier-related disruptions (Svensson 2000; Christopher and Peck 2004; Sheffi 2005), the SCRAM™ data are consistent with reported supply chain risks that rate infrastructure and complexity as greater threats (Elkington 2006; Craighead et al. 2007). A summary of vulnerability rankings are shown in Table 7.

Similarly, each team discussed its assessed capabilities in rank order, beginning with its strengths. Table 8 lists the overall capability rankings based on the average firm ranks.

A closing review of each assessment mapped the factor scores with their relative importance. Both vulnerabilities and capabilities were reviewed; one example of concern is a firm with capabilities that have a low score and high importance: weaknesses that should be prioritized for improvement. Although each firm will have unique results, the initial sample of firms in this study suggests that future research should focus not as much on Deliberate Threats and Turbulence but on supply chain Connectivity and the External Pressures facing a firm (Figure 4). In addition, the data show the need for additional emphasis on Collaboration,

**Table 7:** Vulnerability score rankings

| Ranking | Variable | Vulnerability factor | Average rank* |
|---|---|---|---|
| 1 | V3 | External Pressures | 2.0 |
| 2 | V6 | Connectivity | 2.1 |
| 3 | V5 | Sensitivity | 2.9 |
| 4 | V4 | Resource Limits | 3.7 |
| 5 | V1 | Turbulence | 4.7 |
| 6 | V7 | Supplier/Customer Disruptions | 5.9 |
| 7 | V2 | Deliberate Threats | 6.7 |

*Note*: *Using firm ranking among the seven companies in the main sample (i.e., rank 1 = highest vulnerability to 7 = lowest vulnerability).

**Table 8:** Capability score rankings

| Ranking | Variable | Capability factor | Average rank* |
|---|---|---|---|
| 1 | C12 | Market Position | 2.6 |
| 2 | C8 | Recovery | 3.6 |
| 3 | C14 | Financial Strength | 3.9 |
| 4 | C13 | Security | 4.3 |
| 5 | C11 | Organization | 4.9 |
| 6 | C9 | Dispersion | 5.3 |
| 7 | C4 | Efficiency | 5.9 |
| 8 | C7 | Anticipation | 9.3 |
| 9 | C5 | Visibility | 9.7 |
| 10 | C1 | Flexibility in Sourcing | 10.1 |
| 11 | C6 | Adaptability | 10.4 |
| 12 | C2 | Flexibility in Order Fulfillment | 11.0 |
| 13 | C3 | Capacity | 11.6 |
| 14 | C10 | Collaboration | 12.6 |

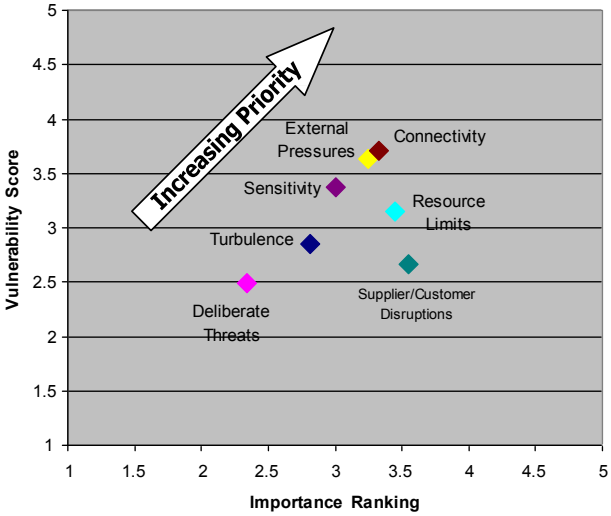
*Note*: *Using firm ranking among the seven companies in the main sample (i.e., rank 1 = strongest capability to 14 = weakest capability).

Capacity, Flexibility, and Adaptability (Figure 5). One other observation from the data is that participating firms averaged a relatively strong capability to recover from disruptions (Recovery), but they show less capability to predict and prevent disruptions (Anticipation).

### Influence of resilience on performance

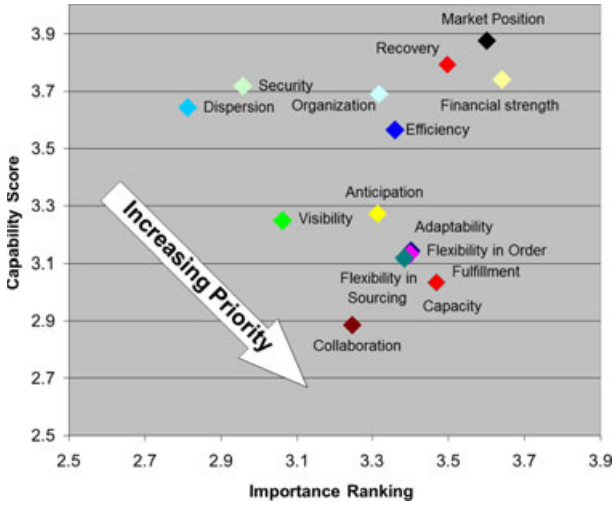
Before investing in any SCRAM™ recommendation, it is imperative to determine if in fact there is a connection between resilience and overall operational performance. Without longitudinal data or large-scale testing, this initial sample of seven firms was surveyed for supply chain performance measures

**Figure 4:** Prioritization of vulnerabilities averaged across all firms.




*Note*: Reduced graph scale to improve readability.

**Figure 5:** Prioritization of capabilities averaged across all firms.




*Note*: Reduced graph scale to improve readability.

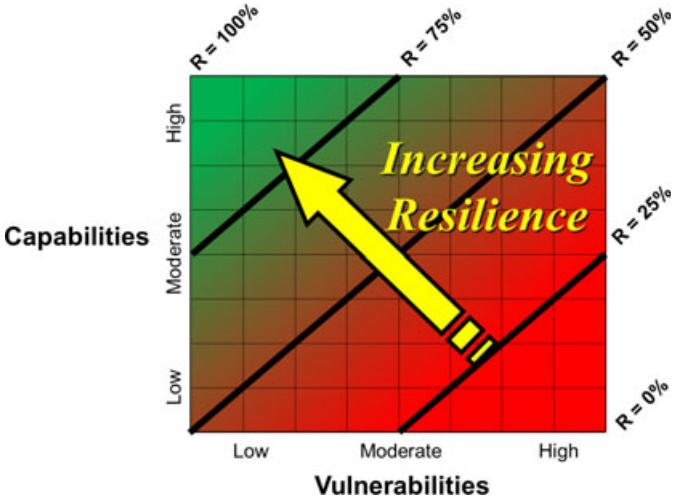
over the 12-month period prior to their SCRAM™ assessment, and data were compared with their overall resilience score to determine if the initial data justified advancement of the research.

For this analysis, the calculation of a resilience score, $R$, ranging from 0% to 100% as depicted in Figure 6, is based on a firm's average vulnerability score, $V$, and the average capability score, $C$, as given by

$$R = \frac{C - V + 4}{8},$$

when utilizing the 5-point Likert scale employed by the SCRAM™ tool. Construct scores are computed by averaging the factor scores, assuming equal weights for each factor, in the manner of

**Figure 6:** Resilience computation.



$$V = \frac{\sum_{i=1}^{n_V} V_i}{n_V}, n = 7,$$

and

$$C = \frac{\sum_{j=1}^{n_C} C_j}{n_C}, n_C = 14.$$

Factor scores are averaged from the associated subfactors in a similar manner, again assuming equally weighted items, as

$$V_i = \frac{\sum_{k=1}^{n_{Vi}} V_{i,k}}{n_{Vi}}, i = 1 \rightarrow n_V,$$

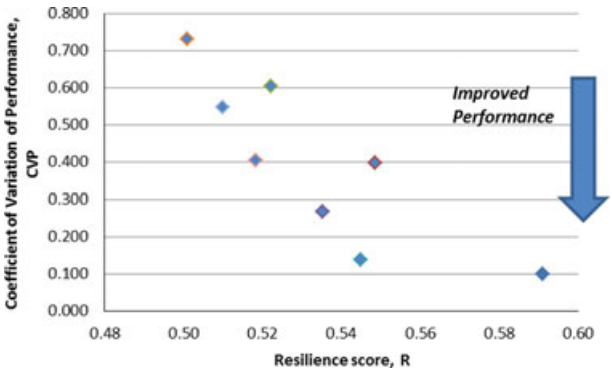
where $n_{Vi}$ varies with the number of items in the $i$th vulnerability factor and

$$C_j = \frac{\sum_{k=1}^{n_{cj}} C_j, k}{n_{Cj}}, j = 1 \rightarrow n_C,$$

where $n_{Cj}$ varies according to the number of items in the $j$th capability factor. Note that the goal is not to achieve a resilience score of 100%, as that suggests the firm is probably overinvested in capabilities given the level of vulnerabilities it faces.

We postulate that improved resilience will, in the short-term, result in lower performance volatility. Therefore, to represent firm performance in relation to resilience, the volatility of supply chain performance measures was computed for each firm. However, to compare multiple metrics, each targeting a separate dimension of supply chain operations, the CV was used, defined as the ratio of the standard deviation to the mean. In this study, each participating firm provided between three and 12 performance measures. Examples include availability, delivery lead-time, inventory position, order accuracy, and customer complaints. As shown in Figure 7, firms in this sample reporting higher resilience scores reported lower volatility of supply chain performance metrics (note: one additional firm participated in a later study, $n = 8$), thus inferring that there is a potential for performance gains due to improved resilience ($R^2 = .7004$). Although this sample size was small, these exploratory results provide motivation to advance the resilience methodology.

**Figure 7:** Resilience inference on performance volatility.




## The application of mixed methods to improve resilience

Knowing your current state of resilience is only the first step—managers need reliable advice on how to improve their resilience to meet corporate strategies for survival and long-term growth. The Supply Chain Resilience Framework considers vulnerabilities as inherent characteristics of the supply chain environment and therefore fixed in the short-term. Managers require identification of linkages between their vulnerabilities and the capabilities that they can directly control. For instance, if a manager identifies Connectivity as a key vulnerability, what are the capabilities to best protect the firm from this risk? And more importantly, looking across all the firm's vulnerabilities, what is the portfolio of capabilities that will best protect from disruptions? As previously stated, the goal is to create and maintain a state of balanced resilience that mitigates risks without overly investing in excessive capabilities, as shown in Figure 1 (Pettit et al. 2010).

Based on the breadth of the Supply Chain Resilience Framework, identifying linkages between the 111 subfactors is a very complex task. Editors of the *Journal of Operations Management* recently asserted that "it is our strong belief that multiple approaches are required to develop a holistic understanding of operations and supply chain management phenomena" (Boyer and Swink 2008, 339). When applicable methods are applied with a variety of data, the convergence of multiple methods provides additional validation (Jick 1979). As quantitative methods alone frequently do not capture the complex interactions of the business environment, organizational issues, and societal culture (Kiessling and Harvey 2005), this study's comparison of theoretical data, survey data, and case study data creates a mixed-methods approach to produce results with the required depth and breadth.

*Method A: theoretical linkages*

During the first phase of this research, extant literature was consolidated and combined with insightful anecdotal evidence from practitioners building the researchers' baseline understanding of the concepts involved, which is necessary for theory construction (Yin 2003). Following an in-depth literature review and validation discussions with leadership from each of the seven participating firms, potential linkages were theorized by the research team. This method is validated by a recent investigation of published logistics research, which concluded that significant contributions can be made "by the researcher spending time in organizations and observing and/or communicating with professionals performing logistics in action" (Frankel et al. 2005, 203). This initial set of potential linkages is clearly biased by the researchers' knowledge, experience, and deductive reasoning. Therefore, triangulation with empirical data searches for the confluence of conclusions to develop less biased, more reliable results.

*Method B: correlation of survey responses*

Survey data were then gathered as a low-cost, noninvasive method for collecting expert perceptions on the complex issue of resilience (Mentzer and Kahn 1995). Statistically significant correlations ($\alpha = .10$) between vulnerability scores and capabilities scores are of interest. For example, firms in the sample may

**Table 9:** Summary of factor-level linkages by methodology

| One-way comparisons | Two-way comparisons | Three-way comparisons | Number of linkages*, ** |
|---|---|---|---|
| A or B or C | | | 97 |
| | A and B | | 9 |
| | A and C | | 42 |
| | B and C | | 20 |
| | Unique links | | 54 |
| | | A and B and C | 9 |

*Notes*: A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Linkages.
*Maximum possible linkages = 7 vulnerabilities × 14 capabilities = 98.
**$\alpha$ = .10 for correlations.

employ well-balanced resilience in a particular area by design and therefore these vulnerabilities will be positively correlated: low vulnerabilities matched with low capabilities, high vulnerabilities with high capabilities. However, from an exploratory perspective, this study does not attempt to define or predict the relationships or the direction of the relationships. It is noted that the absence of a significant correlation does not by itself negate the possibility of a linkage existing, only that the firms in the limited sample did not assess the relationship similarly.

*Method C: pattern matching of focus group responses*

Focus groups are an excellent source of qualitative data when exploring complex issues (Eisenhardt 1989; Morgan 1996; Yin 2003). Using the 1,369 line items from the 14 focus groups discussed previously, pattern matching was employed within each firm—each line item reflecting one or more statement of high/low capability and/or high/low vulnerability. Thus, an empirical set of potential linkages between capabilities and vulnerability can be determined, although biased by this data set. However, if such qualitative data are triangulated with quantitative methods, the results lead to improved theory development (Frankel et al. 2005).

*Identification of critical linkages*

At the factor level, this research identified 45 theoretical linkages (Method A), 20 survey correlations (Method B), and 95 focus group linkages (Method C), resulting in 97 unique linkages. Table 9 summarizes the comparisons between these potential linkages using the two-way and three-way triangulation methodology. For maximum validity, the confluence of all three methods is desirable; however, the absence of results from a single method does not negate a potential linkage. Therefore, balancing the desire to create a reliable list of potential linkages with the exploratory goal of identifying the maximum possible linkages for managers to consider when developing or modifying their portfolio of capabilities, Table 10 lists the two-way and three-way triangulations by vulnerability factor.

However, for managers to take action, linkages need to be identified at the subfactor level. Therefore, a similar process was performed at the subfactor level. Subfactor linkages by methodology are: (A) 590 theoretical linkages (20.8% of total 2,840 possible links), (B) 414 survey correlations, and (C) 232 focus

**Table 10:** Vulnerability factor linkages

| Vulnerability factor | Linked capability factors |
|---|---|
| Turbulence (V1) | Flexibility in Sourcing (C1)* |
| | Flexibility in Order Fulfillment (C2)* |
| | Capacity (C3)* |
| | Visibility (C5)** |
| | Adaptability (C6)* |
| | Anticipation (C7)* |
| | Recovery (C8)* |
| | Dispersion (C9)* |
| | Collaboration (C10)** |
| | Security (C13)*0 |
| Deliberate Threats (V2) | Adaptability (C6)* |
| | Anticipation (C7)* |
| | Recovery (C8)* |
| | Dispersion (C9)* |
| | Security (C13)* |
| External Pressures (V3) | Flexibility in Sourcing (C1)* |
| | Flexibility in Order Fulfillment (C2)* |
| | Visibility (C5)* |
| | Adaptability (C6)* |
| | Anticipation (C7)* |
| | Market Position (C12)* |
| Resource Limits (V4) | Flexibility in Sourcing (C1)** |
| | Flexibility in Order Fulfillment (C2)* |
| | Capacity (C3)** |
| | Efficiency (C4)* |
| | Adaptability (C6)* |
| | Anticipation (C7)* |
| | Dispersion (C9)* |
| | Market Position (C12)* |
| | Financial Strength (C14)** |
| Sensitivity (V5) | Efficiency (C4)* |
| | Adaptability (C6)* |
| | Dispersion (C9)* |
| | Security (C13)* |
| Connectivity (V6) | Flexibility in Sourcing (C1)** |
| | Flexibility in Order Fulfillment (C2)* |
| | Efficiency (C4)* |
| | Visibility (C5)** |
| | Adaptability (C6)* |
| | Anticipation (C7)* |
| | Collaboration (C10)* |
| | Organization (C11)* |
| | Market Position (C12)* |
| | Security (C13)* |
| | Financial Strength (C14)* |
| Supplier/Customer Disruptions (V7) | Flexibility in Sourcing (C1)** |
| | Flexibility in Order Fulfillment (C2)** |
| | Capacity (C3)* |
| | Visibility (C5)* |
| | Recovery (C8)* |
| | Dispersion (C9)* |
| | Collaboration (C10)* |
| | Market Position (C12)* |
| | Financial Strength (C14)* |

*Notes*: *Significant from a two-way comparison only (A–B, A–C, and/or B–C).
**Three-way comparison results.

group linkages. Results of the subfactor-level triangulation are summarized in Table 11, with detailed subfactor linkages presented in Appendix B. Of the 40 vulnerability subfactors, this mixed-methods process identified 311 unique linkages at the two-way level. These exploratory results provide an initial guide for firms that have completed the SCRAM™ assessment and are taking the next step toward improving their resilience.

### Improving balanced resilience

If the goal is to be in the Zone of Balanced Resilience, then calculating a Resilience Gap for each vulnerability/capability linkage can help organizational leaders develop insight into potential improvement opportunities. We define the Resilience Gap as the amount of imbalance from the theoretically optimal state of balanced resilience for each vulnerability/capability linkage. We calculate the Resilience Gap as the percentage distance from the Resilience Score to the centerline of the Zone of Balanced Resilience (see Figure 1), in the form of

$$R_{GAP_{i,j}} = \frac{C_i - V_j}{4},$$

for all *i,j* in which a linkage exist, where *Ci* and *Vj* range from 1 to 5.

Positive gaps represent higher capability than the associated vulnerability, potentially eroding profits; negative gaps show lower capability than the associated vulnerability, exposing the firm to potential risks. Note that a positive gap does not necessarily indicate that a firm should reduce an associated capability, as that capability might be in place for strategic reasons unrelated to resilience. As can be seen in the example in Figure 8, managers can use this visualization to show where to focus their attention. For example, this notional data set suggests that the firm is vulnerable to Turbulence, and while they lack Flexibility in Sourcing, Visibility, Dispersion, and Collaboration, they have some excess Capacity to protect themselves against this risk.

### The resilience process

Creating and maintaining supply chain resilience is not a one-time event—it is a process. As part of this research effort, the authors created a process flow to assist companies in their resilience journey. This process involves scoping the project, selecting an appropriate team, performing the SCRAM™ assessment, analyzing the data, validating the business case, then evaluating results and re-assessing. This process is described in more detail in Appendix C.

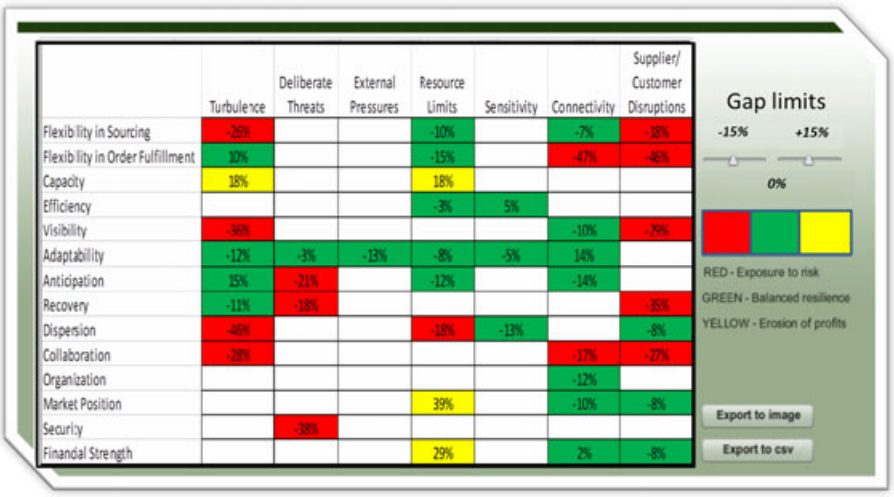
In an initial application of this process, the Dow Chemical Company applied this resilience process to their Glycol Ethers P-Series family of products, and their results were recognized as a Finalist in the Supply Chain Innovation Award competition. Their SCRAM™ analysis led to a scenario exploration of right-sizing fixed assets and working capital, which provided a potential $1.1 million savings for this business and represented a 500% Return on Modeling Effort (McIntyre and Hemmelgarn 2011).

**Table 11:** Summary of subfactor-level linkages by methodology

| One-way comparisons | Two-way comparisons | Three-way comparisons | Number of linkages*, ** |
|---|---|---|---|
| A or B or C | | | 1,021 |
| | A and B | | 95 |
| | A and C | | 232 |
| | B and C | | 36 |
| | Unique links | | 311 |
| | | A and B and C | 36 |

*Notes*: A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Linkages.
*Maximum possible linkages = 40 vulnerabilities × 71 capabilities = 2,840.
**$\alpha$ = .10 for correlations.

**Figure 8:** Depiction of resilience gaps by linkages.




*Note*: Notional data.

## RECOMMENDATIONS FOR FUTURE RESEARCH

Several concerns were noted during this research and are presented here for future research. Larger scale implementation is necessary to validate the measurement scales, identifying critical zones and clusters, particularly expanding the range of resilience scores recorded and testing of the impact of resilience on performance. A longitudinal study could explore the results of enhancements to balanced resilience on long-term performance, specifically focusing on the profitability aspect of erosion of profits versus exposure to risk. Also, future research may determine multiple measures at each subfactor level, with the addition of objective measurements where appropriate. As these measures become more specialized, it may be necessary to create industry-specific items or even firm- or product-level assessment items. Such efforts may benefit from individualized subfactor weights for more refined analyses.

Now that we can measure the current state of a firm's resilience, the next step is to refine the process of integrating the vision of resilience into the entire supply chain. It is recommended to apply this assessment tool with both upstream and downstream partners to get a full view of the supply chain's resilience. Additionally, evolving capabilities such as sustainability should be included in more depth. The final barrier to resilience is ideological (Hamel and Välikangas 2003). Educating corporate leaders on the concept of resilience and providing tools such as SCRAM™ will enhance current risk management strategies to allow supply chains to survive, adapt, and grow in the face of turbulent change.

## CONCLUSIONS

The SCRAM™ tool showed initial promise toward evaluating the current level of resilience of a firm. Presentation of results to corporate sponsors and their functional leaders in this initial sample provided excellent feedback as to the breadth of the Supply Chain Resilience Framework and the ability of the SCRAM™ tool to accurately measure the sources of change facing the firm as well as the firm's strengths and weaknesses. By analyzing results from seven firms with global supply chains, it was found that External Pressures and Connectivity are the highest vulnerabilities facing this diverse group of companies. Although the firms in the sample reported relatively low threats from Supplier/Customer Disruptions, these results validate previous studies by placing the highest importance on these issues impacting the supply chain.

Firms in this study reported capability strengths in the areas of Market Position, Recovery, and Financial Strength. However, consistent reports of low Collaboration, lack of excess Capacity and minimal Flexibility raised serious concerns to the corporate sponsors. When highly rated vulnerabilities were discussed in relation to linked capabilities, sponsors were compelled to improve their resilience within the fitness space to best match the Zone of Balanced Resilience.

Managing change is essential. In the corporate environment, not being prepared for change and not designing and managing a supply chain that can react and adapt quickly can be very costly. "After adjusting for industry and economy effects, the average effect of disruptions is a 107% drop in operating income, 7% lower sales growth and 11% growth in cost" (Hendricks and Singhal 2005, 36). This exploratory study used supply chain performance measures to provide an initial assessment to infer that there is a positive relationship between increased resilience and improved operating performance for the firms within this study. Results show a potential for a 26% improvement in performance volatility for a single percentage point increase in resilience score as assessed by the SCRAM™ tool for these seven companies. Larger studies will be needed to confirm these results, but the evidence from business literature, industry leaders, and academics also confirms the necessity for resilience (Council on Competitiveness 2007; FM Global 2007; Sheffi 2008).

Traditional risk management is a successful tool when potentially disruptive events can be clearly identified. In an increasingly complex society, assumptions of future events are becoming less and less applicable. However, the concept of resilience for supply chain operations has proven potential to improve overall operational performance, both in times of dramatic change and in times of relative stability (Flynn 2008). With the SCRAM™ tool, managers can now quickly assess their current state of supply chain resilience and evolve their resilience with proactive strategy selections instead of waiting for the next disaster to strike.

## APPENDIX A
## FOCUS GROUP PROTOCOL

### PART I: INTRODUCTIONS

### PART II: EVALUATION OF A DISRUPTION—IDENTIFICATION, MITIGATION, AND ADAPTATION

1. Before the disruption

   a. When was the disruption first identified?
   b. How did it actually begin?
   c. Did you have any warning?
   d. How was the disruption first identified?
   e. Who were the first to identify the problem? Who else was affected?

2. Severity and frequency of the impact of the disruption

   a. What was the immediate impact of the disruption?
   b. When, if at all, did your customers notice any negative impacts? How?
   c. Are your customers the end consumer?
   d. Does this type of event happen often?

3. During the disruption

   a. What was the initial response to the disruption?
   b. Was this completely successful?
   c. Did any of your actions make the problem worse?
   d. Was your primary concern the length of time that the disruption would last or the severity of the disruption (i.e., minimize impact of longer period, or short but painful)?

e. Were you able to quantify the total impact of the disruption?

i. Financial?
ii. Performance?
iii. Customer service/satisfaction?

f. Once the initial disruption was resolved, were there any longer term impacts? Were there any changes that were made?

4. Causes

a. Did you attempt to analyze the root cause of this disruption?
b. How was this cause related to:

i. Characteristics of your product?
ii. Aspects of your production process?
iii. Factors of your distribution network?

5. Learning from the disruption

a. What did your company learn from this disruption?
b. How did the firm change following this disruption (policy, structure, etc.)?
c. How long did it take to implement these changes?
d. Have these changes become 'permanent' or have procedures reverted to previous methods?

## PART III: REDESIGNING THE SUPPLY CHAIN

1. Internal Processes

a. Preparation:

i. What are the methods that you use to prepare for potential disruptions?
ii. What types of security do you employ to protect against threats? (natural disasters, stock-outs, deliberate threats)
iii. Anticipation: How do you anticipate disruptions?

b. Response

i. What are the first steps that taken when a disruption is discovered?
ii. What are key roles that you play during recovery operations?
iii. Do you inform your customers of current or projected disruptions?
iv. Is your customer the end consumer?
v. How do you use the media during crises?
vi. Are your preparedness plans used during recovery?

2. Suppliers

a. How can your suppliers help you to be prepared for a disruption?
b. How can your suppliers help you respond to an event?
c. Do your suppliers provide any insight into future events or trends?

3. Customers

a. How can your customers help you to be prepared for a disruption?
b. How can your customers help you respond to an event?
c. Do your customers provide any insight into future events or trends?

4. Distributors: How can your distributors help you respond to an event?

5. Others: Who else can assist you in responding to an event?

6. Learning

a. Following a disruption, do you discuss the event and create an after-actions report?
b. What are some key aspects of an "after actions report"?
c. Are the lessons learned communicated to the entire workforce? How?
d. What types of issues can impede implementation of improvements?

7. Using positive change to create opportunities

a. How do you anticipate positive change?
b. What are some ways that you create positive change?

## APPENDIX B
## SCRAM LINKAGES

**Table B1:** Turbulence linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Turbulence (V1) | Unpredictability in customer demand (V1.1) | Commonality (C1.1)*<br>Product modularity (C1.2)**<br>Multiple pathways (C1.3)*<br>Supply contract flexibility (C1.4)*<br>Alternate suppliers (C1.5)*<br>Logistics multisourcing (C2.1)*<br>Postponement (C2.2)*<br>Demand pooling (C2.3)**<br>Inventory management (C2.4)**<br>Reserve capacity (C3.3)*<br>Labor productivity (C4.1)*<br>Asset utilization (C4.2)*<br>Information technology (C5.1)*<br>Asset visibility (C5.2)*<br>Information exchange (C5.3)*<br>Business intelligence (C5.4)*<br>Strategic gaming and simulation (C6.2)*<br>Seizing advantage (C6.3)*<br>Lead-time reduction (C6.5)*<br>Learning from experience (C6.6)*<br>Demand forecasting (C7.1)*<br>Risk identification and prioritization (C7.2)*<br>Recognition of early warning signals (C7.4)*<br>Contingency planning and exercising (C7.5)*<br>Recognition of opportunities (C7.6)*<br>Resource mobilization (C8.1)*<br>Consequence mitigation (C8.4)*<br>Dispersion of markets (C9.5)*<br>Collaborative forecasting (C10.1)*<br>Collaborative information sharing (C10.2)*<br>Postponement of orders (C10.3)**<br>Product life cycle management (C10.4)**<br>Risk sharing (C10.5)*<br>Creative problem solving (C11.1)*<br>Accountability (C11.2)*<br>Benchmarking (C11.5)*<br>Market share (C12.3)*<br>Customer relationships (C12.5)*<br>Customer communications (C12.6)*<br>Price margin (C14.4)* |

Continued.

**Table B1:** (Continued)

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Turbulence (V1) | Fluctuations in currencies and prices (V1.2) | Consequence mitigation (C8.4)* |
| | | Price margin (C14.4)* |
| | Exposure to geopolitical disruptions (V1.3) | Alternate distribution channels (C2.5)* |
| | | Business intelligence (C5.4)* |
| | | Seizing advantage (C6.3)* |
| | | Learning from experience (C6.6)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Communications strategy (C8.2)* |
| | | Consequence mitigation (C8.4)** |
| | | Risk sharing (C10.5)** |
| | | Substitute leadership (C11.4)* |
| | | Collaboration with governments (C13.4)* |
| | | Financial reserves (C14.1)* |
| | | Portfolio diversification (C14.2)* |
| | Exposure to natural disasters (V1.4) | Demand pooling (C2.3)* |
| | | Back-up utilities (C3.1)* |
| | | Asset visibility (C5.2)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Recognition of opportunities (C7.6)* |
| | | Resource mobilization (C8.1)* |
| | | Crises management (C8.3)* |
| | | Caring for employees (C11.6)* |
| | | Employee involvement (C13.3)* |
| | Unforeseen technology failures (V1.5) | Lead-time reduction (C6.5)* |
| | | Demand forecasting (C7.1)* |
| | | Consequence mitigation (C8.4)* |
| | Pandemic (V1.6) | Empowerment (C9.4)* |
| | | Dispersion of markets (C9.5)* |
| | | Collaboration with governments (C13.4)* |
| | | Personnel security (C13.6)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

**Table B2:** Deliberate Threats linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Deliberate Threats (V2) | Terrorism and sabotage (V2.1) | Alternate sources (C1.5)* |
| | | Redundant assets (C3.2)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Decentralization of resources (C9.1)* |
| | | Distributed capacity (C9.2)* |
| | | Distributed leadership (C9.3)* |
| | | Location-specific empowerment (C9.4)* |
| | Piracy and theft (V2.2) | Asset visibility (C5.2)* |
| | | Lead-time reduction (C6.5)* |
| | | Learning from experience (C6.6)* |
| | | Consequence mitigation (C8.4)* |
| | | Decentralization of resources (C9.1)* |
| | | Distributed capacity (C9.2)* |
| | | Distributed leadership (C9.3)* |
| | | Location-specific empowerment (C9.4)* |
| | | Layered defenses (C13.1)* |
| | | Access restriction (C13.2)* |
| | | Insurance coverage (C14.3)* |
| | Union activities (V2.3) | Reserve capacity (C3.3)* |
| | | Rerouting requirements (C6.1)* |
| | | Learning from experience (C6.6)* |
| | | Contingency planning (C7.5)* |
| | | Communications strategy (C8.2)* |
| | | Crisis management (C8.3)** |
| | | Consequence mitigation (C8.4)* |
| | | Location-specific empowerment (C9.4)* |
| | | Risk sharing (C10.5)* |
| | | Market share (C12.3)* |
| | Special interest groups (V2.4) | Lead-time reduction (C6.5)* |
| | | Decentralization of resources (C9.1)* |
| | | Location-specific empowerment (C9.4)* |
| | | Geographic dispersion (C9.5)* |
| | Industrial espionage (V2.5) | Back-up utilities (C3.1)* |
| | | Redundant assets (C3.2)* |
| | | Risk identification and prioritization (C7.2)* |
| | | Monitoring normal deviations (C7.3)* |
| | | Decentralization of resources (C9.1)* |
| | | Distributed capacity (C9.2)* |
| | | Distributed leadership (C9.3)* |
| | | Collaborative information sharing (C10.2)* |
| | | Brand equity (C12.1)* |
| | | Layered defenses (C13.1)* |
| | | Access restriction (C13.2)* |
| | | Employee involvement in security (C13.3)* |
| | | Collaboration with governments (C13.4)* |
| | | Cyber-security (C13.5)* |
| | | Personnel security (C13.6)* |
| | | Portfolio diversification (C14.2)* |
| | Product liability (V2.6) | Distributed leadership (C9.3)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).

**Three-way comparison results.

**Table B3:** External Pressures linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| External Pressures (V3) | Competitive innovation (V3.1) | Product/service modularity (C1.2)* |
| | | Supply contract flexibility (C1.4)* |
| | | Delayed commitment/postponement (C2.2)* |
| | | Demand pooling (C2.3)* |
| | | Inventory management (C2.4)* |
| | | Alternate distribution channels (C2.5)* |
| | | Information exchange (C5.3)* |
| | | Business intelligence (C5.4)* |
| | | Lead-time reduction (C6.5)* |
| | | Learning from experience (C6.6)* |
| | | Recognition of early warning systems (C7.4)* |
| | | Brand equity (C12.1)* |
| | | Customer loyalty/retention (C12.2)* |
| | | Market share (C12.3)* |
| | | Product differentiation (C12.4)* |
| | | Customer relationships (C12.5)* |
| | | Customer communications (C12.6)* |
| | Government regulations (V3.2) | Business intelligence (C5.4)* |
| | | Recognition of early warning signals (C7.4)* |
| | Price pressures (V3.3) | Customer loyalty (C12.2)* |
| | | Product differentiation (C12.4)* |
| | | Customer communications (C12.6)* |
| | Corporate responsibility (V3.4) | Business intelligence (C5.4)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Customer relationships (C12.5)* |
| | Social/cultural changes (V3.5) | Recognition of early warning signals (C7.4)* |
| | | Customer relationships (C12.5)* |
| | | Customer communications (C12.6)* |
| | Environmental issues (V3.6) | *No specific linkages* |

Notes: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

**Table B4:** Resource Limits linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Resource Limits (V4) | Supplier capacity (V4.1) | Commonality (C1.1)* |
| | | Alternate sources (C1.5)** |
| | | Recognition of early warning signals (C7.4)** |
| | | Contingency planning (C7.5)* |
| | | Resource mobilization (C8.1)** |
| | | Risk sharing (C10.5)* |
| | | Customer communications (C12.6)** |
| | Production capacity (V4.2) | Alternate sources (C1.5)** |
| | | Logistics multisourcing (C2.1)* |
| | | Inventory management (C2.4)* |
| | | Alternate distribution channels (C2.5)* |
| | | Redundant assets (C3.2)** |
| | | Reserve capacity (C3.3)** |
| | | Preventative maintenance (C4.4)* |
| | | Failure prevention (C4.5)* |
| | | Rerouting of requirements (C6.1)* |
| | | Seizing advantage (C6.3)** |
| | | Learning from experience (C6.6)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Contingency planning (C7.5)* |
| | | Crises management (C8.3)* |
| | | Consequence mitigation (C8.4)* |
| | | Market share (C12.3)** |
| | | Customer relationships (C12.5)* |
| | | Customer communications (C12.6)* |
| | | Price margin (C14.4)* |

Continued.

**Table B4:** (Continued)

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Resource Limits (V4) | Distribution capacity (V4.3) | Supply contract flexibility (C1.4)* |
| | | Logistics multisourcing (C2.1)** |
| | | Demand pooling (C2.3)* |
| | | Alternate distribution channels (C2.5)* |
| | | Reallocation of production (C2.6)* |
| | | Redundant assets (C3.2)* |
| | | Reserve capacity (C3.3)* |
| | | Information technology (C5.1)* |
| | | Information exchange (C5.3)* |
| | | Rerouting of requirements (C6.1)* |
| | | Lead-time reduction (C6.5)* |
| | | Learning from experience (C6.6)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Contingency planning (C7.5)* |
| | | Resource mobilization (C8.1)* |
| | | Consequence mitigation (C8.4)* |
| | | Distributed capacity (C9.2)* |
| | | Dispersion of markets (C9.5)* |
| | | Collaborative forecasting (C10.1)* |
| | | Collaborative information sharing (C10.2)* |
| | | Postponement of orders (C10.3)* |
| | | Risk sharing (C10.5)* |
| | | Customer communications (C12.6)* |
| | | Access restriction (C13.2)* |
| | | Financial reserves (C14.1)* |
| | | Price margin (C14.4)* |
| | Raw material availability (V4.4) | Alternate sources (C1.5)* |
| | | Contingency planning (C7.5)* |
| | | Insurance coverage (C14.3)* |
| | Utilities availability (V4.5) | *No specific linkages* |
| | | Reserve capacity (C3.3)* |
| | | Labor productivity (C4.1)* |
| | | Communications strategy (C8.2)* |
| | | Crises management (C8.3)* |
| | Human resources (V4.6) | Accountability (C11.2)* |
| | | Diversity of skills (C11.3)* |
| | | Substitute leadership (C11.4)** |
| | | Customer relationships (C12.5)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

**Table B5:** Sensitivity linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Sensitivity (V5) | Utilization of restricted materials (V5.1) | Alternate sources (C1.5)*<br>Consequence mitigation (C8.4)** |
| | Importance of product purity (V5.2) | Commonality (C1.1)*<br>Reallocation of production (C2.6)*<br>Redundant assets (C3.2)*<br>Information exchange (C5.3)*<br>Lead-time reduction (C6.5)*<br>Learning from experience (C6.6)*<br>Risk identification and prioritization (C7.2)*<br>Crises management (C8.3)*<br>Consequence mitigation (C8.4)*<br>Customer relationships (C12.5)*<br>Customer communications (C12.6)* |
| | Fragility (V5.3) | Learning from experience (C6.6)*<br>Recognition of early warning signals (C7.4)**<br>Communications strategy (C8.2)*<br>Customer relationships (C12.5)**<br>Customer communications (C12.6)** |
| | Complexity of process operations (V5.4) | Reserve capacity (C3.3)*<br>Failure prevention (C4.5)*<br>Alternate technology (C6.4)*<br>Learning from experience (C6.6)*<br>Recognition of early warning signals (C7.4)*<br>Communications strategy (C8.2)*<br>Consequence mitigation (C8.4)* |
| | Reliability of equipment (V5.5) | Commonality (C1.1)*<br>Alternate distribution channels (C2.5)*<br>Redundant assets (C3.2)*<br>Asset utilization (C4.2)*<br>Failure prevention (C4.5)*<br>Information exchange (C5.3)*<br>Learning from experience (C6.6)*<br>Resource mobilization (C8.1)*<br>Crises management (C8.3)*<br>Consequence mitigation (C8.4)* |
| | Potential safety hazards (V5.6) | *No specific linkages* |
| | Visibility of disruption to stakeholders (V5.7) | Seizing advantage (C6.3)*<br>Consequence mitigation (C8.4)*<br>Postponement of orders (C10.3)* |
| | Symbolic profile of brand (V5.8) | Brand equity (C12.1)*<br>Layered defenses (C13.1)*<br>Access restriction (C13.2)*<br>Employee involvement in security (C13.3)*<br>Cyber-security (C13.5)* |
| | Concentration of capacity (V5.9) | Decentralization of key resources (C9.1)*<br>Distributed suppliers (C9.2)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

**Table B6:** Connectivity linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Connectivity (V6) | Scale and extent of supply network (V6.1) | Commonality (C1.1)* |
| | | Supply contract flexibility (C1.4)* |
| | | Alternate sources (C1.5)* |
| | | Demand pooling (C2.3)* |
| | | Alternate distribution channels (C2.5)* |
| | | Reallocation of production (C2.6)* |
| | | Reserve capacity (C3.3)* |
| | | Asset visibility (C5.2)* |
| | | Information exchange (C5.3)* |
| | | Alternate technology (C6.4)* |
| | | Lead-time reduction (C6.5)* |
| | | Learning from experience (C6.6)* |
| | | Distributed suppliers (C9.1)** |
| | | Dispersion of markets (C9.5)* |
| | | Collaborative information sharing (C10.2)* |
| | | Risk sharing (C10.5)** |
| | | Customer loyalty (C12.2)* |
| | | Market share (C12.3)* |
| | | Customer relationships (C12.5)* |
| | | Price margin (C14.4)* |
| | Import/export channels (V6.2) | Alternate sources (C1.5)* |
| | | Labor productivity (C4.1)* |
| | | Lead-time reduction (C6.5)** |
| | | Demand forecasting (C7.1)* |
| | | Distributed suppliers (C9.1)* |
| | | Distributed assets (C9.2)* |
| | | Dispersion of markets (C9.5)* |
| | | Market share (C12.3)* |
| | | Customer relationships (C12.5)* |
| | | Collaboration with governments (C13.4)* |
| | | Cyber-security (C13.5)* |
| | | Personnel security (C13.6)* |
| | | Price margin (C14.4)* |
| | Reliance upon specialty sources (V6.3) | Alternate sources (C1.5)* |
| | | Quality management (C4.3)* |
| | | Preventative maintenance (C4.4)* |
| | | Failure prevention (C4.5)* |
| | | Business intelligence (C5.4)* |
| | | Alternate technology (C6.4)* |
| | | Product differentiation (C12.4)* |
| | | Layered defenses (C13.1)* |
| | | Employee involvement in security (C13.3)* |
| | | Collaboration with governments (C13.4)* |
| | | Price margin (C14.4)* |

Continued.

**Table B6:** (Continued)

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| | Reliance upon information flow (V6.4) | Back-up utilities (C3.1)*<br>Quality management (C4.3)*<br>Preventative maintenance (C4.4)*<br>Failure prevention (C4.5)*<br>Information technology (C5.1)*<br>Asset visibility (C5.2)**<br>Information exchange (C5.3)**<br>Rerouting of requirements (C6.1)*<br>Learning from experience (C6.6)*<br>Recognition of early warning signals (C7.4)**<br>Resource mobilization (C8.1)*<br>Communications strategy (C8.2)*<br>Consequence mitigation (C8.4)*<br>Collaborative forecasting (C10.1)*<br>Collaborative information sharing (C10.2)*<br>Product life cycle management (C10.4)*<br>Accountability (C11.2)*<br>Customer communications (C12.6)**<br>Layered defenses (C13.1)*<br>Access restriction (C13.2)*<br>Employee involvement in security (C13.3)*<br>Collaboration with governments (C13.4)*<br>Cyber-security (C13.5)* |
| Connectivity (V6) | Degree of outsourcing (V6.5) | Product modularity (C1.2)*<br>Inventory management (C2.4)*<br>Labor productivity (C4.1)*<br>Quality management (C4.3)*<br>Failure prevention (C4.5)*<br>Information exchange (C5.3)*<br>Dispersion of markets (C9.5)*<br>Collaboration with governments (C13.4)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

**Table B7:** Supplier/Customer Disruption linkages

| Vulnerability factor | Subfactor | Linked capability factors |
|---|---|---|
| Supplier/Customer Disruptions (V7) | Supplier disruptions (V7.1) | Commonality (C1.1)* |
| | | Supply contract flexibility (C1.4)** |
| | | Alternate distribution channels (C2.5)** |
| | | Backup utilities (C3.1)* |
| | | Asset visibility (C5.2)* |
| | | Information exchange (C5.3)** |
| | | Lead-time reduction (C6.5)* |
| | | Learning from experience (C6.6)* |
| | | Risk identification and prioritization (C7.2)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Contingency planning and exercising (C7.5)* |
| | | Communications strategy (C8.2)* |
| | | Crises management (C8.3)* |
| | | Consequence mitigation (C8.4)* |
| | | Dispersion of markets (C9.5)* |
| | | Postponement of orders (C10.3)* |
| | | Risk sharing (C10.5)* |
| | | Creative problem solving (C11.1)* |
| | | Accountability (C11.2)* |
| | | Benchmarking (C11.5)* |
| | | Customer loyalty (C12.2)** |
| | | Customer communications (C12.6)** |
| | | Price margin (C14.4)** |
| | Customer disruptions (V7.2) | Commonality (C1.1)* |
| | | Product modularity (C1.2)* |
| | | Multiple pathways (C1.3)* |
| | | Supply contract flexibility (C1.4)* |
| | | Alternate suppliers (C1.5)* |
| | | Logistics multisourcing (C2.1)* |
| | | Production postponement (C2.2)* |
| | | Demand pooling (C2.3)* |
| | | Asset visibility (C5.2)* |
| | | Recognition of early warning signals (C7.4)* |
| | | Recognition of opportunities (C7.6)* |
| | | Resource mobilization (C8.1)* |
| | | Collaborative forecasting (C10.1)* |
| | | Postponement of orders (C10.3)* |
| | | Risk sharing (C10.5)* |
| | | Price margin (C14.4)* |

*Notes*: *Significant from a two-way comparison only (A–B, B–C, and/or A–C).
**Three-way comparison results.

## APPENDIX C
## IMPLEMENTATION PROCESS

SCRAM™: Supply Chain Resilience Assessment and Management

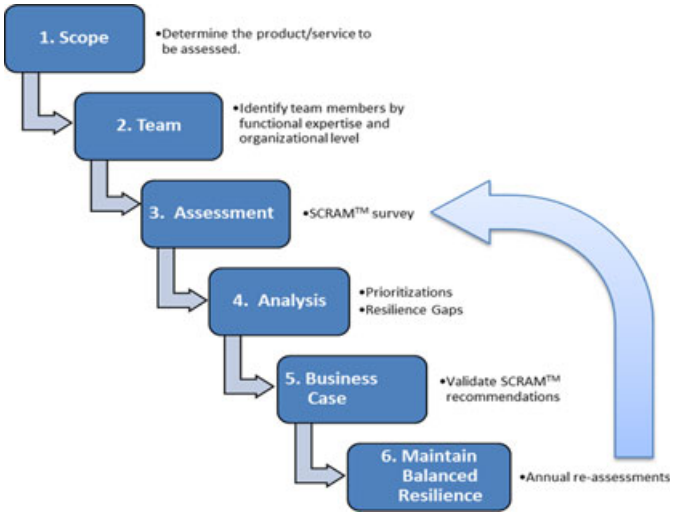
The SCRAM™ framework is based on the following core concepts:

- **Vulnerabilities**—fundamental factors that make an enterprise susceptible to disruptions, for example external pressures, deliberate threats, and resource limits.
- **Capabilities**—attributes that enable an enterprise to anticipate and overcome disruptions, for example flexibility, adaptability, capacity, visibility and anticipation.

The goal of the resilience improvement process is to assess current state vulnerabilities and capabilities to compute Resilience Gaps, which can be used to direct managerial actions toward creating and maintaining balanced resilience.

**The Process-**

Figure C1. The Process




1. **Scope:** The first step in the SCRAM™ assessment process is to define the business scope for the project based on your goals. Rationale to assess a business unit can include issues such as turbulent or unpredictable demand patterns, unstable or potential changes to the supplier or distribution base, changing environmental patterns, risks associated with availability of raw materials, adding a new product, or other concerns related future unknowns. Results are best if a product-line or product-family is scoped into a single assessment. Products included in scope should represent similar levels of complexity, demand patterns and supplier/customer base.
2. **Selection of participants:** Resilience requires an enterprise view of business operations; therefore, participants should be selected from multiple functional areas to encompass the scope of your operations to provide full insights into the current state of resilience. By providing multiple insights, a firm is able to decipher particular weaknesses and strengths within the firm and the relationship between these functions. The following list is a generic summary of functions to consider when selecting participants, but should be tailored to meet the scope of your operations:

**Recommended functional areas**

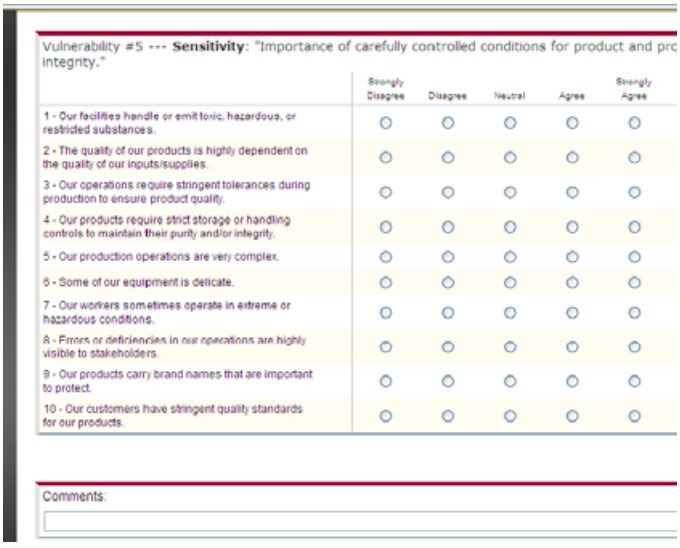
- Research and Development
- Marketing
- Sales
- Procurement/Sourcing
- Information Systems
- Risk Management
- Planning/Scheduling
- Production
- Logistics
- Financial Planning/Accounting
- Quality Control

Also consider team representation from multiple levels within the organization—senior managers with a broad, strategic outlook, as well as operational personnel with a more tactical focus. This works well by complementing the team with at least two individuals from each functional area. Total team competition should be at least 20 individuals, but can be as large as necessary to encompass the scope of your objectives.

3. **Assessment:** The assessment includes subjective questions on each vulnerability and capability subfactor. Respondents indicate their level of agreement to each statement, providing insight into these complex issues. The SCRAM™ assessment is available as a secure, online survey that will take approximately 30 minutes per person to complete. The survey consists of three parts:

**Part I—Vulnerabilities:** Each vulnerability should be presented one at a time. Questions are arranged in a parallel format to ease response. Each page contains multiple questions—one for each subfactor. Responses are in the format of "Strongly Disagree" to "Strongly Agree" to each statement presented. Participants are instructed to select "Don't Know" if they are not exposed to that particular portion of the business (e.g.: a machine operator will typically not have detailed information on the insurability of the firm). A screen-shot of an actual assessment page is shown below:

Figure C2. Vulnerability sample page.



**Part II—Capabilities:** This section assesses each of the 16 capabilities in the same format as the previous section.

**Part III—Importance:** Now that participants have been exposed to all of the resilience factors, SCRAM™ addresses the relative importance of each vulnerability and capability. Participants are asked to rate each factor from "Minor Importance" to "Critical."

4. **Analysis:** After all participants have completed the assessment, computations of consolidated scores and Resilience Gaps must be accomplished. A validation session where the SCRAM™ team discusses the results is critical before continuing. This session should review:

- **Vulnerability rankings**
  - Identification of highest threats to the supply chain
  - Presentation of the most significant components to each vulnerability factor
  - RESULT: Provides insights of the key areas of concern
- **Capability rankings**
  - Identification of both strengths and weaknesses of the supply chain
  - Presentation of the strongest and weakest components to each capability factor
  - RESULT: Provides insight into potential areas of over-investments and areas that may require management attention to strengthen
- **Prioritization of factors**
  - Vulnerabilities—comparing the relative factor score with the importance score, a visual 2 × 2 chart highlights those potential threats which are assessed as most important to the supply chain
  - Capabilities—a similar comparison highlights capabilities based on their level of importance
  - RESULT: Reinforces those strong capabilities that are important to the firm; highlights area of potential concern for weak capabilities that are critical to operations; however, low capabilities that are only of minor importance may have less priority for managerial action or left as acceptable risks
- **Resilience Gaps**
  - For areas in which previous research has identified a potential connection between a specific vulnerability and a specific capability—that is, a Critical linkage (see Appendix B), Resilience Gaps should be reviewed in depth. A Resilience Gap exists where there is imbalance between the vulnerability and a critically linked capability. Resilience Gaps should be presented in a Stoplight fashion:
    - A ***negative Resilience Gap*** means that there are too little capabilities for a certain vulnerability resulting in the firm being exposed to risk—shown in RED (lower right of resilience fitness space).
    - A ***positive Resilience Gap*** means that there are too many capabilities for a certain vulnerability resulting in potentially wasted resources—shown in YELLOW (upper left of resilience fitness space).
    - Critical linkages that are ***balanced***—capabilities are approximately equal to the vulnerability—shown as GREEN (balanced center area of the resilience fitness space).

5. **Validating the business case:** Although the SCRAM™ assessment provides recommendations for balancing resilience, it does not provide performance or financial predictions. Therefore, it is necessary to next conduct a detailed Business Case Analysis for each specific resilience initiative. Organizational standard models should be employed; however, due to the inherent dynamics of business operations, simulation modeling of AS IS operations with specific resilience enhancements may be the best method of evaluating multiple scenarios and a variety of conditions.
6. **Maintaining balanced resilience:** Organizations and markets are inherently dynamic; therefore, periodic re-assessment is in order. Based on the rate of implementation of resilience enhancements, the SCRAM™ survey should be re-administered within six months to a year, and at least annually thereafter. Another recommendation is to take the SCRAM™ assessment to key suppliers and customers, comparing strengths, weaknesses and Resilience Gaps to truly balance the supply chain!

## APPENDIX D
## THE SUPPLY CHAIN RESILIENCE ASSESSMENT AND MANAGEMENT (SCRAM™)

1. **Introduction**

a. **Overview:** You have received a special invitation to participate in a unique questionnaire designed to assess the resilience of your supply chain.
b. **Our Goal:** To strengthen the resilience of the supply chain, giving the enterprise greater ability to cope with a turbulent business environment, and thus creating a competitive advantage.
c. **Confidentiality:** Your responses to this assessment will be kept strictly confidential by the research team. Your honest and accurate assessment is important for gaining meaningful insights into supply chain resilience.
d. **Thank you** for participating in this project.

**Completion of the assessment requires *approximately 30 minutes*.**

2. **Project Overview**

a. **The Problem:** The business environment is becoming more and more turbulent. Supply chain disruptions, whether an accident, natural disaster, security breach, competitive threat, or shift in demand, can be costly in the short-term and may have lasting adverse impacts. It is essential for companies with complex supply chains to develop a clear understanding of their supply chain vulnerabilities then to proactively strengthen their capabilities to anticipate, respond, and adapt.

*Executives identify supply chain risk as the highest threat to their firms. (Green, 2005)*

b. **The Solution:** Based on research in management, economics, ecology and sociology, the concept of **resilience** has emerged as a critical characteristic of complex, dynamic systems such as business enterprises. In the business context, we define **resilience** as *the capacity for an enterprise to survive, adapt, and grow in the face of change and uncertainty*.

Change not only presents threats to business continuity, but can also **create opportunities** for business value creation. When disruptions change the competitive landscape, a resilient company can often take advantage by introducing business innovations, increasing market share, and enhancing its reputation.

c. **The Framework:** To analyze the myriad of issues that contribute to enterprise resilience, a structured framework was created that captures the fundamental factors that make an enterprise susceptible to disruptions—**Vulnerabilities—**and compares them with attributes that enable an enterprise to anticipate and overcome disruptions—**Capabilities**. We believe that continuously examining these factors and strengthening enterprise capabilities will help maintain competitiveness.

***Your contribution today is a first step on the journey toward enhanced resilience!***

## PART 1—VULNERABILITIES

First, you will be asked to assess the **vulnerabilities** that currently challenge your operations.

Each vulnerability will begin with an overall definition, followed by a question for each factor.

For each statement, indicate the extent of your agreement or disagreement based on your personal knowledge of your products, organization, and operations. If you do not have personal knowledge of the subject, *select "Don't Know."*

| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Don't Know |
|---|---|---|---|---|---|

***Vulnerability #1—Turbulence: "Environment characterized by frequent changes in external factors beyond your control."***

***V1.1 Our products face unpredictable demand shifts.***
***V1.2 We depend on supplies and/or export markets that experience severe currency or price fluctuations.***
***V1.3 Our imports or exports face recurring disruptions due to geopolitical turmoil.***
***V1.4 Our facilities or markets are frequently exposed to severe natural disasters.***
***V1.5 We regularly face unforeseen technology failures in our operations.***
***V1.6 Our operations are susceptible to a potential health pandemic affecting our employees.***

***Vulnerability #2—Deliberate Threats: "Intentional attacks aimed at disrupting operations or causing human or financial harm."***

***V2.1 Our facilities or personnel may be targets of terrorism or sabotage.***
***V2.2 Our products are regularly stolen or vandalized.***
***V2.3 We depend on unionized labor which can be hostile to the firm.***
***V2.4 Our operations are frequently impeded by Special Interest Groups.***
***V2.5 Our products or technologies may be compromised by industrial espionage.***
***V2.6 Our operations or products may face liability claims.***

***Vulnerability #3—External Pressures: "Influences, not specifically targeting the firm, that create business constraints or barriers."***

***V3.1 Our products are threatened by frequent competitive innovations.***
***V3.2 Our operations and/or products are subject to stringent and/or changing government regulations.***
***V3.3 Our products face strong price competition.***
***V3.4 Public opinion can exert significant pressure on our operations.***
***V3.5 Social or cultural changes have had significant impact on our ability to serve our markets.***
***V3.6 Environmental concerns influence how we design our products and/or conduct our operations.***

***Vulnerability #4—Resource Limits: "Constraints on output based on availability of the factors of production."***

***V4.1 Our supply chain has a large number of members.***
***V4.2 Our suppliers have limited capacity.***
***V4.3 Our production capacity is limited.***
***V4.4 We have limited access to capacity for distributing products.***
***V4.5 Raw materials for our products are scarce or in high demand.***
***V4.6 Utilities are over-extended and our utility infrastructure is poor.***
***V4.7 We have difficulty recruiting and retaining highly skilled workers.***

***Vulnerability #5—Sensitivity: "Importance of carefully controlled conditions for product and process integrity."***

***V5.1 We depend on the use of regulated or restricted materials.***
***V5.2 The quality of our products is highly dependent on the quality of our inputs/supplies.***

*V5.3 Our products require strict storage or handling controls to maintain their purity and/or integrity.*
*V5.4 Our production operations are very complex.*
*V5.5 Some equipment in our operations is delicate or failure-prone.*
*V5.6 Our workers sometimes operate in extreme or hazardous conditions.*
*V5.7 Errors or deficiencies in our operations are highly visible to stakeholders.*
*V5.8 Our products carry brand names that are important to protect.*
*V5.9 Our suppliers or production facilities are geographically concentrated and/or co-dependent.*

*Vulnerability #6—Connectivity: "Degree of interdependence and reliance on outside entities."*

*V6.1 Our supply chain has a large number of members.*
*V6.2 We are part of a globally distributed supply chain.*
*V6.3 Many of our products require specialty components.*
*V6.4 Continuous information flow is critical to regular operations.*
*V6.5 We outsource our operations to many different suppliers.*

*Vulnerability #7—Supplier/Customer Disruptions: "Susceptibility of suppliers and customers to external forces or disruptions."*

*V7.1 Our suppliers frequently face significant disruptions.*
*V7.2 Our customers frequently face significant disruptions.*

## PART 2—CAPABILITIES

Next, you will be asked to assess the **capabilities** that enable your firm to anticipate and overcome disruptions, as well as seize opportunities for competitive advantage.

For each statement, indicate the extent of your agreement or disagreement based on your personal knowledge of your products, organization, and operations. If you do not have personal knowledge of the subject, select *"Don't Know."*

*Capability #1—Flexibility in Sourcing: "Ability to quickly change inputs or the mode of receiving inputs."*

*C1.1 Our supplies are used in multiple finished goods.*
*C1.2 Our finished goods use modular designs.*
*C1.3 Our products can be made by a variety of machines and workers.*
*C1.4 Our supply contracts can be easily modified to change specifications, quantities, and terms.*
*C1.5 We have many alternate sources for key inputs.*

*Capability #2—Flexibility in Order Fulfillment: "Ability to quickly change outputs or the mode of delivery."*

*C2.1 We can quickly vary outsourced storage, distribution, and other services.*
*C2.2 We are able to delay production to be more responsive to demand.*
*C2.3 We pool inventory for a wide variety of customers at centralized locations.*
*C2.4 We have a sophisticated inventory management system that regularly computes both safety stock and cycle stock at all storage and retail locations.*
*C2.5 We can quickly change the routing and mode of transportation for outbound shipments.*
*C2.6 We can quickly reallocate orders to alternate suppliers and reallocate jobs between different production units.*

*Capability #3—Capacity: "Availability of assets to enable sustained production levels."*

*C3.1 We have reliable back-up utilities (electricity, water, communications, etc.).*
*C3.2 We maintain access to duplicate or redundant facilities and equipment.*
*C3.3 We have significant excess capacity of materials, equipment, and labor to quickly boost output if needed.*

*Capability #4—Efficiency: "Capability to produce outputs with minimum resource requirements."*

*C4.1 Our labor productivity is very high.*
*C4.2 Our assets are effectively utilized with no limiting bottlenecks.*
*C4.3 We consistently produce high-quality products with little waste.*
*C4.4 We have effective preventative maintenance programs.*
*C4.5 Our equipment is very reliable.*

*Capability #5—Visibility: "Knowledge of the status of operating assets and the environment."*

*C5.1 We have information systems that accurately track all operations.*
*C5.2 We have real-time data on location and status of supplies, finished goods, equipment, and employees.*
*C5.3 We have regular interchange of information among suppliers, customers, and other external sources.*
*C5.4 We have effective Business Intelligence gathering programs.*

*Capability #6—Adaptability: "Ability to modify operations in response to challenges or opportunities."*

*C6.1 We can quickly reallocate orders to alternate suppliers and reallocate jobs between different production facilities.*
*C6.2 We use strategic gaming and simulations to design more adaptable processes.*
*C6.3 We excel at seizing advantages from changes in the market.*
*C6.4 We develop innovative technologies to improve operations.*
*C6.5 We continually strive to further reduce lead-times for our products.*
*C6.6 We effectively employ continuous improvement programs.*

***Capability #7—Anticipation: "Ability to discern potential future events or situations."***

***C7.1 We effectively use demand forecasting methods.***
***C7.2 We have a formal risk identification and prioritization process.***
***C7.3 We closely monitor deviations to normal operations, including near misses.***
***C7.4 We quickly recognize early warning signals of possible disruptions.***
***C7.5 We have detailed contingency plans and regularly conduct preparedness exercises and readiness inspections.***
***C7.6 We recognize new business opportunities and take immediate steps to capitalize on them.***

***Capability #8—Recovery: "Ability to return to normal operational state rapidly."***

***C8.1 We can quickly organize a formal response team of key personnel, both on-site and at corporate level.***
***C8.2 We have an effective strategy for communications in a variety of extraordinary situations.***
***C8.3 We are very successful at dealing with crises, including addressing public relations issues.***
***C8.4 We take immediate action to mitigate the effects of disruptions, despite the short-term costs.***

***Capability #9—Dispersion: "Broad distribution or decentralization of assets."***

***C9.1 Our key inputs are sourced from a decentralized network of suppliers.***
***C9.2 Our production facilities are distributed at various locations.***
***C9.3 Our senior leaders are based at a variety of different locations.***
***C9.4 Our organization empowers on-site experts to make key decisions, regardless of level of authority.***
***C9.5 Our products are sold to customers in a variety of geographic locations.***

***Capability #10—Collaboration: "Ability to work effectively with other entities for mutual benefit."***

***C10.1 We effectively employ collaborative demand forecasting techniques using shared data.***
***C10.2 Our data flow transparently between supply chain members, with full access by all firms to facilitate collaborative decision making.***
***C10.3 Our customers are willing to delay orders when our production capacity is hampered.***
***C10.4 We have proactive product life-cycle management programs that strive to reduce both costs and risks.***
***C10.5 Our firm invests in facilities and equipment at suppliers' plants and is prepared to share risks with both suppliers and customers.***

***Capability #11—Organization: "Human resource structures, policies, skills, and culture."***

***C11.1 We encourage creative problem solving.***
***C11.2 We enforce individual accountability for performance.***
***C11.3 We train employees in a wide variety of skills.***
***C11.4 We are capable of filling leadership voids quickly.***
***C11.5 We are a learning organization, regularly using feedback and benchmarking tools.***
***C11.6 We have a culture of caring for employees.***

***Capability #12—Market Position: "Status of a company or its products in specific markets."***

***C12.1 Our brands have excellent customer recognition and a strong reputation for quality.***
***C12.2 Our customers are very loyal to our products.***
***C12.3 Our products command a significant share of the market.***
***C12.4 Our customers can clearly differentiate our products from competitors' products.***
***C12.5 Our firm has strong, long-term relationships directly with each of our customers.***
***C12.6 Representatives of our firm communicate effectively with our customers.***

***Capability #13—Security: "Defense against deliberate intrusion or attack."***

***C13.1 We employ layered defenses and do not depend on a single type of security measure.***
***C13.2 We use stringent restrictions for access to facilities and equipment.***
***C13.3 We have active security awareness programs that involve all personnel.***
***C13.4 We effectively collaborate with government agencies to improve security.***
***C13.5 We have a high level of information systems security.***
***C13.6 We use a variety of personnel security programs such as awareness briefings, travel restrictions, and threat assessments.***

***Capability #14—Financial Strength: "Capacity to absorb fluctuations in cash flow."***

***C14.1 We have significant financial reserves to cover most potential needs.***
***C14.2 Our portfolio of businesses is very diverse.***
***C14.3 We have significant insurance coverage for facilities, equipment, goods, and personnel.***
***C14.4 We sell our products at a relatively high margin.***

**PART 3—IMPORTANCE**

Finally, all of the vulnerabilities and capabilities presented in Parts 1 and 2 will be summarized, and you will be asked to rate the relative level of **importance** for each factor. Response choices will be in the form of "Critical," "Important" or "Minor Importance."

**Vulnerabilities:**

Please rate the relative level of importance for each factor.

**Capabilities:**

Please rate the relative level of importance for each factor.

**You are complete!**

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