TOWARD A FRAMEWORK OF SUPPLY CHAIN SUSTAINABILITY: THE FRAGILITY INDEX

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ABSTRACT

Organizational and operational sustainability has become of increasing concern to both operations managers and senior executives. Though the reasons are myriad, certainly three factors bear mightily on these emerging concerns. Increased complexity of products and production processes is a central factor; however, the increasingly diverse and global nature of commerce and production and the extension of supply chains to better use efficiencies of scope and scale may be equally or even more important. Unfortunately, little research has emerged to define the factors and identify the risks associated with supply chain sustainability, and less has been put forward to posit the factor relationships and to model supply chain sustainability. To this end, the authors propose a "Fragility Index", which can be used by practitioners to model their supply chains, and by academics to anticipate and model the contingencies of supply chain risk. The increasing fragility of the supply chain also increases the burden on the natural and man-made physical environment; which, in turn, increases the fragility of the supply chain. This is a set of economic interactions which has not yet been taken into account by operating systems and supply chain design and management.

Keywords:

Supply Chain
Sustainability
Disruption
Fragility

INTRODUCTION – SUSTAINABILITY AND THE SUPPLY CHAIN

Operations management literature abounds with discussions of the emerging supply chain, and simultaneously of the "greening" of supply chain processes. These notable developments in the production operations management field, however, generally ignore their interrelationship and the resulting increased potential for both supply chain disruption (fragility) and increased damage to the environment. Such issues are addressed in both practitioner and academic literature (Anderson, 2006; Kleindorfer, Singhal, and Van Wassenhove, 2005, among numerous others), though a central thrust or focus of content has not yet emerged.

The history of supply chain integration has been broadly discussed from a variety of perspectives, including Harrigan (1985), Kleindorfer *et al* (2005), Stonebraker and Afifi (2004), and Stevens (1989), among others. This literature generally suggests the evolution from high volume manufacturing / distribution processes through JIT (or lean) toward various subsequent approaches to internal and external integration. Economic efficiencies, cross-functional communication, information and communications technology, flexibility, and decision modeling have formed a major component of this emerging supply chain integration theory (Sawhney, 2006). Certainly, the rapidly growing globalization of resources, production, and markets (Misser, 2006) have both facilitated and resulted from these developments. Simultaneously, the extended supply chain creates greater stress on the physical environment and management is increasingly involved with greater accountability for processes and events that are beyond their traditional sphere of control (Tebo, 2005; Druckman, 2005; Iansiti and Levin, 2004). Such an environment notably increases the potential for unanticipated, difficult-to-respond-to, and potentially catastrophic disruption of the supply chain.

At the same time, operations management, as the central source of added value (Kleindorfer *et al*, 2005) has been the focus of very serious concerns of sustainability, often involving the 3Ps, planet, people, and profit (or variations thereof). In that context, Ehrenfeld (2005, 24) labels sustainable development an "oxymoron", and suggests that the reduction of unsustainability is not the equivalent of true sustainability. In fact, Ehrenfeld perceives the current state of unsustainability as a systemic failure of management's inability or unwillingness to responsibly address the issues. A second dimension of the question is offered by Laszlo (2003) who reviews the historical evolution of business activities from the early hunter-gatherer societies to the post-industrial, knowledge-based activities. She suggests that human ethics have not correspondingly progressed from the ego-centric behaviors of earlier eras to homo-centric and eco-centric behaviors which are required by current business activities. Organizational ethics education, she concludes, is a primary task for both business leaders and educators. For an earlier discussion of this phenomena, see "Tragedy of the Commons". (Hardin, 1968)

Even the definition of "sustainability" itself does not appear to have converged. For example, Tebo (2005, 29) identifies DuPont's perspective as "creating shareholder and societal value while reducing the environmental footprint…" Alternatively, Kleindorfer *et al* (2005, 484) address the futurity issue with: "development that meets the needs of the present without compromising the ability of future generations…" And Ehrenfeld (2005, 24) proposes the more absolute definition: conditions such that: "all life forms will flourish forever," which, for humans, means survival and maintenance, as well as dignity and authenticity. This lack of clarity and consistency regarding the focus and definition of sustainability (both from a macro-ecological focus and a micro-economic operations perspective) has, in fact, increased the potential for anticipatable, longer-term, and potentially catastrophic disruption of the supply chain.

Certainly, as noted by Kleindorfer and Saad (2005) and Krajnc and Glavic (2003), these issues should be a high priority to top management, and, most so, to the operations manager. Operations management, they reason, is responsible for most of the firm's material flows and for most exchanges with the environment. But, unfortunately, to date, there does not appear in the literature or the more general public dialogue, a process to address, from an operations management perspective, the dual, and somewhat overlapping, threats of externalization (diversification) and sustainability to the supply chain.

At the highest and most general levels, there is vague concurrence on the convergence of social needs and competitive advantage (Kleindorfer *et al*, 2005; Iansiti and Levin, 2004; Ehrenfeld, 2005; Coates and McDermott, 2002; Husted, 2005). But, industry and corporate publications offer a very limited perspective of the risks of supply chain disruption (Tebo, 2005; Baxter, 2005; Tallis, no date). For example, the sustainability metrics recommended for use in process industries by the Institution for Chemical Engineers include resource usage, emissions, some social equity issues and the like. However, that document does not address weather, governmental and quasi-government actions, such as war or terror, or accidents such as Bhopal (Tallis, no date). Additionally, the Baxter 2005 Sustainability Report presents such efforts as managing supplier performance and diversity, and "greening" of the supply chain; however, there is little discussion of other factors that could notably disrupt or impact supply chains, such as governmental, supplier, or people issues. (Baxter, 2005).

This failure to directly and proactively address the vicissitudes of supply chain disruption is highlighted in a recent Executive Survey by McKinsey (2006). That survey found that almost 40% of 3000+ executives adjudged their firm to be slightly or not capable of handling a supply disruption, while only 43% of respondents affirmed that there were corporate standards and practices in place for overseeing the mitigation of supply chain risk. Of that 43%, only 70% (or about 900 of 3000 respondents) reported that the standards and practices were enforced. Clearly, in addition to the noted lack of clarity and focus of perspectives and definitions, there is a notable need to practically and substantively redefine, test, implement, and enforce policies to mitigate the potential for supply chain disruption.

This paper defines and dimensionalizes the supply chain, identifies the theoretical foundations for the interrelationship between environmental sustainability and operations robustness, discusses the measurement of supply chain fragility and suggests the mechanics of a measurement process. On that basis, the Fragility Index is proposed and methods of representing and communicating that Index are discussed. As such, this paper assists in the measurement of unsustainability / fragility and works toward identifying the true costs of operations fragility and environmental unsustainability.

THE PREEMINENCE OF THE SUPPLY CHAIN

The "supply chain" has been widely represented as a series of interconnected resource input transformations, and outputs in multiple stages from raw materials to the end user. This input may be part of a vertically integrated firm or a third party outside supplier. Components include breadth, degree, form, and number of stages (Harrigan, 1985), flexibility of the process and output (Sawhney, 2006), communication (Holmberg, 1998) and interactivity (Stonebraker and Liao, 2004). Technically, customer expectations are outside the chain until the consumer enters the market-place. The supply chain can thus be visualized as a figurative pipeline; however, Holmberg (1998) adds a time dimension to the diagram by suggesting the resource funnel. That is, over time, as the business or industry matures, the funnel gets smaller due to decreased resource availability and greater global demand for resources. These concepts are dimensionalized at Figure 1.

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The fundamental perceptions and assumptions of corporate sustainability / unsustainability and supply chain robustness against disruption (fragility) are differently defined, (Szekely and

Knirsch, 2005; Kleindorfer and Saad, 2005). Corporate sustainability has been variously defined as focused toward the triple bottom line (3bl), people, planet and profit (P^3), or 3E (environment, equity, and economics) (Anderson, 2006; Kleindorfer *et al*, 2005). These notions are generally longer term and quite visible, with relatively slower impacts. Further, they are generally multi-factor and sequential in their impact or outcomes. An example would be global warming or pollution of air and water masses. Clearly, this is a matter for operations concern, within the broader aegis of corporate responsibility. Notably, operations processes are responsible for a major proportion of the transformation of materials and of interaction with the environment (Kleindorfer *et al*, 2005; Freeman, 2006; Krajnc and Glavic, 2003).

However, operations must also be concerned with the robustness of the supply chain against other forms of disruption, here called "fragility". The more immediate concerns of operations relate to the traditionally defined competitive priorities (cost, quality, flexibility, and delivery) or more recent variations. These considerations are generally short- and mid-term, monotonic, single events which have simultaneous impacts on many operations activities. They are less anticipatable and have a more rapid and visible impact. An example is the destruction of a Mississippi River bridge by an errant barge or the illness or death of a consumer due to food poisoning or tainting. The operations function, thus must be concerned with both sustainability and robustness. This general distinction between sustainability and robustness is shown at Table 1.

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The Theory of Sustainability

For many years, profit maximization was the rubric toward which business aspired. However, by the 1930s and 40s, the classical and Taylor-esque optimization theories, were gradually supplanted by increased emphasis for the concerns and needs of people; certainly the Hawthorne experiments were a part of this movement. Further, by the 1950s, limited appreciation of environmental issues, such as water and air pollution emerged. These concerns were broadened through the end of the 20th Century to encompass global warming, loss of flora and fauna, and changes in weather patterns. Thus, issues of sustainability can be viewed as a tradeoff of profits with people and planet, or more broadly, profits and sustainability. These relationships are shown at Figure 2.

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Following Wagner and Schaltegger (2003), the traditionalist perspective is that of a decreasing linear or curved relationship between profits and sustainability. That is, as sustainability initiatives are addressed, profits decrease. Initially, government or industry standards may mandate minimal sustainability initiatives such as those of OSHA or the EPA. These strictures are represented by the diagonally shaded area. However, as a result, in part, of public pressure, a revisionalist perspective has emerged which suggests that a profit increase can result from sustainability initiatives. Examples include hybrid automobiles and certain more acceptable food products (free range and organic), recycling, reverse logistics, and others. This is shown by an inverted u-shaped curve, which, over time would reach an efficiency frontier, shown as a dotted curve. Ultimately, a long-term relationship of profits and sustainability is represented by the upwardly angled arrow.

This theory of sustainability does not hold for operations or supply chain robustness – or its inverse, fragility – for two reasons. Firstly, the sustainability of the traditional firm is based on profits, while operations robustness is based on cost, which, because (in a basic format) revenues minus cost equal profits, is an inverse of profits. Secondly, sustainability deals with healthfulness while fragility deals with collapse, the inverse of sustainability. Because of this inversion of both dimensions, it can be shown that, as fragility increases, the costs to reduce fragility (or the consequences of fragility) also increase. This is shown at Figure 3.

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All supply chain management decisions should be based on a simultaneous evaluation of cost and fragility quotients. The term quotient is used here to suggest a quantification of various supply chain fragility factors, using a scale of 0 to 10. For example, in coastal Florida, the risk of hurricanes is rather high, thus building managers might spend extra money to address the fragility of their property by using stronger glass or window mountings. In this case, both the fragility and cost values might be higher, possibly a fragility quotient of 7 and a corresponding cost quotient of 7 (7, 7). Alternatively, the risk of hurricanes is not as high in central New York State, thus fragility and cost quotients might be somewhat lower, possibly a (3, 3). This potentially continual linear relationship is shown at Figure 3 by points A_1 and A_2, respectively, and the associated upwardly sloped line.

However, the relationship of fragility and cost can also be non-linear. For example, the risk of a summer afternoon thundershower may be rather high and the costs of getting soaked (wet clothing, a summer cold, etc) rather high, say 8. However, the fragility of an agricultural worker, particularly one who needs the income, may be rather low, possibly a 4. The (8, 4) relationship is shown at point B, with variations of that curvilinear pattern shown. Alternatively, cost may have a lesser quotient than fragility. Point C shows the (5, 8) relationship, which might be exemplified by any of numerous safety constraints. Most recently-built power lawnmowers and almost all industrial equipment have hand controls or restraints, which, in the case of the lawnmower, brakes the blade to a stop or, with most industrial equipment, prevents activation of the equipment. Though the risk of an injury is rather low, however, because the cost of a safety restraint is low and human fragility and related medical and insurance costs of such an injury are potentially very high, such restraints are standard on most industrial equipment. These individual human-focused examples could easily be replicated in more broadly defined industrial and distribution situations. Air and water sampling devices, airport and port sensors of various sorts, numerous automobile safety restraints and devices, weather warning and organization shut-down processes, and the like are examples.

It is also possible that the cost-fragility quotients are a combination of various parametric structures. For example, human fragility to toxins may not be apparent or, at low levels, may be benign; however, as toxicity is increased, fragility increases geometrically. This situation is shown by the solid "S-shaped" curve. Alternatively, the risk with other situations may increase notably at low levels; however, as a person becomes habituated to the environment, that risk may level for part of the range. This second condition would be represented by the dotted inverted "S-shaped" curve.

Costs and fragility must be evaluated together in complex situations. For example, the risks for a food producer of an incidence of product impurity or contamination, whether purposeful or not, can involve high levels of publicity, notable loss of market share, and extremely high costs. Well-publicized examples include Beech-Nut Apple Juice, Tylenol, numerous safety-related product recalls, including automobiles and various agricultural and drug products. Additionally, the failure of the supply chain to deliver for any number of reasons can have disastrous impacts, if not managed properly. The delayed release of flue vaccines and of various computer software upgrades are examples. Transportation system shutdowns and accidents (weather shuts highways and airports), language or cultural issues (shipping the "Nova" – "Won't go" – to Hispanic speaking countries), and industrial accidents (Bhopal) are all examples.

Thus, producers respond in a variety of ways to minimize the impacts of such events and reduce the product's or supply chain fragility. Child- and tamper-proof closures, sealed packaging, and the like are used extensively because the product is handled by numerous persons at various stages of the supply chain. These examples show how the cost-fragility quotients are not easily separated.

The Measurement of Fragility

The Scope of Measurement. Most agree that the measurement of either sustainability or robustness is difficult (Krajnc and Glavic, 2003; Veleva and Ellenbecker, 2000; Callens and Tyteca, 1999; Figge and Hahn, 2004, among others). In part, the difficulty results from the simultaneous interactivity of multiple variables measured in different units and by different methods for different periods and in different entities. Further some measures are highly subjective. Most contributors agree, however, with Valeva and Ellenbecker (2000) that there is no best universal approach and that the target is always moving. On this basis, the following criteria are suggested as desirable characteristics for supply chain fragility measures.

1) Ability to compare the current state and progress of different entities, including plants, companies, industries, cities and states against a benchmark, standard, target, or goal. (Atkinson, 2000; Krajnc and Glavic, 2003; Callens and Tyteca, 1999; Labuschagne, Brent, and van Erck, 2005)
2) Use of cardinal scales of performance as an indicator of improvement over time against a target or benchmark. (Spangenberg, Pfahl, and Deller, 2002).
3) Ability to provide absolute measures, relative measures, and indexed measures for various applications. (Figge and Hahn, 2004)
4) Ability to facilitate reactive as well as proactive, sequential as well as simultaneous responses. (Sawhney, 2006)
5) Ability to support a cost-benefit analysis to identify Pareto-like most critical efforts.
6) Ability to consider elasticities of substitution between different types of capital and resources. (Gutes, 1996)

The Measurement Process. Many different processes have been proposed to measure environmental sustainability and operational robustness variables (Krajnc and Glavic, 2005; Holmberg, 1998; Kleindorfer & Saad, 2005). However, commonalities among these various processes permit measurement to be reduced to four steps: 1) selecting and grouping factors, 2) measuring and weighting factors, 3) evaluating the fit and cost of alternatives, and 4) managing implementation policies and adjustments. Such a model, with minor terminology variations and with different numbers of steps is used in numerous decision modeling and management processes.

What Should Be Measured. Ultimately, the operations manager, supported by several supply chain executives, must define and measure the robustness of their supply chain. Rather than use a positively reinforcing approach which might lead to *groupthink* (Janis, 1982), this study suggests identifying the "what could go wrongs" – or the Fragility Factors. Certainly the appropriate factors will vary from industry to industry, from company to company, and from entity to entity. Like other operations measures, such as productivity and quality, definition and adjustment of these measures must be done by each individual entity and would likely be proprietary, though the publication of industry-wide or governmental goals or standards should be used in many situations to establish a baseline and targets (for example, global emissions targets for the next decade). Various enumerations of Fragility Factors include operations-focused product design, supply chain, and operational control (Kleindorfer & Saad, 2005), indicators of sustainable production, such as economic viability, workers, and social justice (Veleva and Ellenbecker, 2000), and other more broadly defined efficiency and effectiveness indicators (Figge and Hahn, 2004: Krajnc and Glavic, 2003; Szekely and Knirsch, 2005). Note that these indicators all can be evaluated in ways that are consistent with the six criteria for measurement suggested above. These different factors have been aggregated as internal factors of the supply chain, externalities, and unanticipated / random events in Table 2.

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A dynamic, possibly Delphi-like process of corporate executives, operations managers, and functional staffs should cull the list of factors and define for each situation the weak links. This assessment is evaluated using the Goldhar-Stonebraker Supply Chain Fragility Index Matrix, as shown at Figure 4.

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Each stage of a particular supply chain is evaluated for the selected Fragility Factors, several of which are included on the diagram, with example evaluations and solutions, mitigations, and costs. For each stage and each factor, a threat level and an impact are quantified as scales of 0-10. Then the threat level and impact are multiplied and summed to give the Fragility Factor. For each factor, each stage, then globally, the analyst can calculate an assessment of the risk, either comparatively, absolutely, or relatively (out of the total value possible). This value is shown as the G-S Index. Solutions to the Fragility Factor situations are applicable to specific stages of the supply chain then can be considered in terms of feasibility and cost (or disregarded). In this way, the G-S Fragility Index Matrix captures a top-management brainstorming or dialoguing process about the fragilities of a specific supply chain and the costs of mitigating that fragility. Ultimately the use of a cardinal scale of 100 or an index to represent the relative importance of each fragility objectives would be appropriate.

Additionally, the use of a SCOR (Supply Chain Operational Reference (Stevens, 1997)) – like diagram is facilitated by the conversion to cardinal or index measures. Figure 5 shows a representative modeling of the G-S Fragility Index.

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Note that on Figure 5, for ease of reference, the external, internal, and random factors have been separated. Additionally, the 14 Fragility Factors (selected for this situation) have been set up on a cardinal scale of 0 – 1 or 0 – 100%. This permits the benchmarking of a facility against internal targets, as well as against industry goals or known competitor values. Of course, it highlights the current status and presents strengths and weaknesses. Further comparative data, such as an industry standard, a future government standard, or a benchmark could be noted as a second, differently colored series of lines. Additionally, the graphic could have shown overlaid cost data. For example, a $100,000 expenditure in supplier communications would net an index improvement from .71 to .4, while a similar expenditure in logistics might only net an index improvement from .61 to .52.

The Sustainability / Robustness Imperative

Ultimately, through such mechanisms as noted in Table 2, Figure 4, and Figure 5, supply chain managers will be able to refocus the current tradeoff between environmental sustainability of operations and operations robustness, suggested in Figure 2, to a win-win relationship where environmentally sustainable practices directly contribute to operations robustness. This process will likely involve bringing external costs currently born by the government or the population at large (such as superfund clean up or health consequences of pollution) into the firm. Currently it is difficult to measure the true costs of this unsustainability (fragility), thus it is likely that firms are undercharged for the use of public resources (Hardin, 1968). This shift is shown by Figure 6.

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An example of such a shift is suggested by the Ford Motor Company automobile paint operations in England. DuPont initially supplied the paint to Ford for its auto assembly with the objective to sell as much paint as possible, based on the profit center concept. Ford then asked

DuPont to paint cars, rather than supply paint. As a result, DuPont established a strategy to minimize the quantity of paint used; they also changed the formulation and improved the efficiency of the spray guns. DuPont now uses less paint and creates less overspray, thus less waste. The use of paint by DuPont is now a cost center, rather than a profit center.

Ehrenfeld (2005) suggests that this will require notable cultural and perspective changes, as well as measurement changes at the macro and micro levels. Ultimately these changes must be driven by more responsible and ethical choices of increasingly pluralist business, governmental, not-for-profit, and professional organization managers (Jones, 2000; Ehrenfeld, 2005). Redirection of the supply chain processes must occur because a fragile supply chain will produce a fragile planet. The alternative is a global "Tragedy of the Commons", which, as described by Hardin (1968), suggested that livestock owners would over-graze public lands unless such organizational processes were adjusted to reflect the true costs of public grazing.

CONCLUSIONS AND IMPLICATIONS – FOR THE PLANET AND THE PROCESS

The growing competitive pressures on global supply chains, as well as the sustainability / robustness pressures on each stage individually suggest the increased need to diagnose and communicate issues of supply chain fragility. Past are the days that such issues could be ignored until they generate a costly catastrophe for the company. This paper has outlined a diagnostic process which may be used by senior management of business entities, including for profit, not-for-profit, governmental, and non-governmental organizations. It defines a flexible and adaptable model that can be adjusted to a specific need, defined in terms of fragility and cost. Importantly, it provides a tool for senior executive brain-storming on ways to minimize supply chain disruptions by creating a mechanism for "feed forward" as well as "feedback" communication and control.

This paper thus has clearly identified, from the operations perspective, two meanings of sustainability: 1) the impact of the supply chain on environmental systems and 2) the robustness as supply chains become more global and diverse. We generally propose that, if the true global costs of unsustainability and fragility are identified and accurately measured, then incorporated and managed in the internal business accounting systems of organizations, the unsustainability and fragility of both environmental and manufacturing activities would be reduced. For example, Electrolux recently stopped selling washing machines in Sweden, and began to sell washing machine service. They gave the machines to their customers who paid for each use. The washing machines were used more efficiently (full loads and off peak-utility periods), and used less water. After a prescribed number of washings, Electrolux would replace the machine. They refurbished these machines and put them back in service.

Further, academics could found numerous research agendas on such quantification. Questions such as the slope or curve of various fragility - cost relationships, various company or industry differences, or comparisons of national or geographic fragility are, today, primarily hypothetical. Additionally, academics would likely be able to facilitate and conceptualize these issues and to provide quantitative directions. Further, academics could readily suggest the further empirical processes and statistical methods to identify those areas of greatest global payback.

While the strengths of this paper are to dimensionalize and structure a relatively little examined, yet increasingly useful, body of knowledge for the operations manager, its weaknesses are that it is a conceptual and theoretical piece only. The further work of applying these concepts to specific situations and of developing and testing current business practices has been left for future study. This paper has, however, offered an integrated, cross-disciplinary summarization which will guide and provide a road-map for those future efforts.

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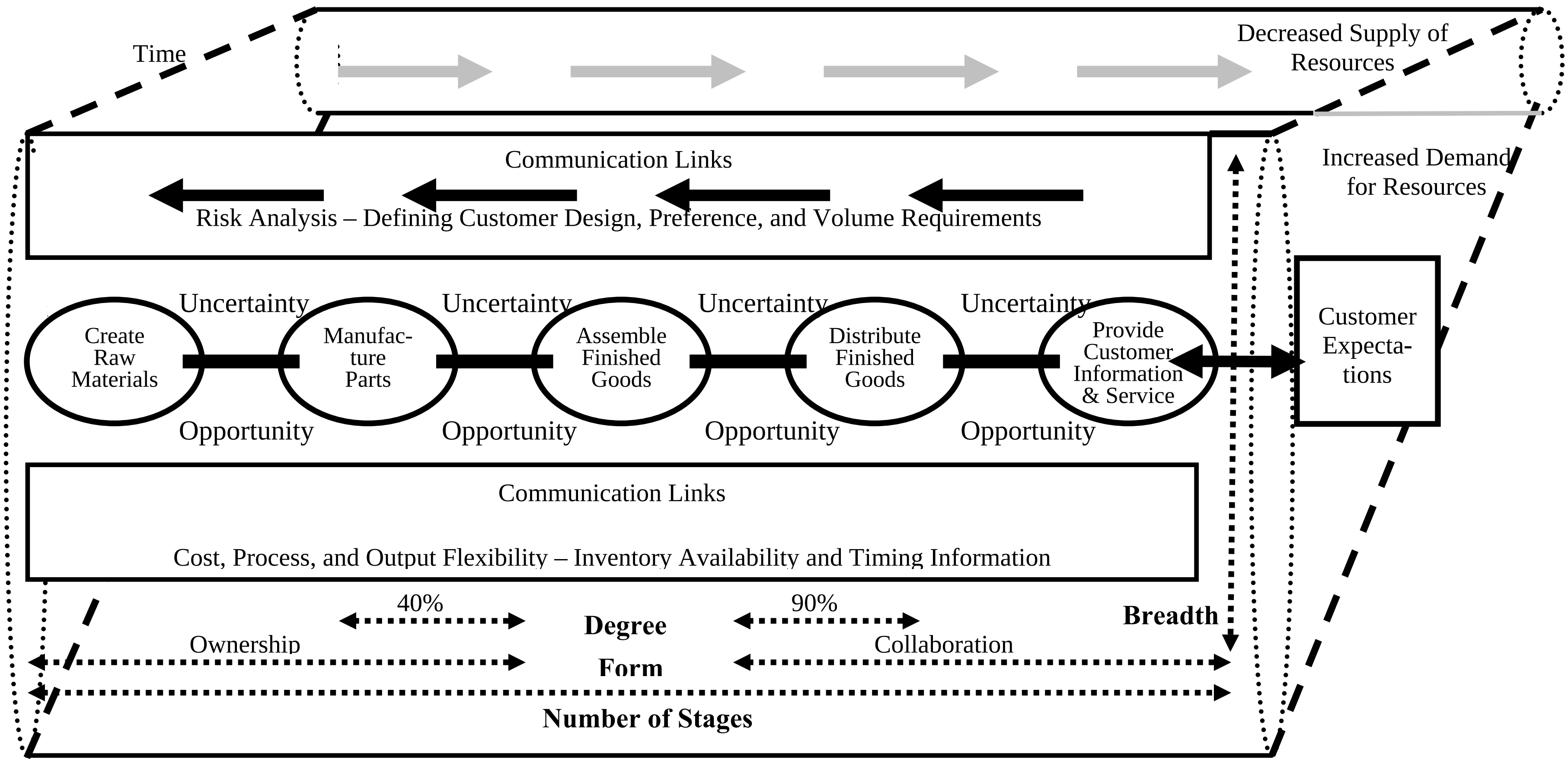
Figure 1 - A Stylized Representation of the Supply Chain with Integration and Time Dimensions Superimposed



Note: The supply chain pipeline is represented with a third dimension of time (Holmberg, 1998) and the four Harrigan (1985) dimensions are superimposed with heavily dotted lines:

Breadth	– "the number of activities that firms perform in-house at any particular level of the vertical chain."
Degree	– the percent of total production exchanged with sister units (shown here as 40% and 90%).
Stages	– "the number of steps in the chain of processing which a firm engages in – from ultra raw materials to the final customer."
Form	– ownership, quasi-ownership, or other more collaborative means of control of the integrative mechanisms.

Table 1 - Corporate Sustainability and Operations Robustness

Sustainability	Robustness
1. Corporate 3bl, P^3, or 3E	1. Operations C, Q, F, D
2. Long Term	2. Short and Mid-Term
3. Anticipated / Known Threat	3. Unexpected / Unknown Risk
4. Generally Visible	4. Less Visible
5. Relatively Slower Impact	5. Relatively More Rapid Impact
6. Lead / Proactive	6. Lag / Reactive
7. Multi-factor, Sequential evolving impacts	7. Monotonic, Single events with simultaneous impacts

Figure 2 - The Theory of Sustainability

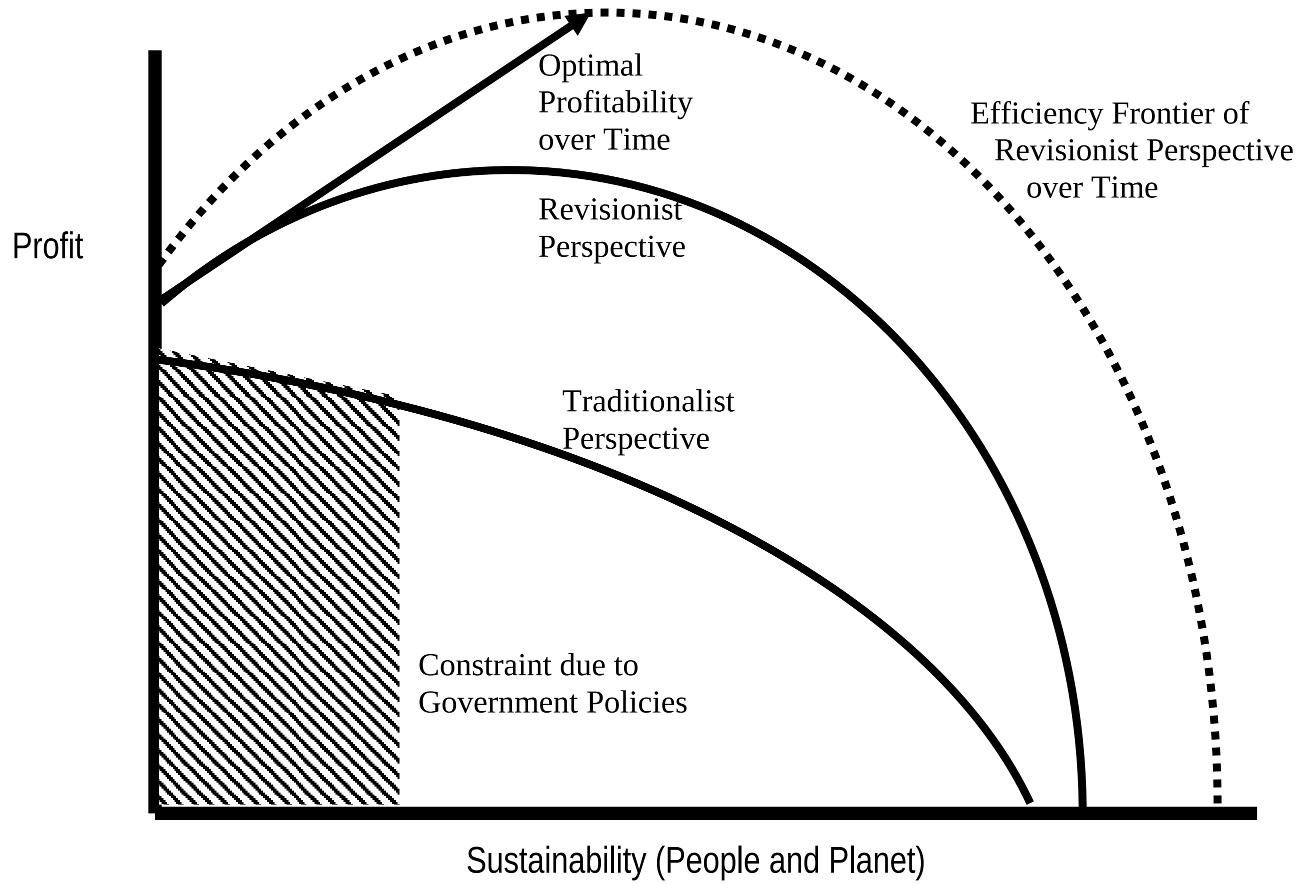


Figure 3 - Cost and Fragility Quotients

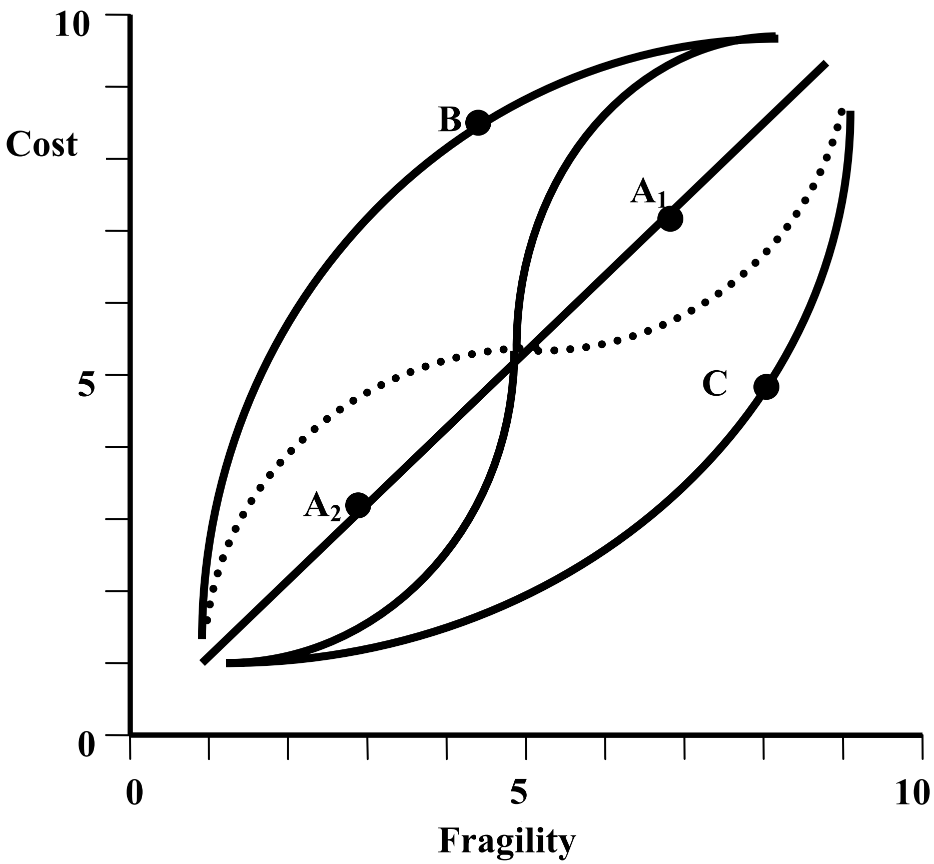


Table 2 - The Supply Chain Fragility Factors

Internal Factors to the Supply Chain	
1. Physical Logistics	Mechanical Breakdowns; Damage en-route; Shipping Mishaps; Accidents (Oil Spill, Sunken Ship)
2. Behavior of Suppliers	Key Supplier Going Out of Business; Significant Increase in Prices; Contract Limitations
3. Behavior of Customers	Changes in Market Share (Change in Customer Preferences) Changes in Customer's Perceptions of Company's Product; Law suits or other legal actions
4. Information, Communication & Control Systems	Data Accuracy & Integrity, Feedback & Feed Forward Quality Control, Inventory Control, Scheduling, Delivery & Control
5. Product and Process Design	Safety, maintainability, appeal, efficiency, cost, non-replicability
6. People	Labor, training, professionalism
Externalities	
1. Legal, Political & Acts of Government	Import duties, Trade Barriers, Lack of Political Stability Form of Government (Dictatorship, etc); Extent of Government Interference & Control
2. Behavior of Competitors	Price wars, Competitors Acquiring a Key Supplier
3. Financial and Economic Factors	Foreign Exchange Risk, Interest Rate Risk, State of the Economy,
4. Environmental Impact	Pollution, recycling, eco-health, reverse supply chain
Unanticipated / Random Events	
1. Acts of Nature (Weather)	Earthquake, Flood, Storm, Fire, etc.
2. Other External Factors	War & Terrorism, Piracy, Distance, Time, Language, Culture
3. Other Factors	Corruption, Subversion, Lack of Cooperation, Failure of Communication

Figure 4 - The Goldhar - Stonebraker Supply Chain Fragility Index Matrix

Supply Chain Threat Level & Impact (based on participant inputs from different positions, functions)	Create Raw Materials		Manufacture Parts		Assemble Parts		Distribute Finished Goods		End User Interface		G-S Factor Index	Solution/ Mitigation and Cost
FRAGILITY FACTORS	**TL**	**I**	**TL**	**I**	**TL**	**I**	**TL**	**I**	**TL**	**I**		
1. Physical/Mechanical Technology	5	7	2	4	8	3	6	2	4	3	91/500	Disregard these issues
2. Acts of Nature	7	5	3	3	2	1	8	9	6	3	156/500	Increase distribution inventory
3. Legal, Political & Government Acts												
4. Behavior of Competitors												
5. Behavior of Suppliers												
6. Behavior of Customers												
7. Information, Communication & Control Systems												
8. External Factors												
9. Financial Factors												
10. Others												
G-S INDEX FOR EACH STAGE OF THE SUPPLY CHAIN	**70**		**17**		**26**		**84**		**30**			**◀Global G-S Global Index ▼ G-S Global Solution**
SOLUTIONS											**COST**	
1. Increase distribution Inventory							$30,000				$30,000	
2.												
3.												

TL – Threat Level**; I** – Impact; **Scale** – 1 = lowest; 10 = highest;

Global G-S Index = Σ (TL x I) across both rows and columns

Figure 5 - Representing the G-S Fragility Index Matrix

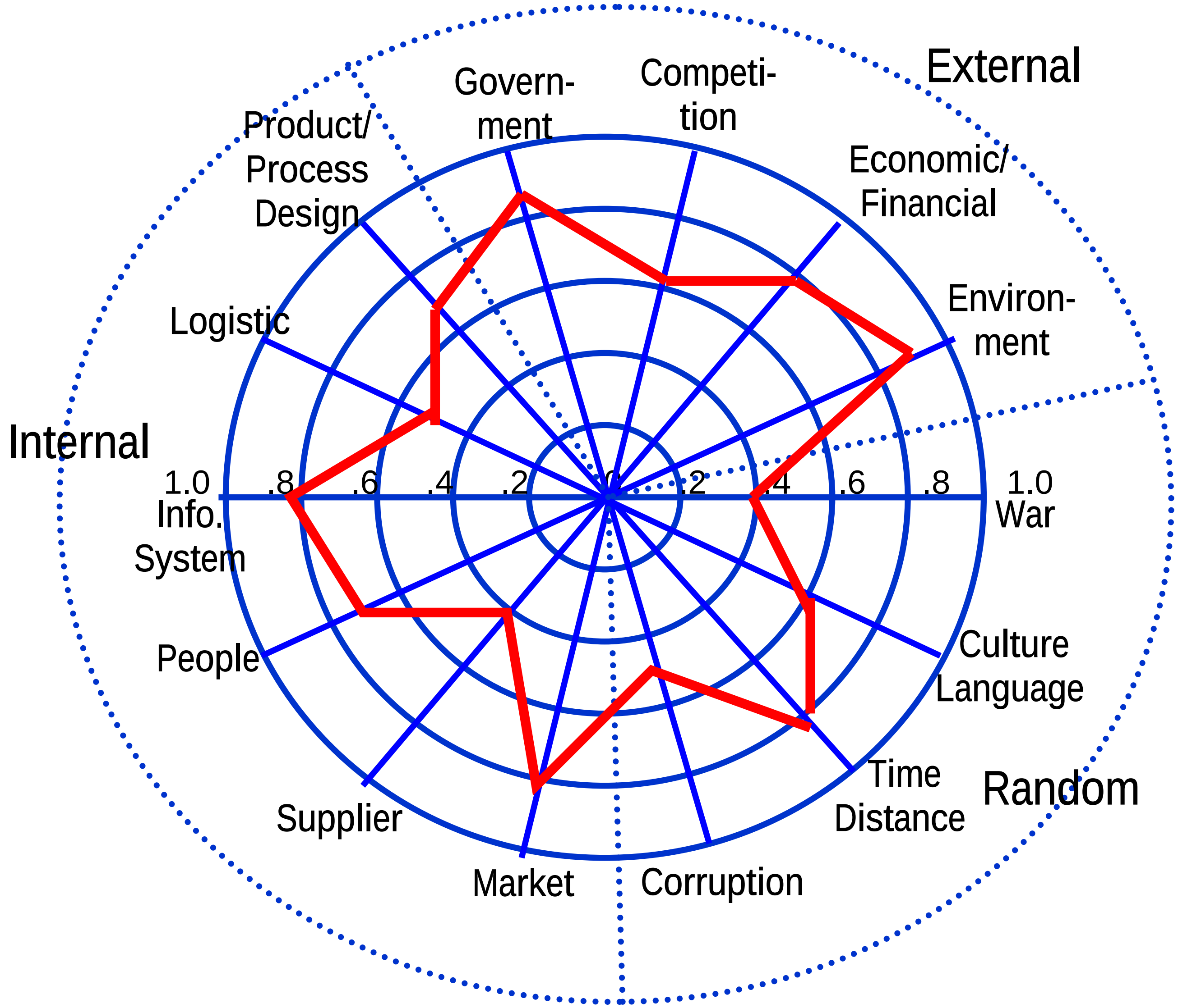


Figure 6 – The Sustainability / Robustness Imperative