

Supply Chain Risk Management: A Delicate Balancing Act

*A multi-faceted view on managing risk
in a globally integrated enterprise*



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Risk management practices, techniques and tools have been used extensively in the financial community for years. Risks with respect to a company's supply chain have begun to receive attention only more recently, as the push to increase supply chain efficiencies has illuminated the delicate balance between financial considerations and those of the customer.

During the last twenty-odd years, supply chain management practices have evolved toward more lean process approaches in order to reduce waste within the overall chain. Concepts such as just-in-time, virtual inventory, supplier rationalization, and reductions in the number of distribution facilities have reduced total supply chain costs, but the result has been increased risk.

Trade-offs between achieving optimal supply chain efficiencies and management of supply chain risk have created a conundrum of sorts. Businesses have witnessed many supply chain malfunctions (with substantial consequences) due to supply and demand disruptions: the affected companies reported, on average, 14% increase in inventories, 11% increase in cost, and 7% decrease in sales in the year following the disruption.^{1,2}

Today's industrial supply chains face risks from many factors, including:

- Increased globalization through outsourcing, which elongates end-to-end supply chains
- Additional regulatory compliance imposed by government entities, further complicating international trade
- Increased levels of economic uncertainty, which create additional variability in demand and supply and make it more difficult to accomplish demand-supply balancing
- Shorter product lifecycles and rapid rates of technology change, which increase inventory obsolescence
- Demanding customers who have created additional time-to-market pressures by requiring better on-time delivery, order fill rates and overall service level efficiencies.
- Supply side capacity constraints, making it more difficult to meet demand requirements, and
- Natural disasters and external environmental events, which can wreak havoc on global supply chains.

The above list includes operational and catastrophic risks because they are both important for firms to consider. From an operational perspective, complex networks

of suppliers, customers and third party service providers as well as large interdependencies among multiple firms exist, making inter-organizational coordination of risks a critical requirement. In addition, the leaner and more integrated supply chains become, the more likely it is that uncertainties, dynamics and accidents in one link will affect other links in the chain.³

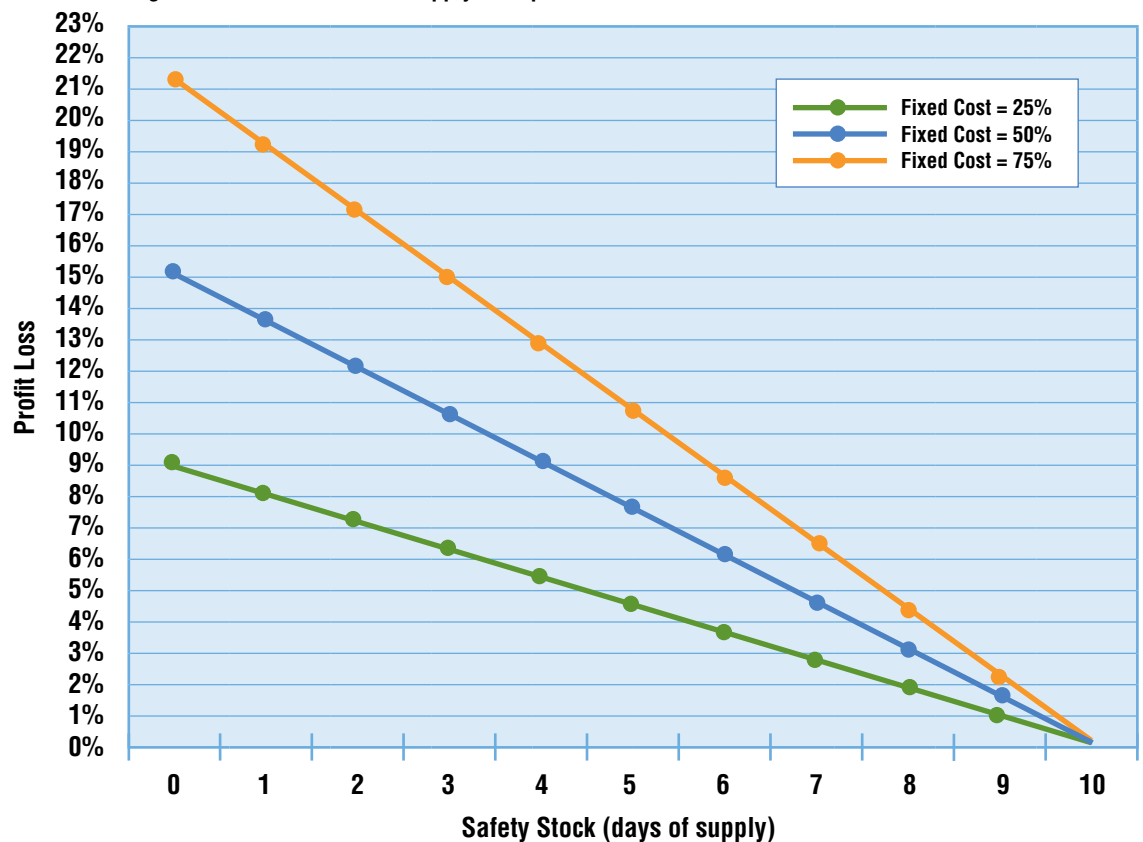
Figure 1: Scatter Plot: Logarithmic Relationship between Forecast Error and Ship Volume
(correlation coefficient = -0.59)



Let us take a closer look at a couple of examples. As commonly known, low volume items are hard to forecast. In Figure 1 (above), we have plotted the forecast errors of 288 components that are used in computer manufacturing against their demand volume. The chart shows that there is a clear logarithmic relationship between demand volume and forecast error (indicated by a correlation coefficient of -0.59). That is, the higher the demand volume, the lower the forecast error. Volume risk would be particularly high during product launches and phase-outs. Although during product launches inventory cost can

be remedied, during the phase-outs, manufacturers face significant component obsolescence risks. The dilemma is that high customer service targets might require prohibitively high levels of safety stock during these periods.

Figure 2: Profit Loss due to Supply Disruptions



Next, consider a manufacturer that keeps safety stock for a product it makes. In many commodity products, profit margins are low. Suppose profit margin is 10%. The chart above shows the impact of a 10 day supply disruption on profits. Since safety stock can cover for some of the supply disruption, the higher the safety stock the lower the profit loss. For instance, if safety stock is 8 days, only 2 days of revenue is lost and hence the profit loss is for 2 days of sales only. The corresponding profit loss varies from 2% to 4% depending on how high the fixed costs are. Figure 2 (above) shows that a manufacturer with 75% fixed costs (in some manufacturing industries such as semiconductors, fixed costs can be very high) can lose more than twice as much as a manufacturer with 25% fixed costs in case they don't hold any safety stock.

Highlights

In supply chain management, the industry has shown that survival of the unexpected is not an accident.

Risk and Consequence: Tales from the Industry

There are quite a few well-known case studies illustrating situations of supply chain risk and subsequent consequences. Here, we review a sample of them – emphasizing diversity both in terms of nature (operational or catastrophic) and consequence (financial and beyond).

A well-known example of supply chain risk management is no doubt the fire that destroyed an electronics component plant in New Mexico in 2000. This plant supplied both Nokia and Eriksson. Nokia reacted promptly, securing components from the market. Eriksson, on the other hand, was left with supply shortages which translated into direct lost sales estimated at \$390M. The most significant consequence of this event may have been the subsequent loss of Eriksson's market share dominance to Nokia.⁴ The different reactions from similar players to a single event in time has become a key illustration point, showing the benefits of monitoring and managing risks in supply chains.

Supplier issues often lead to large and visible consequences because of their upstream position in the supply chain. In 1997, raw material and part shortages resulted in Boeing losing \$2.6B. That same year, Toyota halted production for 20 days after single supplier location burned.⁵

Transportation is one of the most critical supply chain functions, and has the potential to bring just-in-time supply chains to an abrupt halt when something unexpected happens. Several events illustrate this point. In 1997, a 15-day Teamsters' strike severely affected the UPS Company, which at the time controlled 80% of all the package deliveries in the US. The strike subsequently crippled the logistics of numerous U.S. manufacturers.⁶ Similarly, the September 2002 shutdown of all the West Coast ports due to the dockworkers' strike idled manufacturers and/or incurred high costs while parts were flown in.⁷

Cross-border issues, from delays due to random inspections at customs to sudden border closure such as those that followed the 9/11 attacks, lurk constantly and create vulnerability in global supply chains. There are memorable images of trucks full of parts queued up for miles at the US-Canadian border on 9/11, starving the automotive production plants (and others) of materials needed for their just-in-time assembly. While it has long been recognized that reducing

inventory buffers is an excellent means of cost savings in the short run, such strategies also place risk on operations when catastrophe hits.

Supply chain visibility, or rather a lack thereof, can further compound problems. During the summer of 2007, toy maker Mattel repeatedly made the headlines for a recall of toys containing significant amounts of lead in the paint. In one specific case, the culprit seemed to be a sub-sub-contractor that decided to use paint from a non-authorized third-party supplier.⁸

Information Technology systems, while sometimes invisible, often play a central role in coordinating the supply chain. While they may attempt to enable optimal transactions among the various supply chain actors, they also introduce significant global dependencies in the supply chain operations and can have dire consequences when unreliable. For example, a glitch in Nike's demand planning software in early summer 2000 caused supply shortages for the popular Air Jordan footwear. As a result, Nike announced a \$100 million sales loss.⁹

There are notable examples of successful proactive risk management where potentially major supply chain weaknesses were identified prior to an event occurring, allowing time to develop appropriate action plans to remove or mitigate the risk factor.

In the first example, a tier one automotive supplier realized that all its suppliers providing one specific component were in financial trouble. They consequently engaged designers to develop an alternative to that component. A similar example involves an aerospace and aviation company, who discovered that two independent business units (helicopters and jets) relied on the same supplier for key material. They subsequently chose to diversify suppliers. In both cases, companies reduced their risk positions significantly.¹⁰

While there may be many more successful examples of proactive risk management of supply chains, companies involved tend not to advertise such events, as this may place them in a vulnerable position with regards to suppliers and/or customers. However, the limited data points that we do have, point to collaborative activity with suppliers and customers as a way to reduce risk in the supply chain.

Highlights

Not all supply chain risks are equal.

Supply Chain Risk Categories

It is often useful to consider categories of risks as a starting point to guide organizations in an initial assessment of their supply chains. Table 1 summarizes various forms of supply chain risks and vulnerabilities.

Table 1: Supply Chain Risk Categories, with examples¹¹

Category	Examples
Operational/ Technological	Forecast errors, component/material shortages, capacity constraints, quality problems, machine failure/downtime, software failure, imperfect yields, efficiency, process/product changes, property losses (due to theft, accidents, etc.), transportation risks (delays, damage from handling/transportation, re-routing, etc.), storage risks (incomplete customer order, insufficient holding space, etc.), budget overrun, emergence of a disruptive technology, contract terms (minimum and maximum limit on orders), communication/IT disruptions
Social	Labor shortages, loss of key personnel, strikes, accidents, absenteeism, human errors, organizational errors, union/labor relations, negative media coverage (reputation risk), perceived quality, coincidence of problems with holidays, fraud, sabotage, pillage, acts of terrorism, malfeasance, decreased labor productivity
Natural/Hazard	Fire, wild fire, severe thunderstorm, flood, monsoon, blizzard, ice storm, drought, heat wave, tornado, hurricane, typhoon, earthquake, tsunami, epidemic, famine, avalanche
Economy/ Competition	Interest rate fluctuation, exchange rate fluctuation, commodity price fluctuation, price and incentive wars, bankruptcy of partners, stock market collapse, global economic recession
Legal/Political	Liabilities, law suits, governmental incentives/restrictions, new regulations, lobbying from customer groups, instability overseas, confiscations abroad, war, tax structures, customs risks (inspection delay, missing data on documentation)

Source: Adapted from Deleris and Erhun (2007)¹¹

Highlights

The starting point for managing risk is recognition of uncertain future events, likelihood of occurrence, and potential impact.

Disruptive Events, Uncertainty and Impact

A straightforward approach for viewing supply chain risk management focuses on two fundamental aspects of a potentially disruptive event:

1. Probability (likelihood) of the event actually occurring
2. Impact (consequence) of the event on the supply chain, and subsequently the overall business

A first step in risk analysis is to identify potentially disruptive supply chain events. These should be customized for a particular firm. Both operational and catastrophic events should be considered, including those that involve suppliers, production, distribution and demand. As mentioned earlier, it is often useful to collaborate with suppliers and customers when possible – joint planning can help to insure that supply chain risk planning which may be costly and resulting decisions are mutually valuable to all parties.

Once all of the events that could potentially disrupt the supply chain are identified, various methods can be used to quantify their probabilities and impacts, as well as the potential impacts. The results may then be used to assess overall risk and vulnerability within the extended supply chain.

Events determined to have high likelihood and high impact, e.g. a product recall, can then be called out for further attention and analysis. The identification and classification of risky events enables supply chain managers to better understand where their supply chains are vulnerable.

One essential caveat of considering the list of hazards and their frequency and impact is that it does not capture dependency relationships between different events, both at the frequency and the impact levels. Thus, listing risks factors, assessing their probability and impact is just a first, albeit important, step toward rigorous risk management in supply chains. A holistic approach to supply chain risk management is required in order to better understand the vulnerabilities within the supply chain.

In addition, the assigned probabilities and impacts of these events can be highly subjective. This further highlights the importance of a collaborative effort, particularly for quantification of risk probabilities and impacts, with input gathered from multiple functions within and beyond the firm including marketing, finance, human resources and logistics. In fact, this exercise should be a part of the overall corporate risk management strategy.

Once risk events and their potential impacts have been identified, effective methods for managing the risks must be developed. Effective risk management requires quantifying risks to place them in their proper context and to weigh the risk costs and benefits of making particular decisions. Stochastic and simulation modeling, which embody a wide range of mathematical and numerical approaches considering random variables, offer general means to formally represent the uncertainties related to risk events. Based on these models, various forms of analysis are available to develop measures to manage and mitigate potential disruptive events that may adversely impact supply chains. In the next section, we review some of the approaches that have been suggested in the recent literature for supply chain risk management.

Highlights

Math, economic and simulation models are essential to comprehensive supply chain risk analysis.

Models and Methods for Supply Chain Risk Management

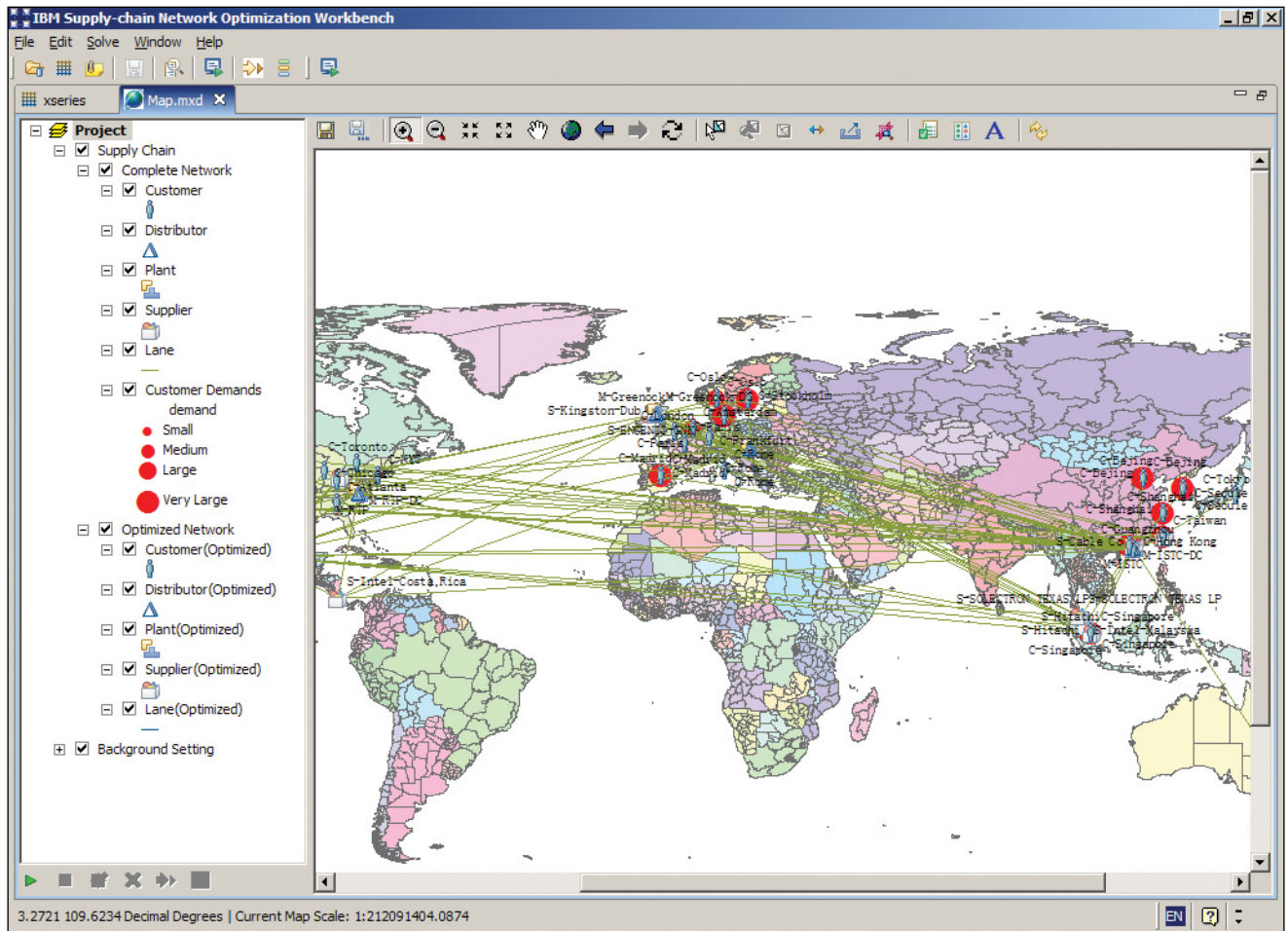
Although supply chain engineering methods have advanced rapidly in sophistication over the past two decades, the application of modeling and methods to explicitly consider and manage uncertainties and risks in supply chain activities are required for firms to advance to the next level of sophistication. The ability to identify, assess, manage, mitigate and control the impact of disruptive events within the extended supply chain sits at the heart of comprehensive supply chain risk management. For a more detailed discussion on general mathematical modeling and risk analytics, see Ray, Apte, McAuliffe and Cope (2008).¹²

Supply Chain models may be categorized into four categories:¹³

1. Deterministic analytical models, which include mathematical programming models (e.g. linear, nonlinear, integer, dynamic programming). Applications to supply chain include scheduling production, distribution planning, raw material sourcing, facility location, inventory level setting, replenishment timing and order quantity specification, and resource balancing.
2. Stochastic analytical models, where at least one of the variables involves uncertainty, and is assumed to follow a particular probability distribution. Examples of supply chain applications include inventory and production management problems, where demand and yield are represented as random variables respectively.
3. Economic models, which tend to be focused on buyer-supplier relationships. These models have a traditional base in determining the financial risks to either sellers or buyers, given various assumptions.
4. Simulation models, which are (usually) data driven representations facilitated by sampling from specified probability distributions.

All of the above modeling approaches may be useful for supply chain risk management. Typical analysis is performed by observing the impact of changes to input patterns on model output. Changes, in this case, could reflect “what if” scenarios characterizing the occurrence of a risky event. Note that the analyses are limited to the impact on the decisions for which the original model is designed to support. Of the four, simulation is the most versatile for general modeling and analysis for supply chain risk management. However, note that simulation models are usually complex to build and maintain. Note also that, to be useful in risk management, deterministic models must be embedded into a framework that simulates uncertain events.

Figure 3: Deterministic analytical models include traditional network planning tools used for evaluating facility location, supply chain sourcing decisions and transportation policy analysis.



Several other authors have discussed variants on supply chain modeling with the objectives of risk management. Some of the most notable include:

- Cachon (2003) discusses a few supply chain models at various levels of complexity, from the perspective of contract coordination and the risks of both supplier and receiver in the supply chain.¹⁴
- Datta et al (2007) propose the adaption of methods from the finance domain to risk management within supply chain.¹⁵
- Fisher et al (1997) use models to examine supply chain levers with the objective of improving the match between supply and uncertain demand, which represents a type of risk mitigation strategy applicable to virtually all product and service domains.¹⁶
- Swaminathan et al (1998) consider agent based simulation models for supply chain modeling, which enable rapid development of customized decision support tools that could certainly include risk management.¹⁷

No discussion of risk management modeling and methods would be complete without mention of Failure Mode and Effect Analysis (FMEA). Dating back to 1949 and use by the US Military, FMEA is a general method for identifying and analyzing potential failure modes within a system, and then for impact or severity analysis of the failures.¹⁸ By considering risky events as “failures,” it is easy to see how the methodologies can be applied directly to supply chain risk management.

FMEA is widely used among the reliability engineering community. Another thread with this community is the idea of building in system redundancy.¹⁹ Mitigation and contingency strategies are also discussed by several current authors,^{20, 21, 22} all of whom take various levels of approach with respect to modeling and analytics to make their arguments.

Highlights

The server supply chain risk study illustrates an end-to-end approach for risk management.

Process, people and information flow are essential in the course of identifying supply chain risks.

Example of Risk Management for IBM's Product Supply Chain

IBM's product supply chains span multiple geographies and cover a complex network of suppliers, manufacturing sites and shippers. Recently, IBM focused on its supply chain for the System X server product. Using probabilistic risk analysis, which is based on methods originally developed to analyze complex engineering systems such as nuclear power plants and NASA space missions, the System X study provided a comprehensive and unified perspective on risk factors affecting the supply chain: from frequent operational problems to catastrophic events, and from local delays to industry-wide phenomena. Not only did the study identify risks, it also quantified the impact of loss events on the cost and order-to-delivery time for supplying the servers to its customers.

An Approach for Identifying Supply Chain Risks

IBM used a systematic approach to identify risks to the server product's supply chain performance:

1. The study first identified risks by mapping the business processes needed in order to procure parts, and assemble and deliver machines.
2. The human, capital, and informational resources required by these processes were then mapped to indicate how they supported component activities and decisions.
3. A series of interviews with key managers and engineers identified key risk factors and root causes, which were arranged into an influence diagram indicating the cause-effect chains of failures and disruptions that impact supply chain performance. Root causes of risk included both sources of catastrophic risk as well as sources of everyday problems affecting the efficiency of the supply chain operation.
4. These influencing factors were further integrated into the business process and resource maps to pinpoint the exact location and means by which disruptions propagate into the supply chain.

Figure 4: An illustration of business process mapping, from sales through assembly and outbound logistics (Sale-to-Ship)

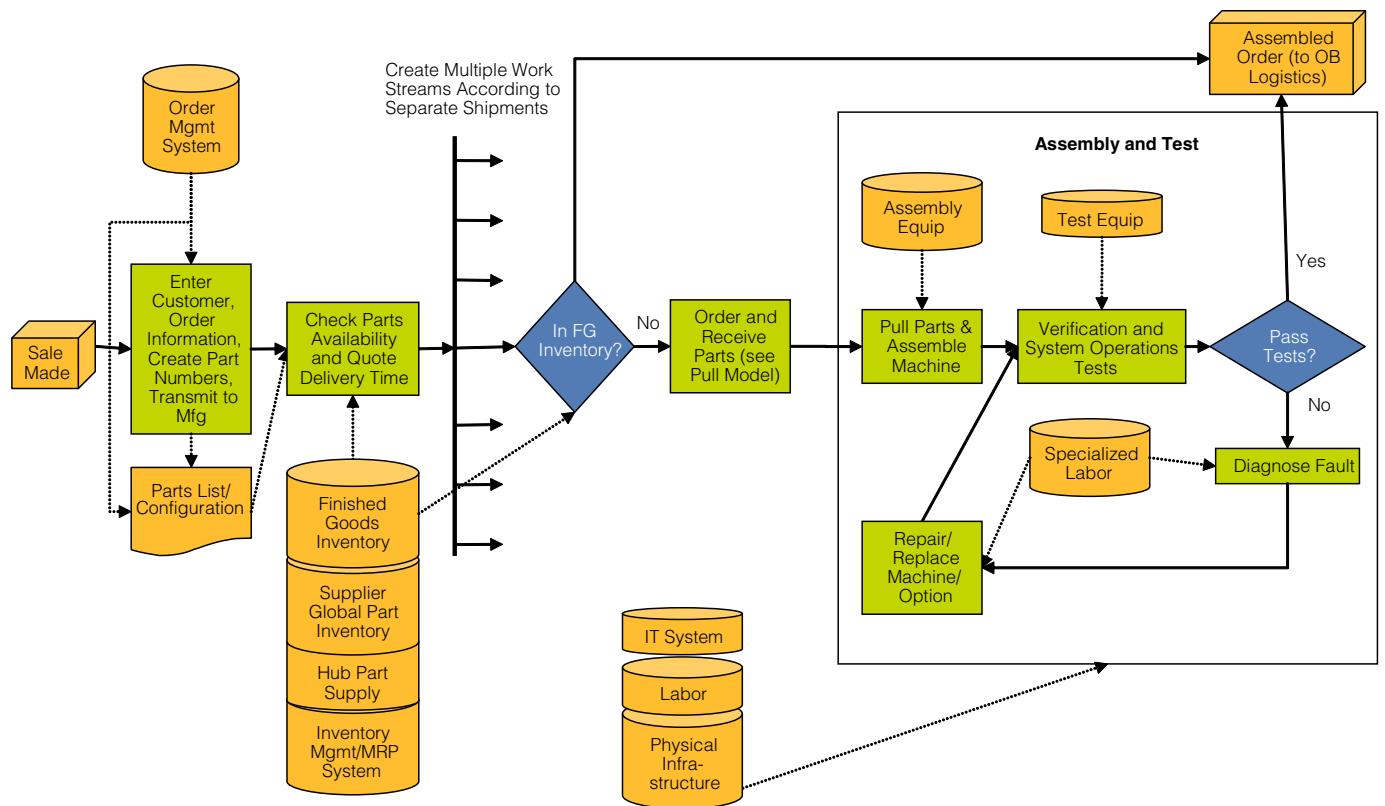
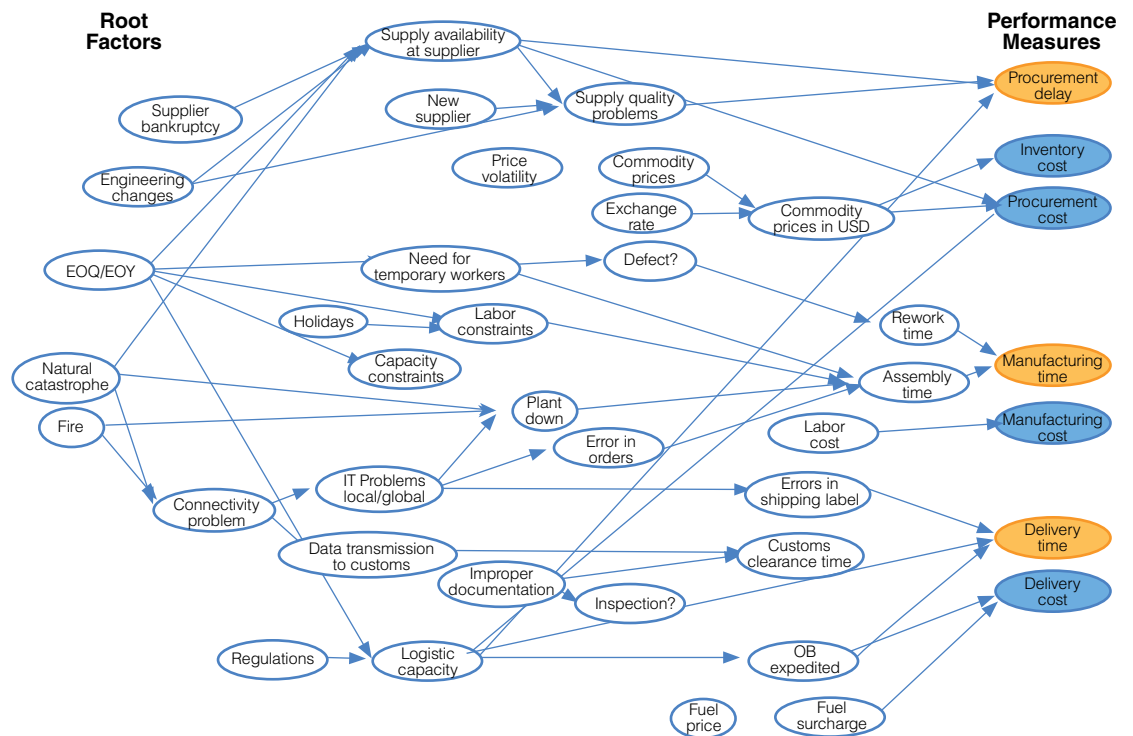


Figure 5: Example of Bayesian network, illustrating root causes of risks and how they may impact supply chain operations



In the course of the study, special attention was paid to identifying common factors and resources simultaneously influencing the performance of several activities and processes. In addition, resources and activities were grouped according to geographical region, ownership, and other categories that would indicate a common source of vulnerability. Examples of this type of grouping included:

- Infrastructure, people, and computing facilities located near the coast of the Gulf of Mexico, which could be subjected to a common risk of hurricanes
- A group of suppliers owned by the same holding company facing a common risk of financial insolvency

Highlights

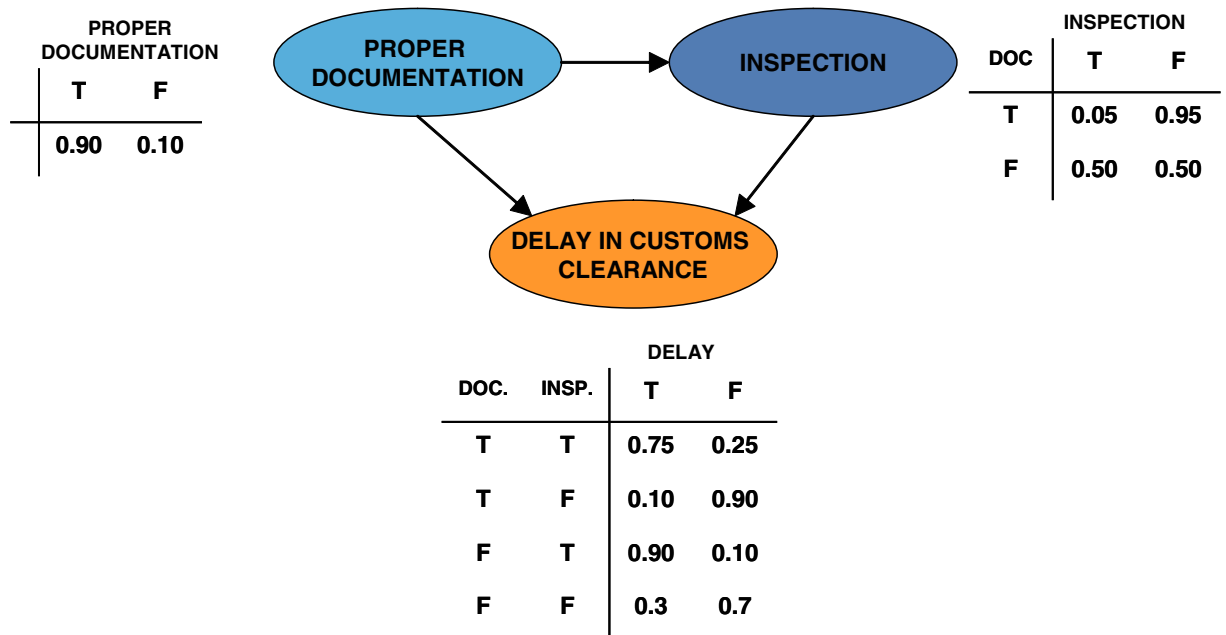
Combining process maps with Bayesian networks is one approach for analyzing supply chain risks. A Bayesian network is a graphical model that represents a set of variables and their probabilistic interdependencies.

An Approach for Measuring the Impact of Identified Supply Chain Risks

The IBM systematic approach for System X supply chain risk management extends into a method for measuring impact. An approach based on Bayesian network modeling was used for quantification of identified supply chain risks:

1. The combined map of business processes, resources, and risk causes and factors became the basis of the Bayesian network model. (Figure 6 illustrates a simple Bayesian network model.) The model was generated by assigning quantities to each element in the map which functionally determined the distribution of overall system performance, measured in terms of cost and order-to-delivery time. For example, root causes of risks were associated with frequency and severity distributions, resources were associated with availability statistics, and time and cost distributions were assigned to each component activity.
2. Once these quantities were identified, the map provided a structured template for gathering all the required data needed to populate the quantification model. The study used a combination of publicly available data, expert knowledge, and internal incident tracking databases to supply the required numbers to the model.
3. The combined map of business processes provided a blueprint for a simulation model for computing the effects of disruptions and failures on supply chain performance.

Figure 6: Example of a Bayesian network model



A simulation model of this type can be used to identify the most important sources of risk in terms of impact, key points of failure within the chain, and the total distribution of performance measures. Once validated against observed performance statistics, the model of the “as-is” supply chain can then be altered to determine the effects of desired changes in supply chain operation, allowing one to assess the effects of risk mitigation strategies and countermeasures, or the effects of supply chain redesigns. Such a model can provide a very powerful tool for supply chain managers and executives to directly measure the total costs and benefits of making changes to the existing operations, and thus explicitly take risk factors into account when making strategic and tactical decisions.

Highlights

Artifacts used in supply chain risk projects include: business process models, resource maps, geographical information and analytical frameworks for evaluating uncertain events and their impact.

Key Lessons from IBM's Supply Chain Risk Management Approach

A few key themes emerging from IBM's System X Server supply chain risk management study are worth noting:

- Business process models provide a valuable starting point for identifying those activities and resources which are needed to accomplish the goals and objectives for supply chain performance. Process maps facilitate the systematic identification and location of risks, and the casual pathways that link root causes to impacts on overall supply chain performance measures.
- Resource maps, including human, capital, and IT resources, are instrumental for indicating key vulnerabilities and central points of failure in supply chain operations.
- Geographical information is crucial for identifying various processes and resources that are co-located. Local knowledge of supplier dependence, labor relations, political and market forces, and natural disasters is also essential in understanding how risks may differ depending on location.
- Both catastrophic and everyday loss events can be placed into a common risk quantification framework. In IBM's study, both catastrophic, low-frequency/high-severity risks as well as more everyday, high-frequency/low-severity risks were incorporated together into one risk model. This was useful for directly comparing widely different sources of risk and the impacts of possible countermeasures.

Finally, it should be noted that the simulation models enabled by this approach can be complex and can take considerable time to build and run. In the IBM study, a simpler method was developed for scoring risks in terms of their impact on total performance that provided approximate results much more quickly.

Highlights

More and more companies are considering risks, and the avoidance of potential disruptions, when evaluating alternative suppliers in their upstream supply chain operations.

The Landscape: Supply Chain Risk Management

In addition to development methods and tools for managing its own supply chain risks, IBM has invested in several joint university programs to further explore topics related to supply chain risk. Among these was a survey designed to understand how supply managers attempt to manage risk in procurement. Their conclusion was as follows:

“Overall, it appears that supply management professionals do recognize that risk exists in their upstream supply chains, though often it is discussed only when a problem occurs. The extent of formal systems to make risk visible is not prevalently used.”

While this statement focuses on upstream risks in the supply chains, downstream risk is also of concern, e.g. damaged goods in transit to customers.

Furthermore, survey findings indicated that supply risk is often explicitly considered when selecting and evaluating suppliers. In terms of tools, firms tend to use them to understand the business impact of possible cost or price increases, rather than to address issues such as supply chain disruptions. It was also noted that supply chain mapping tools do not appear to be widely used for understanding where risk can originate in the supply chain.

In terms of current management techniques, most purchasing professionals appear to focus on facilitating inter-organizational integration with suppliers to manage supply risk. In particular, the most prevalent techniques involve establishing close relationships with suppliers and managing risk before designs are formalized. In addition, the use of pre-qualified suppliers is also viewed as an important practice to manage supply risk.

Highlights

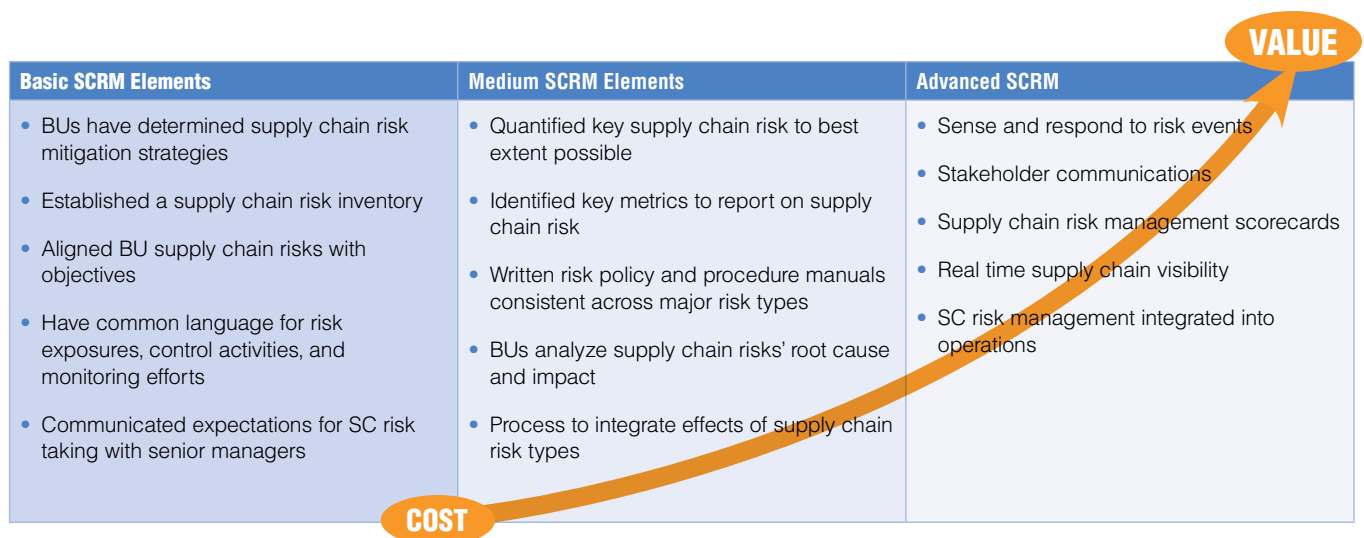
Establishing supply chain risk management involves organizing information and activities that often already exist.

Supply Chain Risk Management: Getting Started

There are five general steps in formulating a risk strategy and implementation plan:

1. **Understand the Risk Environment:** Review the management model and understand the current business strategy. Review related documentation (operations, contracts). Review compliance documentation (OSHA, HIPAA, ISO, etc.). Review risk-related metrics (accidents, auditor reports, insurance claims, contract claims, disasters, demand spikes).
2. **Identify and Assess Current Risk:** Evaluate current process, and external factors, highlighting specific threats and assess risk maturity. Evaluate current processes. Validate and improve existing metrics. Identify opportunities for risk management improvement. Identify specific external influences on the process (identify trigger, resolution, and point of contact). Identify key drivers of current risk maturity.
3. **Quantify and Prioritize Risk:** Measure the likelihood or impact and ease of detection. Weight risk according to risk factors and financial implications. Estimate costs and investments.
4. **Develop Risk Mitigation Strategy and Business Case:** Develop improvement recommendations and risk mitigation plans for the enterprise and extended supply chain. Develop cost/benefit analysis.
5. **Develop Implementation Roadmap:** Select a course of action. Develop tentative list of implementation partners. Generate initial timeline.

Figure 7: Supply Chain Risk Management Maturity Model - Moving up the maturity continuum of Supply Chain Risk Management can help companies to improve financial return



While many of the supply chain risk factors discussed thus far are typical considerations in application of supply chain management techniques, there are many areas of emerging concern that may not previously have been considered in the context of supply chain risks. For example, companies face increasing risks to their overall reputation due to certain supply chain practices related to corporate responsibility, such as: use of child labor, excessive emissions associated with certain supply chain activities, or lack of adequate safety controls in manufacturing.

Additionally, consideration needs to be given to potential regulatory risks posed from supply chain practices. Companies need to take a proactive stance to consider potential risks associated with future regulatory non-compliance, e.g. environmental regulation changes, and make smart decisions today so as to minimize supply chain risks over the long run. These risks can result from actual regulation changes as well as perceived behavior norms expressed by the customer base.

Highlights

The direct benefit of supply chain risk management is effective risk mitigation, including cost avoidances associated with reduced disruptions and reduced recovery time when disruptions are unavoidable.

In Summary

The supply chain has become increasingly more global and complex which presents greater challenges and risks. Customers present ever-changing requirements and emerging market penetration oftentimes requires a completely different segmentation approach – not only to products and services, but also to associated cultural, environmental, and governmental influences. With the constantly shifting geographical sourcing of supply and the movements towards outsourced/contracted manufacturing, supply shortages, outages and quality control are increasing costs in many cases, and decreasing predictability and reliability. Direct and indirect suppliers impose additional risks. To the global manufacturer, all of these factors are compounded by increased product complexity, distributed information, and even environmental factors.

Supply Chain Risk Management offers improved focus on risk and therefore, more effective risk mitigation. Other benefits include the elimination of potential and unexpected costs, reduced disruptions and time to recovery. Monitoring and managing supply chain events, with an eye on potential, predictable, and even uncertain risk elements, generally evidences an improvement in overall supply chain performance. And finally, avoiding or at least confronting risks in today's complex supply chain ecosystem, can strengthen competitive advantage and even financial longevity.

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