Supply Chain Management

Strategy, Planning, and Operation

SEVENTH EDITION

Sunil Chopra

Seventh Edition
Global Edition

Supply Chain Management

Strategy, Planning, and Operation

Sunil Chopra
Kellogg School of Management

Pearson

Harlow, England • London • New York • Boston • San Francisco • Toronto • Sydney • Dubai • Singapore • Hong Kong
Tokyo • Seoul • Taipei • New Delhi • Cape Town • Sao Paulo • Mexico City • Madrid • Amsterdam • Munich • Paris • Milan

TABLE 6-3 Supply Chain Risks to Be Considered During Network Design

Category	Risk Drivers
Disruptions	Natural disaster, war, terrorism
	Labor disputes
	Supplier bankruptcy
Delays	High capacity utilization at supply source
	Inflexibility of supply source
	Poor quality or yield at supply source
Systems risk	Information infrastructure breakdown
	System integration or extent of systems being networked
Forecast risk	Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base
	Information distortion
Intellectual property risk	Vertical integration of supply chain
	Global outsourcing and markets
Procurement risk	Exchange rate risk
	Price of inputs
	Fraction purchased from a single source
	Industry wide capacity utilization
Receivables risk	Number of customers
	Financial strength of customers
Inventory risk	Rate of product obsolescence
	Inventory holding cost
	Product value
	Demand and supply uncertainty
Capacity risk	Cost of capacity
	Capacity flexibility

Source: Based on Sunil Chopra and Manmohan S. Sodhi, "Managing Risk to Avoid Supply Chain Breakdown." *Sloan Management Review* (Fall 2004): 53–61.

Acquiring multiple suppliers mitigates the risk of disruption but increases costs because each supplier may have difficulty achieving economies of scale. Thus, it is important to develop tailored mitigation strategies during network design that achieve a good balance between the amount of risk mitigated and the increase in cost. Some tailored mitigation strategies are outlined in Table 6-4. Most of these strategies are discussed in greater detail later in the book.

Global supply chains should generally use a combination of mitigation strategies designed into the supply chain along with financial strategies to hedge uncovered risks. A global supply chain strategy focused on efficiency and low cost may concentrate production in a few low-cost countries. Such a supply chain design, however, is vulnerable to the risk of supply disruption along with fluctuations in transportation prices and exchange rates. In such a setting, it is crucial that the firm hedge fuel costs and exchange rates because the supply chain design itself has no built-in mechanisms to deal with these fluctuations. In contrast, a global supply chain designed with excess, flexible capacity allows production to be shifted to whatever location is most effective in a given set of macroeconomic conditions. The ability of such a flexible design to react to fluctuations decreases

TABLE 6-4 Tailored Risk Mitigation Strategies During Network Design

Risk Mitigation Strategy	Tailored Strategies
Increase capacity	Focus on low-cost, decentralized capacity for predictable demand. Build centralized capacity for unpredictable demand. Increase decentralization as cost of capacity drops.
Get redundant suppliers	More redundant supply for high-volume products, less redundancy for low-volume products. Centralize redundancy for low-volume products in a few flexible suppliers.
Increase responsiveness	Favor cost over responsiveness for commodity products. Favor responsiveness over cost for short–life cycle products.
Increase inventory	Decentralize inventory of predictable, lower-value products. Centralize inventory of less predictable, higher-value products.
Increase flexibility	Favor cost over flexibility for predictable, high-volume products. Favor flexibility for unpredictable, low-volume products. Centralize flexibility in a few locations if it is expensive.
Pool or aggregate demand	Increase aggregation as unpredictability grows.
Increase source capability	Prefer capability over cost for high-value, high-risk products. Favor cost over capability for low-value commodity products. Centralize high capability in flexible source if possible.

Source: Based on Sunil Chopra and Manmohan S. Sodhi, "Managing Risk to Avoid Supply Chain Breakdown." *Sloan Management Review* (Fall 2004): 53–61.

the need for financial hedges. Operational hedges such as flexibility are more complex to execute than financial hedges, but they have the advantage of being reactive because the supply chain can be reconfigured to best react to the macroeconomic state of the world.

It is important to keep in mind that any risk mitigation strategy is not always "in the money." For example, flexibility built into Honda plants proved effective only when demand for vehicles shifted in an unpredictable manner in 2008. If there had been no fluctuation in demand, the flexibility would have gone unutilized. Flexibility in the form of the intelligent body assembly system (IBAS) built by Nissan in the early 1990s almost bankrupted the company because the state of the automotive markets was relatively stable at that time. Similarly, the use of fuel hedges that made billions for Southwest Airlines cost it money toward the end of 2008 when crude oil prices dropped significantly.

It is thus critical that risk mitigation strategies be evaluated rigorously as real options in terms of their expected long-term value before they are implemented. In the following sections, we discuss methodologies that allow for the financial evaluation of risk mitigation strategies designed into a global supply chain.

Flexibility, Chaining, and Containment

Flexibility plays an important role in mitigating different risks and uncertainties faced by a global supply chain. Flexibility can be divided into three broad categories—new product flexibility, mix flexibility, and volume flexibility. *New product flexibility* refers to a firm's ability to introduce new products into the market at a rapid rate. New product flexibility is critical in a competitive environment wherein technology is evolving and customer demand is fickle. New product flexibility may result from the use of common architectures and product platforms with the goal of providing a large number of distinct models using as few unique platforms as possible.

The consumer electronics industry has historically followed this approach to introduce a continuous stream of new products. New product flexibility may also result if a fraction of the production capacity is flexible enough to be able to produce any product. This approach has been used in the pharmaceutical industry, in which a fraction of the capacity is very flexible with all new products first manufactured there. Only once the product takes off is it moved to a dedicated capacity with lower variable costs.

Mix flexibility refers to the ability to produce a variety of products within a short period of time. Mix flexibility is critical in an environment in which demand for individual products is small or highly unpredictable, supply of raw materials is uncertain, and technology is evolving rapidly. The fashion and consumer electronics industries are good examples for which mix flexibility is essential in production environments. Modular design and common components facilitate mix flexibility in the electronics industry. Zara's European facilities have significant mix flexibility, allowing the company to provide trendy apparel with highly unpredictable demand.

Volume flexibility refers to a firm's ability to operate profitably at different levels of output. Volume flexibility is critical in cyclical industries. Firms in the automotive industry that lacked volume flexibility were badly hurt in 2008 when demand for automobiles in the United States shrank significantly. The steel industry is an example in which some volume flexibility and consolidation have helped performance. Prior to 2000, firms had limited volume flexibility and did not adjust production volumes when demand started to fall. The result was a buildup of inventories and a significant drop in the price of steel during a downturn. In the early 2000s, a few large firms consolidated and developed some volume flexibility. As a result, they were able to cut production as demand fell. The result has been less buildup of inventory and smaller drops in price during downturns, followed by a quicker recovery for the steel industry.

Given that some form of flexibility is often used to mitigate risks in global supply chains, it is important to understand the benefits and limitations of this approach. When dealing with demand uncertainty, Jordan and Graves (1995) make the important observation that as flexibility is increased, the marginal benefit derived from the increased flexibility decreases. They suggest operationalizing this idea in the concept of *chaining*, which is illustrated as follows. Consider a firm that sells four distinct products. A dedicated supply network with no flexibility would have four plants, each dedicated to producing a single product, as shown in Figure 6-1. A fully flexible network configuration would have each plant capable of producing all four products. The production flexibility of plants is beneficial when demand for each of the four products is unpredictable. With dedicated plants, the firm is not able to meet demand in excess of plant capacity. With flexible plants, the firm is able to shift excess demand for a product to a plant with excess capacity. Jordan and Graves define a chained network with one long chain (limited flexibility), configured as shown in Figure 6-1. In a chained configuration, each plant is capable of producing two products with the flexibility organized so that the plants and their products form a chain. Jordan and Graves show that a chained network mitigates the risk of demand fluctuation almost as effectively as a fully flexible network. Given the higher cost of full flexibility, the results of Jordan and Graves indicate that chaining is an excellent strategy to lower cost while gaining most of the benefits of flexibility.

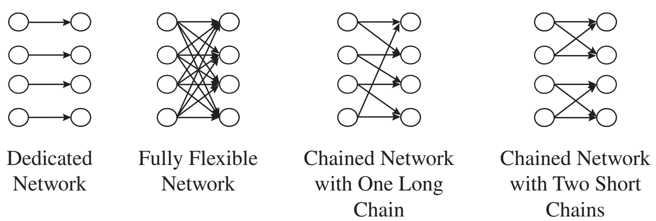

Figure 6-1 Different Flexibility Configurations in Network

The desired length of chains is an important question to be addressed when designing chained networks. When dealing with demand uncertainty, longer chains have the advantage of effectively pooling available capacity to a greater extent. Long chains, however, do have a few disadvantages. The fixed cost of building a single long chain can be higher than the cost of multiple smaller chains. With a single long chain, the effect of any fluctuation ripples to all facilities in the chain, making coordination more difficult across the network. It has also been observed by several researchers that flexibility and chaining are effective when dealing with demand fluctuation but less effective when dealing with supply disruption. In the presence of supply disruption, Lim et al., (2008) have observed that designing smaller chains that contain or limit the impact of a disruption can be more effective than designing a network with one long chain. An example of containment is shown in the last example in Figure 6-1, which shows four plants with the flexibility to produce the four products in the form of two short chains. In this design, any disruption in one of the chains does not affect the other chain. A simple example of containment is hog farming: The farms are large to gain economies of scale, but the hogs are kept separated in small groups to ensure that the risk of disease is contained within a group and does not spread to the entire farm.

SUMMARY OF LEARNING OBJECTIVE 2

The performance of a global supply chain is affected by risk and uncertainty in a number of input factors such as supply, demand, price, exchange rates, and other economic factors. These risks can be mitigated by building suitable flexibility in the supply chain network. Operational strategies that help mitigate risk in global supply chains include carrying excess capacity and inventory, flexible capacity, redundant suppliers, improved responsiveness, and aggregation of demand. Hedging fuel costs and currencies are financial strategies that can help mitigate risk. It is important to keep in mind that no risk mitigation strategy will always pay off. These mitigation strategies are designed to guard against certain extreme states of the world that may arise in an uncertain global environment.

EVALUATING NETWORK DESIGN DECISIONS USING DECISION TREES

6.3 *Understand decision tree methodologies used to evaluate supply chain design decisions under uncertainty.*

Decision makers should design global supply chain networks considering a portfolio of strategic options—the option to wait, build excess capacity, build flexible capacity, sign long-term contracts, purchase from the spot market, and so forth. In any global supply chain, demand, prices, exchange rates, and several other factors are uncertain and are likely to fluctuate during the life of any supply chain decision. Thus, the various options should be evaluated in the context of future uncertainty. A design methodology that does not account for uncertainty typically undervalues flexible options. The result is often a supply chain that performs well if everything goes according to plan but becomes terribly expensive if something unexpected happens. A manager makes several different decisions when designing a supply chain network. For instance:

- Should the firm sign a long-term contract for warehousing space or get space from the spot market as needed?
- What should the firm's mix of long-term and spot market be in the portfolio of transportation capacity?
- How much capacity should various facilities have? What fraction of this capacity should be flexible?

If uncertainty is ignored, a manager will always sign long-term contracts (because they are typically cheaper) and avoid all flexible or backup capacity (because it is more expensive). Such decisions can hurt the firm, however, if future demand or prices are not as forecast at the time of the decision. Executives participating in the Accenture 2013 Global Manufacturing Study "cited a variety of volatility-related factors as potential impediments to their ability to grow—including global currency instability, unpredictable commodities costs, uncertainty about customer demand, political or social unrest in key markets, and potential changes in government regulations." It is thus important to provide a methodology that allows managers to incorporate this uncertainty into their network design process. In this section, we describe such a methodology and show that accounting for uncertainty can have a significant impact on the value of network design decisions.

Discounted Cash Flows

Global supply chain design decisions should be evaluated as a sequence of cash flows over the duration of time the decisions will be in place. This requires the evaluation of future cash flows accounting for risks and uncertainties likely to arise in the global supply chain. We first discuss the basics of analysis to evaluate future cash flows before introducing uncertainty.

The present value of a stream of cash flows is what that stream is worth in today's dollars. *Discounted cash flow* (DCF) analysis evaluates the present value of any stream of future cash flows and allows management to compare two streams of cash flows in terms of their financial value. DCF analysis is based on the fundamental premise that "a dollar today is worth more than a dollar tomorrow" because a dollar today may be invested and earn a return in addition to the dollar invested. This premise provides the basic tool for comparing the relative value of future cash flows that will arrive during different time periods.

The present value of future cash flow is found by using a discount factor. If a dollar today can be invested and earn a rate of return k over the next period, an investment of \$1 today will result in $1 + k$ dollars in the next period. An investor would therefore be indifferent between obtaining \$1 in the next period or $\$1/(1 + k)$ in the current period. Thus, \$1 in the next period is discounted by the

$$\text{Discount factor} = \frac{1}{1 + k} \tag{6.1}$$

to obtain its present value.

The rate of return k is also referred to as the *discount rate*, *hurdle rate*, or *opportunity cost of capital*. Given a stream of cash flows $C_0, C_1, \ldots, C_T$ over the next T periods, and a rate of return k, the net present value (NPV) of this cash flow stream is given by

$$\text{NPV} = C_o + \sum_{t=1}^{T} \left(\frac{1}{1 + k}\right)^t C_t \tag{6.2}$$

The NPV of different options should be compared when making supply chain decisions. A negative NPV for an option indicates that the option will lose money for the supply chain. The decision with the highest NPV will provide a supply chain with the highest financial return.

EXAMPLE 6-1

Trips Logistics, a third-party logistics firm that provides warehousing and other logistics services, is facing a decision regarding the amount of space to lease for the upcoming three-year period. The general manager has forecast that Trips Logistics will need to handle a demand of 100,000 units for each of the next three years. Historically, Trips Logistics has required 1,000 square feet of warehouse space for every 1,000 units of demand. For the purposes of this discussion, the only cost Trips Logistics faces is the cost for the warehouse.

Trips Logistics receives revenue of \$1.22 for each unit of demand. The general manager must decide whether to sign a three-year lease or obtain warehousing space on the spot market each year. The three-year lease will cost \$1 per square foot per year, and the spot market rate is expected to be \$1.20 per square foot per year for each of the three years. Trips Logistics has a discount rate of $k = 0.1$. Should the general manager sign a lease?

Analysis

The general manager decides to compare the NPV of signing a three-year lease for 100,000 square feet of warehouse space with obtaining the space from the spot market each year. If the general manager obtains warehousing space from the spot market each year, Trips Logistics will earn \$1.22 for each unit and pay \$1.20 for one square foot of warehouse space required. The expected annual profit for Trips Logistics in this case is given by the following:

$$\begin{aligned}\text{Expected annual profit if warehousing} &= (100{,}000 \times \$1.22)\\ \text{space is obtained from spot market} &\quad - (100{,}000 \times \$1.20) = \$2{,}000\end{aligned}$$

Obtaining warehouse space from the spot market provides Trips Logistics with an expected positive cash flow of \$2,000 in each of the three years. The NPV may be evaluated as follows:

$$\text{NPV(No lease)} = C_o + \frac{C_1}{(1+k)} + \frac{C_2}{(1+k)^2} = 2{,}000 + \frac{2{,}000}{1.1} + \frac{2{,}000}{1.1^2} = \$5{,}471$$

If the general manager leases 100,000 sq. ft. of warehouse space for the next three years, Trips Logistics pays \$1 per square foot of space leased each year. The expected annual profit for Trips Logistics in this case is given by the following:

$$\begin{aligned}\text{Expected annual profit with three-year lease} &= (100{,}000 \times \$1.22) - (100{,}000 \times \$1.00)\\ &= \$22{,}000\end{aligned}$$

Signing a lease for three years provides Trips Logistics with a positive cash flow of \$22,000 in each of the three years. The NPV may be evaluated as

$$\text{NPV(Lease)} = C_o + \frac{C_1}{(1+k)} + \frac{C_2}{(1+k)^2} = 22{,}000 + \frac{22{,}000}{1.1} + \frac{22{,}000}{1.1^2} = \$60{,}182$$

The NPV of signing the lease is \$60,182 − \$5,471 = \$54,711 higher than obtaining warehousing space on the spot market.

Based on this simple analysis, a manager may opt to sign the lease. However, this does not tell the whole story because we have not yet included the uncertainty in spot prices and valued the greater flexibility to adjust to uncertainty that the spot market provides the manager. We introduce decision tree analysis that allows for uncertainty and discuss how the inclusion of uncertainty of future demand and costs may cause the manager to rethink the decision.

The Basics of Decision Tree Analysis

A *decision tree* is a graphic device used to evaluate decisions under uncertainty. Decision trees with DCFs can be used to evaluate supply chain design decisions given uncertainty in prices, demand, exchange rates, and inflation.

The first step in setting up a decision tree is to identify the number of time periods into the future that will be considered when making the decision. The decision maker should also identify the duration of a period—a day, a month, a quarter, or any other time period. The duration of a period should be the minimum period of time over which factors affecting supply chain decisions may change by a *significant* amount. “Significant” is hard to define, but in