INTERNATIONAL SOURCING AND SUPPLY CHAIN STABILITY

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Abstract. An international supply chain is conceptualized as a complex, dynamic system in which disruptions interact with long shipping and lead times to generate costs. Findings from a case study and simulation model indicate that demand-related disruptions created substantial and unexpected costs in terms of expedited shipping, high inventories, and lower demand fulfillment. Production-related disruptions declined over time, but demand-related disruptions did not. Implications for management are discussed.

As national boundaries become more permeable to economic activities and capital becomes more mobile, industry value chains are becoming increasingly international in their scope [Dunning 1992; Julius 1990; Kotabe and Swan 1994; Levy and Dunning 1993; UNCTC 1991]. This globalization of production entails substantial growth of international sourcing for both components and finished goods. A key issue facing managers is deciding which activities in the value chain[1] can successfully be sourced internationally, and which need to be conducted in geographical proximity to each other. To address this question, we need to understand the costs generated by geographically separating activities in the value chain, and evaluate whether these costs outweigh the benefits.

Explanations of the location and extent of international sourcing have traditionally focused on two sets of factors, location-specific factors and what can be called "relational" factors. Location-specific factors pertain to the relative attractiveness of particular locations and include, inter alia, relative production costs, the availability of technology and resources, political and economic stability, and the attractiveness of the local market [Moxon 1973; Swamidass and Kotabe 1993]. "Relational" factors, by contrast, address the relationships, or linkages, between the activity being sourced and other activities in the value chain. These linkages comprise flows of goods, information and money [Bartlett and Ghoshal 1989; Kotabe 1992]. Relational factors are of particular importance because international sourcing involves the geographic dispersal of the value chain, creating a strong

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The author gratefully acknowledges financial support for this research from the Harvard Business School, Division of Research. The author wishes to thank Professors Louis T. Wells, Therese Flaherty, Ben Gomes-Casseres, the editor of *JIBS*, and four anonymous reviewers for their helpful and constructive comments on earlier drafts. A previous version of this paper was presented at the Academy of International Business, Northeast Region Conference, June 1993.

Received: October 1993; Revised: July, September & October 1994; Accepted: October 1994.

need for integration and coordination. International sourcing is thus consistent with the high-dispersion, high-coordination quadrant of Porter's [1986] typology of strategies.

It has been widely recognized that international sourcing is part of a strategy of global integration and therefore entails high levels of international coordination compared to multidomestic or pure export strategies [Kotabe and Omura 1989; Kotabe 1992; Martinez and Jarillo 1991; Porter 1986; Roth, Schweiger and Morrison 1991]. Several researchers have identified factors that make international dispersion and integration of the value chain particularly difficult, such as technological complexity, product immaturity and high transportation costs [DuBois et al. 1993; Moxon 1973; Swamidass and Kotabe 1993]. Nevertheless, the existing research sheds little light on the fundamental processes and mechanisms that make international sourcing difficult, nor does it examine the relative magnitude of the costs involved. Moreover, existing literature does not allow management much of a role in reducing the costs of international sourcing.

The purpose of this paper is to begin to construct and test empirically a conceptual framework that relates the costs of international sourcing to the stability of the complex system constituting a firm's supply chain. The configuration and coordination of a supply chain is obviously a broad topic, involving interdependencies among R&D, marketing and production functions, generating substantial flows of goods and technical, market and financial information [Kotabe 1992]. The present paper focuses on flows of goods rather than information in the supply chain, addressing logistical issues such as production scheduling, orders to and deliveries from suppliers, and shipping times. The benefits of international sourcing, such as labor cost savings, are assumed to be known and are not considered here. Where earlier work has examined the impact of both location-specific and relational factors on sourcing patterns, this study emphasizes relational factors and analyzes their impact on costs rather than on sourcing patterns. The study also probes how these relational factors change as a product matures.

The research examined the international value chain of a personal computer manufacturer called CCT.[2] Costs and lead times for products sourced from Singapore for the U.S. market were compared with those for similar products sourced locally in California for the same market. The quantitative data were supplemented with a series of interviews to collect more qualitative information. A simulation model of the company's supply chain was developed using these data; the model was used to examine the impact of distance on indicators of supply chain performance such as demand fulfillment and inventory levels.

The paper develops a conceptual and empirical model in which disruptions to the supply chain interact with distance to generate substantial costs. The disruptions are primarily caused by unstable demand, defective and late deliveries from suppliers, and internal production problems. The results demonstrate the extent of the costs and how they can exceed management expectations. Finally, the study suggests ways in which management can control the costs of international sourcing.

BACKGROUND

Contradictory views exist concerning the overall costs and benefits of international sourcing. Many writers point to technological and organizational advances that have reduced the cost and increased the speed of transportation and communication, thereby facilitating international sourcing (e.g., Antonelli [1984]; Reich [1991]). In addition to the obvious benefits of access to cheap labor or specialized resources, Kogut [1985] and Flaherty [1986] argue that the operation of an international but tightly integrated production system gives a firm valuable flexibility through the potential for dual sourcing and shifting production in response to cost and demand changes. Venkatesan [1992] argues that outsourcing of non-critical commodity components enables a firm to focus resources on aspects of the product that are key to competitive success. The beneficial role of international sourcing in competitive strategy has been supported in empirical work by Kotabe [1989, 1990] and Kotabe and Swan [1994], who found that offshore sourcing was positively correlated to both global market share and to the propensity to innovate.[3]

The alternative view is that distance remains a significant barrier to conducting business and that the costs of international sourcing are often underestimated. According to Morgan and Sayer [1988: 7],

> It matters to buyers of computer systems that service engineers are close at hand ... and that areas of cheap labour may be distant from the richest markets and from R&D centres, and so on. Improvements in transport and communications technology may have reduced the barriers of distance, but in many activities face-to-face contact is still felt to be important.

Markides and Berg [1988] assert that offshore sourcing not only raises the cost of inventories, transportation, and administration, but also leads to a loss of economies of scale, lower quality, longer lead times, and the "freezing" of current technology. A number of industry-directed publications support the view that firms engaging in offshore sourcing often fail to account for the added costs of international sourcing, particularly intangible costs such as less flexibility and the potential loss of competitiveness in core technologies [Curtin 1987; Davis 1992; McClenahen 1990; NTMA 1987]. A study by the National Tooling and Machining Association estimated that offshore sourcing could add from 24% to 78% to the quoted price, while longer lead times and lower quality could impose further costs which could not be reliably assessed.[4] A number of case studies used for teaching also illustrate the substantial operational problems that international sourcing can generate [Beamish 1988; Mankin and Flaherty 1988; Austin and Aguilar 1986].

Rather than argue over the general costs and benefits of international sourcing, it is probably more useful to identify the relational factors that influence the cost of separating activities on the value chain. Moxon [1973], in a study of sourcing in the electronics industry, observed that:

> Almost all managers said that custom products, products with frequent engineering changes, and products requiring rapid delivery (short lead times) were made in the United States. Anything on which a close liaison

> between sales, production and engineering was required was too difficult to do offshore. A few managers also mentioned that quality requirements were important to consider.

Swamidass and Kotabe [1993] noted that local sourcing offers convenience and flexibility, and several authors have argued that international sourcing is costly for firms attempting to implement lean production systems, because of the difficulty in operating just-in-time production and maintaining close contacts with remote plants and suppliers [DuBois et al. 1993; Hoffman and Kaplinsky 1988; Jones and Womack 1985]. One of the few empirical investigations of relational factors in international sourcing found that high technology products were typically manufactured close to the R&D function; products manufactured close to the market tended to be fashion items with a finite life, industrial products where buyers demanded reliable deliveries and short lead times, or products with a low value-to-weight ratio [DuBois et al. 1993].

Conceptual Framework and Research Questions

A preliminary analysis of CCT's international supply chain was undertaken to help develop an analytical framework that would build on existing literature. This framework was used to develop a number of research questions that were then subject to empirical testing.[5]

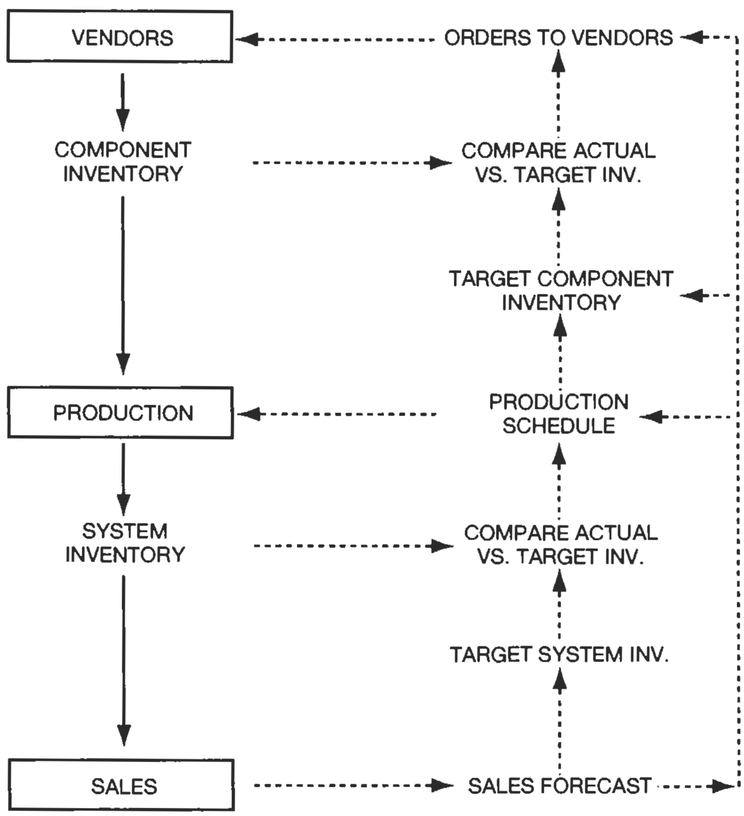
Figure 1 is a simplified representation of a supply chain, showing in schematic form the flows of goods and information. Solid lines represent flows of goods, dotted lines flows of information.

The geographical configuration of a supply chain depends on location-specific and relational factors. Location-specific factors, such as wages and resource availability, determine the optimum location for each activity in the chain when considered in isolation from the rest of the chain. Relational factors influence the cost of integrating activities in the chain and depend on the relationship between one activity and the rest of the chain. The two relational factors examined here are distance between activities and the stability of the linkages that bind them.

The supply chain is traditionally characterized as a stable system in which components and goods move smoothly from suppliers to assembly to customers. By contrast, the analysis of CCT's operations led to a conceptualization of the supply chain as a complex, dynamic system in which each stage of the chain is subject to disruptions, or "shocks". Various sources of disruption can affect the system. Demand fluctuates in an unpredictable way, production problems affect output, and suppliers do not always deliver usable products on time. Senior management can also cause disruptions by taking decisions that are unexpected at the operating level, for example, to discontinue a product or to reduce a price dramatically.

The flows of goods and information that link the supply chain together are also subject to time lags and disruptions, which are a function of the distance between stages of the supply chain and the mode of integration. For example, distance not only increases shipping time but also the possibility of long delays caused by weather, strikes, or customs problems. Time zones, cultural and language differences, and the lack of face-to-face communication can impair flows of information.

FIGURE 1
A Model of CCT's Supply Chain



In this complex, dynamic system, a disruption to one element of the chain generates a sequence of changes and adjustments in other parts of the system [Levy 1994a]. If distances are small, short lead times and good communication should help the supply chain to react quickly to the disruption. If, on the other hand, elements of the supply chain are separated by considerable distances, poor communication and long lead times would make the supply chain much less responsive, generating costs in terms of expedited freight, unfulfilled demand, extra inventory, and managerial time spent "fire-fighting".

The above conceptual framework leads to the following exploratory research question: How do disruptions to an international supply chain interact with time lags in the chain? More specifically, what is the impact of disruptions related to demand, internal production, and supplier deliveries on two measures of supply chain performance, demand fulfillment and inventory levels? The empirical research does not address the role of unexpected managerial decisions in causing disruptions, which was inferred from initial interviews, because of the lack of quantitative data. The impact of international sourcing on communication and control is also not addressed here, but has been discussed elsewhere [Levy 1992, 1994b].

A secondary research question is: Does the level of disruptions to the supply chain decline over time? Vernon's product life cycle (PLC) theory [1966] proposed that U.S. firms would prefer domestic production in the early stages of a product's life in part because specifications and the production process would not yet be stable. As the product matured, its specifications and production process would stabilize, price competition would become more intense, and foreign markets would emerge, all of which would contribute to more international production. Although a positive relationship between product maturity and the degree of international sourcing has been established in several empirical studies [DuBois et al. 1993; Swamidass and Kotabe 1993], there has been little research into the way specific product attributes that make dispersed production difficult change over time.

It is suggested here that the maturation of production takes place at two levels, the industry and the firm. At the industry level, standards emerge, specifications become more standardized, and best practice production processes surface. Individual firms adopt industry practices, have fewer product and process changes to implement, and benefit from a longer learning curve between each change. This research examined whether CCT's internal production problems declined over time. One would also expect the ability of suppliers to deliver acceptable product on time to improve as products matured, but insufficient data were available to examine this.

Given that demand instability was the leading source of disruption to the supply chain, the behavior of demand instability over time was also investigated. Although PLC theory recognizes the role of demand only as it pertains to product specifications, Vernon's earlier work [1960] does discuss the tendency for firms facing rapidly fluctuating demand volumes to cluster near their markets in order to avoid long supply lines. One might expect demand instability to become less disruptive over time as demand growth slows, product specifications become more stable, and managers learn to forecast more accurately.

METHODOLOGY

An intensive study was conducted of the supply chain of a single company in the personal computer industry, CCT. Less detailed interviews were conducted at five other companies in electronics-related industries, and with a number of printed circuit board (PCB) manufacturers, representing the supplier end of the value chain. The case study approach was chosen due to the need for an in-depth understanding of the costs of international sourcing and the lack of appropriate aggregate data at the firm or industry level. In such situations, the case study provides a rich source of qualitative and quantitative data that allow inductive research to be combined with theory testing [Eisenhardt 1989; Parkhe 1993; Yin 1984].

Description of Research Site

In 1990, CCT had three manufacturing sites, in California, Ireland and Singapore. CCT purchased peripheral products such as printers and monitors from outside vendors. These OEM suppliers, as well as CCT's suppliers of bare printed circuit boards (PCBs), were predominantly located in Japan and other Pacific Rim countries. Each plant assembled PCBs from bare boards and electronic components, and then assembled computer systems. Most systems were sourced from two facilities, with the California plant tending to specialize in the newer, higher-end products, while Singapore concentrated more on high volume, lower-end products. Ireland manufactured primarily for Europe, but also served as the second source for some products.

CCT's product line comprised eight basic models, each of which was offered in a variety of configurations. Sales were organized into three regions, the United States with about 55% of revenues, Europe with 30%, and Pacific (i.e., everywhere else) with 15%. Approximately 30% of total revenues were of products manufactured in a different region from which they were sold, indicating a degree of global rationalization.

By most criteria, CCT's performance had been very good in the years preceding this study. Sales had grown at an annual compound rate of more than 27% from 1986 to 1991, with return on equity averaging 31% during this period. This implies that observations about CCT's international supply chain cannot be simply attributed to poor management.

Data Collection

Forty-six CCT employees were interviewed for this study, with interviews lasting from forty-five to ninety minutes. Repeat interviews were conducted with ten people. Some of the interviews were exploratory in nature, but most were semi-structured. The interviewees were at various managerial levels and from a broad span of functions. Quantitative data were collected on CCT's monthly bookings, sales, production, and inventories for each product. In addition, data were taken from internal reports that estimated the full cost of sourcing products. The basic unit of analysis, called a "product-market combination," was a product family assembled in a specific plant and shipped to a specific market.[6] Monthly data were collected for one year on nine different product-market combinations. These data were also used to develop and calibrate a simulation model which enables one to observe the effect of changing one variable while holding others constant.

The Simulation Model

The complexity of interactions along the supply chain is such that one cannot easily predict how the system will operate under various conditions, but a computer model of these processes can simulate the outcome [Lant and Mezias 1990; Morecroft 1984]. Most of the recent supply chain simulation models attempt to find optimal, cost-minimizing solutions using linear or nonlinear programming (e.g., Breitman and Lucas [1987]; Cohen and Lee [1989]; Hodder and Jucker [1985]; Hodder and Dincer [1986]). These models do not, however, deal adequately with uncertainty in a dynamic, multiperiod setting.

The simulation model developed for this study is described in more detail in the Appendix and in Levy [1992]. The model assumes a set of decision rules and linkages among the stages of the supply chain, which are used to determine the production plan, orders to vendors, and other variables each month. Three stages of the supply chain are subject to random fluctuations: demand, production, and deliveries from suppliers. The chain evolves in a dynamic fashion, with the outcome from the previous month serving as the starting point for the next. Each iteration of the model runs for thirty-six months, and the results reported here were calculated as the mean of 100 iterations, by which point results converged. The model was calibrated based on actual data from CCT.

Monthly demand was modelled as the previous month's demand plus a percentage change that was a normally distributed random variable with mean zero. Demand instability was measured as the standard deviation of this variable. CCT's products exhibited demand instability that ranged from .2 to .36, with an average around .28, so this was the range of values used for the simulations. Similarly, production was modelled as the production plan less a percentage that was an exponentially distributed random variable, whose mean represented the level of production instability in CCT. This parameter ranged from .02 to .1. Finally, supplier delivery was modelled as the amount ordered less a randomly distributed percentage. Reflecting CCT's experience, suppliers usually delivered in full, but in some "problem" months deliveries might fall very short. The vendor delivery performance parameter represents overall average order fulfillment by vendors, which ranged from 92% to 98%.

Two output variables were captured to measure performance of the supply chain. Average finished goods inventory levels were expressed in terms of months' sales. Demand fulfillment, CCT's key measure of supply chain performance, was measured by summing the total number of units of demand that could not be met due to inadequate inventory, and dividing this total by total demand.

The effect of distance on shipping times and of different vendor lead times was modelled by using four different versions of the basic model.

	Production available for sale same month	Production available for sale next month
Vendors ship in one month	Version 1 U.S. Assembly/ Responsive Vendors	Version 2 Singapore Assembly/ Responsive Vendors
Vendors ship in two months	Version 3 U.S. Assembly/ Slow Vendors	Version 4 Singapore Assembly/ Slow Vendors

Versions 1 and 3 represent assembly in the United States for the U.S. market, and Versions 2 and 4 represent assembly in Singapore followed by thirty-day sea shipment to the U.S. market. Air shipment of assembled computer systems was considered too expensive to use under normal circumstances. Versions 1 and 2 represent sourcing from responsive vendors who can ship in one month, while Versions 3 and 4 represent sourcing from less responsive vendors who take two months to ship orders. The responsiveness of suppliers was a vendor-specific issue unrelated to location because most components were shipped by air-freight.

While this model presents a very constrained set of choices, it does capture the main options considered by CCT and the trade-offs involved. CCT had also experimented with a more complex supply chain that entailed assembly of PCBs in CCT's Singapore facility, and then air shipment of the PCBs to the U.S. for final assembly of finished systems. CCT considered this configuration too complex to manage effectively, and only used it when PCB capacity was constrained in the U.S. In any event, modelling such a four-stage supply chain was beyond the scope of this study.

FINDINGS

Impact of Disruptions to the Supply Chain

If CCT's supply chain were stable, the incremental cost of international sourcing would have been very low. Table 1 below shows CCT's estimate of the extra costs involved in sourcing computer systems for the U.S. market from CCT's assembly plant in Singapore rather than from California.

TABLE 1
Incremental Cost of Sourcing from Singapore Compared to California, Products Destined for the U.S. Market, with Stable Value Chain (as percentage of Cost of Goods Sold)

Transportation (by sea)	.8%
Inbound Freight and Duty[a]	-2.5%
Inventory Carrying Cost	1.4%
Duty on Finished Goods	4.0%
TOTAL	3.7%

[a] This item is freight and duty on imported components and materials. It is lower for Singapore because many of CCT's suppliers are located in the region.
Source: CCT internal document on supply chain costing for several products

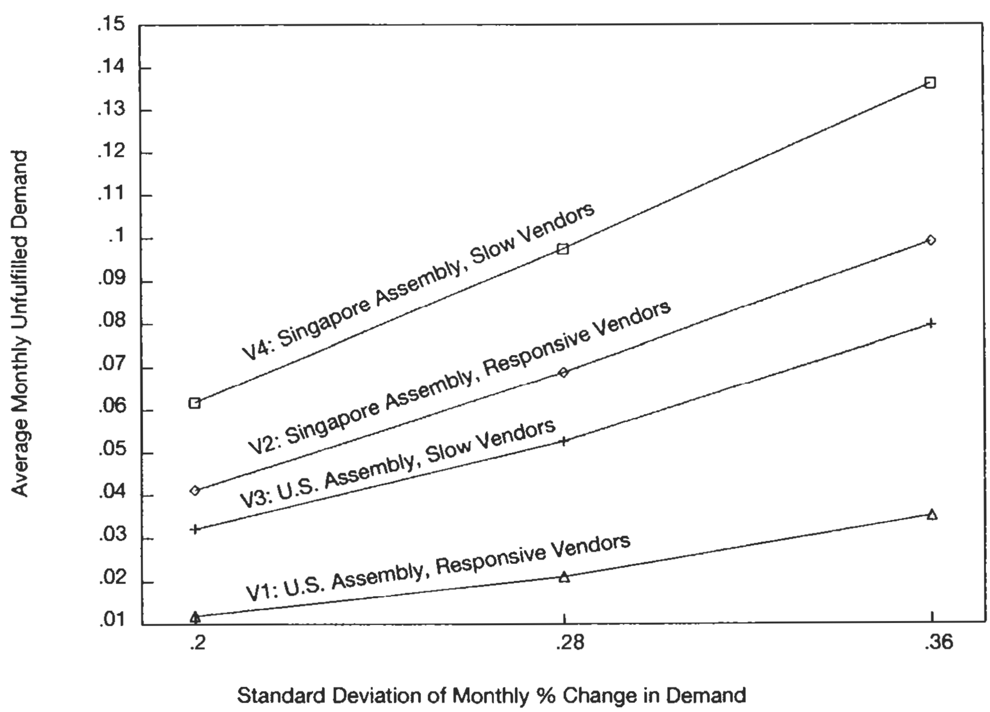
The additional 3.7% cost of sourcing from Singapore was very low compared to the savings available from Singapore's lower wages and overhead, estimated to be about 15% of cost of goods sold (COGS).

In reality, CCT experienced much higher costs than these because the supply chain was not stable. Sharp and unpredictable fluctuations in demand were the most important source of disruption, leading CCT to use air-freight to expedite deliveries when demand exceeded forecasts; while sea-freight from Singapore to the U.S. cost about 1% of COGS for a typical system, air-freight cost about 10%, wiping out much of the cost advantage of Singapore assembly. Nevertheless, CCT managers preferred to incur this cost rather than wait thirty days for sea shipment and lose sales, especially when a new product was being introduced. Managers did not anticipate, however, how difficult it would be to restart sea shipment, because they needed to build up one month's inventory to fill the sea pipeline if deliveries were to continue smoothly. When demand was lower than expected, inventories of finished systems sometimes reached twelve weeks of sales or more, instead of the planned level of two weeks. It was estimated that carrying twelve weeks' inventory would add about 9% to COGS, offsetting more than half the cost savings from offshore production.[7]

Demand-related disruptions to the CCT's supply chain substantially raised the cost of international sourcing. The decision to source from Singapore was made based on the costs given in Table 1, which assumed a stable supply chain. Clearly, an understanding of the cost of operating an international supply chain in the face of demand and other disruptions might have led to a different geographic configuration of production.

The impact of disruptions on the supply chain was further investigated using the simulation model. Figure 2 below shows the simulated impact of demand instability (X-axis) on demand fulfillment (Y-axis) for each of the four versions of the model. Each point on the graph shows the mean outcome of one hundred iterations of a thirty-six-month time period. The level of production instability and vendor delivery performance were held constant at values representing the average for CCT's products. The results illustrate how demand instability raises the proportion of demand unfulfilled for each version of the model; the interaction effect shows itself in the form of a steeper slope for versions of the model representing longer lead and shipping times.

FIGURE 2
Demand Fulfillment and Demand Instability for Different Shipping and Lead Times



The implication of this interaction effect is that, by themselves, neither demand instability nor long shipping and lead times have a substantial detrimental impact on demand fulfillment. Under Version 1 (U.S. assembly/responsive vendors), even products with very unstable demand achieve demand fulfillment better than CCT's target level of 95%. Similarly, if the supply chain were completely stable, demand fulfillment would stay at 100% however long shipping and lead times might be. It is the combination of disruptions and long shipping and lead times that causes problems. Figure 2 shows that if products have above average demand instability (greater than .28), are sourced from Singapore, and vendors are slow (Version 4 of the model), then demand fulfillment falls below 90%, which CCT considered very unsatisfactory.

One approach to estimating the cost of the thirty-day pipeline from Singapore is to estimate, using the simulation model, the extra inventory (expressed in terms of month's sales) required to maintain demand fulfillment at 95%. For products with average demand instability, this incremental inventory was about two months' sales, representing one-month inventory in transit plus a further one month's buffer inventory needed to cope with fluctuating demand and the longer lead time. The cost of these extra inventories was substantial, at about 6% of COGS.

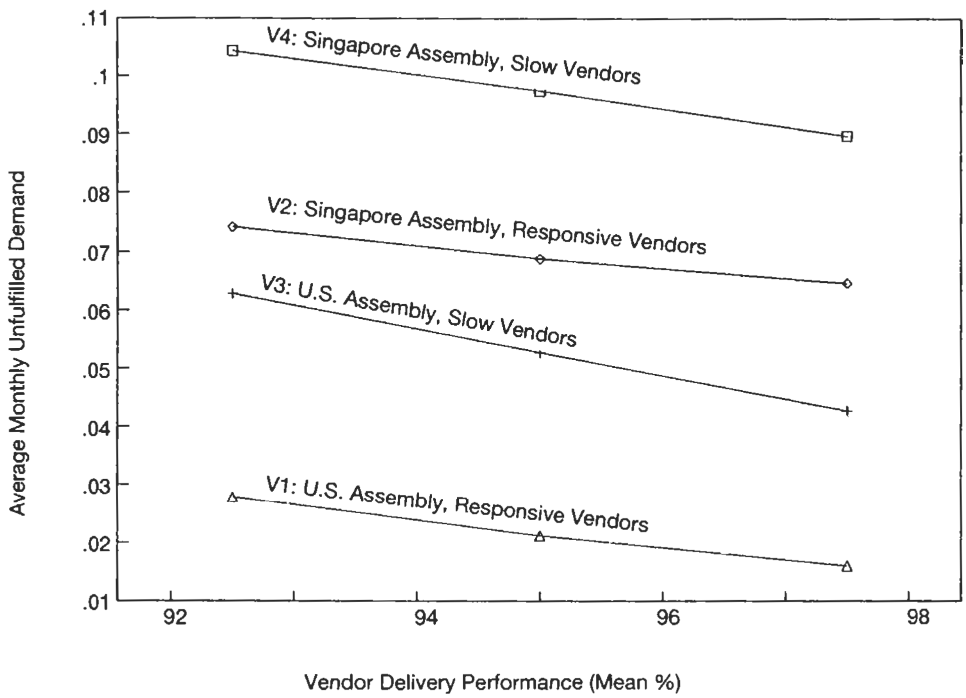
In a similar way, the simulation model was used to examine the impact of disruptions to internal production and to supplier deliveries on demand fulfillment and inventory levels. Both sources of disruption reduced demand fulfillment and increased inventory levels, but to a much lesser degree than demand instability. Figure 3 shows the impact of vendor delivery performance on demand fulfillment; demand fulfillment falls by about two percentage points for unresponsive vendors with two months' lead time, but only by about one percentage point for responsive vendors with one month's lead time.

Disruptions to internal production had very little impact on the supply chain. Varying the production instability parameter from .02 (most stable) to .1 (least stable) resulted in demand fulfillment falling by less than one percentage point. This result is interesting because the existing literature emphasizes unstable production and technology rather than demand as factors that hinder international sourcing. Even CCT's own managers considered technology but not demand stability in sourcing decisions. It should be noted, however, that CCT's products appeared to face unusually volatile demand. Moreover, technical problems did appear to cause substantial communication issues with factories and vendors overseas [Levy 1992, 1994b].

Product Maturity and Disruptions to the Supply Chain

To examine the relationship between supply chain disruptions and product maturity, longitudinal data were analyzed for two sources of disruption, demand and production. The levels of disruptions were compared over two consecutive periods of six months. Product lives in this industry are only about two years, so one year of data covers about half of a product's life.

FIGURE 3
Vendor Performance and Demand Fulfillment for the Four Versions of the Model



Two measures of demand-related disruptions were constructed from CCT's monthly bookings and sales reports. Demand volatility for each product was measured by taking the absolute value of the percentage change in bookings from one month to the next, and then computing the mean over a six-month period. While volatile demand was clearly a problem facing CCT, it was inaccurate sales forecasts that really made it hard to plan production, inventories and orders to vendors. Sales forecast accuracy, therefore, was added as a second measure of demand disruption.[8] The thirty-day sales forecast error was computed by taking the absolute value of the percentage difference between actual dollar bookings and the sales forecast made thirty days prior, and then computing the mean over a six-month period. Table 2 shows both these measures for nine products for the two periods.

In terms of demand volatility, seven of the nine products exhibited a decline in instability, and the mean figure declined slightly. Forecast accuracy, however, only improved for two out of nine products, while the average forecast error for all products increased. Overall, demand-related disruptions do not appear to decline over time. This is a very significant finding because CCT's managers had traditionally followed conventional wisdom and transferred production offshore once they thought production had stabilized. They had not taken other sources of instability into account, even though demand-related disruptions were by far the major source of instability in CCT's international supply chain. This explains, at least in part, why managing CCT's international supply chain was more difficult than expected.

Data on production-related disruptions were gathered from a CCT monthly report on the proportion of scheduled shipments missed for various reasons, for products that were currently being manufactured in California.[9]

TABLE 2
Product Maturity, Demand Stability and Sales Forecast Accuracy

	Demand Volatility (% change monthly)		30 Day Sales Forecast Error	
Product #	1st period	2nd period	1st period	2nd period
1	25.1	18.9	18.1	18.8
2	5.7	22.9	3.7	9.0
3	24.9	23.5	16.2	11.8
4	28.2	18.9	14.5	25.8
5	29.9	17.4	11.0	19.9
6	6.3	21.2	5.7	31.8
7	52.1	24.1	21.8	43.1
8	22.8	17.7	12.0	8.7
9	48.7	47.2	23.6	12.0
Mean	27.1	23.5	14.1	20.1

Source: CCT internal plant data

TABLE 3
Product Maturity and Production Stability
Proportion of Scheduled Shipments Missed for Specified Reasons

Reason for Missing Shipment:	1st period	2nd period
Quality/Specification Problem	6.6%	4.9%
Equipment Problem	8.7%	7.5%
Internal Logistics	2.3%	1.5%
Other Production Problem	12.6%	7.9%
Subtotal	30.2%	21.8%
Planning Problem	1.3%	7.7%
Material Shortage	2.3%	1.5%
Change in Customer Demand	3.1%	.0%
Total	36.8%	30.9%

Data are for six products for fourteen months.
Source: CCT internal plant data

The first four reasons in Table 3 relate most directly to the types of internal production problems expected to decline as products mature, according to PLC theory. The proportion of shipments missed for these four reasons declined by about 28%, falling from 30.2% to 21.8%, suggesting that production did indeed stabilize over time. This improvement was, however, offset in part by a sharp jump in missed shipments due to problems designated as "planning," but for which the precise source was unclear. Despite the decline in production-related problems, the proportion of missed shipments was still considered too high to transfer these products offshore.

CONCLUSIONS AND IMPLICATIONS

The conceptual framework and empirical findings in this paper suggest that disruptions to an international supply chain can generate substantial and unexpected costs when shipping and lead times are long. These costs take the form of expedited shipping, high inventories, and lower demand fulfillment. The sources of disruption can be considered "relational factors" that raise the cost of geographically dispersing value chain activities, and should be distinguished from location-specific factors that pertain to the relative attractiveness of particular locations. Demand-related disruptions were the most important source of instability in CCT's supply chain. Production-related disruptions did not have a severe effect in terms of production shortfalls and demand fulfillment, although they did seem to create a need for significant international communication. Production-related disruptions declined over time, as predicted by PLC theory, although demand-related disruptions did not.

If the findings at CCT are typical, managers will frequently underestimate the costs of international sourcing. Not only are these costs hard to quantify, but they are also difficult to anticipate if managers conceptualize the supply chain as a simple static system rather than a complex dynamic one. Moreover, managers tend to assume that offshore sourcing is feasible once the product and production process have stabilized and may neglect other sources of disruption, such as demand volatility. When crises do arise, managers tend to treat them as one-time events rather than as part of the instability inherent in the chain.

The exploratory nature of this study does not permit the results to be generalized to other firms or industries, but it does suggest directions for future research. We need a much deeper understanding of the difficulties of geographically separating various types of value chain activities. While this study has examined the impact of demand, production, and vendor-related disruptions in one company, we might expect that the cost of integrating an international supply chain depends on the particular product and tasks involved. If certain product attributes make international production difficult, then we need to investigate more thoroughly how these attributes change over time. Perhaps most neglected in the current literature is the potential role of management in improving the performance of international supply chains. More sophisticated simulations could help managers understand the trade-offs entailed in international supply chains and make better decisions concerning facility location, shipping mode, choice of vendors, and inventory levels. Moreover, there is a need to examine ways in which managers can reduce the level of disruptions to the supply chain, thereby decreasing the costs and difficulties of international sourcing.

APPENDIX

The supply chain was simulated using a Lotus spreadsheet model, with columns representing the variables in the system, and rows representing successive months. In order to model the stochastic nature of the supply chain, a simulation package called "Risk" was used, which allows a variety of probability distributions to be assigned to each cell of the spreadsheet. Actual data and decision criteria from CCT were used to determine the structure of the model and the range of values to be used for various parameters. More details of the model can be found in Levy [1992].

Three sets of input parameters were used for the model. The first set represents the level of disruptions affecting demand, supplier deliveries, and production. The "standard" or default values of these parameters were selected to represent typical CCT products. These values were .28 for demand instability, .06 for production instability, and .95 for vendor delivery performance. To give these parameters meaning, production fell short of the plan by 6% on average, while vendors delivered 95% of units on time.

The second set of parameters represents the target levels of system and component inventories. The standard values for these were set at half a month's sales for finished goods, excluding any inventory in transit, and one week's production for components. The third group of input parameters represent lead times for finished goods and for vendors. The main output variables of the system were the levels of system and component inventories and the level of demand fulfillment. Using these parameters, the model simulates a thirty-six month time period. The model begins at time zero with a nominal level of demand and production of one hundred units, but these values evolve over time. The simulation package enables the spreadsheet to be recalculated a specified number of times. On each iteration, the entire thirty-six-month spreadsheet is recalculated with a new set of random numbers. A large number of iterations can thus be used to build up a probability distribution for these output variables and to calculate a mean (expected) value. The results presented here were obtained using one hundred iterations for each simulation; tests with more iterations yielded the same results. Each simulation of one-hundred iterations was run using a different set of input parameters. A list of variables recalculated on a monthly basis is given here.

Variables Recalculated on Monthly Basis for Simulation Model

ACTUAL DEMAND:	Demand for systems each month was equal to the previous month's demand plus a random percentage change.
ACTUAL SALES:	Sales of systems each month were equal to demand unless constrained by lack of inventory.
SALES FORECAST:	The best sales forecast for the next month was the previous month's demand, as no trend was built into demand fluctuations.
ENDING COMP. INV.:	The level of component (or material) inventory each month was the level the previous month plus deliveries from vendors less whatever was consumed in production.
TARGET COMP. INV.:	The target level of component inventory was adjusted each month to equal a proportion of the current sales forecast.
ORDERS TO VENDORS:	Orders to vendors were based on the sales forecast, the production schedule for the following month, and a comparison of actual with target component inventory levels.
DEL. FROM VENDORS:	Deliveries each month equalled orders placed one or two months previously, depending on the version, less a random percentage.
ENDING SYSTEM INV.:	System inventory at the end of each month was equal to the inventory the previous month less sales plus production the same or the previous month, depending on the model version.
TARGET SYSTEM INV.:	The target level of system inventory was adjusted each month to equal a proportion of the current sales forecast.

(continued)

Variables Recalculated on Monthly Basis for Simulation Model (continued)

PRODUCTION PLAN:	The production plan for the following month was based on the sales forecast, adjusted for the difference between actual and planned system inventory.
ACTUAL PRODUCTION:	System production each month was equal to the production plan of the previous month, less a random percentage, and constrained by the availability of material inventory.
UNFUL. DEMAND:	Unfulfilled demand equalled monthly demand less monthly sales.

NOTES

1. The terms value chain and supply chain are used interchangeably in this paper.

2. The name of the company has been disguised.

3. Kotabe and Swan [1994] also found a weak negative relationship between profitability and the degree of international sourcing. They argued that this was because international sourcing was a reaction to declining profits. It is possible, however, that the direction of causation is the reverse, implying that sourcing reduces profitability.

4. The NTMA is an industry association promoting a "buy American" policy, so might be considered somewhat biased. The cited study, however, was conducted by an external consulting firm.

5. This iterative methodology follows procedures recommended for case research by Eisenhardt [1989] and Parkhe [1993].

6. A product family was defined around the microprocessor. Within each family are several configurations with various combinations of memory and disk capacities. Markets were defined at the regional rather than at the country level.

7. The cost of inventory included price depreciation, which was estimated to be 15% annually in the personal computer industry.

8. Although one might expect these two measures to be highly correlated, this was not the case. One reason is that if sales are actually flat but were forecast to increase rapidly, demand volatility will be low but the forecasts will be inaccurate.

9. The report shows the number of shipment lots for each product to which the factory commits itself two days in advance, and the number that are missed for various reasons.

REFERENCES

Antonelli, Cristiano. 1984. Multinational firms, international trade and telecommunications. *Information Economics and Policy,* 1 (4):333-43.

Austin, James & Francis J. Aguilar. 1986. Nike in China. Case No. 9-386-037. Cambridge, Mass.: Harvard Business School.

Bartlett, Christopher A. & Sumantra Ghoshal. 1989. *Managing across borders: The transnational solution.* Boston: Harvard Business School Press.

Beamish, Paul W. 1988. Ikea Canada Ltd. 1986. Case No. 9-88-M010. London, Canada: Western Business School, University of Western Ontario.

Breitman, Robert L. & John M. Lucas. 1987. PLANETS: A modeling system for business planning. *Interfaces,* 17 (1):94-106.

Cohen, Morris A. & Hau L. Lee. 1989. Resource deployment analysis of global manufacturing and distribution networks. *Journal of Manufacturing and Operations Management,* 2:81-104.

Curtin, Frank. T. 1987. Global sourcing: Is it right for your company? *Management Review,* 76 (August):47-49.

Davis, Edward W. 1992. Global sourcing: Have U.S. managers thrown the baby out with the bath water? *Business Horizons*, July-August:58-65.

DuBois, Frank L., Brian Toyne & Michael D. Oliff. 1993. International manufacturing strategies of U.S. multinationals: A conceptual framework based on a four-industry study. *Journal of International Business Studies*, 24 (2):307-33.

Dunning, John H. 1992. *Multinational enterprises and the global economy*. Reading, Mass.: Addison-Wesley.

Eisenhardt, Kathleen M. 1989. Building theories from case study research. *Academy of Management Review*, 14 (4):532-50.

Flaherty, Therese. 1986. Coordinating international manufacturing and technology. In M. Porter, editor, *Competition in global industries*. Boston: Harvard Business School Press.

Hodder, James E. & James V. Jucker. 1985. International plant location under price and exchange rate uncertainty. *Engineering Costs and Production Economics*, 9:225-29.

Hodder, James E. & M. Cemal Dincer. 1986. A multifactor model for international facility location and financing under uncertainty. *Computers and Operations Research*, 13 (5):601-609.

Hoffman, Kurt & Raphael Kaplinsky. 1988. *Driving force*. Boulder, Colo.: Westview.

Jones, David T. & James P. Womack. 1985. Developing countries and the future of the automobile industry. *World Development*, 13 (3):393-407.

Julius, DeAnne. 1990. *Global companies & public policy: the growing challenge of FDI*. Chatham House Papers. London: Pinter/Royal Institute of International Affairs.

Kogut, Bruce. 1985. Designing global strategies: Profiting from operational flexibility. *Sloan Management Review*, Fall, 27-38.

Kotabe, Masaaki. 1989. "Hollowing-out" of U.S. multinationals and their global competitiveness. *Journal of Business Research*, 19 (August):1-15.

____. 1990. The relationship between offshore sourcing and innovativeness of U.S. multinational firms: An empirical investigation. *Journal of International Business Studies*, 21 (4):623-38.

____. 1992. *Global sourcing strategy*. New York: Quorum.

____ & Glenn S. Omura. 1989. Sourcing strategies of European and Japanese multinationals: A comparison. *Journal of International Business Studies*, 20 (1):113-30.

Kotabe, Masaaki & K. Scott Swan. 1994. Offshore sourcing: Reaction, maturation, and consolidation of U.S. multinationals. *Journal of International Business Studies*, 25 (1):115-40.

Lant, Theresa K. & Stephen J. Mezias. 1990. Managing discontinuous change: A simulation study of organizational learning & entrepreneurship. *Strategic Management Journal*, 11:147-79.

Levy, David L. 1992. *The costs of coordinating international production*. Unpublished DBA Thesis, Harvard Business School.

____. 1994a. Chaos theory and strategy: Theory, application, and managerial implications. *Strategic Management Journal*, 15 (Summer):167-78.

____. 1994b. Lean production as a constraint on globalization. Paper presented at Academy of International Business Conference, November, Boston.

____ & John D. Dunning. 1993. International production and sourcing: Trends and issues. *Science, Technology and Industry Review*, 13 (December):13-59.

Mankin, Eric & Therese Flaherty. 1988. International Sourcing at Intercon. Case #9-688-055. Cambridge, Mass.: Harvard Business School.

Markides, Constantinos C. & Norman Berg. 1988. Manufacturing offshore is bad business. *Harvard Business Review*, September-October:, 113-20.

Martinez, Jon I. & J. Carlos Jarillo. 1991. Coordination demands of international strategies. *Journal of International Business Studies*, 22 (3):429-44.

McClenahen, John S. 1990. Sources of frustration. *Industry Week,* September 1:74-81.

Morecroft, John D. 1984. Strategy support models. *Strategic Management Journal,* 5:215-29.

Morgan, Kevin & Andrew Sayer. 1988. *Microcircuits of capital.* Boulder, Colo.: Westview.

Moxon, Richard W. 1973. *Offshore production in the less developed countries by American electronics companies.* Doctoral dissertation, Harvard Business School.

National Tooling and Machining Association. 1987. *Contracting for machining and tooling: The hidden costs of sourcing abroad.* Ft. Washington, Md.: NTMA.

Parkhe, Arvind. 1993. "Messy" research, methodological predispositions, and theory development in international joint ventures. *Academy of Management Review,* 18 (2):227-68.

Porter, Michael E. 1986. Changing patterns of international competition. *California Management Review,* 28 (2):9-40.

Reich, Robert B. 1991. Who is them? *Harvard Business Review,* March-April: 77-88.

Roth, Kendall, David M. Schweiger & Allen J. Morrison. 1991. Global strategy implementation at the business unit level: Operational capabilities and administrative mechanisms. *Journal of International Business Studies,* 22 (3):369-402.

Swamidass, Paul M. & Masaaki Kotabe. 1993. Component sourcing strategies of multinationals: An empirical study of European and Japanese multinationals. *Journal of International Business Studies,* 24 (1):81-100.

UNCTC. 1991. *World investment report: the Triad in foreign direct investment.* New York: United Nations.

Venkatesan, Ravi. 1992. Strategic sourcing: To make or not to make. *Harvard Business Review,* November-December:98-107.

Vernon, Raymond. 1966. International investment and international trade in the product cycle. *Quarterly Journal of Economics,* 80 (2):190-207.

____. 1960. *Metropolis.* Cambridge, Mass.: Harvard University Press.

Yin, Robert K. 1984. Case study research: Design and methods. Beverly Hills, Calif.: Sage.