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Improving electronics manufacturing supply chain agility through outsourcing

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Abstract *The highly competitive electronics manufacturing marketplace demands that suppliers provide low-cost, high-quality products to their customers in a timely fashion. Shortened product life cycles and increasingly global competition have caused traditional manufacturers to focus on their company core competencies, such as product design and development, choosing to outsource the actual manufacturing of their products to contract manufacturers. Although the decision to outsource can have both positive and adverse effects on key areas of the manufacturing supply chain, one positive effect is that the manufacturer's supply chain agility is increased. Outsourcing has caused an increase in the amount of information that is shared between supply chain partners. As a result, a greater reliance on suppliers and alliance partners has become essential for company survival. We examine the ways in which contract manufacturing has increased the agility of the electronics manufacturing supply chain.*

1. Introduction

Electronics manufacturing has accounted for at least 30 percent of the USA's Gross National Product since the Second World War (Landers *et al.*, 1994). Since that time, the importance of electronics manufacturing to the world's economy has continued to grow. For the year 2000, the worldwide semiconductor industry enjoyed sales of US$204 billion (*Semiseek News*, 2001). Dataquest, Inc., a leading semiconductor industry research group, projects this market to reach US$375 billion by 2005 (*Semiconductor Business News*, 2001).

In the past, original equipment manufacturers (OEMs) designed, built, tested, and serviced all of their own products. According to Hassig (1995), OEMs bought equipment that became obsolete quickly, cyclically hired people during economy upswings, and fired these same people during production slumps. The pace of new technology has quickened, making electronics manufacturers reluctant to invest in expensive manufacturing equipment and to hire/fire skilled workers at the first sign of a shift in market direction. As electronics manufacturers realized that they were unable to keep up with every aspect of industrial change, contract manufacturing started to grow.

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Conklin (1994) asserts that no single enterprise in today's global marketplace is able to realize market opportunities in a timely and cost-effective way, mainly due to the lack of solid skills and experience bases. When electronics and contract manufacturers work together to harness the combined knowledge of both parties, the result can be powerful. Calaf (1995) cites an increasing trend of companies choosing to outsource many of their products to other companies that specialize in manufacturing products. Carter and Narasimhan (1996) suggest that outsourcing will be one of the eight most important factors in the future for supply chain management. Lakhal *et al.* (2001) define a superior supply chain as one that maximizes the value of internal activities while developing strong partnerships that lead to high value external activities.

Martin (1999) estimates that the outsourcing of electronics manufacturing through contract manufacturing will continue to grow approximately 25 percent per year for the foreseeable future. Today, a typical integrated device manufacturer outsources approximately 20 percent of its chip production (Smith, 2001). The main factors that support the continuation of this trend include shortened product life cycles, increasingly global competition, cost reductions achieved through large volume procurement of consumables and components, and better utilization of high cost capital infrastructure.

Veeramani and Joshi (1997) define the concept of agility as the ability to respond quickly and effectively to satisfy customers. Manufacturing agility has become a defining characteristic of competition in industry today. Companies must quickly identify, design, manufacture, and deliver products that meet customer desires, while maintaining stringent cost and quality standards. More specifically, greater importance is being placed on agility in terms of producing a broad range of low-cost, high-quality products with short lead times in varying lot sizes, built to individual customer specifications (Narasimhan and Das, 1999).

To be competitive from an agility standpoint, companies must adapt their supply chains efficiently and build strong relationships with customers and suppliers more quickly (Tolone, 2000). A company cannot become agile unless its relationships with the supply chain are also agile. Supply chain agility is a key to inventory reduction, adapting to market variations more efficiently, enabling enterprises to respond to consumer demand more quickly, and integrating with suppliers more effectively.

The agile supply chain is market sensitive – it is capable of reading and responding to real demand. Most organizations are forecast-driven rather than demand-driven. In other words, because they are not market sensitive in terms of actual customer requirements, they tend to make forecasts based upon historical sales data and use those forecasts to determine their inventory requirements (Christopher, 1999). The sharing of information between supply chain partners has become increasingly important as companies focus on their core competencies, choosing to outsource all other activities. In this environment, a greater reliance on suppliers and partners becomes inevitable, and new types of relationships are needed.

There is a growing recognition that individual businesses no longer compete as stand-alone entities but rather as supply chains. Individual businesses that previously competed as stand-alone entities are now aligning themselves in network relationships and competing as supply chains. Organizations that can effectively coordinate and manage relationships with their partners in a network committed to closer and more agile relationships with their final customers should quickly gain the advantage. Emphasis will be placed on leveraging the strengths of network partners to achieve a greater response to marketplace demands (Christopher, 1999).

This paper examines the impact of contract manufacturing in terms of improving electronics manufacturing supply chain agility. The remaining sections of this paper are organized as follows. Section 2 provides a brief introduction to electronics manufacturing and the electronics manufacturing supply chain. Section 3 highlights several ways that contract manufacturing improves electronics manufacturing supply chain agility. We propose a conceptual model for assessing the impacts of contract manufacturing on the agility of the electronics manufacturing supply chain in Section 4. Finally, some conclusions and areas for future research are given in Section 5.

2. Electronics manufacturing

Electronics manufacturing comprises the process of design, development, fabrication, assembly, and testing of electronics parts, tools, technology, components, and systems (Landers *et al.*, 1994). The history of electronics manufacturing can be divided into three eras: vacuum tube era (1920-1950); transistor era (1950-mid-1960s); and integrated circuit era (mid-1960s-present). The evolution of electronics manufacturing occurred with the discovery of better techniques to produce smaller, more reliable electronics components at lower costs. However, the manufacturing process has become more complicated and costly to develop. For example, Kumar (1999) states that an initial investment of US$3.5 million is required to establish a world-class surface mount technology line for circuit board population. Current generation wafer fabrication facilities can cost upwards of US$2 billion. Further, areas of facility support such as process engineering and quality control also come with their own significant costs. As a result, this high price of admission has caused many start-up electronics manufacturers to seek the assistance of contract manufacturers.

Though contract manufacturing began primarily in printed circuit board (PCB) assembly, the significant cost reduction and efficiencies offered by contract manufacturers have led to expanded contract offerings in other areas beyond assembly. Today's contract manufacturers are capable of taking care of almost every aspect of electronics manufacturing. In fact, some contract manufacturers, such as Taiwan Semiconductor Manufacturing Corporation (TSMC), have mastered the latest processing technologies that rival all but the largest electronics manufacturers. Some of the larger players in the contract manufacturing marketplace today include Solectron, Celestica, Flextronics, TSMC, and United Microelectronics Corporation.

Ballou (1999) asserts that a company's products must be in the possession of the customer at the proper place and time that they wish to consume them. Effective management of the electronics manufacturing supply chain is important due to the existence of short product life cycles and the resulting cyclical demand. In addition, the heightened expectations of customers for electronics products have made managing the electronics products supply chain a very challenging task. The increasing use of contract manufacturers has totally altered the electronics manufacturing supply chain in both positive and adverse ways. Although the outsourcing of manufacturing to contract manufacturers typically results in a significant reduction of cost and production time and an increase in supply chain agility, contract manufacturing can also complicate the electronics manufacturing supply chain.

3. Contract manufacturing's impact on the electronics manufacturing supply chain

Contracting or partnering with an external manufacturer involves a significant commitment from a company. This decision is not one that is taken lightly by OEM firms. The firm must know both the benefits and risks of outsourcing in order to outsource intelligently (Vining and Globerman, 1999). Outsourcing production to contract manufacturers can cause changes to the product development process, manufacturing strategy, and labor needs, as well as the loss of market visibility, the ability to manufacture, control of the manufacturing process, the ability to repair, and the ability to monitor the inventory levels of the OEM's products. According to Kumar (1999), OEMs have no direct control or ability to benchmark their own contract manufacturer's product quality, flexibility, and cost management.

More and more in today's high-tech industry, contract manufacturers are being used not only to produce components, but also to design and build entire systems. Contract manufacturers have proven over time that they are able to produce at equivalent or even higher quality levels when compared to OEMs (Carbone, 1999). The reasons for this shift in philosophy are the reduced manufacturing costs associated with contract manufacturing, a new focus on core competencies, and the need for electronics manufacturers to build and integrate agile supply chains into their operations. In today's environment, many OEMs do not consider manufacturing as a core competency (Carbone, 1999). By effectively managing their supply chain and contract manufacturing partnerships, OEMs can secure manufacturing capacity without expensive capital investments.

A typical distribution system in a supply chain consists of a supplier, a manufacturer, and a warehouse (see Figure 1). However, the distribution and assembly system network becomes very complicated if the company decides to outsource some of its system's parts and manufacture the rest in-house. Some examples of different distribution system scenarios under a contract manufacturing partnership are as shown in Figure 1.

The assembly system contained within the supply chain of an electronics manufacturing process will also be altered. The manufacture-versus-outsource decision may be based upon factory capacity constraints during high seasonal demand, unforeseen changes in demand, and/or the proprietary nature of the product(s) to be manufactured. The decision could also be due to technological ability of the company. A company may look to contract manufacturing to increase its supply chain agility without investing capital. A manufacturer must often reformulate its logistics strategy due to the changes caused by contract manufacturing. The following sections focus on the effects of contract manufacturer location, and various transportation, distribution, and warehousing strategies during outsourcing on the electronics manufacturer's supply chain.

3.1 Location

The geographical location of facilities, warehouses, and supplier are the base elements of a logistics network. For an electronics manufacturer, the location of the contract manufacturer is key. Many contract manufacturers set up their organizations in low-cost manufacturing areas. However, OEMs not only look to cut manufacturing costs, but also look to streamline their supply chain. This leads to selecting contract manufacturers not only in low-cost manufacturing locations, but also in locations with strong transportation facilities.

Also, contract manufacturers that are located in close proximity to the company are often selected in order to reduce transportation cost and lead time. Companies can receive significant cost benefits as well as dramatically increase their own supply chain's agility by utilizing a geographically close contract manufacturer (Kumar, 1999). Close proximity can also be important for new and/or complex products that require a high level of interaction between the OEM and the contract manufacturer.

3.2 Transportation, distribution, and warehousing

Transportation is one of the most important elements in the execution of the supply chain. Transportation decisions include modal selection (e.g. rail, truck, air, or water), shipment size, vehicle routing, and scheduling, all of which are directly related to the location of warehouses, customers, and plants. The strategy for distributing outsourced products is also a major concern for companies who employ contract manufacturers. The introduction of contract

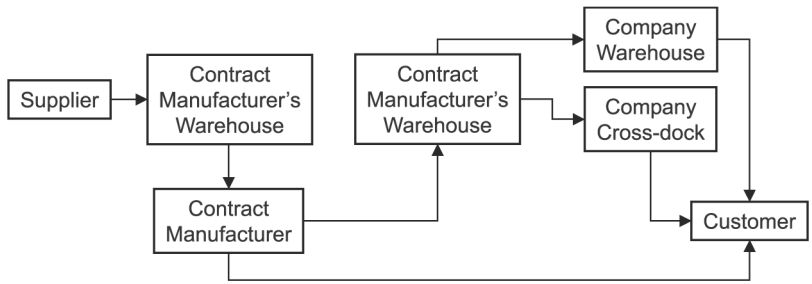

Figure 1.
Potential distribution system scenarios with contract manufacturing

manufacturing into the logistics network can alleviate the need for electronics manufacturers' warehouses, traditionally used for storing both raw material and finished product inventory. There are three main distribution and warehousing options for the OEM who chooses to outsource.

First, the OEM could choose to allow the contract manufacturer to ship products directly to end customers. If the OEM uses a direct shipment strategy, no warehouses are needed, as the finished products will be stored in the contract manufacturer's warehouse. This decision can potentially increase the agility of the OEM's supply chain by reducing both on-hand inventory and lead-time. However, OEMs often receive customer orders that, if shipped directly from the responsible contract manufacturer, would not be large enough to fill an entire trailer. These less-than-full truckload (LTL) shipments sent directly from the contract manufacturer are very costly. Also, manufacturer transportation costs would increase, when compared to simply shipping from one large warehouse, because the manufacturer would have to send more small trucks to more locations. Economies of scale favor large shipment sizes, which lower the transportation cost on a per-unit basis.

A second option for OEMs is to ship finished products from the contract manufacturer to one of their own warehouses or distribution centers. Although the outsourcing of the manufacturing process alleviates the need for raw material warehouses and potentially the need for finished goods storage, some companies prefer contract manufacturers to ship the finished products to their warehouses before they are distributed to customers. This enables the company to monitor the inventory level of finished products. Most companies that deal with low volume orders use lower-rate, full-truckload shipments to ship finished product from the contract manufacturers to intermediate distribution warehouses located near their customers. These warehouses improve supply chain agility by being able to respond more quickly to customer demand.

Finally, electronics manufacturers may choose to employ cross-docking at their warehouses. This strategy is especially useful for companies who have outsourced many different components to numerous contract manufacturers. By setting up a cross-dock facility, an OEM can consolidate components of an entire system without the components ever coming to rest as static inventory in the warehouse. This value-added technique impacts the supply chain in a positive way by minimizing inventory levels and implementing a very flexible "build to order" aspect in the warehouse. However, cross docking requires a fast, responsive transportation system, as all pick-ups and deliveries need to be made within specified time windows. Failure to meet these stringent delivery windows can dramatically reduce a cross-docking warehouse's effectiveness.

3.3 Order processing

Order processing is an important information flow along the logistics network. Information from customers' orders determines the demand for products. Order processing consists of customer order transmittal, order processing and assembly (warehouse), and order delivery. If the warehouse is out of stock, the

process requires transmittal of backorder items, factory time to manufacture and/or supply the product, and express order delivery. When an OEM partners with a contract manufacturer, the customer's order is first transmitted to the OEM, then on to the contract manufacturer. One problem that can occur during order processing is the mismatching of system component quantities.

For example, suppose Acme Computer Company decides to outsource the manufacturing of a monitor to a contract manufacturer. Further, assume the company receives an order of 1,000 computer systems. Even though Acme manufactures 1,000 central processing units (CPUs) and keyboards, the contract manufacturer only ships 500 monitors to Acme's warehouse. Now, Acme can only satisfy 500 customer orders for this situation. Although order batching, a process of collecting orders into batch processes in order to reduce processing cost, could cause this problem, the fact that there is a lead-time associated with getting the product from the contract manufacturer to Acme necessitates more advanced order processing techniques. To avoid such potential problems, electronics manufacturers often share information more frequently with contract manufacturers. By increasing the frequency of information sharing with contract manufacturers, supply chain agility is increased as companies can maintain and/or improve their ability to quickly respond to customer orders and requests. In fact, the explosion of the Internet in business-to-business transactions has led to significant gains in this arena. By implementing electronic order transmission, the electronics manufacturer can sharply reduce production lead-times, add flexibility in order modification, and speed the supply chain.

3.4 Purchasing

The growing acceptance of contract manufacturing has also altered the purchasing policies of many electronics manufacturers. Traditionally, electronics manufacturers purchased raw material and manufactured them into finished products. Outsourcing often eliminates the OEM's need to purchase raw materials. Today, electronics manufacturers must decide which processes should be outsourced, as well as how much of each product to outsource. As a result, electronics manufacturers have somewhat lost their relationship with suppliers.

In the realm of forging strong supply chain relationships, the contract manufacturer selection process has replaced the vendor-selection process. Start-ups and partnership changes with contract manufacturers are expensive and time consuming. Electronics manufacturers need to select the appropriate contract manufacturer and the right quantity of product to be outsourced for every product in their portfolio. The right purchase quantity at the right time will hopefully lead to proper fulfillment of customer requirements. Mistakes made on the selection of a contract manufacturer can be catastrophic, resulting in the loss of customers, market share and, potentially, company reputation. Building the right relationship with the contract manufacturer, one based on shared information and leveraging each other's strengths, can lead to a strong,

agile supply chain for the electronics manufacturer and improved customer satisfaction.

4. Modeling the impacts of contract manufacturing on supply chain agility

Cole *et al.* (2001) present a detailed mathematical model for minimizing the total cost of a logistics network that includes contract manufacturers. Their model is an extension of Wu and Golbasi (1999), which does not explicitly consider contract manufacturing. For extensive surveys on similar models in the literature, see Vidal and Goetschalckx (1997).

The model of Cole *et al.* (2001) is a multi-period, multi-commodity network model with complicating side constraints. It can be used to model the agility implications of dynamic capacity management (hiring/firing of contract manufacturers). Further, the model forms an integral part of an approach to consider agility implications of uncertainty. In words, the model can be described as follows:

Minimize:
Production cost (fixed, "minimum revenue", hire/fire, variable)
+ warehousing cost (fixed, variable)
+ transportation cost (variable)
+ inventory cost (variable)
subject to:
production capacity
warehousing capacity
service requirements (e.g. demand satisfaction).

Although the model is comprehensive, we are most interested in the production features. The cost elements for production comprise both fixed and variable components:

- Variable cost per unit produced.
- Fixed cost: independent of production level.
- "Minimum revenue" fixed cost in which a factory is guaranteed a certain dollar amount of revenue. Variable costs are charged against this fixed cost. Thus, the company pays the higher of the "minimum revenue" or total variable cost. This fee structure is popular among large contract manufacturers because it enables them to better plan their capacity usage.
- Hire/fire cost to open or close a production line.

As for production capacity, contract manufacturers are often modeled as having infinite capacity. The contract manufacturer often is required to produce a predetermined dollar volume of products by the OEM (i.e. "minimum revenue") without the need for the OEM to worry about the contract manufacturer's capacity limitations/issues.

The fixed cost structure and capacity features of the model have an interesting effect. Since both the original manufacturer and the contract manufacturer must allocate fixed costs over the units actually produced, the cost model tends to find extreme solutions in which all products are either produced in-house or outsourced. This is sometimes called the "internal manufacturing death spiral." See Cole *et al.* (2001) for numerical examples. One mitigating factor is that the original manufacturer often must maintain at least some capability for manufacturing prototypes of new designs, or to handle warranty service.

In experiments based on real-world data, inventory costs (especially for work-in-process inventory held over between planning periods) do not play a big role in the final objective value. Due to very high obsolescence costs, it rarely makes sense to keep finished goods or work-in-process from one planning period to the next. This aids modeling because precise estimation of inventory cost parameters is difficult. Similarly, warehousing is not a dominating factor since product is not stored for long periods of time in the fast-changing electronics industry. Since electronics products tend to have high value to size ratios, transportation and warehousing costs are usually a small portion of total logistics costs. Furthermore, transportation and warehousing are relatively easy to obtain for such products; thus transport and warehouse capacities do not drive the model solution.

Service is often the most difficult feature to model in a logistics network. For the agile logistics networks considered in this research, service is defined by fraction of demand satisfied within a certain time. As mentioned before, electronics products become obsolete rapidly. Thus, the time period for demand satisfaction and the production-planning period are set to be approximately equal.

One of the key difficulties in finding the "best" logistics system design using mathematical modeling is that model parameters (demands, costs, capacities) are often subject to uncertainties. Given the ability to design a minimum cost logistics network for a specific scenario, a suggested approach to design an agile logistics network design is as follows:

(1) Develop a number of scenarios with features related to agility (e.g. low demand variability over time, high demand variability over time).

(2) Optimize each scenario separately (i.e. determine minimum cost solutions).

(3) Evaluate each individual scenario optimum against every other scenario.

(4) Evaluate results to determine which designs are "agile". Depending on the company's definition of agile, this can include designs which meet any one of the following (incomplete) list of criteria:

- acceptable performance over a wide range of scenarios;
- results in the minimum expected total costs (based on the likelihood of each scenario);
- produces the minimum probability of a poor result;
- results in the maximum probability of a great result.

Note that no single design will likely meet all criteria. In fact, each criterion might best be satisfied by a different design. In the end, the human decision maker retains a key role in actually deciding which design is "best" for the company.

Conclusions and future work

The introduction and rapid acceptance of outsourcing production to contract manufacturers in electronics manufacturing has altered the electronics manufacturing supply chain. We have discussed the impacts of outsourcing on supply chain agility, such as facility location, customer service, and product distribution. Outsourcing has impacted both capital investment plans and the management cost of the manufacturing process. Future advances in the development of information technology-intensive decision support systems will play an important part in helping to improve the agility of the electronics manufacturing supply chain.

Some areas for future work on the outsourcing in electronics manufacturing problem include developing a better understanding of the "business" side of the contractual agreements with contract manufacturers. For example, how much time is required before the company's products are qualified for production in the contract manufacturer's facility? What is the usual length of a contract with a contract manufacturer? Is there any minimum amount of time in which the company may not terminate their agreement with the contract manufacturer? Finally, who is responsible for insuring the proper subcomponents are on hand at the contract manufacturer's facility so that the specified product mix can be manufactured, the company or the contract manufacturer? Answers to these and other open questions will allow for future model refinements that will foster a better understanding of the importance of contract manufacturing on the electronics manufacturing supply chain.

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