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Abstract: Collaboration between original equipment suppliers (OEMs) and their suppliers can enhance product development. Forces pressing OEMs to collaborate with suppliers are time to market, technology availability, cost pressures, and advanced information technology. OEMs must carefully evaluate which technologies to collaborate on, and be cautious and selective of which suppliers they collaborate with. Collaboration should build competencies and fit product strategies. Leakage of technology must be prevented and project control must be retained by the OEM. The Japanese model of OEM/supplier collaboration in product development uses bureaucratic controls such as targets and prototypes to keep a stable hierarchy of suppliers in line. These can be more successful than pure market competition if implemented properly. The Japanese method provides a balance between maintenance of core competencies and an efficient distribution of tasks amongst a group of tiered suppliers. European and "traditional" US models of collaboration are not as effective. However, the US is becoming more similar to the Japanese in the auto manufacturing industry all the time. A case study of an industrial machinery OEM is presented, describing their evolution in supplier collaboration. Lessons learned from experience, the "best in class" industrial machinery firm, and Japanese auto manufacturers are applied as appropriate to recommend improvements.

OEM/Supplier Collaboration in Product Development

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OEM/SUPPLIER COLLABORATION IN PRODUCT DEVELOPMENT

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ABSTRACT

Collaboration between original equipment suppliers (OEMs) and their suppliers can enhance product development. Forces pressing OEMs to collaborate with suppliers are time to market, technology availability, cost pressures, and advanced information technology. OEMs must carefully evaluate which technologies to collaborate on, and be cautious and selective of which suppliers they collaborate with. Collaboration should build competencies and fit product strategies. Leakage of technology must be prevented and project control must be retained by the OEM. The Japanese model of OEM/supplier collaboration in product development uses beaurocratic controls such as targets and prototypes to keep a stable hierarchy of suppliers in line. These can be more successful than pure market competition if implemented properly. The Japanes method provides a balance between maintenance of core competencies and an efficient distribution of tasks amongst a group of tiered suppliers. European and "traditional" US models of collaboration are not as effective. However, the US is becoming more similar to the Japanese in the auto manufacturing industry all the time. A case study of an industrial machinery OEM is presented, describing their evolution in supplier collaboration. Lessons learned from experience, the "best in class" industrial machinery firm, and Japanese auto manufacturers are applied as appropriate to recommend improvements.

INTRODUCTION

A firm and its system of suppliers form a web of relationships that share risk, capital, and knowledge in the pursuit of creating value for their customers. The crucial process in creating value is product development. Much has been written about the rewards and risks of collaborating in high-technology product development. Much of the attempts to collaborate in these industries have been unsuccessful. However, in relatively mature industries, manufacturing firms can have a much higher success rate in collaborating with their suppliers to develop products if they leverage their technology to provide more value to their customers. With less differentiation between competitor's performance, price and service are the predominant strategic advantages. Keeping prices down and service up requires a product development process which creates high-value, robust products at the lowest possible cost. A more stable product structure allows a more stable network of suppliers to be formed, and structure is the key in successful collaboration.

What forces are driving "stable" manufacturing firms to collaborate with their suppliers in product development? Even if they could, should they? How do they evaluate what development to outsource and what to keep in-house? How should suppliers be chosen for this type of collaboration? What are the risks and pitfalls of collaborative product development? What are some strategies used in the US, Europe and Japan? These are some of the questions this paper will address. In addition, this paper will describe how the leader in the air compressor industry collaborates and tell the story of a local manufacturing company in transition from one model of supplier involvement to another.

FORCES DRIVING OEMs TO COLLABORATE WITH THEIR SUPPLIERS IN PRODUCT DEVELOPMENT

Time to market is the most frequently cited reason in the literature for collaboration of this kind. It goes without saying that product life cycles are reducing all the time, and the effectiveness of an organization to develop new products faster than the competition is a strategic advantage. Much of the Japanese auto manufacturer's advantage in time to market, 3 years vs. 5 for the US in the 1980's, has been attributed to supplier involvement in product development [1],[2]. Essentially, this comes down to the efficiency of an organization to pull together the technical resources to design a manufacturable product. It takes very specific knowledge about processes and products to do this quickly. A supplier who has specialized in a particular system for a long time has these resources.

Supplier technology has become more specialized with the trend toward "core competencies" [3],[4]. Suppliers are aware of the best technologies available in their domain of specialization. It is also too expensive for OEMs to keep completely abreast of all developments in component technology. However, OEMs that "dumb down" and outsource all their expertise can lose control of their suppliers. It is my belief that OEMs should have a high degree of intimate knowledge of the supplier's processes and technology, in order to make partnering efficient and to establish realistic targets. More will be discussed on these topics further in the paper.

Manufacturing cost reduction pressure from increased global competition is driving OEMs to work with their suppliers to reduce costs continuously. Suppliers are the best source for "design for manufacturability" information that aligns the product with the process that creates it [3]. The most efficient partnering needs to be made so that there is no redundancy or overlap, yet no gaps between the OEM and supplier. The benefits of early supplier involvement are likely to be higher when industries move toward maturity, because cost-effectiveness does not depend on major design breakthroughs as much as a myriad of small innovations or process improvements, which are easier for the supplier to make [5].

Development cost reduction can be achieved by having the right people do the right tasks. Instead of having a generalist system design engineer detail a component he has no depth of experience with, wasting much time and rework expense in training him, the supplier's expertise can be used, most of which has been paid for by their own investment or other customers.

Advanced information technology has enabled distributed collaboration where only Collocation could have worked without it. Electronic file transfers and CAD are just the beginning. Recent technologies such as the world wide web allow real-time interaction on a common database from different hardware and software platforms.

SHOULD PRODUCT DEVELOPMENT BE OUTSOURCED TO SUPPLIERS?

Why can't OEMs design and manufacture all components in their assemblies? Transaction Cost Economics (TCE) argues that buying from outside suppliers is fraught with transaction costs. Since suppliers are not owned by the buyer, they can't be trusted to act in the buyer's interest, and will act to exploit the relationship [6]. Adherents to TCE argue that specialization of a supplier's goods to the buyer's assets creates switching costs for the buyer when it changes sources. If the switching costs are high, the firm is vulnerable to opportunistic behavior of the supplier [6]. This provides an incentive for tasks such as product development to be done in-house. Such an analysis would lead risk-averse OEMs to develop all custom components in-house and use competitive bidding and market forces to keep the suppliers in line.

More important than either of these is the OEM's strategy. There needs to be synergy between the organization, its culture and its strategy, or "strategic fit" [7]. Strategies focus organizations on a mission, based on an understanding of the environment they are in.

As discussed above, an analysis of relative costs of manufacturing in-house or not is only part of the answer. If the technology is critical to allowing the OEM to achieve or sustain competitive advantage, and it is not available at the OEM, one author from the computer industry, Nayak, recommends that it should be developed by the OEM rather than purchased [8]. Prahalad and Hamel emphatically state [4, p. 84]:

> "Outsourcing can provide a shortcut to a more competitive product, but it typically contributes little to building the people-embodied skills that are needed to sustain product leadership."

They criticize Chrysler for outsourcing engine design, a core technology, which Honda would never do. However, their article focuses criticism on outsourcing core technology development, not prudent collaborative development. In fact, Chrysler learned its new practices of collaborative development from Honda [9]!

If the technology does not appear to be mature at the OEM, it might be mature in other industries, and is less costly to buy already developed than develop in-house. The following are some times when Nayak recommends a "buy" decision:

1. The technology is of low consequence to your competitive advantage.

2. The supplier has proprietary technology that you need.

3. The supplier's technology is better and/or cheaper than yours - and reasonably easy to integrate.

4. The strategy is based on system design, marketing, and service rather than development and manufacturing. The crucial issue here is whether the supplier will be a future competitor. Critical to success is control of the supply chain.

5. The technology development process requires special expertise not available in-house or swing capacity.

I would add three comments to this perspective. First, the integration issue is critical. The tighter a system is integrated, the more difficult it is to use off-the-shelf technology, and vice versa. For instance, components in laptop computers are almost all developed specifically for the OEM, in contrast to desktop systems that can use interchangeable parts. Similarly, mobile mechanical equipment such as portable generators, compressors or automobiles tend to be more compact and integrated than stationary equipment, and thus the unique part count is higher. This is one way that product structure should drive product strategy, which should drive the partnering strategy. Decisions about whether to make or buy depend on the particulars of the system that the manufacturer produces, not accounting issues separated from product realities.

Second, the "strategic intent" approach should be kept in mind [10]. Depending on the capabilities of the supplier, caution should be exercised in collaborating, since they might gain more from the OEM than vice versa. The higher the capability of the supplier, the higher the risk, but the higher the potential benefit for the OEM. If it is in the OEM's long term strategic vision to dominate a particular technology, this expertise should be learned, and the partnership should be a means to that end. Below is a diagram showing this approach to evaluating the make/buy decision.

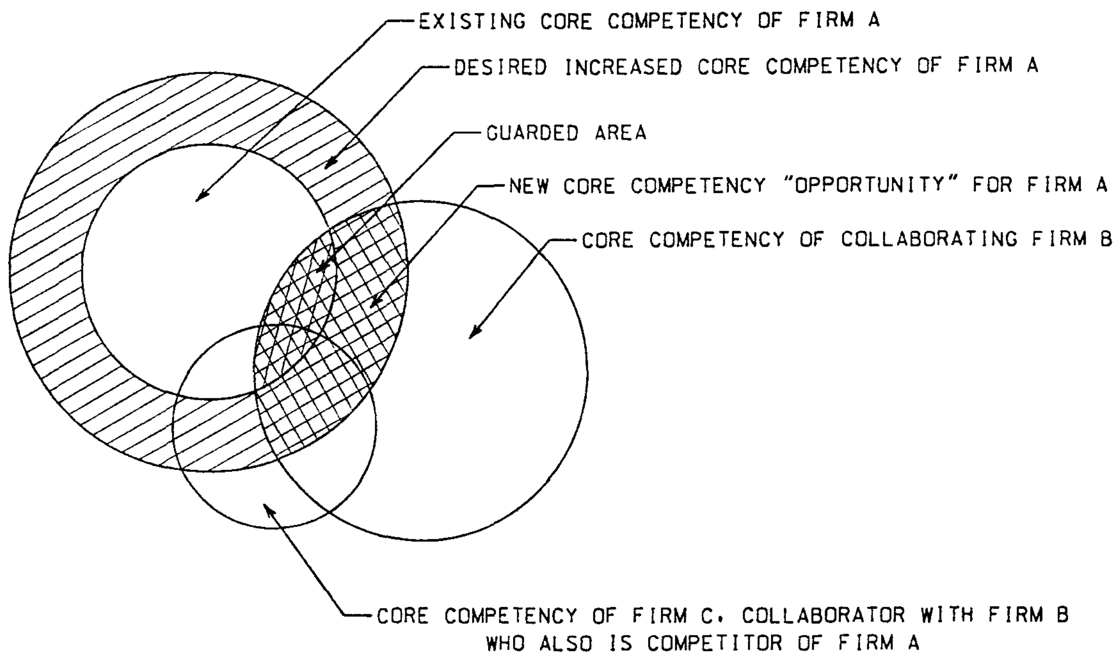

Figure 1. Competency Overlaps in Product Development Collaboration

The "partnership" to develop new technology should be viewed as a strategic learning process. An OEM's competency in the area of strategic intent should be expanding. The area of overlap between the existing competency and the supplier's competency should be guarded to avoid losing critical technology, business process, or marketing information to the supplier. The area of overlap between the OEM's desired competency and the supplier's is the opportunity area or the OEM. Outside the opportunity area it is economically and strategically sound for the OEM to leave product development to the supplier or to buy off-the-shelf components. Note also in the diagram that competitors to the OEM are also "partnering" with the supplier, and knowledge the supplier gains from the OEM needs to be guarded from dissemination to the competitor.

Third, the strategy based on system design can succeed as long as the OEM is relatively small compared to the supplier of critical technology. In the air compressor industry, almost all OEMs manufacture their own bare air compressors, or "air ends" rather than buying them. They optimize them for their packages, and sometimes sell them to other packagers. If one of those packagers gets close to the size of the supplier, they can threaten the supplier with competition for the system business, unless the technology purchased goes in to a different industry than the supplier uses it, or the supplier is geographically remote to the OEM's sales territory.

Not only is the "make/buy" decision critical, but the "design/buy" decision. In an extensive analysis of 29 auto companies, Clark [2] discusses the choice of unique parts designed for the application vs. use of off-the-shelf parts. He also discusses the choice of involving the supplier in the development of the unique parts. The larger the number of unique parts, the higher the quality, due to the parts being designed specifically for the application. However, it costs more to design unique parts than to use existing parts. Designing these parts in-house increases the complexity of the planning process.

An example of this is a recent evaluation in a local manufacturing firm of two heat exchanger supplier's bids on a new product being developed. Both coolers are unique to the application. One supplier included the fan, shroud, fan motor, and motor mount at a competitive cost, but the bare cooler core at a high cost. The other did the reverse. The first was attractive as a system supplier, which was less complex for project management. Scarce design resources could remain focused in a critical area rather than on designing the components that could be supplied with a unique part. It also eliminated a critical path problem with the supplier of fabricated metal.

Clark [2] compares Japanese auto manufacturers (in 1989) to American in the area of the "scope" as defined above. He measures product development resources used, and correlates them with scope. He showed that the Japanese use much higher supplier involvement in "black box" design, and much lower off-the-shelf and re-used parts. Even with this, they still used much fewer engineering hours and took less elapsed time to develop new vehicles. They were able to do this because of the capability of their supplier network. Since he only measured engineering effort at the OEM, it masked the engineering effort that the supplier was performing. There was no discussion about the "shifting of overhead". Suppliers that perform more design will eventually raise their costs.

There is a huge spectrum of OEMs that design and manufacture almost everything in-house to those that manufacture nothing, but just configure, assemble, and test systems. At the one extreme are OEMs like some military aerospace companies, that even design and make their own jigs and tools [11]. They often use reasons such as security or technological risk to keep from outsourcing. At the other extreme are OEMs like Firm A, which design very few components, buy mostly off-the shelf components, and only do assembly and test in their manufacturing process. This will be discussed in more detail later.

HOW SHOULD SUPPLIERS BE SELECTED FOR PRODUCT DEVELOPMENT COLLABORATION?

Not all suppliers can provide the level of service needed to outsource product development, nor are all compatible with the OEM. EDMAR [12] lists the following selection criteria :

1. Design and engineering capability.

2. Willingness to be involved in the design effort.

3. Ability to meet the schedule for the development effort.

4. Research and development capability.

5. Willingness to share cost and technology information.

6. Cultural compatibility with the OEM.

7. Willingness to collocate design/engineering personnel.

LeDuc adds another critical characteristic of a supplier that is necessary. In speaking of the automobile OEMs, they are looking for system integrators who assume considerable responsibility for integrating components into a vehicle [13]. They are moving toward the

"Japanese model" of giving top tier system suppliers "black box" specifications and giving them freedom to design the best system to meet those specifications. This might sound simple for those who are familiar with less integrated systems, a building or power plant for instance. However, in an extremely tightly integrated system such as an automobile, every part directly interfaces with many other parts, and changes in one can easily affect the others. The best system integrators are held accountable to interface with the other inter-relating parts or system suppliers them selves.

Early supplier involvement in product development tends to favor "full-service" suppliers, according to a 1991 Purchasing article [14]. They give the example of how Ingersoll-Rand, the largest domestic air compressor and air tool OEM, chose Phillips Plastic to mold the housing for their new generation of air grinders. The supplier provided "excellent design services" in addition to the ability to provide quality moldings.

A reduced supplier base is key to increasing quality, increasing speed and reducing costs. Only the top "tier" are appropriate for the OEM to collaboratively develop products with. In the Mustang project, Ford reduced the number of electronics suppliers for the platform from 300 to 200 [15]. The suppliers were chosen by both engineering and purchasing together, before the design work had commenced. The suppliers were virtually guaranteed the business for the life cycle of the platform. Competitive bidding was completely eliminated.

Therefore, the lowest price is not the only selection criteria, as is most often used. The traditional arms-length, competitive bidding relationship is at the opposite end of the spectrum, while collaborative product development with key suppliers is at the other. This doesn't mean that competitive bidding is "bad" and collaborative product development is "good". There is a place for both, depending on the type of supplier, technology content supplied, and maturity of the product offered.

WHAT ARE THE RISKS AND PITFALLS OF COLLABORATING WITH SUPPLIERS?

If collaboration is so wonderful, why don't all manufacturing companies pursue it? Certainly the perspective of Transaction Cost Economics discussed above, as well as engineering pride and paranoia are a few reasons. However, this paranoia can be based on some real risks. When the supplier is a very capable technology leader, qualifying them to be a good collaboration partner, they also have the highest ability to turn into a competitor. In the case of Firm A, a local air compressor manufacturer, some of its suppliers control the core technology, and actually produce final packages comparable to Firm A's. The only restraints from the supplier turning into a competitor is the positive and profitable relationship they have with Firm A. If the benefits of selling core technology are outweighed by the lost opportunity that could be gained by cutting off supply and turning into a competitor, the relationship would be precarious. In this environment, collaboration is difficult, because both sides risk giving the other knowledge regarding the fringes of the relationship where competition could exist.

The risks of collaboration with suppliers rise as the technology becomes less mature. The structured relationships that exist between OEMs and suppliers in the auto industry, especially Japan, are largely successful due to the slower pace of evolution of the technology. As Kamath and Liker state in the November-December 1994 Harvard Business Review article [16], the conclusions from their research on the auto industry are less relevant to high technology industries. Liker does not elaborate on this, but it is due to product structure and its relationship to business structure. Just as an automobile is a tightly integrated system of sub-systems, all working together for a common purpose, so is the OEM/supplier network web. Since the technology doesn't change quickly and the functional characteristics of each of the subsystems are very well understood, the behavior, processes and cost structure of the suppliers is well-known. Brake system suppliers are highly regulated, and know their place in the hierarchy of the auto "kingdom." It is very unlikely for them to become competitors with the OEM.

In high technology industries, the product structure changes rapidly and the division between subsystems is not well understood. In the same way, the supplier partners change rapidly and are not understood well by the OEM. Small suppliers can quickly grow into large OEMs, and OEMs can shrink into vassals of the new OEMs who are thrust into leadership of the industry they don't understand either. This paper is primarily about supplier/OEM relationships in more mature industries. A good discussion of the risks and failures of high technology collaboration is Littler-Leverick-Bruce's paper about collaboration in the UK information and communications technology industry [17]. The research shows mostly negative results from the collaborations they studied, which has a sample of 106 firms. The primary risks are leakage of a firm's experience and knowledge, reduction in direct control, and additional financial and time costs of managing the collaboration. These risks are also present in more mature industries, although to a lesser degree.

Leakage. According to research cited in EDMAR [18] more than 40% of the respondents indicate their organization's view of confidentiality is a major limiting factor to early supplier participation. The primary leakage in mature industries is through the suppliers and customers. If the supplier does not deliver a large percentage of its capacity to the OEM, or if the OEM has no equity ownership in the supplier, they are less likely to keep confidential information about product development with that supplier from another that they have a larger relationship with. Figure 1 describes this. If the OEMs customers hear about a new development (or rumor of one) from a salesman from a competing OEM, they have very little motivation to keep the rumor quiet. Leaks abound, particularly in the sales and engineering staff. Without "gatekeepers" of information, it is almost impossible to keep product development plans confidential. This is the case in Firm A. They are by nature an open, customer-oriented company, not accustomed to keeping information to themselves that will eventually benefit a customer.

Loss of control. When a supplier invests in product development for a smaller OEM, the risk is that they are more interested in selling the technology to the competition than to them. Therefore, the OEM loses some control on the direction of development, since it isn't being optimized for the OEM's specifications. Also, the risk of enhancing a competitor arises. This risk can be moderated by non-disclosure agreements, but not eliminated. The supplier can sell a slight variant of the technology that is jointly developed to competitors. Larger OEMs have more control over their suppliers, since they have a larger percentage of their business. Control mechanisms will be discussed in the strategy section of this paper.

Additional Costs. Indiscriminately "partnering" with too many suppliers just to imitate the Japanese can lead to increased cost and time, the opposite they were supposed to bring to the product development process. According to Kamath and Liker, if manufacturing managers copy the Japanese models inappropriately, they may involve too many suppliers who add too little value to the design process [16]. In addition, OEMs risk sending the wrong signals to their suppliers and jeopardizing the benefits of shorter development time and reduced cost. Some suppliers might design new components from scratch when it is more appropriate for them to supply off-the-shelf parts [16]. Calling all suppliers "partners" because it is the trendy thing to do can cloud the real meaning of the term. As will be discussed in the following section on the Japanese auto manufacturer's strategy, "partner" is reserved for only a handful of suppliers.

Administrative costs rise due to many reasons. A lack of trust can breed a very formal, highly documented communication pattern that adds much overhead. "Gatekeeper" time is not for free either. These people usually are important people that could use their time for value-added tasks if they weren't monitoring the relationship. Therefore, partnership in product development should be done very selectively, and so that the benefits outweigh the costs.

WHAT STRATEGIES OF COLLABORATIVE PRODUCT DEVELOPMENT ARE USED?

Much discussion has surrounded the strategies of the American and Japanese auto manufacturers. In fact, 11 of the 27 articles cited in this paper are exclusively about those firms. Older articles such as that of Clark [2] seem to stereotype the American manufacturers as having combative, arms-length relationships with their suppliers while the Japanese have friendly, collaborative partnerships with them. Liker cites many other authors that promote this stereotype, but Clark is representative of them. More recent literature shows that the US is not all that different from the Japanese, from Liker and Kamath [6][16]. Liker and Kamath are very knowledgeable of the Asian methodologies, but teach in universities near the "Big 3" and tend to be biased toward the US, while Clark at Harvard seems to favor the Japanese. There also are 3 articles that deal with the European strategies.

THE "JAPANESE MODEL"

Liker and Kamath have by far the best description in the literature about the "Japanese model". They describe a structured relationship between the OEM and various levels of suppliers, each with very distinct roles and responsibilities. The "keiretsu" is a network or family of companies that are linked by long term relationships, contracts, and equity ownership, all feeding a "parent" OEM with products and services to dominate a market area. Many point out that this type of relationship is based on Japanese cultural and historical experiences that are very different than those that shaped US industries and companies and wonder if they can be applied in the US [9]. This network has far fewer companies in it than a typical American OEM and its suppliers number. In this "family", a tier structure exists, somewhat like a feudal hierarchy, with greater serfs and lesser serfs, all bound to the same lord (or Samurai). The first tier suppliers coordinate the work of the second tier, and so on down the structure. This simplifies communication between OEMs and suppliers[16].

Figure 2 summarizes the four roles that Kamath and Liker identified in their study of Japanese auto manufacturers and their suppliers [16, p.158]. These are not formal titles originated in Japan, but the author's definitions based on observation.

Role	Description	Responsibilities During Product Development
Partner (Full Service Provider)	Relationship between equals; supplier has technology, size and global reach.	Entire subsystem. Supplier acts as an arm of the customer and participates from the preconcept stage onward.
Mature (Full-System Supplier)	Customer has superior position; supplier takes major responsibility with close customer guidance.	Complex assembly. Customer provides specifications, then supplier develops system on its own. Supplier may suggest alternatives to customer.
Child	Customer calls the shots, and supplier responds to meet demands.	Simple assembly. Customer specifies design requirements, and supplier executes them.
Contractual	Supplier is used as an extension of customer's manufacturing capability.	Commodity or standard part. Customer gives detailed blueprints or orders from a catalog, and supplier builds.

Figure 2. Four Supplier Roles

Partners Partners top the hierarchy. As stated earlier, only a handful of suppliers fulfill this role. They develop systems based on broad specifications, incorporating the latest developments in technology to provide the best performance at the lowest cost. They work together with the OEM as early as the concept stage. This information sharing is two-way, though. The supplier divulges his costs, process data, internal infrastructure information, and product technology. These are "full service" suppliers, particularly in the technological arena. They invest in technology specifically for their supplier, like purchasing the same CAD/CAM system for quick and easy data interchange. On the other hand, the OEM invests in the supplier. Even if there is no equity ownership, they invest time and money to help the supplier achieve the quality, schedule, and cost targets that the OEM sets down.

Some of these partners rival the OEMs they work with in size. Nippondenso, a partner of Toyota's for a broad range of components, is almost as large as Toyota. However, the size of the company is not the only indicator of influence. The parent company in the keiretsu has power far in excess of its size, due to the control it has over the entire family.

Mature Suppliers Just as the partners do, these suppliers design and manufacture complex systems, but have less influence on design as the partners, due to lower technological capabilities. They influence the specifications to a degree, and provide prototyping and testing services. An OEM might not even re-test the component due to long-term trust.

Child Suppliers With these suppliers, the design of components or systems is joint, between the OEM and the supplier. They have very little influence on the OEM. As discussed earlier, the compactness of the assembly affects the closeness of the relationship between the OEM and supplier. If the "child " is supplying a component like a gearshift lever, it doesn't interface with very many existing components, its development can proceed independently from most of the car. Typically, in these cases there is little need to do intensive product development, because older designs can work well in new assemblies. The OEM just specifies a few key parameters, and the supplier makes the part based on standard designs for that customer and the particular specifications given by the OEM. In an automobile, the gear shift lever would be a good example.

Contractual Suppliers These are the suppliers that are most often seen as the standard for American companies. The OEM does all the product development and sends out detailed specifications for competitive bidding and manufacture by multiple suppliers, without much input from them in the design. If anything, they provide manufacturing process information to help guide the design to be compatible with the manufacturing process. Steel fabricators, circuit board and sheet metal job-shops often are in this role. Also are the suppliers of off-the-shelf commodity parts. Many have characterized American manufacturing companies as treating *all suppliers* this way. Much of that is not true now, but was largely true 10 years ago or more.

Partnering is a relationship of trust, but with control mechanisms. As former President Reagan said often to Russia's Gorbachev in the negotiations for reducing nuclear armaments, "Trust, but verify". The Japanese system of partnering is reinforced with a disciplined method of setting targets and requiring prototypes on a rigorous schedule.

Targets These are clear goals set for the supplier, including performance, cost, and time. The most unique target is the cost target. Cost targets are developed by the OEM in a "budget" methodology that allocates a certain amount of cost to each system and component, so that the entire assembly meets its target cost and profit level. Rather than send out specifications and get blind bids, virtually all Japanese auto manufacturers include a cost target with specifications to meet that guides the supplier in developing the component. Target pricing is a bureaucratic mechanism to control the costs of an outside firm, unlike the "pure market forces" of competition [6]. Some would assert that this cannot be efficiently imposed on an outside firm. However, since the Japanese OEM knows enough about the processes of the supplier to provide realistic targets, and since they are the majority customer for most of the suppliers, they can be successful in controlling costs this way. They also have target price contractual arrangements with the supplier to reduce costs over time, assuming that the increased "learning curve" will increase efficiency, and that the benefits will be passed on to the OEM [5].

Targets are also used to guide the development of components so that less communication and coordination between suppliers is necessary. Well understood and carefully thought-out interfaces between components are part of the targets, allowing multiple suppliers to design parts independent of each other and still allowing the parts to fit together [16]. Thus, they act as a coordinating mechanism as well as a cost control mechanism.

Prototypes The Japanese manufacturers require complete prototypes on a strict schedule as a method of ensuring performance of the supplier. The OEM knows that developing an actual, complete prototype forces the supplier to go through all the steps necessary to develop it, so they don't micromanage the supplier with lots of small milestones. Since it is practically impossible to track the day-to-day progress of a supplier, the OEM uses each prototype delivery as a way of measuring the supplier's progress. This structures the development process and simplifies the management [16].

Prototype evaluations are rigorous. The prototype is installed in a complete assembly, and is tested for compatibility in the assembly, not adherence to a specification that can only be reproduced in a laboratory. If the component or system does not work properly in the system, it does not matter if it meets the specifications. It has to work, period.

Equity ownership According to Liker et al., Japanese OEMs owned an average of 17.5% of sub-system suppliers [6]. Nissan owns an average of 33% of equity shares in 29 of its largest suppliers. This reduces the chance of exploitation by either party. The OEM has considerable control over the behavior of the supplier, but they will be less likely to abuse them because that would reduce their share price. Japanese suppliers are also very dependent on their OEM customers because of the percentage of business they give to them. Over 60% of the average subsystem supplier's business is sold to its largest customer [6].

In addition, the OEM maintains a high level of knowledge about the supplier's technology to maintain control and to make coordination simpler. Japanese OEMs stated that they would only have a difficult time replicating the product development of 39% of the subsystem supplier's effort [6]. They don't outsource the knowledge to control the technology, just the execution based on the knowledge. Suppliers commented that Toyota engineers are knowledgeable enough to engage in meaningful discussions aimed at improving their particular products (4 p.166). One Toyota executive stated it this way, "It is the integration of technology of the supplier that is the basis of the long-term relationship" [16].

This reinforces the observations of Hamel and Prahalad in "Strategic Intent" [10] and "Core Competence" [4]. They show how many Japanese manufacturers had a very long term intent to become leaders in an industry that they were small players in 20 or more years ago. They were intent on capturing the competencies necessary to dominate the key technologies and processes. So "outsourcing" to the Japanese is not so much a subcontracting strategy for optimum short term gain, but a learning method to obtain the necessary technologies to dominate and an efficiency measure to maintain focus on key technologies in house while out-sourcing non-critical ones. However, even in the "non-critical" areas, they largely maintain in-house competencies that match or exceed their suppliers. Non-critical technologies can become critical as time goes on. Small players can grow into giants quickly.

It should be noted that collaboration within a Keiretsu is viewed much different by Japanese manufacturing companies than collaborating with foreign firms, particularly competitors. There is a high degree of trust and control in the "family". The higher risk collaboration outside that circle is the area where the Asian firms learn more than their Western counterparts, and come out stronger.

Concurrent engineering techniques Much has been written about design for manufacturability (DFM), quality function deployment (QFD), cross-functional teams, and other concurrent engineering (CE) techniques. The Japanese manufacturers probably execute on them better than the US and Europe. One area that demonstrates the different execution of CE techniques between them is the underlying paradigm of design. Most Western design techniques are linear, or point-based, according to Liker et al [19]. For instance, design engineers quickly develop a particular design solution – then iterate from that starting point until they get a satisfactory solution. Manufacturing engineers then evaluate whether that design is manufacturable, suggesting incremental changes. The design engineer iterates the design to comply, and so on. The two engineers might be on a "CE team", but not operating in the parallel manner that is the essence of CE.

Japanese CE is more "set based", which is a paradigm that facilitates true parallelism. According to Liker et al., when using a "set-based" approach,

> "...designers explicitly communicate and reason about sets of design alternatives, both at conceptual and parametric levels ... By defining the set of designs under consideration, team members can safely make any decisions within their area as long as they are valid for the entire set of possibilities. In contrast to the point-based methodology, decisions do not need to be changed because of decisions made by others, because decisions merely narrow the set under consideration" [19, pp.165-6].

Instead of picking a clear early winner in the concept design stage, a set-based approach would be to gradually reduce the scope of alternatives as the design progresses. Suppliers who use a set-based product development process produce many prototypes for parallel testing, and build a database of the "solution space". This becomes a valuable resource for later design modifications and product support.

Collocation of supplier engineers at the OEM's facility is a common CE method that the Japanese use. This investment is only possible if a large percentage of the supplier's business is sold to the OEM. In addition, Japanese engineers collocate at the supplier's facility to help them solve production problems and reduce costs.

THE "TRADITIONAL MODEL"

Since the late 1980's US auto-makers have been rapidly adopting many aspects of the "Japanese model". Chrysler is the furthest along in this process, with Ford next, and GM taking up the rear. However, since this was the predominant method until recently, and since many firms still work this way, it is worth discussing.

Contractual suppliers only In this model, suppliers are involved after the design is completed and technical specifications are issued [5]. The design process is a black box for the supplier and the OEM discloses limited information. Suppliers must provide a blind quote and technical specifications. Typically, suppliers had shorter contracts than their Japanese counterparts, and had no guarantee of business beyond the contract.

The author's personal experience in Navy facilities research and development illustrate the inappropriateness of using contractual relationships with suppliers of new technology. It was required to outsource at least 50% of all development, so interfacing with suppliers was a constant effort. Unfortunately, the competitive bidding process was used for all but a few service providers who had "level-of-effort" contracts. A project engineer who was designing a system was forbidden to "sole source", and was required to provide three suppliers for the contract administrator to get bids from and select based on the lowest price only. The contract administrator was in a different location and completely out of touch with the strategy and technology, so the project engineer had to spend an inordinate amount of time writing a specification tight enough to get exactly what he wanted to work properly in the system, but not too tight to appear to be a "sole source" specification. They were encouraged to use "performance specifications" to reduce the potential for sole sourcing that design specifications tend to have. Unfortunately, this technique which can work well with a "partner" was used in competitive bidding, where there is no trust that the supplier will do what is in the interest of the customer or ensure proper interfacing with other suppliers.

Other branches of the Department of the Defense used more collaborative partnering with first tier suppliers, such as military aircraft development, but in the mundane world of facilities development, there was very little partnering. Project engineers who figured out how to use this moribund system for new technology development were promoted. The way they did it was to spend most of their time finding a way around the system. Thus, they tended to lose touch with technology leadership.

Serial engineering process Product development was performed in a serial manner, or "point-based" approach as described above. The classic "throw it over the wall" technique comes from this paradigm, with each function performing work on the design, and the next one modifying it and sending it back. It led to 5 year development cycles in the US auto industry, versus the 3 years in which Honda developed an automobile. This is inherently inefficient, and often it is ineffective in achieving the quality levels required.

Competitive bidding In this paradigm, price, quality and delivery are compared between suppliers constantly, and the best "deal" at the time is taken. This can lead to less loyalty from the supplier and less investment specifically for the OEM. Less investment makes it harder for the supplier to implement cost reduction measures, particularly redesign for manufacturability, so cost can actually go up. Typically, quality is not monitored as closely as price and delivery, so they tend to dominate the supplier's evaluation. Quality can suffer in such an arrangement. Competition, the "essence of the free enterprise system", can actually increase cost and degrade quality, the opposite that many think it naturally does.

RECENT COMPARISONS BETWEEN THE US AND JAPAN IN SUPPLIER INVOLVEMENT

Liker et al. in the 1996 Research Policy paper is probably the most comprehensive comparison of the US and Japan in this area [16]. In summary, they observed that the American auto manufacturers exhibited at least as much supplier involvement in product development as the Japanese. However, the collaborative effort is not executed as well by the US firms. The authors spent much discussion criticizing other authors who promote the older stereotype, rather than explaining why the American firms seemed to have quickly reformed themselves. The other authors, such as Clark, could not all be manufacturing the same stereotype. My observation is that until the 1980's, most US manufacturers had the more competitive "traditional" model, and were shamed into copying the Japanese by all of the authors Liker criticized. These are broad characterizations, though, and there is surely a mixture of both paradigms occurring in the American manufacturing landscape. Below are some of the more interesting contrasts between the US and Japan that Liker pointed out from data in his surveys.

Communication between OEMs and suppliers The US firms communicated significantly more than the Japanese, particularly in the vehicle concept and full production stages. However, frequency of communication doesn't mean quality of communication. The efficiency of the communication was lower, due to the multitude of people that are responsible for different issues located in different facilities, the lack of experience of OEM engineers responsible for communication with the suppliers, and lack of knowledge of OEM engineers about technical product issues.

This points out a critical issue in the comparison of Japanese and US manufacturer's product development. The individual engineers in Japanese firms tend to be more technically knowledgeable than their American counterparts, particularly engineers at the OEM level. This makes a huge impact on the efficiency of product development communication. As mentioned earlier in this paper, detailed knowledge of the supplier's product technology and processes is one of the most powerful sources of cost control that an OEM can have. Possibly this increased depth of knowledge comes from "lifetime employment" in Japan, increasing the depth of knowledge that engineering staff have. This practice can reinforce "institutional knowledge" without vast amounts of written "design rules". The more experienced mentor the less experienced in this context. Much has been written about the end of such employment practices in Japan, but my experience reinforces that by and large, it is still true in manufacturing. The strategic impact of engineering employee longevity needs to be investigated more to raise the awareness of American firms that do not promote loyalty and erode the effectiveness of strategic efforts such as product development.

Target prices Japanese firms used this method more often than US firms.

Prototypes US firms tend to view prototypes as a method to experiment, and throw them together incompletely and not on schedule. Japanese OEMs use prototypes as a coordination mechanism and require complete, almost production-ready prototypes on a strict schedule. For example, US suppliers involved in developing Toyota's new Avalon model met deadlines 47% of the time, while Japanese suppliers did not miss a single deadline [16]. What is not mentioned is the ease of communication that the Japanese OEMs had with their suppliers versus with the US suppliers.

Equity ownership As discussed earlier, Japanese firms own a much larger percentage of their partners than American firms do. There are more automobile manufacturing OEMs in Japan than in the US, and suppliers give a higher percentage of their business to one OEM than in the US. This is due to the more structured relationships between them, partly due to equity ownership.

EUROPEAN SUPPLIER INVOLVEMENT

Prominent writers in the area of collaborative product development are Littler, Leverick and Bruce from Manchester School of Management in the UK [17]. They studied collaborative product development amongst information and computer technology (ICT) products in the UK. In summary, they found that most firms that collaborated were not satisfied with the results. Generally speaking, the cost and time reduction goals that they entered the collaboration to obtain were not met. In fact, the opposite occurred more often. This is not surprising, since the UK is not known for being on the "leading edge" of ICT products. Thus they are less experienced at collaborating in this dynamic arena. It also shows the difficulty of collaboration in areas not well understood. As previously discussed, the newer the technology, the more unpredictable the results of collaboration are.

According to Birou and Fawcett, the cooperative orientation present in European buyer-seller relationships has not been extended to the development of new products [1]. Due to their more sheltered domestic markets, they have not made the shift to include suppliers in product development.

One example from my experience highlights the lack of supplier involvement in UK product development. A UK manufacturer of portable generator sets collaborated with a US manufacturer of industrial air compressors to develop a portable compressor package. They paid the US firm for engineering and building a working prototype. Then they changed many of the key components from the original and went into production. Most of these substitutions caused problems that were very costly to repair. They stubbornly insisted on going their own way even after paying an experienced firm to provide the design originally. I believe this is a result of attempting to internalize skills too early. They didn't realize the real-world operational characteristics of the air compressor, and were too proud to continue the collaboration throughout production and startup of the machines.

Another example of this firm's behavior is in developing the mechanical drive system. Instead of giving basic system specifications to a drive supplier, they actually developed a detailed design of the gear, a commodity item. They insisted on keeping design control in-house when they didn't have the expertise to do so. In my experience, this engineering pride and stubbornness is common amongst machinery manufacturers in Europe. This works against true collaboration, which requires teamwork, trust, and humility.

THE "ADVANCED MODEL"

Bonaccorsi and Lipparini [5] present another model of early supplier involvement in product development that they promote as being superior to both the Japanese and traditional models. They describe dual development of supplier systems without commitment to primary sourcing until the scale-up stage. The aircraft industry uses this approach, particularly the military aircraft. All of the invited suppliers invest in pre-selection development work. Unfortunately, this will not work well for smaller projects with lower volume and low profit margins. Based on my experience, these suppliers with limited resources will be hesitant to do development work if they don't have a good chance at the contract. If they do development, they might not do a thorough enough job. I would question the use of the aircraft industry as an example of the "advanced model." Military aerospace is particularly slow to pick up on the lessons the auto industry has learned about early supplier involvement [11].

However, if potential revenue is high enough to lure suppliers into this type of arrangement, having dual development develops dual sourcing from the beginning. This gives the benefits of early supplier involvement with those of competition. It requires a consistent and sometimes delicate handling of suppliers to keep them interested in continuing development. The "carrot" of potential future business must be dangled continuously.

BEST IN CLASS EXAMPLES, AUTOMOTIVE INDUSTRY

American auto company In the US, Chrysler is acknowledged as the leader in adopting a "Japanese model" of supplier collaboration in product development. In the 1980's, Chrysler was in trouble. Profits were down, quality was down, and their product development time was too long. They determined to make a change and started by benchmarking the Honda Motor

Company [9]. At that time, Chrysler had poor supplier relationships and a functionally-based engineering structure, while Honda had a cross-functional team approach to development. Upon the purchase of American Motors Corporation (AMC) in 1987, they got some first hand experience at the "Japanese model." Due to limited resources, AMC was operating with an integrated team approach, and involved the suppliers heavily in the development process. When Chrysler's chief engineer retired in 1988, Lutz replaced him with AMC's chief engineer, Castaing. He immediately recommended revamping the LH program, which is what they did. That program saved the company.

They adopted most of the strategies discussed in the "Japanese model" section of this paper. In addition, they pre-sourced suppliers before development of a vehicle, permitting many engineering tasks to be carried out simultaneously versus sequentially [9]. To initiate a change in the formerly adversarial relationship between Chrysler and its suppliers, Lutz gathered the top executives from their top 25 suppliers and assured them, "All I want is your brain power, not your margins" [9 p.53]. They previously gave responsibility for separate phases of a project to separate suppliers, such as design by one, manufacture of prototypes by another, and testing by a third. This led to inefficiencies and lack of accountability. The pre-sourced suppliers that were selected had the most advanced engineering and manufacturing capabilities. They adopted a systematic program to entice the suppliers to reduce costs, called Supplier Cost Reduction Effort (SCORE). The savings from SCORE ideas were either split 50/50 or more in favor of Chrysler to boost their performance rating. SCORE annual savings were up to $1.7 billion in 1996 alone! Ford also has recently initiated a 1/3 cash-back program to suppliers who reduce costs [20], but it is not nearly comprehensive a program as Chrysler has.

The main two differences between Chrysler's "keiretsu" and a Japanese one is the lack of equity ownership of the suppliers by Chrysler and the large percentage of executives at the suppliers that formerly worked for their OEM customers (20% Nissan's and Toyota's).

Japanese auto company Toyota has a global reach in collaborative product development, while maintaining core technology control in Japan. They balance centralization for core competency maintenance with distributed development for economy and speed. Engine, under-body, systems, safety systems and basic electronics development are centralized, providing the backbone technology for their unsurpassed and consistent durability. The Avalon team in Georgetown, KY (Toyota Motor Manufacturing USA) was introduced to Toyota's development process, and it was a challenge to meet their high standards [21]. The entire interior was engineered in the US, and intensive teamwork and interaction was necessary to perform the design and manufacturing planning. The entire plant was trained in detail, including the tearing apart and rebuilding of a vehicle six times.

BEST IN CLASS EXAMPLE, INDUSTRIAL AIR COMPRESSOR INDUSTRY

This industry is mature and extremely competitive. Domestically, four to five firms capture the majority of the business, but one dominates them all, Ingersoll-Rand (IR). They are approximately one hundred years old, and have the broadest variety of compressed air equipment available domestically from one firm. They have a good reputation in the portable air compressor market, and are known as the value leaders, although not the technology leaders in terms of raw performance. Based on the commoditized nature of the compressed air industry today, this strategy is appropriate to dominate.

In order to dominate the industry with low cost compressors, IR has learned how to develop products with increased value, but with virtually no increase in price inflation. One portable compressor model sells for only $50 more today than it did 10 years ago [22]! How did they do it?

Concurrent engineering "Simultaneous engineering" was adopted in 1989 in the portable compressor division, including the Boothroyd and Dewhurst design for manufacturing and assembly (DFMA) method, development of detailed specifications, early supplier involvement, CAD/CAM, advanced engineering analysis, rapid prototyping, and a formalized review process and advanced testing techniques. Although most of IR's enhanced product development process was internal to the organization, the supplier's part on the team is critical.

Early supplier involvement (ESI) The following are examples of ESI at IR:

Major suppliers do their own testing and provide process data to IR. This is similar to the Japanese process, but with less emphasis on hard prototypes.

IR worked with Modine to develop a new aftercooler for high discharge temperature, small air compressors. The design was developed by Modine for IR, and they fielded 20 prototypes for evaluation on actual compressors [23]. This is similar to the Japanese process of "exploring the solution space" with multiple prototypes, a set-based approach.

They worked with plastics supplier, a very long lead-time vendor, very early in the design process to develop a plastic motor liner, a complex, high tolerance, demanding application for plastic. LNP Engineering Plastics supplied a high level of engineering service support early in the process [24]. LNP invested in the same CAD/CAM as IR, an expensive proposition. Meetings were held throughout the design process, not just at the end, providing early awareness of process-product interaction. LNP was selected due to their technical capabilities, not their minimum cost, due to the new technology involved. IR brought in the Phillips Plastics, the plastics molder, early in the design process for a new air grinder product. ESI tends to favor "full-service suppliers", according to a buyer at IR. This supplier offered "excellent design services".

Both of these plastics suppliers illustrate the point made earlier in the paper regarding the product structure affecting the business relationships. Plastic moldings are integral to the entire product, completely dimensionally, thermally, vibrationally, etc. linked with the rest of the system. This makes it imperative to link closely with these suppliers, just as the product is linked.

The remainder of this paper will discuss Firm A's progress in collaborative product development. Due to the sensitive nature of the subject and the specificity of the material, it will remain confidential. Conclusions and recommendations are based on the case study, so they are confidential as well.

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