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Company Actors on the Look Out for New Compromises
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VEHICLE MODULARIZATION: CHALLENGES FACING LEVEL-1 SUPPLIERS AND PREREQUISITES FOR ITS IMPLEMENTATION

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VEHICLE MODULARIZATION: WHAT SIGNIFICANCE DOES IT HOLD FOR LEVEL-1 SUPPLIERS?

Since the early 1990s, modularization has become the subject of keen interest in the automotive industry. This may be a managerial trend or the result of extensive research, but it is clear that an increasing number of "bulk" subassemblies are being delivered pre-assembled to manufacturer assembly lines. The principal examples are seats, engines and tanks; more recently we have seen modules for cockpits, front faces, rear trunks and doors. But despite this initial interest, ten years have passed and we are still in the testing phase. Only a very few manufacturers have adopted a modular architecture for their entire product line, or have taken the necessary steps to work with suppliers of modular equipment to acquire the necessary expertise. The goal of our research is to identify, in greater detail, the deeper underlying mechanisms governing the move toward modularization in the automotive industry. We felt it would be more interesting to consider this issue not from the perspective of automobile manufacturers, but rather from that of the suppliers who deliver these modules. The challenges faced by the two groups are different: manufacturers must decide whether to adopt modularization as a design option (Baldwin and Clark, 2002), while suppliers must decide whether to tackle this new market at all or, indeed, whether they have a choice. On what basis will an OEM (original equipment manufacturer) responsible for delivering components or systems decide to establish a presence in the module market?

The methodology that we have used to consider these issues draws on research conducted at a company that we will call Sysmod. Sysmod supplies modules to the automotive industry. From 1998 to 2002, the author was a participant in the creation of Sysmod's modules division, as the manufacturing and purchasing director for the start-up unit developing a front-face module. From this privileged vantage point, we were able to gain a detailed understanding of the decisions with which the company was faced at every step of the process. After a four-year investment in creating the modules division, and despite undeniable commercial success[1], Sysmod's management came to a conclusion that ultimately gave rise to this research: modularization in the automotive industry does not necessarily yield the projected results – "it's more problematic than we expected"[2]. The factor that proved most damaging to the economic model was the issue of profitability. Consequently, we framed the inquiry of our research as follows: given the fact that, for Sysmod, modularization had apparently proven unprofitable, what strategic position should the company take? Should it remain in the module market at any cost? Should it abandon the market, regardless of the risk? Or should it find some sort of middle ground? And what would such a middle ground be? What are the challenges and conditions that level-1 automotive suppliers must meet in order to implement modularization?

Our intention in this research is to provide a functionalist assessment, in that we are attempting to focus on the key causes and variables involved in modularization. We have taken what we consider to be an innovative approach: by using the current literature detailing all the benefits of modularization as our starting point, and by simultaneously defining the specific conditions that govern the adoption of modularization, we have been able to reveal the limits of the model proposed in the current literature and to broaden those limits. We have recreated the four-year history of modularization at our chosen supplier. Our primary hypothesis is that modularization has failed to yield the anticipated rewards not because it is inapplicable to the automobile industry, but because the proper procedure for implementing modularization has not been identified and therefore has not been followed. Like project management, modularization can be beneficial to both manufacturers and OEMs[3] with the adoption of so-called "metarules", which we will define. In this study we will propose a timeless theoretical model for meeting the challenges posed by a modularization strategy. We will also explain the prerequisites for the implementation of this strategy by level-1 suppliers as well as by car manufacturers.

CURRENT RESEARCH ON MODULARIZATION

Definitions:

As Carliss Baldwin has shown (Baldwin and Clark, 2000), the notion of a module has proven helpful in many fields of inquiry, including neurology and psychology, theories of language, artificial intelligence, and so on. Therefore, given the breadth of this research, we must define exactly what we mean by a module and related ideas.

First, let's consider the notion of an architecture. Ulrich (Ulrich, 1995) states that the product's architecture plays a fundamental role in a company's performance, and that any decision to modify this architecture is the result of a decision by management and not simply the company's R&D department. He defines the **architecture** of a product as the assignment of functions to physical components by means of a three-step process: the organization of functional elements, the mapping of these elements to physical components, and the identification of interfaces between these interacting components. This is the definition of architecture that we have adopted for our study. Henderson and Clark (Henderson and Clark, 1990) define **components** as "physically distinct portions of the product that carry out

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1 Sysmod's market share, which was marginal in 1998, had grown to a respectable size by 2002, placing it among the top three manufacturers of front-face modules.

2 J. M. Folz, "New Factory" conference, June 2002.

3 Our finding is that modularization as it is currently practiced allows manufacturers to reduce their costs by transferring these costs to the supplier, but suppliers find it difficult to acquire the compensatory income needed to maintain profitability.

specific functions and are linked to each other through a set of interfaces defined by the product architecture." For example, in automobiles the condenser is a component. When the condenser is connected to an evaporator, a compressor, fluid and tubing, along with their various interfaces, these components perform a function – in this case, they provide air conditioning for the car. If a form of intelligence is added to this set of components – if, to use our example, we add a device for regulating the car's interior temperature by means of sensors, electrical wiring and an electronic board incorporating the appropriate computer program – we have **a system**: in this case, the car's air-conditioning system. Now, in order to define a module, let's stay with this example of the condenser. If we look at the condenser's "neighbours" in the car, we find the cooling radiator, the hood latch, the vehicle's front headlamps, the parts (often metallic) that make up the vehicle chassis, and so forth. Each of these items is a single element among many that combine to perform a function, but each of these functions may be different. The radiator helps to cool the engine, the latch helps to close panels, and the metallic parts help to keep the car rigid and/or absorb energy upon impact. These functions are all quite distinct, and yet they can all be delivered as part of a single, pre-assembled unit. This is referred to as **a module**. Baldwin[4] speaks in this regard of "Physical Modularity", as opposed to "Design Modularity", which would involve the enhancement of each function. For practical reasons I will use the terms component supplier (or OEM), module supplier and systems supplier to refer to any company devoted to the design and delivery of a component, module or system, respectively. Karl Ulrich (Ulrich, 1995) uses the product's architecture to define modules: an architecture is considered modular if there is a one-to-one relationship between the function and the module and if the interfaces are sufficiently distinct that any modification of the component does not entail a redesign of the interface. An important concept that links all these fields is the notion of intra-module interdependence and inter-module independence. With integral architectures, by contrast, there is no such one-to-one mapping, and functions are shared among several components.

Prerequisites for implementing a modular product architecture and opportunities for modular architectures

In the current literature, modularization is generally considered from the standpoint of the principal manufacturer and rarely from that of its direct suppliers. When seen from this perspective, modularization is primarily a design option that includes certain initial prerequisites. If these prerequisites are met, the choice of a modular architecture for a given product opens up new opportunities for the principal manufacturer in terms of strategy, economic output and engineering, both for the product and for the manufacturing process. Modularization also presents some risks. Most of the literature is based on examples taken from manufacturing sectors such as computer hardware and software and microelectronics. The automotive industry presents its own distinct complications, which lead us to assert that modularization is a contingent concept.

Prerequisites for implementing modularization

Starr (Starr, 1965) remarks that the economic significance of choosing a modular architecture lies in the potential new combinations of end products that can be inexpensively manufactured. At the same time, he notes that "the new concept (modularization) will not come into being overnight", thereby highlighting the problems inherent in coordinating the

4 Transcript of an interview given in November 2002 at Harvard University.

process. Both Sanchez (Sanchez and Mahoney, 1996) and Langlois (Langlois, 1997) link product architecture to organizational architecture, and the computer industry's success with modularization can, in their view, be attributed to the one-to-one mapping between product and organization. Coase (Coase, 1937) states that a system of exchanges is effective only if there is a balance between organizational costs for inter-firm transactions and those for transactions within the firm itself. Baldwin (Baldwin, 2002 #41) reiterates this point and shows that modularization is effective only if the product is segmented precisely at that point where the necessary relationship between the firms is the least intense, in terms of both volume and the number of problems to which the relationship gives rise.

Ulrich (Ulrich, 1995) emphasizes the necessary task of defining the "design rules" prior to beginning the design process itself. The product should be segmented in such a way that there is a functional specification for each module and the interfaces are defined beforehand. This work can be conducted using the "black box" tracking system [Clark, 1989 #21]. This entails much more work than an integral architecture, but the principal manufacturer will presumably reap the rewards of this effort in its ability to enhance the product, while its partners will be able to focus on their module without having to renegotiate the interfaces, and as a result work can proceed more quickly[5]. Similarly, Fujimoto (Fujimoto and Clark, 1995) notes that modularization is efficient because it simplifies the links between functions and components.

The tools for meeting these initial conditions have also been studied in the research literature. Researchers at MIT[6] have indicated the methods by which a modular architecture can be obtained. Eppinger (Eppinger, Whitney et al., 1994) has noted that modularity can be incorporated into the design process with the use of a Design Structure Matrix (DSM) and a Task Structure Matrix (TSM) as part of a three-step process for module-based design: the definition of design rules (Baldwin and Clark, 1997), the independent development of the modules, and integration of the system and the test phase.

Will the emergence of modularization reduce the need for coordination? J. Galbraith (Galbraith, 1973) indicated two possible ways in which it could do so: by enhancing the ability of firms to coordinate their activities via high-speed information networks, and by reducing the need for information. He proposed the idea of a "self-contained task", and we can similarly speak of a "self-contained module". At the St. Gobain conference, Baldwin returned to this idea and combined it with the DSMs and TSMs. The design rules should be developed with this in mind – that is, that modularization will reduce the need for coordination and thereby accelerate development.

As indicated in the literature, in order to obtain a high-performance modular architecture, manufacturers must define both preliminary design rules that will allow for one-to-one mapping, thereby reducing the need for coordination among the various companies, and a "plug-and-play" assembly process that is based on precise specifications. The organization must be compatible with the product via a similar one-to-one mapping, without considerable latitude between the modules, and must include a kind of "black box" tracking system within each module.

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[5] Ulrich, K. (1995), "The role of product architecture in the manufacturing firm." Research Policy **24**: 419-440. Ulrich cites this issue on p. 437 ll 28. In most cases, the drawbacks (?) in terms of system design related to modular architecture are offset by gains in product development, set-up costs, etc.

[6] The major contributors cited here are K. Ulrich, D. Whitney, S. Eppinger and, more recently, David Sharman on the use of DSMs and TSMs as tools for segmenting products.

The four benefits of a modular architecture

If these initial conditions are met, the choice of a modular architecture will affect the principal manufacturer's strategy, its economic output, the efficiency of its manufacturing process and the performance of its product.

Strategy of the principal manufacturer

Ulrich (Ulrich, 1995) notes that, given its numerous and profound implications, product architecture can represent a strategic decision for the firm. The latter must decide whether to gamble on this design option, one that it may or may not exercise (Mitchell and Hamilton, 1988; Baldwin and Clark, 1992; Jacquet and Navarre, 2000; Baldwin and Clark, 2002).

The principal manufacturer's economic output

Starr (Starr, 1965) remarks that the economic significance of choosing a modular architecture lies in the potential new combinations of end products that can be inexpensively manufactured. Modularization provides diversity at a lower cost than an integral architecture. For Ulrich (Ulrich, 1995), there are two forces driving the creation of modular design: the need for greater combinability of products coming directly from the production process, and the need to streamline product design. With a modular architecture, the design process can be broken down into discrete tasks that can be performed simultaneously, and the need to reconcile interfaces is reduced. Ulrich addresses the matter of modularization's economic efficiency by citing three factors. First, modularization should lead to more efficient project management. Second, modularization makes it easier to upgrade the product over the course of its life, either by enhancing its performance or by adding optional features. Clark and Baldwin argue that streamlining the design process is necessary in order to accelerate innovation, since each company specializes in its own module. Baldwin (Baldwin and Clark, 2000, pp. 12-13) notes that the choice of a design and a modular architecture will affect how the design can evolve over time. Their study shows that the value of modular architecture lies in six potential operators[7].

New possibilities for the product

Herbert Simon (Simon, 1969) was first in seeking to understand how complex systems should be designed. The concept of the module is central to his thinking, although he is never cited, and his parable of the watchmaker provides an effective illustration of the concept. In Simon's view, the complexity of a system (e.g. the programming language, organization, purpose) can be clarified by establishing a hierarchy: lesser elements act in response to greater elements at each level in the hierarchy. These "lesser" elements are less complex and consequently easier to design.

Another factor in the projected performance of a modular architecture is its capacity for effective "plug-and-play" standardization. If the product breakdown and interfaces are

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7 Splitting (a design and its tasks), Substituting one module for another, Augmenting (adding a new module to the system), Excluding a module from a system, Inverting to create new design rules, and Porting a module to another system.

available prior to the design stage, then theoretically it is easier to make modules interchangeable without affecting the product's other functions.

Finally, with regard to innovation, modularization's major advantage over integral architectures, according to Ulrich & Eppinger (Ulrich and Eppinger, 1999), is its capacity to promote innovation and product flexibility. If performed properly, modularization promotes innovation at two levels – within the module itself, and in the potential for combining different modules.

New possibilities for the process

In the days when customers initially began to call for "product uniqueness", just as batch-based production was getting underway, Starr (Starr, 1965) referred to modularization as a new concept that would place production supervisors at the top levels of the company's operations. He defines modularization as a concept that provides "a newly developing capacity to design and manufacture parts which can be combined in the maximum number of ways". Ulrich (Ulrich, 1995) emphasizes that production flexibility can be obtained more easily through a(n) […]-type product organization than with a production system like that of Toyota. He remarks (p. 429 ll 38) that, "A modular architecture allows for easier differentiation as late in the process as possible, even in the distribution network. This is known as postponement (H. Lee and C. Billington)."

The use of a modular architecture therefore opens up new possibilities for the principal manufacturer, but it also poses new problems.

The potential pitfalls of modularization

The first disadvantage of modular architectures that we should note is that they may not ensure an optimal product cost, given that some functions are duplicated. Consequently, according to Ulrich (Ulrich, 1995), modularization may not be the best option for optimizing the business[8]. Another drawback, highlighted by Henderson and Clark (Henderson and Clark, 1990), is the fact that, with a modular architecture, module designers are effectively insulated from one another; as a result, architectural innovations are all but impossible. The design can then fall into a rut that will be difficult to escape, so-called "path dependency" (Chesbrough and Kusunoki, 1999). Ethiraj and Levinthal (Ethiraj and Levinthal, 2002) share Ulrich's view that too much modularization may prove uneconomic, and argue that a moderate level of product segmentation should yield the best results. Finally, in terms of project expertise, a modular architecture will require more planning and systems expertise at the outset, whereas integral architecture will require more coordination.

Modularization – a contingent concept

It is clear from the research literature that modularization is a contingent concept. The adoption of a modular architecture will have markedly different consequences, depending on your perspective. Three primary variables[9] emerge from the literature: the type of industry, the type of product architecture and the positioning in the supply chain.

8 In economic terms (p. 432): local performance of a component can be optimized by a modular architecture, but global performance characteristics can only be optimized through an integral architecture.

Modularization and the manufacturing sector

Research into modularization in the automotive industry has focused on, among other issues, the rationales guiding manufacturers, and has identified the potential problems that may arise in any attempt to adopt modularization for automobiles. Mari Sako has provided a useful overview of this issue (Sako and Murray, 2001). She identifies three strategies among car manufacturers[10]: modularity in design (MID), modularity in use (MIU) and modularity in production (MIP). We know from Baldwin (Baldwin and Clark, 2000) that modularization arose in the personal computer industry out of a need for compatibility among various models as well as a need for more rapid innovation. In the aviation construction industry, modularization emerged when industry partners began pooling their capital. Clearly, modularization can result from factors that vary from one manufacturing sector to the next. We must be careful with regard to applying conclusions drawn from one industry to another that is entirely different.

Modularization and the product architecture

Daniel E. Whitney of MIT (Whitney, 1996) has compared electronics products (VLSI: Very Large Scale Integration – chips) and complex electrical engineering products. He attempts to explain the basic differences that exist between the two products, in such a way as to show that architectural models cannot be transferred from one to the other. With regard to modularization, he states quite clearly (p. 11) that, "A modular approach works sometimes [in complex electrical engineering systems], but not in systems subjected to severe weight, space, or energy constraints." Fujimoto has provided a macroscopic analysis of the link between modularization and modular architectures: the more open a product's architecture, the more effective modularization will prove to be[11].

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9 Ulrich concludes his paper by raising some major uncertainties that relate directly to our study: How will the existence of a solid supplier base influence a particular type of architecture? Will vertically integrated manufacturers adopt a specific architecture more readily than manufacturers that are not vertically integrated? How will the size and geographic location of a firm determine the use of a particular architecture? Can companies change the product architecture without changing their organization? And if so, what organizational structure will offer the greatest flexibility with regard to product architecture? We will not be addressing all of these questions, but we will consider the main strategies that led these industries to adopt modularization for their products, particularly the specific instance of an OEM participating in the modularization of the automotive industry. We hope to shed some light on some existing uncertainties by proposing a different theoretical model that adds to the current literature.

10 Modularity in design: reduction in complexity resulting from interdependance of design parameters, shorter development lead times through parallel development of modules, and rapid adoption of new technologies by upgrading individual modules separately.

Modularity in use: high product variety by offering consumers the choice of "mix & match" options (or modules) to suit their tastes.

Modularity in production: flexible manufacturing through taking complex and ergonomically difficult tasks off the main assembly line, and by postponement of final assembly to achieve high product variety without increasing production costs.

11 Outline constructed with the assistance of T. Fujimoto at the St. Gobain conference, held in June 2002 in La Défense.

Today, personal cars have so-called integral architectures (larger trucks and buses have different architectures). This means that if the diameter of a wheel is changed, for example, a great number of other factors, including braking, stability, maximum speed, fuel consumption and aerodynamics, will be affected. This would entail discussions with the engineers responsible for each of these functions. In so-called open architectures, each component is "autonomous" and can be altered without affecting the rest of the system.

Architectures:
Modular vs. Integral
Open vs. Closed
(Matrix: T. Fujimoto)

	Integral	**Modular**
Closed	Small cars Motorcycles Games software	Computer mainframes Machine tools
Open		PCs (hardware & software) Bicycles Internet products

A product's architecture plays a fundamental role in any attempt to improve performance through modularization. With an open architecture, modularization is simple so long as the initial prerequisites are met. With an integral architecture, the product's integrity (Fujimoto, 1991) will dictate the level of modularization that can be applied.

Modularization and the supply chain

Baldwin uses the theory of real options (Baldwin and Clark, 2002) to express the potential value to be gained from applying one of the six operators cited previously. Using a four-case typology (p. 288) – Large, Small, Visible, and Hidden – we see that the net value of modularization is strongest for small, hidden modules. The consequences for each supplier's module under Baldwin's typology will differ; the modules will not be handled in the same way. With regard to automobiles, the hidden modules will undoubtedly be standardized, while the visible modules will be different on each vehicle. The economic models associated with each module will certainly differ as well.

Mari Sako (Sako and Murray, 2001) has looked into the connection between modularization and subcontracting. She indicates the possible paths that a manufacturer might follow in switching from an integral architecture to an outsourced modular architecture:

For car manufacturers whose vehicles use an integral architecture, the switch to a modular architecture may [as in (1) above] or may not [as in (3) above] include outsourcing of the module's design and assembly. The question is: Should component suppliers confronting this new product architecture move into these new markets? Do they have a choice?

We will now apply this research to a particular field, that of automotive modularization as seen by a level-1 supplier. We have chosen this example in part because the modularization of an entire object, in this case a personal car, poses specific problems, and we felt it would be interesting to examine this process in detail. In addition, it seems to us that an analysis from the perspective of the OEM will raise new questions that are largely overlooked in the current research, notably with regard to the reconfiguration of the supply chain and the value chain. Finally, my position as a former Sysmod employee has also played a role in our use of this example.

ANALYSIS OF A PROCESS: SYSMOD'S FRONT-FACE MODULE DIVISION

First of all, we will trace the history of Sysmod's "front-face module" division during the years 1998-2002, with a specific emphasis on Sysmod's activities prior to beginning work on these modules. We will then analyze the division's economic profitability, which proved to be the critical factor that led Sysmod to reassess the project on the basis of the research that we are currently conducting.

The origins of the division

Sysmod began its adventure in modularization in 1993 with the hiring of a trainee in the field of industrial design. At the time, Sysmod was producing heat exchangers: radiators, condensers, charge air coolers, oil coolers and so on. Another division of Sysmod was manufacturing front lighting systems, while yet another was manufacturing hood latch mechanisms. Finally, following an outside acquisition, Sysmod was providing electronics components such as ultrasound sensors used for parking assistance systems. The trainee was asked to consider ways in which all of these elements performing separate functions (cooling, lighting, etc.) could be cleverly integrated into a single component. He was also asked to look at technology that could potentially be used to design a central "support" piece to which, eventually, all Sysmod components within a certain parameter could be attached. It should be noted that Sysmod was not a forerunner in this regard, but was following in the path of other firms; one manufacturer and its long-standing supplier were already producing these front-panel subassemblies or modules. Sysmod's aim therefore was to enhance its credibility, not, as in the past, by mastering a particular function, but by mastering the process used to integrate the core components performing these various functions into the car. This was a completely new business for the company to master. Drawing on its research, Sysmod began showing its work to manufacturers, which gradually came to consider the company a credible partner. As a result, in 1996 Sysmod was motivated to submit bids on front-face modules that encompassed not just Sysmod components but other components as well, such as a bumper girder, painted cowls, and tanks for windscreen and headlamp washer fluid. Another problem for Sysmod was that these modules had to be delivered in just-in-time mode[12]. Given the nature of the core components that made up its business, Sysmod had never been exposed to this logistical issue and was forced to acquire the appropriate expertise – here, too, was a new skill that had to be mastered. The company relied on consulting firms to help develop and present its first bids to manufacturers.

In 1997, as the number of contracts put out for tender began to multiply, Sysmod bolstered its research division, assigning two project managers to this new market: one was a veteran of the lighting department with a background in sales, while the other came from the cooling department and had trained in R&D. Their task, for which they were allocated a budget, was to learn about this market and find ways to expand it. They were joined by a three-person design team responsible for designing the modules. In late 1997, Sysmod's lighting division was contacted by a car manufacturer that was coping with a problem of

[12] Delivery in just-in-time mode requires that modules be delivered in the order in which vehicles travel down the assembly line. Manufacturers decide on this order only an hour before the vehicles arrive on the line for assembly; this creates a certain tension all along the supply chain established by the module supplier.

inadequate space in its factory. Sysmod was asked whether it would be willing to deliver a front-face module; the answer was yes. Shortly thereafter, and for similar reasons, Sysmod acquired a second contract in a different country. In terms of volume, these were small projects[13] in which Sysmod was responsible only for assembly and logistics, but they gave the company an opportunity to accelerate its learning curve significantly. The decisive moment that was to usher in a new phase of Sysmod's module operations was an agreement signed on 15 October 1998 with a car manufacturer (following several preliminary contracts) to produce a million front-face units per year, to be delivered to four different countries.

Following the presentation of an economic model to the chairman of the Sysmod group on 21 October 1998, a new division was created on 2 November. This was an essential step in terms of cementing the team's credibility within the Sysmod organization. Each division at Sysmod generated its own income statement, so it became possible to monitor the economic data generated by this new market in detail.

It then became necessary to appoint teams, to acquire expertise and tools, and so on. The division's initial members only just barely managed to hang on until reinforcements arrived in the form of a wave of newly hired long-term[14] trainees with backgrounds in purchasing and manufacturing. During this highly rewarding phase, Sysmod's small teams would use problems encountered in one project to enhance its proposals for the next project; in this way, Sysmod was able to acquire credibility while gaining expertise. It was also thanks to this initial contract that Sysmod gained the necessary credibility, in the eyes of a different manufacturer, to rise from the status of a future level-2 component supplier to that of partner as part of a joint venture with a plastics firm; in the process, Sysmod won a second contract, and then a third as well in 1999.

Finally, some bad news came along with the good when the first contract was terminated. One of the manufacturers decided to retain the front-face module design and assembly operations in its home country, and consequently Sysmod lost 25% of the contract's original volume. Then, after eight months of sustained work by Sysmod's teams at the principal manufacturer, Sysmod refused to commit to a price schedule that it found overly ambitious and was in effect removed from the contract for Europe, which had been the most consistent. The company retained only the Latin American portion of the contract. With regard to the second contract it had won, which gave Sysmod 100% of the international assembly market, the manufacturer, on the basis of Perform or Purchase research[15], reneged on its commitment and withdrew 20% of the contract volume destined for assembly outside Europe.

Three years later, in 2002, these three projects went into production, and Sysmod became one of the top international suppliers of front-face modules. Sysmod's team consisted of about 100 employees, one-third of whom were conducting research into an innovative new front-face module. We will now attempt to assess the overall results at this stage of the project through an analysis of the skills and expertise that Sysmod acquired as its front-face module division gained in strength.

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[13] Between 100 and 150 vehicles per day, compared to over 1,000 per day for high-volume projects.

[14] i.e. six to eight months.

[15] Strong pressure from the directors of local factories was another factor prompting the manufacturer to go back on its initial commitment.

Expertise acquired by Sysmod

We will now attempt to assess the expertise that Sysmod lacked prior to the creation of the front-face module division but had since firmly acquired. This assessment will not be exhaustive, but will focus on six areas: logistical expertise, R&D expertise (products and projects), knowledge of the client's operations, the discovery of internal organizational challenges, the challenges posed by reconfiguration of the supply chain, and the challenges posed by the economic model for the modules.

Logistical expertise

In four years, Sysmod established six advanced manufacturing sites in six different countries, with daily production ranging from 150 front-face modules at the smaller facilities to 1,200 at the larger plants. Specifically, Sysmod had become a credible supplier in terms of its ability to produce modules in just-in-time mode[16]. Such expertise was not revolutionary in the automotive industry, since suppliers delivering a wide range of large-scale components had already been confronted with the problems raised by this system and had generated the necessary skills. But for Sysmod this was a new experience, since the products in its core business were delivered directly from inventory and there had previously been no need for the company to acquire this expertise. Sysmod's lack of experience in 1998 had not prevented the firm from winning a number of contracts. It may be noted that one of the advantages that Sysmod's partner brought to their 1998 joint-venture contract was experience with just-in-time delivery. Sysmod's front-face module division was now self-sufficient in this regard, having acquired an internally developed information system that had already garnered interest outside the Sysmod group.

R&D expertise

As Sysmod undertook the process of learning how to develop modules, a number of new job functions emerged. For example, the firm had not previously employed module architects; these were responsible for the physical incorporation of each component into the module – genuine architectural work that had to be performed in conjunction with the manufacturer.

Since the front-face module division was responsible for defining the interfaces among the components, as well as for jointly defining[17] the interfaces between the car and the module, it needed to learn more about the chassis of a car, not to mention bumper girders and painted cowls[18]. This understanding of new components is still in play today. I think it is important to note here that the division's "naiveté" in this respect was a major factor in its ability to come up with innovative ideas regarding components outside Sysmod's traditional domain. As Brusoni explains (Brusoni and Prencipe, 2001), it appears to be important for companies to extend their scope of expertise beyond the needs of their internal production. Sysmod's teams were now capable of re-segmenting a product in innovative ways to yield new benefits in terms of engineering performance.

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[16] With just-in-time mode operation, the delivery of components must be synchronized with the movement of vehicles along the manufacturer's assembly line. A vehicle assembly schedule is provided to the equipment supplier 90 minutes in advance in the form of a "production film".

[17] A front-face module is created using the joint-development method defined by C. Midler (….).

[18] These components are not part of Sysmod's product range.

Technical challenges

We will cite two major challenges that, based on our observations in the field, have had negative consequences for the value created by the module[19]. These involve conflicts between modules and systems and between modules and standardization.

Modules and systems:

A systems supplier seeks to optimize a particular function, while a module supplier seeks to optimize the placement of components so as to preserve or enhance optimum functional performance. Neither can exist without the other. Given the manner in which manufacturers select module suppliers, this process now occurs sequentially rather than simultaneously: functions are optimized first, followed by the component and module architecture. As a result, when a module supplier wishes to create value by re-evaluating an engineering decision, the systems supplier that made the decision explains that it is too late.

Modules and standardization:

From the standpoint of the OEM, the value- added provided by the module supplier lies in its enhancement of each component's architecture. The manufacturer may also view modularization as a way of making vehicles more standardized (Ulrich, 1995). Component suppliers may therefore look unfavourably on attempts by the manufacturer to standardize components. The hood latch provides a good example, since it applies to virtually every manufacturer in the industry. All carmakers attempt to optimize the cost of this component through volume purchasing. Our observations in the field revealed instances when the cost of interfacing this standard component with the vehicle chassis were three times greater than the cost of the component itself. When this added expenditure is multiplied by a million units annually, it is fair to ask whether the advantage conferred by standardization has been lost.

Knowledge of the client's operations

Sysmod's first task was to rebuild a client-supplier relationship, since its front-face modules were purchased by departments at the manufacturer that differed from those that purchased Sysmod's traditional products. In addition, the company had to undergo a further learning process. Consider our example of the front-face module. On average, this module consists of 30 separate components, from large components like the bumper and the radiator to smaller components like the warning lights and attachments. Most automobile manufacturers structure their operations along functional lines. There is a designer and a purchaser for the cooling function, a designer and a purchaser for the shock absorbers, and so on. Other manufacturing personnel play a significant role as well – architects, for example: there are architects for the area under the engine hood, architects for the external components, et cetera. To our knowledge, even the manufacturers that are most advanced in terms of modularization have not altered their procedures for working with component suppliers on projects (or have made only surface changes in their relationship). As a result, suppliers must coordinate their client's activities – a difficult role to play when the supplier is not integrated into the manufacturer's organization. In practice, this means that an enormous amount of time

[19] By the creation of value, we mean the creation either of new functions that allow the manufacturer to sell the vehicle at a higher price while still paying the supplier, or of solutions that enhance productivity for both the supplier and the manufacturer with regard to a single function.

is required to make decisions. For example, it took over two months for the manufacturer's internal manager in charge of working with the module supplier to sign an agreement regarding a lock because input was required from so many different people. All in all, through its initial experiences in module development, Sysmod gained a much better understanding of how its clients operate.

Moreover, to illustrate the level of contingency at work in module production, we could easily construct a client typology with regard to delegation of responsibility. Sysmod worked with manufacturers that were unwilling to give the firm any responsibility for designing the module, and viewed Sysmod as no more than a logistical firm assembling a product. At the other extreme, Sysmod also worked with manufacturers that called on their OEMs to assume total responsibility for the module's design, the choice of supplier, and the like.

Organizational challenges for the equipment supplier

Over the years, OEMs have adapted their organization so as to establish the most effective relationship with the manufacturer. Most commonly, as at Sysmod, they organized their operations in terms of functional product lines, just as manufacturers do. Therefore, as with manufacturers, a division that is responsible for optimizing a module architecture must establish internal contacts for every function housed within the module under development. In other words, the internal team responsible for developing the modules confronts problems at the internal level that are similar to those that it confronts with the manufacturer. As is the case among manufacturers, cross-departmental ideas rarely survive: either they are rejected on the basis of countervailing policies (systems, standardization, improved cost-effectiveness of one component to the detriment of the system because of profit centre concerns) or they have no internal sponsor because they straddle several divisions.

Reconfiguring the supply chain

Sysmod's teams working in the front-face division necessarily had to learn about and understand the problems raised by each component, but the most difficult problem involved Sysmod's relationship with both its partners in the joint venture and the so-called level-2 suppliers – the battle for position on the value chain. When the lines of authority were not clearly defined by the manufacturer, problems arose that had serious consequences for product quality; moreover, the pace of product innovation slackened, and as a result the financial revenues from the contract were limited[20]. The challenge was to maintain a presumably fruitful position as a level-1 supplier. Although many level-2 suppliers were enjoying considerable success, certain level-1 suppliers for a conventional architecture were unwilling to be "downgraded" to the status of a level-2 supplier by the emergence of a module supplier. In the field, this led to internecine warfare among component suppliers, who lowered their prices (and, consequently, their margins). Companies used various stratagems and were more or less aided and abetted by the manufacturer. Sysmod therefore increased its contacts with its competitors and potential partners in order to gain a better understanding of each

[20] As we will see, the contract's precarious profitability was, in our opinion, directly linked to the degree of innovation in the module that was developed. Without innovation, there could be little profitability.

firm's intentions regarding its strategic positioning. A number of partnerships were concluded over a four-year period with regard to these modules[21].

The challenges of reconfiguring the value chain – the economic model for modules

Although Sysmod rapidly cemented its standing among potential module suppliers and thereby acquired additional revenue, the company's performance led to strong concerns about the actual profitability of this new market. The income statement for the Sysmod division very clearly revealed financial numbers far different from what was expected. The division's payback was considered excessive, the amount of cash tied up in the demand for working capital was considered too high, and so on. We will consider in detail how this profitability came to seem so precarious.

An overly precarious economic model

What happens when we view modularization in terms of a transfer of responsibility – one that has a clear impact on the company's books? Consider the series of decisions that a manufacturer may make before deciding to entrust the assembly process (or more) to a level-1 supplier. At first, everything is conducted internally, at the manufacturer's site. The manufacturer typically cannot break down its accounting in order to determine the precise cost to the company of a particular assembly sequence that would be eliminated by a module. Then the manufacturer decides to have the module assembled elsewhere, away from its main assembly line. This first step allows the firm to assess the number of steps in the assembly line that it no longer has to perform, and also to evaluate the cost of this assembly process, since the assembly will be taking place in a physically defined area by workers whose sole task is to assemble the module. The company can then calculate the direct labour costs involved in assembling the module, the necessary work space, the required number of components in inventory and in use, and the like.

This will prompt the decision to outsource this assembly process to a third party – a level-1 supplier. By agreeing to assemble the module in the manufacturer's stead, the component supplier assumes that it can survive economically on the basis of this business. The manufacturer, meanwhile, which is generally concerned only with its direct costs[22], will make the decision to purchase the assembly process rather than perform the assembly itself, on the assumption that the supplier will agree to a selling price that is equal to or less than the manufacturer's own direct cost.

Why should the component supplier be able to perform this task more efficiently than the manufacturer, whose business is to assemble products? A supplier that agrees to this commitment expects to save money on the salary differential[23], on the assumption that specialization will lead to greater efficiency[24]. In practice, the emergence of numerous

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[21] Examples includes Expert Components, acquired by Venture/Peguform; Hella's joint venture with Behr to construct front-faces, sometimes with the participation of Magna; Kansei's joint-venture with Calsonic to make front-face modules and cockpits; Denso and Magnetti-Marelli; etc.

[22] Direct costs are the only costs that can be isolated in the manufacturer's accounting.

[23] In the automotive industry, for historical reasons and also because of the union presence, manufacturer labour costs exceed those of suppliers, sometimes by as much as 25% in the US, although the figure is lower in Europe.

[24] Component suppliers assume that, since their teams are focusing their work on a limited area, they will be better able to increase productivity – in terms of both assembly and logistics – than the manufacturer.

potential suppliers has largely wiped out this salary differential[25]. Specialization has conferred advantages in some cases, but not on a widespread basis.

Another phenomenon contributes to the equipment supplier's uncertain financial status. Component suppliers believe that by entering the market for modules, they will break free of the commodities market, which is characterized solely by pressures on costs and standardization. In the case of Sysmod and the front-face module, there were more companies entering the module market than were in the initial market for radiators. Component manufacturers back up their potential expertise in module assembly by pointing to their expertise in major functions (e.g. lighting, engine cooling), but at the same time plastics injectors base their credibility on their ability to design structural parts to which any accessory can be attached. Logistics firms are also positioned to enter the module market, citing their expertise in assembly and just-in-time delivery. Even some suppliers of special assembly machinery are positioned to enter this market. In other words, the carmakers themselves have set the terms of the market and the potential competition. Component suppliers may hope to escape the commodities market by investing in the price of admission to the module market[26], but in the end they will find just as many potential competitors there.

Another unpleasant surprise lying in wait for suppliers relates to product strategy. It would seem a simple task for Sysmod to develop a product strategy for a component, even one that is highly technical. Products themselves are not notably affected by the type of manufacturer. For example, every car has a cooling radiator; what differs from one vehicle to the next is the number of calories to be dissipated based on the available flow of cool air.

With modules, the case is different: each product emerges from the manufacturer's design philosophy. For example, one manufacturer may include the engine cooling system and the painted cowl within the scope of the front-face module, while another will have a much narrower concept of the module that includes only the headlamps and excludes the radiator and the cowl. To take a more serious example, some manufacturers may decide that a certain structural part should contribute to the overall rigidity of the chassis and help absorb impact, while for other manufacturers that same part will be used merely to house accessories, without playing any role in the car's structural framework. There are, in other words, as many different products as there are manufacturers, and design philosophies will vary from one brand to the next and from one country to the next (for example, there are different requirements for shock absorbers in Brazil and Europe). In economic terms, this forces the supplier to make a significant investment in design and development that will be difficult to recover through the use of standardization.

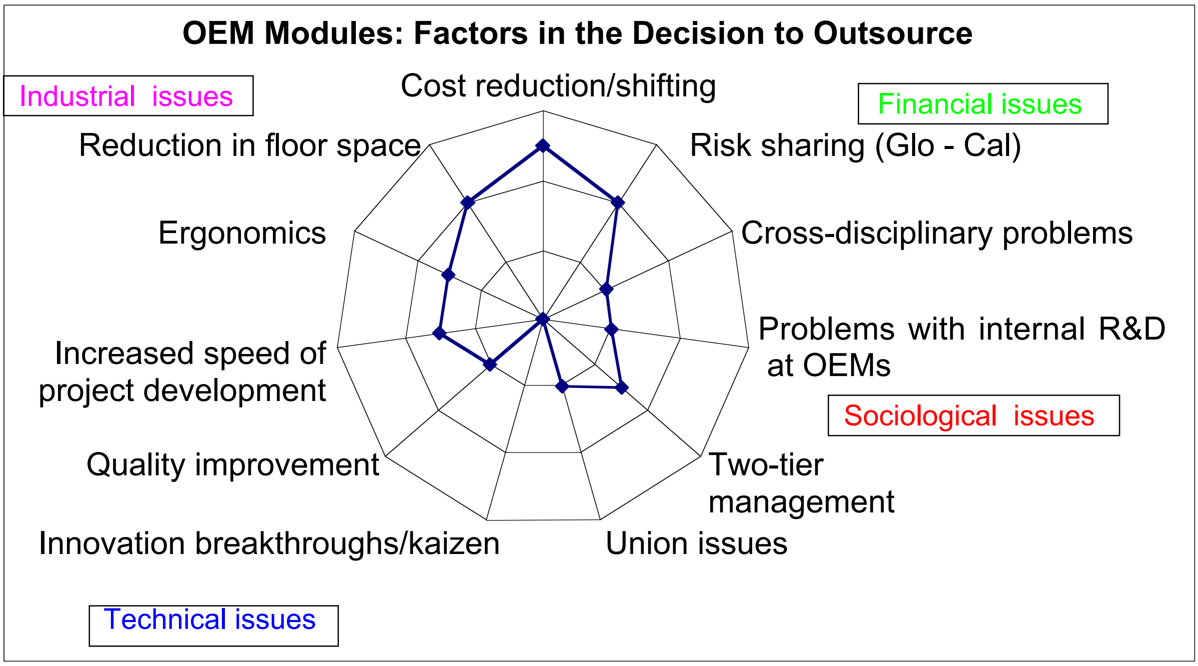
All in all, there is no financial compensation for the margin concessions that have to be made in order to carry out a contract. Apart from potential cost savings that (with luck) will be achieved by protecting and expanding component market share or through specialization, suppliers have assumed that, with regard to the economic model for modules, profitability will result from their ability to redesign the products and thereby generate a source of value to be shared with the manufacturers.

Our observations in the field indicated that, even among those component suppliers who maintain innovative products in reserve that could generate additional profits for both the supplier and the manufacturer, only a few have been able to adapt these innovations to vehicles in mass production. This inability is primarily attributable not just to internal

[25] See the Smart case, for example.

[26] What I call the "price of admission" refers to the financial investment and the investment in human resources required to create module expertise where it did not exist previously.

organizational problems for the manufacturer and the supplier, but also to the fact that module suppliers only become involved at a late stage in the process. We will return to these problems when we describe the prerequisites for implementing our strategic model. As the following graphic shows[27], innovation is not the primary incentive for automobile manufacturers to adopt modular architectures.



Under these circumstances, the component supplier's financial health will worsen, because in order to generate these innovations, the supplier must invest in R&D (human resources, prototypes, testing, and so on). As a result, costs increase even more, without any greater return on investment than is available from an assembly contract.

In other words, suppliers of automotive components gamble to some extent on a putative profitability, but this gamble requires an enormous investment that will eventually weigh heavily on the rate of profitability envisioned at the start of the project. From our observations, we can conclude that modularization in the automotive industry leads to lower profitability for level-1 suppliers.

THEORETICAL LESSONS TO BE DRAWN

Prerequisites for implementing modularization

A study of the literature suggests that, once some specific initial conditions are met, the use of a modular architecture for a complex product should enhance performance in several respects: faster product development, more frequent innovations, easier standardization, simpler coordination and a reduced need for such coordination among the parties involved, and so on.

[27] This graphic was developed on the basis of 35 interviews with managers at Sysmod and other component suppliers that had worked directly with car manufacturers in the field of modules.

The case study we have described here reinforces several points that others have made in the past. First, the design of a car is a very complex exercise in the sense described by Moisdon and Weil (Moisdon and Weil, 1992), given the number of relationships among the participants. In addition, cars are an example of a highly integral architecture – not the most auspicious kind for modularization. Our case study also makes it very clear that the organizational structures we have seen are not at all suited for effective modularization as described by Sanchez and Mahoney (Sanchez and Mahoney, 1996) or Langlois (Langlois 2002). At no time did the manufacturers attempt to create a preliminary product definition and breakdown so as to move ahead more quickly, as recommended in the literature. Both parties to the process were confronting a learning curve (Midler, Garel et al., 1997). For example, the specification was developed as a joint engineering project of the type described by Navarre (Navarre, 1992) as the occasion demanded, contrary to the recommendations made by Ulrich.

Manufacturers continued to select module suppliers via the same process they used to select component suppliers, viewing them as subcontractors rather than as joint developers. For example, since the module suppliers played no role in the process until the later stages, they were deprived of significant leverage in the creation of new architectures[28]. We have not seen any revised product breakdowns in which the finished automobile was identical, in modular design or otherwise.

The move toward modularization in the automotive industry clearly occurred under the most unfavourable conditions possible. Fujimoto (Fujimoto, 2001) seems to suggest that some Japanese manufacturers chose to begin by completely revising the product breakdown within the vehicle to ensure that modularization would be more efficient.

The benefits of modularization

The benefits of modularization from a manufacturer's standpoint are apparent from the literature. Our own observations indicate that modularization can also provide numerous opportunities for component suppliers to expand and transform the market. Nonetheless, it appears that, for the time being in any case, the various strategies that drive OEMs into the module market generally clash with the motivations driving manufacturers. For suppliers, modularization tends to bring an increased financial burden, a higher level of risk-taking, a greater degree of coordination along the supply chain, and so on. It appears that compatible strategies are needed if innovation is to become a motivating factor for manufacturers in the future.

The pitfalls

Car manufacturers have not yet adopted modularization as their dominant design practice for the future, although the use of a range of different suppliers appears to be more and more widespread as a production model[29]. We have therefore not yet reached the stage where the barriers between module designers are preventing architectural innovations (Chesbrough and Kusunoki, 1999).

[28] E.g. in the creation of a style, in the selection of level-2 suppliers, in the identification of products to be included, and so on.

[29] See the GERPISA conference and research, June 2002

Another pitfall for component suppliers is the tendency to give short shrift to this idea of contingency, which may lead them to create excessively large design teams when in fact they have no freedom to generate adequate value and finance their own efforts; or they may be misled by false notions about a platform[30] and assume that one team will be sufficient to develop the module when in fact they need three.

The primary pitfall, in my view, arises from this (possibly short-term) incompatibility between the manufacturer's strategy and that of its supplier. Manufacturers have been aiming not just to reduce their costs but to transfer their costs. In 1991, Ford announced that it would be the first manufacturer without any manufacturing plant of its own. Modularization is one way of initiating a large-scale transfer of expenses from the balance sheet to the income statement. Car manufacturers were not moved to adopt modularization out of a desire for innovation or shorter design timeframes. So it is fair to ask whether modularization really does generate added value, apart from the transfer of cash and risk from the manufacturer to the supplier, possibly at the cost of the latter's existence. These observations prompt several fundamental questions[31] that I believe must be urgently addressed; otherwise, we confront a twofold risk: component suppliers will become excessively weak, and we will return to non-modular designs that, in my view, would rob automobiles of the benefits of modular architectures. More broadly, the question can be posed in two ways: 1) Are there any financial benefits to be gained from modularization as it is practiced today, for both manufacturers and suppliers? Our response, based on our case studies, is at best mixed; 2) to put it another way, What should be done to derive the fullest benefit from modularization in the automotive industry? We will attempt to provide some answers to this question by arguing that modularization does not yet appear to have yielded the anticipated results because of the methods used to implement it.

We will begin by posing another question: Why have component suppliers, facing difficult conditions in their industry, mobilized their operations in order to enter this new market for modules, which scarcely seems to represent a land of opportunity? Finally, what conditions would promote the implementation of a module-based strategy in the automotive industry?

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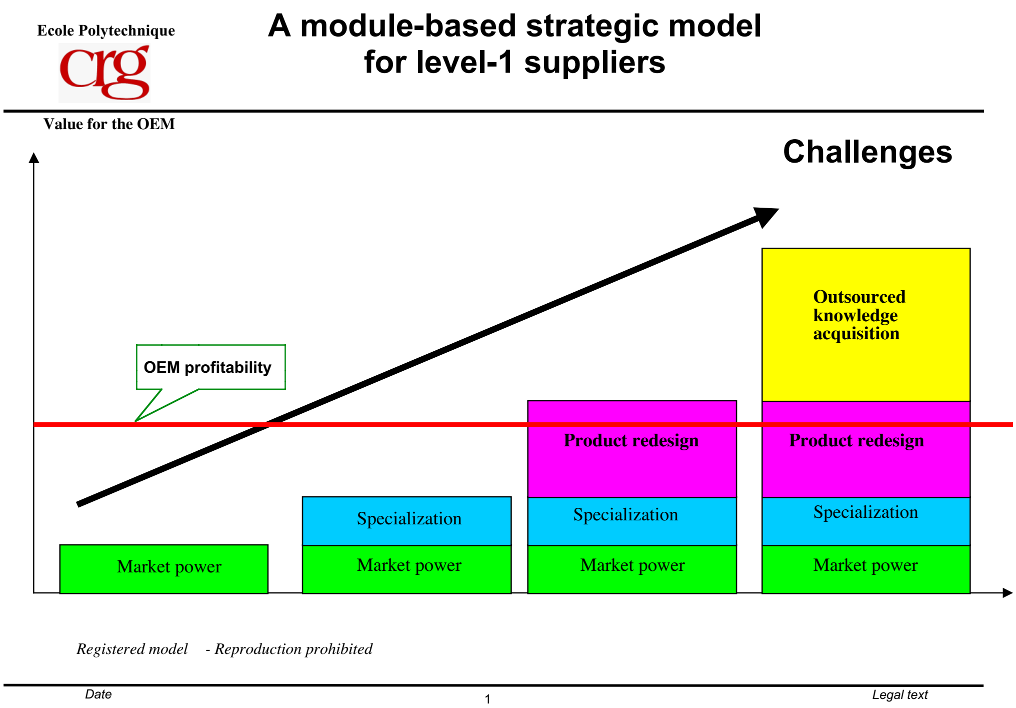
[30] Suppliers view international notions of a platform as a real snare that suggests one vehicle and high volumes but in practice leads to very different architectures within a single platform.

[31] These questions were raised during my many discussions with C. Midler, Sysmod's product management team and Professor Liker in the US.

A THEORETICAL MODEL FOR THE ADOPTION OF MODULE-BASED OPERATIONS BY COMPONENT SUPPLIERS

Our objective in this section is to use our case studies to develop a theoretical model for the path to modularization by level-1 automotive suppliers. We will describe the four steps in this process and the challenges associated with each.



Strategy 1: The concept of market power and the game of "Go"

When, from a present-day standpoint, we consider what prompted Sysmod to enter the module market in 1993, we see that its motives were primarily defensive. First of all, competitors had to be prevented from winning this market. Sysmod feared that these competitors might subsequently insist on the use of their own components, to the detriment of Sysmod components. The challenge, therefore, was to defend market share for the core business. In addition, Sysmod believed that the trend toward outsourcing, driven by increasingly complex vehicles, would accelerate, and that modules would allow manufacturers to use the product breakdown developed by subcontractors. Sysmod had to have a presence and gain a footing in the market while the price was still affordable, even if it had to leave the market later on; this would, in any case, cost less than trying to enter the market five years later. Sysmod was also aware that it had to establish a presence within the world of suppliers, and since it produced neither seats nor painted cowls nor fuel tanks, the only way to do this was by means of large-scale modules and just-in-time delivery. Sysmod's movement toward modularization was also prompted by a general rush to use suppliers. Finally, the company feared that a plan to reorganize components within the vehicle space could lead to architectural innovations that, for better or worse, would have a strong impact on the core market. Sysmod had to be "in the loop". I am using an analogy with the game known as “Go”, since there was a feeling at Sysmod[32] that the company had to bet on the future – hence the game comparison. Moreover, in the game of “Go”, a piece has no value apart from the position it occupies. Similarly, the module market, above and beyond its inherent profitability, will be a good market for the company insofar as it effectively blocks the company’s competitors and provides an opportunity for the Sysmod group as a whole to grow and expand.

In hindsight, we can see that Sysmod, perhaps without knowing it, had implemented a real option strategy (Jacquet and Navarre, 2000). The company had entered the module market with the minimum deployment of resources: three employees and some long-term trainees. In other words, Sysmod decided to take part in the game, then obtained a small share of the market – just enough to strengthen its organization, and then acquired a larger market share that enabled the company to establish teams.

As in a real option approach (Jacquet and Navarre, 2000), a small investment is made as a test, and companies can either drop out of the game with minimal losses, if necessary, or they can spend slightly more and advance a little further.

In the fourth strategy described in our model, we will see the value attached to the option that a company chooses. In this respect, Baldwin’s theory of bets on repeating games is applicable: players will participate once for the future value it represents, rather than the immediate value; Baldwin cites the notion of “self-enforcing contracts”. This idea is behind the attempt by component suppliers to obtain an initial contract. Once they have “a foot in the door”, suppliers can then build on this first contract.

If we think in terms of positioning on the value chain, the challenge for companies adopting this first strategy is to defend their position as a level-1 supplier. Once module suppliers emerge, the position held by each supplier will inevitably shift slightly. Level-1 suppliers who have been delivering components to manufacturers for decades will gradually[33] either reposition themselves as module suppliers or find themselves downgraded to a level-2 supplier. This would mean that, in addition to suffering damage to its ego, the company is placed at an informational disadvantage with respect to the level-1 supplier, which will filter information. As a result, the level-2 supplier may be unable to detect the emergence of a new “dominant design” (Abernathy and Utterback, 1978) in the core market. This dominant design may come from direct competitors or from suppliers outside the current field of competitors[34].

Is this approach, based on “Go”, self-sufficient? Does it allow the company to offset the price of admission to the market in financial terms? Our observations indicate that the answer is no. In some cases, Sysmod protected its component market share and even expanded its share through redesign, but in other cases Sysmod found itself delivering modules that contained a very low share of Sysmod products[35].

Moreover, the product itself has not changed, and, as we have already seen, the market has proven to be much more open to competitors than the components market. In light of the

[32] This notion was corroborated by other module suppliers to whom this question was put during 2002.

[33] In the module projects that we observed, former level-1 suppliers (in some cases with the manufacturer’s approval) continued to “short-circuit” the module supplier, thereby creating a form of entropy that destroyed value. This is an illustration of the high set-up costs cited by M. Sako (Sako, M. and F. Murray, “Modules in Design Production and Use: Implications for the Global Automotive Industry”, 2001).

[34] In this case, radiator or lighting suppliers filed patents for shock absorbers as part of their front-face modules.

[35] Sysmod is currently delivering a front-face module that has no cooling components and contains headlamps manufactured by competitors.

price war and the lack of leverage over productivity, this first strategy is impossible to finance. We need to move on to our second strategy.

Strategy 2: Specialization

One question emerged very quickly: How was Sysmod, using a strategy borrowed from "Go", going to finance the necessary effort to develop module prototypes? By creating an autonomous division that generated its own income statement, Sysmod hoped to provide its teams with the internal and external resources that would give them the leverage to become an international component supplier, such as they have been and continue to be today. This leverage includes research into steps for improving productivity in various ways: purchasing, processes, logistics, packaging, and so on. Companies that manage to survive for 30 years by reducing the thickness of aluminium sheets on radiators should certainly be able to capitalize on a broader scope of products that is more likely to generate ideas for improving productivity. This reflects a "cost killer" approach in which the product remains unchanged.

Profitability results from what I refer to here as a specialization effect. By designing packaging that is more appropriate than the standard packaging used by the manufacturer, Sysmod was able to achieve very significant cost savings, purely on its own behalf. Similarly, since Sysmod had teams that were assigned to specific areas of study and that were also motivated by questions of survival[36], the company could maximize its logistical processes so as to meet (and even occasionally far surpass) the manufacturer's cost objective. How is it that a novice component supplier in this field could achieve better performance than the manufacturer[37]? The answer has to do with specialization.

In support of this idea that supplier costs are lower than manufacturer costs, we should cite the salary differential. The practice of outsourcing pre-assembled subassemblies to suppliers has yielded savings in labour costs of over 20% for manufacturers, with no changes to the product; this has been a primary factor in driving manufacturers toward modularization. If this trend is real, our observations[38] indicate that the existence of a range of suppliers tends to diminish or indeed eliminate[39] this salary differential because of company cohesiveness at each site. Employees performing very similar tasks and lunching in the same cafeteria must be equally compensated; otherwise, destructive tensions may develop at the worksite.

As with the approach represented by the game of "Go", we will here raise the question of the economic model's profitability based on the combined use of two strategies: the game of "Go" and specialization.

It appears that the economic model can be profitable if, and only if, the manufacturer requires no module design work.

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[36] If the manufacturer fails to optimize a particular logistical process, its productivity may fall. If a component supplier fails to optimize its logistical processes for a module, it will begin to lose money on the project and will very quickly pass into a life-or-death situation.

[37] This question was often posed by Sysmod group management to the teams in its front-face module division when the division was requesting authorization for project investment and start-up.

[38] In Europe and Latin America.

[39] In the case of Smart at Ambach.

At the same time, the module supplier can only set itself apart from its competitors on the basis of price, which does not cement the module supplier's long-term standing as a supplier[40]. The most disastrous scenario is one in which the manufacturer indicates to the supplier at the outset of a project that it will be able to generate value by offering a varied choice of suppliers, for example, or a choice of mounting systems. The supplier then appoints design and purchasing teams. If in fact the supplier has no means of isolating productivity ideas, the supplier will never obtain a return on its investment in these additional teams. Therefore, we can say that the combined use of these two strategies does not appear to be adequate to ensure that the market will be truly profitable for the supplier. We must take a further step.

Strategy 3: Product re-engineering

After 1998, the teams in Sysmod's front-face module division very quickly identified the challenges and problems involved in generating sufficient profit to offset the investment and risk associated with module development. They had to go beyond the "Go" strategy and the specialization strategy to find the "buoyancy threshold"[41] and surpass it. Their task was simply to redesign the module by viewing it as a geographically coherent assembly. Their intended approach was to systematically eliminate every functional redundancy[42] and then design new functions[43], on the theory that, as a module designer, Sysmod could find a better approach to the problem[44]. It therefore expanded its research and development teams significantly so as to move forward very quickly in validating some new concepts. Using a real option approach, the company spent a little more in order to take an additional risk that was expected to generate a more convincing return on investment.

As a result, genuinely new ideas and products were presented to the manufacturers. On paper, these new products offered sufficient added value to guarantee greater profitability in the market, while at the same time the module supplier could remain competitive with regard to the objectives established by manufacturers. The manufacturers themselves benefited from the competition created by the constant emergence of firms hoping to rise to the rank of

[40] One international OEM that led the market in terms of volume delivery of front-face modules in 1998 for a manufacturer meeting the conditions indicated was considered virtually dead by 2002. Another supplier in the same position abandoned an entire segment of its front-face module market in 2002, although it had tackled the market with gusto in 1998.

[41] Expression coined by C. Midler of the *Centre de Recherche en Gestion* ("ligne de flottaison").

[42] For example, the lighting function incorporated into the module is run by a dedicated electronics system, while the engine cooling function, also housed in the module, is run by a different dedicated electronics system. By combining these two systems, the company could save on space and reduce its expenses.

[43] As an example, we can cite the so-called "pedestrian impact" function. Previously, Sysmod's various functional divisions had been questioned independently by manufacturers regarding this function. With the creation of the front-face module division, such a design issue could be addressed and coherent solutions could be developed that, given the module's scope, would reflect a greater number of variables.

[44] Using this new approach, the component supplier can offer new ideas, as with the case of the liberty fleet: *Perhaps most remarkable was the diversity of the Americans who built Kaiser's 'Liberty Fleet': "Probably only one in 200 had seen a shipyard before and 25% had never seen the sea. Many of his executives had never before faced ship construction problems, and so they approached their new tasks – as indeed the whole organization did – with open minds and no preconceived theories about conventional shipbuilding but with the determination to get things done quickly, efficiently, and with the minimum wastage of time, materials, and labor…. [This] group considered no task too difficult."* [Italicized text in English in original]

module supplier. The underlying logic behind this product re-engineering was to eliminate competitors. In effect, as we have seen previously, the module market raised logistics firms to the position of level-1 suppliers, which upended the pricing framework in the market. Since the OEMs alone had a thorough technological understanding of the components and the surrounding systems, they could modify the module architecture in appropriate ways, by improving its performance in both functional and economic terms. Clearly, such a module would become the "dominant design", and logistics suppliers and other component suppliers, lacking this thorough technological understanding, would find themselves eliminated from the list of level-1 suppliers.

In reality, if we consider the innovative content of products delivered in 2002, we find considerably less than the current potential. This third strategy, coupled with the two previous strategies, seems to reveal a path toward lasting profitability in the module market for the supplier, but it is clear that specific conditions must be met if these ideas are to be transformed into a favourable economic climate for both the manufacturer and the supplier.

Strategy 4: Outsourced knowledge acquisition

Having decided that the third strategy in our model contains the seeds of a profitable approach to modularization for both the supplier and the manufacturer, we could simply stop there. But our case studies suggest that there is another strategy, which, in our opinion, holds additional potential for creating value.

This approach arises from the module supplier's status as an information sensor (in the electronic sense of the word).

In discussing the first strategy, we asked the question, What is the value of the option that Sysmod purchased when it created teams dedicated to the front-face module?

In order to be a module supplier, companies must enhance their understanding of, and thus their general expertise with, automotive design issues. Any OEM that hopes to become a module supplier will face difficulties that it would not have encountered in its previous experience as a systems or component supplier. There are unfamiliar components that must somehow be incorporated into the modules, as well as architectural constraints imposed by the manufacturer that are passed on to the module supplier. In absolute terms, module designers are more conversant with the subject than in the past and relatively more knowledgeable than competitors from the days prior to modules who chose not to explore that route[45]. Similarly, module suppliers are brought into projects at an earlier stage than component suppliers, and have access to more information earlier on.

Component suppliers who (in what is called "conscious modularization") opt to take steps to acquire this information and distribute it to systems and component suppliers in their own group, or pass it on to their suppliers and partners, can win opportunities (or have others win opportunities on their behalf); they can influence their fate or that of their suppliers; they can detect and amplify weak signals; and so forth. To borrow a term from game theory, the scenario is one of incomplete information. The module supplier can create informational asymmetry, and can gain an advantage from this position. This fourth strategy does not

[45] There are some level-1 suppliers (they are few and far between) who have chosen not to deliver modules but instead have remained in the component or systems market. Bosch is one example.

necessarily lead to immediate and visible results in the project's bottom line[46], but it does represent a major asset in terms of the module supplier's future.

Like the product redesign strategy, this strategy of "outsourced knowledge acquisition" will only generate value under specific conditions with regard to the supplier's internal organization and the relationship between the supplier and the manufacturer, as well as the relationship between the module supplier and its level-2 (and level-3, level-4, etc.) suppliers.

In summary, with the product redesign strategy, the component supplier *[sic]*, value is maximized, and this translates into improved gross profits. Without it, the component supplier is weakened. If, in addition to the re-engineering, companies become aware of the informational advantage they enjoy as a module supplier, they can then maximize the value they create.

When we attempt to position our case studies within this model of successive strategies driving component suppliers toward modularization, the conclusion we draw is that certain manufacturers gave their business to Sysmod in the hope that innovative ideas would emerge in the projects, but in reality there were obstacles to the incorporation of these innovations. If the component supplier takes steps to obtain as much information as possible through its privileged status as a level-1 supplier and to ensure that the information it acquires is conveyed to its organization and appropriated by those who see potential value in it, then it will truly create value by becoming a module supplier.

RELATED CONDITIONS

In this section, we will consider something we observed in the field: even though manufacturers and OEMs alike have sometimes dreamed of an "innovative" module, in terms of its component content and its architecture, such a module has never truly been created. What constraints have prevented the implementation of such ideas? They bring such significant added value that they could offset the new financial burden imposed by modularization. The challenge posed by this question is, in our view, fundamental. As in the example of modules created ten years ago that have now disappeared[47], if the product remains unchanged, the manufacturer will adopt another approach that seems more effective[48] and will forget about modules. There are seven key constraints that we believe must be addressed if modularization is to generate value for the entire chain[49] over the long term.

Integrating level-1 suppliers into module projects

A basic variable emerges from the five module projects we have studied in detail over the past four years: At what point was the module supplier integrated into the project? In the

[46] *[sic]* project plateau. Sysmod identified a competitor's weakness and proposed a solution that allowed it to capture additional value in a highly opportunistic fashion.

[47] The cooling module, which included the radiator, condenser and motor fan, was used on the Saphrane at RSA but disappeared from subsequent models.

[48] E.g. standardization.

[49] A current snapshot could be suitable for certain manufacturers that, thanks to modularization, have removed whole areas of investment from their balance sheet (machinery, inventories and in-process materials, working fund requirements), reduced their visible and invisible direct costs (start-up costs and troubleshooting costs) and outsourced their risk (delayed projects, lower than anticipated volume), without any difficulty.

worst case, the module supplier was brought in two years before the start-up of production. In the best case, the module supplier was brought in three and a half years prior to the start-up of production but had been participating in the so-called concept competition phase for eight months, alongside the "real" project, before actually assuming a full role in the project. This case appears to be the most emblematic. Sysmod won the contract believing[50] that there was some latitude with respect to the choice of design, the choice of components to be included in the module, and the architectural options for certain components that would significantly affect the module's architecture[51]. The company won the contract on the basis of an architecture developed during the concept competition phase, but soon learned that, in the meantime, the car's front styling had been finalized, with consequences for the air intake equipment and thus the choice of components for the engine cooling system. Standard "carryover" components such as the lock had been established, as had the choice of suppliers, and technologies other than those hinging on the chosen supplier were shut out[52].

We stated at the beginning of this article that modularization is a design option that manufacturers are free to adopt or ignore. Clearly, if for any reason a manufacturer chooses this option at a late stage of the process, it will garner only a portion of the module's potential benefits. This may be sufficient for the manufacturer, but from the supplier's perspective, in order to ensure a financial balance in the relationship while adhering to market price levels, modularization must be exploited to its maximum potential. It must therefore be researched very early on in the process, during the project's exploratory phases, so that when the time comes to decide whether a design option will truly generate value for the end client there are as few obstacles as possible in place.

Contractual engineering

In cases where a manufacturer brings a supplier in on a project in the very early stages – where the supplier cannot be certain that it will eventually win the manufacturer's business, and moreover will need to obtain highly confidential information in order to submit the best possible work – then a legal framework is undoubtedly necessary. At what point can the purchasing department challenge the supplier's actions? Can it challenge the supplier over the cost of components, two years prior to mass production, at the risk of reducing the consistency of the modular architecture? These are some of the questions that legal experts must raise so as to leave nothing to chance and ensure that the end result is an optimal product.

Evaluating the performance of the proposed modular architecture

When the module supplier, having participated in the project from the very early stages, submits its proposed modular architecture prior to the vehicle marketing agreement, the design's performance must still be objectively evaluated, and not merely in terms of direct cost savings[53]. The supplier and the manufacturer should jointly develop an evaluation grid so

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[50] Information conveyed by the manufacturer's personnel responsible for negotiating with potential module suppliers.

[51] One example is the hood latch: is it a single or double latch, vertical or horizontal? This will have a sizable impact on the technology to be adopted so as to obtain the necessary rigidity.

[52] If the supplier delivered steel components, Sysmod no longer had the option of using other technologies such as aluminium or composites.

[53] I am referring to design in the broad sense, including both the product and the architecture for the associated supply chain.

that a range of variables – i.e. the design's compactness and weight, its ability to comply with standards at the lowest possible cost and to adhere to the styling established at the outset – can be examined, quantified and weighted as part of a final decision.

The manufacturer's internal organization

The major factor to be considered here is the ability of an organization that is divided both functionally and along project lines to embrace ideas that cross functional boundaries or even come from outside the organization. Several problems can be combined here: project innovation, cross-disciplinary "breakthrough" innovations and those that originate elsewhere.

The supplier's internal organization

The same problems can be observed within the supplier's organization. If, for example, a proposal requires that a cooling system component be merged with a lighting system component, then the module team will need a great deal of energy, diplomacy and shrewdness to make that proposal succeed.

Structuring the manufacturer/supplier relationship

Obviously, the point of contact between the two organizations is critical (Garel, 1999). The ideal, according to the literature (Baldwin and Clark, 2000), is to have a so-called diagonal matrix that depicts the interaction between the two organizations and shows a one-to-one relationship between a manufacturer staff member and his or her contact person at the supplier. The '1's indicate points of sustained contact during the project. This is the simplest matrix that we observed on our projects.

We are far from the one-to-one relationship between the client and its supplier that Ulrich recommends (Ulrich, 1995), and we still have not attained the ideal described by Baldwin (Baldwin, 2002), in which transaction costs are kept to a minimum.

Delegation of responsibility

If the module is to add the greatest possible value, then it is essential that the module supplier have the greatest possible latitude in exercising its responsibilities, notably with regard to managing level-2 suppliers or higher, as well as in terms of mastering the components proposed by the manufacturer or, in any case, of having the option of questioning their appropriateness. The level of responsibility accorded to the supplier should not change over the course of the project, as we have seen; manufacturers run the risk of gaining a few cents in savings on a single component while missing out on greater savings for the module as a whole.

LIMITATIONS AND SUBJECTS FOR FUTURE RESEARCH

Limitations of the study

Before describing our future research, we must point out a major limitation in our study.

Our observations are, broadly speaking, confined to Western firms[54]. This raises several issues – cited by Chanaron (Chanaron, 2001) and described in more detail by Fujimoto (Fujimoto, 2001) – that will enhance our observations by indicating two paths that would be interesting to monitor in the future. The first is the modularization policy adopted by Japanese manufacturers, which are currently performing a component breakdown of their vehicles by merging the notions of a module and a function (Liker, Ettlie et al., 1995[55]; Chanaron 2001). This vehicle segmentation is being conducted internally, and its tangible effect, in the case of Toyota, for example, will be a metamorphosis of the company into several majority-held joint ventures. The other option described by Fujimoto involves Western manufacturers[56] that address these same problems by subcontracting units that pose special difficulties, in the expectation that the OEM will act as the intermediary in streamlining the design and the negotiations. The Japanese model is said to be the quicker model to implement, while the Western model is said to hold the greater potential for innovation. It will be interesting to follow this phenomenon and to see whether integration with the supplier affects the ability to achieve optimal modularization of an integral product.

We have made various contacts in order to conduct a multi-product analysis that covers a wide spectrum of modules, including front-face modules, cockpit modules, door modules, rear trunk modules, seat modules and fuel tank modules.

Subjects for future research

Our current objective is to identify and define the characteristics of an economic model for long-term automotive modularization, with which we can move from a cost-based strategy to a strategy of creating value while enhancing overall economic performance.

For this purpose, as part of the CRG's tradition of research and consistent with studies regarding suppliers in the automotive industry (Garel and Midler 2001; Lenfle 2001), we are conducting research in two major areas.

We will try to influence the initial conditions for a module project undertaken by an automobile manufacturer and thereby attempt to enhance the added value created. We will endeavour to define the rules for product segmentation and organizational structuring so that the product's integrity is preserved (Fujimoto, 1991) and value is distributed along the entire supply chain, while at the same time the benefits of a modular design are retained. For this purpose, we must build tools for assessing the value created by modularization, as well as tools for identifying the best possible hybrid of modular and integral architectures.

Our second focus of research will be Sysmod's internal operations. We will be analyzing the necessary procedure for creating an innovative module, and we will investigate the strategy for design innovation from the standpoint of modularization. This question lies at

[54] USA, Europe, and South America.

[55] Article and transcript of a discussion held in November 2002 in Ann Arbor.

[56] Our observations indicate that what T. Fujimoto describes as a Western model is more accurately an American model, and more common among some manufacturers than others.

the heart of the research activities conducted by the CRG and more specifically those of the ERIC group (a team for research into innovation in design) led by C. Midler. This team has particular expertise in issues relating to innovation in design, not merely from the standpoint of automobile manufacturers (see C. Midler in Benghozi, 2000, #385; Midler, Garel et al., 1997) but also from the perspective of automotive suppliers (Lenfle, 2000; Kesseler, 1998), which is less often examined. We plan to reconstruct the trajectory traditionally followed for modules and components in order to conduct this research.

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