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External Integration in Product Development

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I. Introduction

In recent years, product development has become established as a focal point of competition in an increasing number of industries, as well as a focus of academic research. This emphasis has led to the development of new methods and concepts for understanding and improving a firm's development processes. Much of the discussion of product development in the popular and academic literatures has focused on the question of time to market.[2] Concepts like simultaneous engineering, which attempts to shrink the time required to develop a new product, have moved from the literature to wide spread application. While academics and practitioners have focused on reducing lead time in development, competition in many critical industries has intensified, customers have grown more demanding and sophisticated, and markets have grown more diverse. While the value of speed and responsiveness in development has increased, these factors by themselves are increasingly insufficient to insure a company's competitiveness. Changes in competition and in customer requirements have created an environment in which companies that excel must create products that deliver improved sophistication, performance, and reliability. Moreover, the growing diversity of customer requirements and their demands for products tailored to individual needs has created competitive pressure (and opportunity) to bring to market a broader range of products, and thus to take on an increased number of development projects over time. Thus, the competitive requirements facing manufacturers in a variety of different industries today are not limited to development speed, but include the additional imperatives of increasingly refined, sophisticated products, and to do so productively and efficiently. A central problem in the academic literature on these issues is the organization of development tasks. How to organize development is a question rooted in the discussions of the different ways of achieving specialization and cross-functional coordination in complex organizations. While a full-scale review is not within the scope of this work, it is useful to outline some of the contributions, to set the stage for our discussion. The work of Burns and Stalker (1961) pioneered the field establishing that mechanistic organizations are effective in stable environments, and that organic forms are effective in diverse and

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[2]See, for example, Stalk (1988), and Uttal (1987).

variable environments. Lawrence and Lorsch (1967) also showed that different organizational subunits tend to be adapted to different environmental conditions. For example, effective production subunits tend to be structured more formally than R&D subunits. Effective organizations thus tend to match the degree of differentiation and integration common in their overall environment. Galbraith (1973) postulated that effective organizational design will reflect information processing logic. Efficient organizations will match information processing load with capacity. Thus as the uncertainty in tasks increases, organizations will increasingly develop integration mechanisms, ranging from common goals and lateral relations to matrix or semi-matrix forms of organization. Davis and Lawrence (1977) extensively explored the matrix form of organizational structure, using the information processing point of view. They identify three conditions for the implementation of the matrix form: high information processing workload (task uncertainty, etc...); simultaneous focus on two critical requirements, such as customer orientation and technological expertise; scale economy in information processing, through pools of expertise. Davis and Lawrence also analyzed the evolution of matrix organizations, from functional forms to temporary project management, to permanent project management, to pure mature matrix forms. They emphasized that effective matrix forms need *consistency* in culture, system, structure, and behavior. Finally, they suggest that matrix forms tend to be effective in product development and innovation when continuous product renewal is critical.

The debate between the effectiveness of functional versus project forms in product development is still active. Marquis and Straight (1965) investigated one hundred R&D projects to conclude that project organizations tend to be optimal with respect to cost and lead time, while functional forms excel in projects that emphasize technical expertise. Katz and Allen (1985) found that a balance of power between functional and project managers, complemented by imbalances in crucial decision areas, tends to be optimal. They show that in the most effective projects functional managers tend to be stronger in technical expertise, while project managers are stronger in budgeting/personnel decisions. Keller (1986), on the other hand found team coherence the key variable in assessing project performance, rather than the balance between functional and project managers. Others, such as Peters and Waterman (1982) found that project teams performed better in innovation compared with matrix structures. Allen

(1986) and Allen and Hauptman (1987), concentrating on R&D organizations, postulate that functional structures facilitate the accumulation of technical knowledge while project structures facilitate cross-functional integration. Their hypothesis is that when the rate of technological change is rapid, functional forms will tend to be more effective: engineers will be assigned to an area on a more permanent basis, and they will be able to scan the environment and keep abreast of technical progress. In our work on automobiles and other industries, we have found that the challenges of the new competitive environment have sharpened the conflicts and tradeoffs embodied in the traditional forms of organization.[3] The imperative of the modern development organization has become the *simultaneous* satisfaction of three apparently contradictory challenges: shortening time to market, increasing development productivity, and increasing product quality and technical sophistication, keeping abreast of rapidly changing technologies. As a result, the traditional tradeoffs between functional depth of expertise, cross-functional integration, and boundary spanning activities (such as the development of intimate knowledge of customer requirements, or new technologies) has been put under considerable pressure. From the standpoint of practice, these changes have raised the need for more effective ways to connect customer requirements to efficient engineering design. From the standpoint of academic research, there is a need for better frameworks for understanding the way in which organizational structures and processes influence that connection.

We focus in this paper on the problem of creating organizational processes that achieve high product quality rapidly and efficiently. We introduce the notion of external integration as a critical dimension of the way firms organize and carry out development. We examine its impact on development performance with special emphasis on the quality of the product. Although we recognize the importance and examine in some detail the issue of organizational *structure*, we focus our analysis on the *process* the firms use to achieve external integration. These processes include the activities, the procedures, the methods, and the paths of communication that define the linkages between the large

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[3]Please see Clark (1983), Clark and Fujimoto (1988a; 1988b; 1988c; 1989a; 1989c; 1991), and Fujimoto (1989).

number of engineering tasks to be performed during the development activity and the firm's customers. Drawing on our study of product development in the world auto industry, we examine the relationship between different patterns of external integration and the efficient development of high quality products. The central notion here is that the capability for effective external integration rests on a broad set of skills, physical assets, procedures, organizational routines, values and norms that allow the firm to complete these critical activities better than its competitors. While our observations are quite preliminary, we suggest that a firm's capability for external integration may have a strongly nonlinear character. That is, there exists a critical level of the underlying determinants of capability beyond which the organization may achieve a major improvement in performance. The remainder of the paper is divided into six parts. We first sketch out the framework we use in studying the organization of development in section II. In section III we describe the different mechanisms for external integration encountered during our study. In section IV, we describe the data we use in our study from the auto industry as well as the methods we used to collect it. We focus on two kinds of data, and associated analyses. First, we examine data on performance and organizational characteristics across a sample of development projects conducted in the mid-1980s. Secondly, we present two summaries of in-depth case studies of the introduction of new approaches to external integration and development organization. These case studies focus on the impact of changes in organization leadership on development performance over a time span of about one decade. In section V, we present an analysis of the project level data, focusing on the impact of external integration on product quality, and include a conceptual model of the external integration process. Section VI then turns to the case studies and examines the impact of organizational changes on development performance over time. The paper concludes with a summary and a discussion of implications for practice and research.

II. The Framework : an Information Perspective

i. from information to integrity

The starting point for our framework relating organizational structure and process to development performance is a descriptive model of product development as an integrated system of information creation and transmission.[4] In this context, product development is a process through which an organization transforms data on market opportunities and technical possibilities into information assets for commercial production. During the development process, these information assets are created, screened, stored, combined, decomposed, and transferred among various media. Ultimately they are developed as detailed product and process designs and employed in production systems on the factory floor. But the flow of information does not stop with production of the product. In this framework , the customer consumes an experience delivered by a product rather than the physical product itself. This experience takes the form of information a customer receives about a product and its behavior in the environment in which it is used. The customer's evaluation of the product and the customers behavior in purchasing and using the product creates information about customers needs and requirements that the product developers can use in subsequent development efforts.

Figure II.1 models the development process and its connection to production and consumption as an integrated system of information creation, and transmission. Embedding the development process in this larger system of information flows makes clear a fundamental symmetry between the activities in development and the activities in production and market behavior. In the top half of the figure, the development process is laid out as a set of activities in which marketers and engineers use information from customers and from the technical environment to create a new design concept. Engineers take that concept and build and test prototypes in order to determine whether or not the design is potentially attractive. In building the prototype and in carrying out tests, the engineers are, in effect, simulating the future production of the product and what future customers will experience. In this sense, product development is a rehearsal of future production and consumption of the product. The product concept

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[4]This approach was developed and discussed in Fujimoto (1989) and Clark and Fujimoto (1991).

anticipates future customer satisfaction, the product plan specifies future product functions and the product design represents the product structure and the process design - the production process. In the case of the development of a new automobile, for example, the prototype stands in for the future vehicle, test drivers play the role of future customers, test tracks are designed to simulate actual road conditions, computer aided engineering programs try to reproduce vehicle dynamics, and product planners try to anticipate customer expectations and internalize customer needs several years into the future. An important part of the effectiveness of the development process, therefore, is how well the development group simulates target customers. Management of the linkages between development and the sources of information about future consumption - that is between customers and the market - is critical. In this framework, effective product development rests on a product design's ability to create a positive product experience. This involves a complex translation of product information from customers to engineers to production and sales, back to customers. When products are complex, and customers sophisticated and demanding, the attractiveness of a product is unlikely to depend on raw performance in a particular component in technology or even in basic functionality or cost.

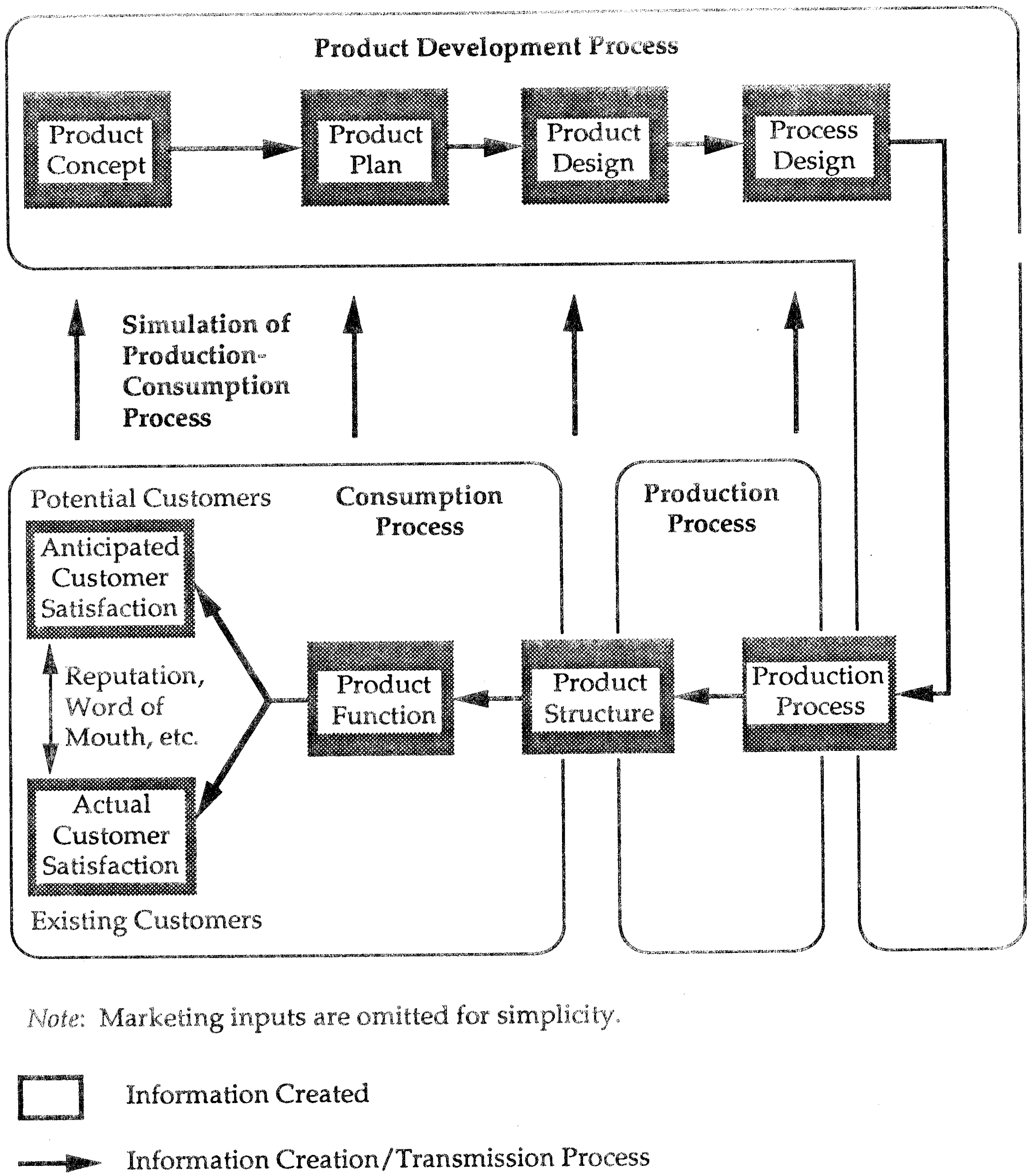

Fig. II.1: The Information Processing Model of Product Development. Adapted from Clark and Fujimoto (1991).

Customers who have accumulated experience with a product, and have become sensitive to subtle differences in many product dimensions, demand a total balance of numerous product characteristics, including basic function, esthetics, semantics, reliability, and economy. The extent to which the totality of a product achieves the desired functionality, coherence and balance, attracting and satisfying customers is a measure of the product's *integrity.*

Product integrity is determined by two principal factors: the *coherence* of the product, and the degree of *fit* with customer objectives and expectations. The product's coherence defines the extent to which the product's details, subsystems and components proactively combine to achieve consistency in concept, character, and technical functionality. Taking a luxury car as an example, the product's distinctiveness will be based on the coherence of the overall concept and package presented to customers. A key component will be the different aspects of the car's functionality. The car's ride and handling characteristics, for instance, will be critical in giving the car the appropriate feel and character. These will depend on a multitude of factors, including the design of the suspension system, the stiffness of various chassis components, and the response of the engine, for example. The achievement of consistent ride and handling characteristics will thus depend on the resolution of a large number of interelated problems approached by different parts of the development organization. Along with the achievement of consistent functional objectives, a distinctive luxury car will embody a large number of critical details in the exterior and interior styling, for example. The degree of effective, consistent, and proactive resolution of the various subsets of interrelated problems that determine the vehicle's design and their harmony with the basic concept will establish the coherence of the system.

The product's fit is a measure of how well a product's function, structure and semantics fit the customer's expectations; their objectives, values, production system, life style or use pattern, for example. Fit will not be achieved without the required level of product coherence as a base. To acquire distinctiveness, however, the product will require an overall identity which is well matched to the customer's objectives. The product's fit is thus a measure of how well the multitude of details involved in the product's design add up to a wholistic product experience that attracts and satisfies customers.

ii. patterns of organization: specialization and integration

Efforts to organize development effectively and design competitive products are rooted in a search for solutions to two fundamental problems. The first is how to get a product's parts and subsystems designed, built and tested, so that each individual element achieves a high level of functionality. Because functionality at the component level is driven by expertise and depth of understanding, achieving it requires some degree of specialization. The degree of specialization in an organization depends on how narrowly an organization is divided into departments and sub-units extending all the way down to individuals. Engineers, for example, may be specialized by component or sub-component system, or by stage in the development process (e.g. functional design, prototyping, testing) or by some combination. There is a large literature on specialization in organizations, and a full review is beyond the scope of this paper. Essentially, functional specialization brings about the classical benefits of the division of labor: learning by repetition, development of special tools and knowledge, ease of coordination (See Mintzberg, 1979, and Allen 1986, for example). The literature, however, also recognizes the potential dysfunction of specialization (for example, see Davis and Lawrence, 1977, and Kanter 1983). Here the problem stems from difficulties in coordinating a large number of separate units, the likelihood of local optimization at the expense of system performance, and parochialism and conflicts between narrowly defined functional groups. How serious these problems are and the balance between the benefits and risks of specialization depends on the nature of the tasks and other organizational characteristics.

The second primary problem facing the organization is how to integrate the many different problem solving efforts in a development project to achieve product integrity. The achievement of product integrity is closely linked to the problem of achieving integration within an organization. We have argued (see Clark and Fujimoto, 1991, for example) that integration has an internal and external dimension. Internal integration is focused on the achievement of coordination between different specialized subunits within the organization. External integration, on the other hand, is focused on the achievement of consistency between the organization and the market. We have argued in the previous section that product integrity has dimensions of product coherence and fit. While internal integration activities should be related to the achievement of product coherence, external integration activities should lead to product fit (Please see Figure II.2).

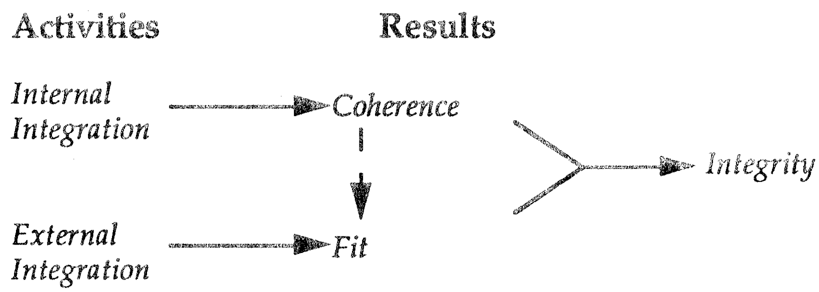

Fig. II.2: The postulated relationships between internal integration, external integration, and product integrity.

The literature on organizational structure has focused on internal integration. For example, mechanisms to achieve internal integration have been discussed at length by Galbraith (1973). Galbraith's mechanisms range from rules and procedures, to shared goals, lateral linkages (e.g. direct contact, liaison roles, integrator roles), and a full scale product (as opposed to functional) subunit. As we mention above, the evidence in the literature suggests that patterns of internal integration to achieve a given level of product coherence differ depending upon the instability (or uncertainty) of the environment, interdependence of the tasks required for functionality, as well as the subtlety of the information content required by cross functional communication. Where customer needs are stable, products are relatively well understood, and competition allows for long development lead times, the organization may have only to rely on very simple measures, (i.e. rules, computer systems, hierarchy, and goal setting) in order to maintain sufficient coordination. In contrast, if customer needs are unstable and difficult to articulate, competition puts pressure on the organization for shorter lead time, and the demands for quality require significant cross-functional integration, then the organization may need some combination of lateral linkages as well as the conventional hierarchical mechanisms noted above. In an extreme case where a very high degree of mutual adjustment is needed within a project, the product sub-unit structure may be appropriate. While specialization and internal coordination among specialized units has been the primary focus of the literature on organizing development, external integration has received much less explicit attention in the literature and in the practical design of development organizations. In this context, external integration refers to those organizational mechanisms which allow the organization to simulate the consumption process effectively. This simulation is not just a passive reflection of the external world, it involves the active creation of models as well as the application of the models to the environment. Consequently, external integration involves mechanisms which enable organizational members to interpret current market information actively and to reconstruct visions of the future market. Moreover, that vision of the future market must be translated and infused throughout the organization so that the details of engineering design deliver a product experience that matches customers expectations. Achieving external integration thus entails developing a distinctive product concept that matches future customers expectations, infusing that product concept into the basic and detailed product designs and bringing that design into the commercial production process. External integration is more than being close to customers, market oriented, or customer driven. Close communication with customers must be augmented with imaginative concept creators capable of translating subtle clues of latent customer needs into a model of the future product and its market. To the extent that they suppress the market and product imagination, strong ties with current customers in current distribution channels (as through marketing surveys or product clinics) may even harm the attractiveness of the product in the future. Nor is passive reaction to the market sufficient. External integration implies mutual adaptation between the product and the market (customer needs may influence product designs, and product attributes may influence customer needs), and mutual learning between producers and customers. In a sense, customers become another department in the organization whose concerns and interests need to be integrated.

iii. modeling the external integration process

To crystallize the characteristics of the external integration process, it may be useful to outline a simple conceptual model of the development activity. Drawing from the information processing framework presented above, product development may be represented as an ensemble of information processing activities. Given the high level of complexity of the product, the development activity is a very large set of individual information processing steps. To help with our analysis it is useful to break down the process into all of the individual problem solving efforts. In this context, we will define a single problem solving activity as the set of steps leading to the definition of a single degree of freedom in the design of an automobile. Individual problem solving activities are thus very narrowly defined. Examples might be the choice of material for the door handle, the choice of steering wheel diameter, or the choice of engine stroke length. The number of individual problem solving activities is thus very large, and their ensemble completely defines the product. The integrity of the product will be a function of the multitude of decisions leading to the complete ensemble of problem solving activities. In keeping with our definition, the external integrity of the product is a function of the outcomes of the whole ensemble of problem solving activities. There are two steps in the process: first of all, the *coherence* of the product will be a function of how all of the individual problem solving outcomes add to produce a product with coherent level of technical functionality, feel and identity. Secondly, the *integrity* of the product will be a function of how well its coherent feel matches up or fits with the customer expectations: i.e. creates a distinctive and favorable experience. The integrity of the system will thus be determined by the extent to which each individual problem solving activity adds to produce a coherent product identity that matches the customer expectations.

Fig. II.3 my help to visualize the situation. The outcomes of problem solving processes are represented by a network of vectors. The projection of each vector on the product concept direction represents the contribution of the particular problem solving activity to the coherence of the system. The integrity of the system will be the magnitude of the projection of the resulting coherence onto the direction of the actual customer expectations.

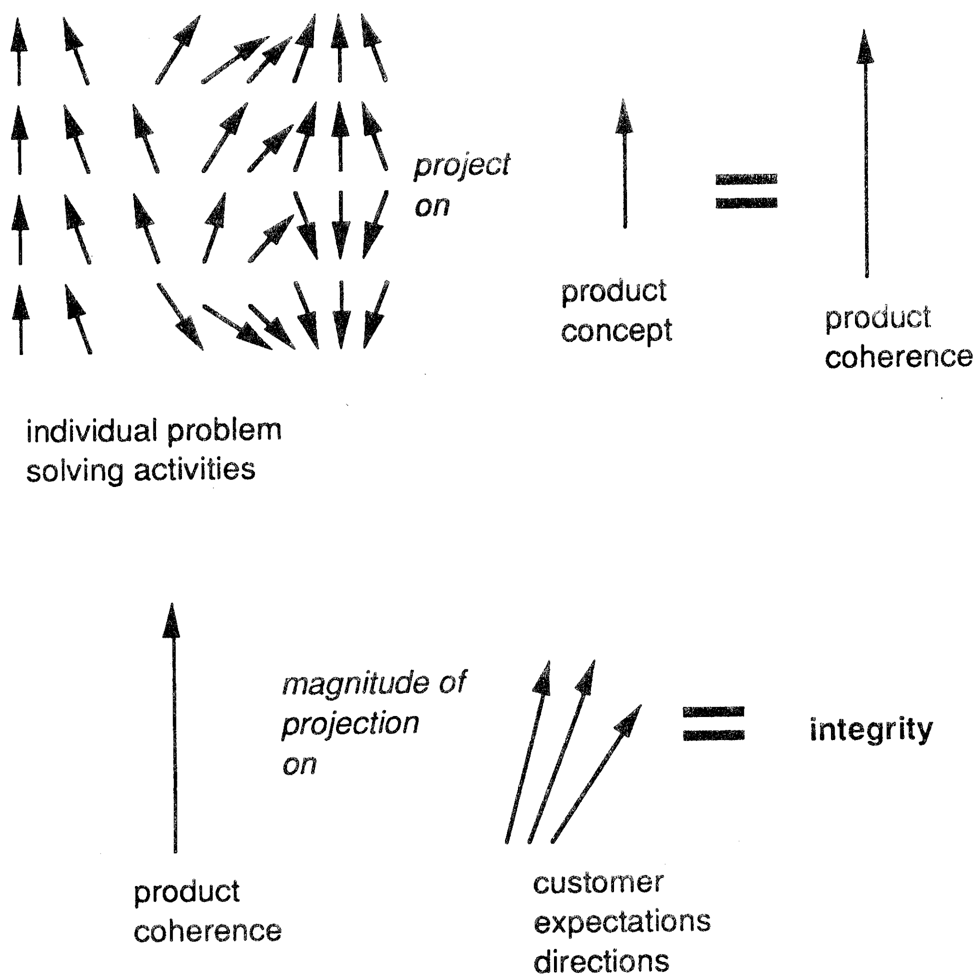

Fig. II.3: a conceptual model of the development process.

One could think of a single small arrow representing the choice of material for the seat covers of a high performance luxury automobile. A choice of vinyl might be negatively oriented with respect to the concept direction, since the material does not contribute to the overall experience of luxury that the automobile is attempting to invoke. A choice of hand-worked Italian leather would instead be well aligned with the concept. The overall experience of luxury would be invoked by the contributions of thousands of such design decisions. The success or failure of the car to evoke that experience would be a function of the whole, not of any individual problem solution.

We can represent this algebraically as follows:

$$\vec{C} = \sum_i (\vec{p}_i \bullet \vec{c})\vec{c}$$

where C is the product coherence vector, p_i are the problem solving outcomes, c is the concept vector, and • denotes the vector inner product. Furthermore, the integrity I will be given by

$$I = \vec{C} \bullet \sum_j \vec{e}_j$$

where e_j represent the customer expectations.

In our simple model, there are two fundamental forces that affect the dynamics of this network of problem solving activities. First, there will be a force on each problem solving activity to achieve an outcome that is *locally* optimal: i.e. to strictly optimize each problem solving activity based on its most immediate considerations. The choice of seat cover material will be affected by cost, design, and reliability considerations related specifically to the function of the seat cover, for example. These considerations will appear random from the frame of reference of the product concept, since they are only related to the specific functionality of the component. Second, there will be an additional influence on each activity that represents the attempts by the organization to implement a coherent approach: i.e. to try to get neighboring arrows to line up. For example, program management will be keen to insure that the seat cover material will be picked so that its color, feel and texture will match the texture and feel of the interior trim, or the dashboard material. The strength of this integrating force will be determined by the extent to which the external integrators in the organization will be able to *recognize* local deviations from the overall product concept, as well as their power and ability to *implement* their decisions. In the model, the dynamics of the network of problem solving activities will be determined by the competition between the local tendency to randomize the problem solving outcomes, and the efforts to achieve coherence between neighboring problem solving outcomes. The integrity of the system will then be given by the sum of the projections of all of the individual problem solving outcomes onto the concept direction.

Clearly, this representation makes a number of implicit assumptions. First of all, we assume the existence of a well defined concept direction that represents the distinctive identity of the particular product. Secondly, we assume the existence of well defined projections of the individual problem solving outcomes on the overall concept. Third, we assume that the influence of external integrators on the system can be summarized in an interaction between problem solving activities.

While the formal justification of this model can thus be easily put in question, we have found it to be nevertheless quite helpful in visualizing the essence of the external integration problem. In particular, the response of systems of this kind will tend to be highly nonlinear. In general, if we keep the local randomizing force constant and gradually increase the strength of the integrating force, the system will tend to pass a critical point beyond which the individual problem solving activities will adopt a characteristically coherent character. For smaller values of the integrating force, the individual problem solving efforts would have a random orientation and the coherence of the system would be zero. Fig. II.4 sketches the expected shape of integrity as a function of the integrating force. This general type of behavior is very robust. It is common for a wide variety of systems which involve very large networks of interacting elements whose behavior is dependent on the balance between local randomizing influences and a force that attempts to coordinate the response of adjacent nodes. There is an extensive body of literature available that studies the behavior of dynamical systems with these general characteristics.[5]

If we use this conceptual model as a rough guide, we should expect the effect of any integrating mechanism on an organization to be distinctively nonlinear. The behavior of the organization might change rather sharply once a critical level of "integrating effort" is achieved. At lower levels of effort, the collective behavior of the system may be largely unaffected by small variations in integrators. Similarly, one should not expect that an attempt by an organization to foster efficient external integration should induce an easily detectable result. Rather, one should expect to find organizations in which optimal behavior occurs, and organizations in which it does not.

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[5]See, for example, Ma (1985) for a review of recent efforts.

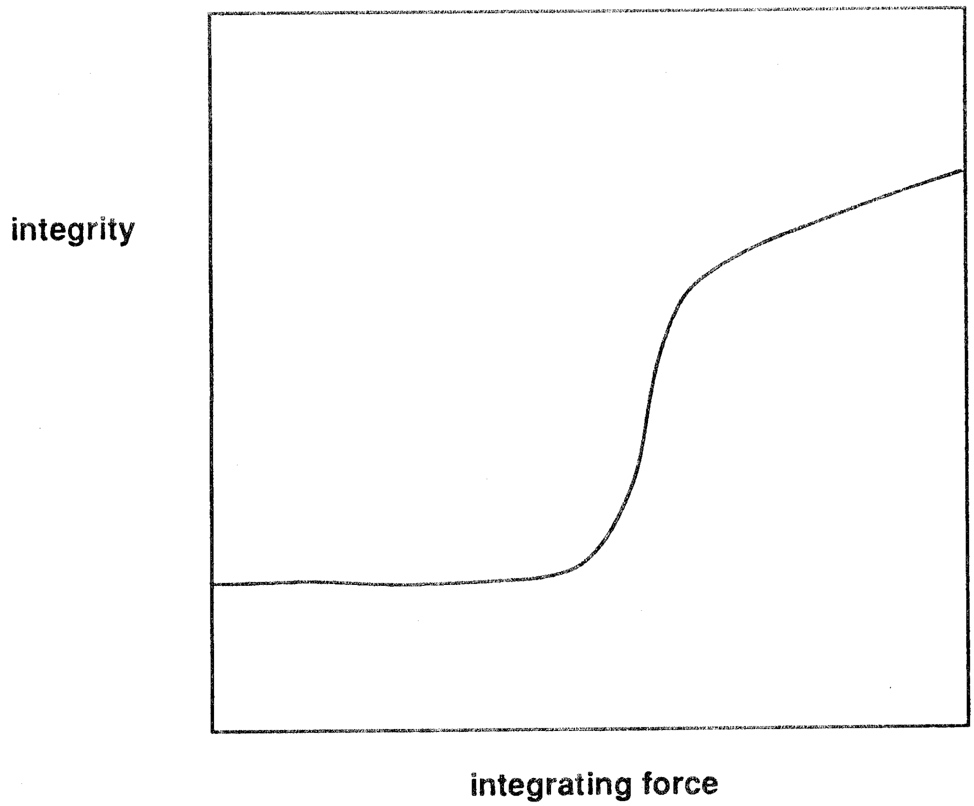

Fig. II. 4: Postulated relationship between integrating force and system integrity

III. Mechanisms for External Integration

i. organizational approaches to external integration

This section is devoted to a discussion of the mechanisms companies have attempted to achieve external integration in their development efforts. The frameworks in the previous section suggest that there are two aspects of the external integration problem. First of all, there is a need for a subset of the development organization to develop a vision of future customer expectations, and translate that vision into a product concept. Secondly, there is a need to foster coherence among the very large number of problem solving activities that make up the development effort, to insure that the outcomes will indeed build up to a result which embodies the desired concept. There are at least three possible approaches to organizational design for external integration: 1) setting up separate organizational sub-units to specialize in external integration; 2) assigning the role of external integration to the existing functional units; and 3) assigning the role of external integration to the internal (cross-functional) integrators. Creating a specialized sub-unit for external integration brings with it strengths and weaknesses similar to those of functional specialization: while it facilitates accumulation of expertise and market translation, coordination between such interpreters and other functional units (the recipients of the interpretations) may become difficult. Dispersing the external integration role throughout the functional organization has the advantage that environmental information can be taken into account directly by the functional sub-unit. On the other hand, if different functional units tend to perceive the environment differently, dispersing the role may cause inconsistency and confusion in the development process. There may also be problems of assigning priority to market interpretation in an organization whose primary mission is achieving functionality. Furthermore, functional sub-units may not be able to develop enough expertise for market interpretation.

The third approach is to merge the role of internal and external integrators. For example, a product manager (internal integrator) may also become a concept champion. In this latter role, the external integrator contacts the market directly, interprets market information, creates a product concept, and continually advocates the concept so that it is realized in product designs. The advantage of this structure is that both internal and external integration may be controlled by one person or group. In this sense, the integrated internal - external integrator is in charge of the total integrity of the development production consumption system. The risk is that such a critical role is in the hands of one group or person. Whether an individual or a small number of individuals within an integration group develop enough capabilities to cope with the significant responsibility this entails is a matter of concern.

How a firm chooses to organize for integrity is likely to depend on the character of the markets it serves, how difficult integrity is to achieve, and how important it is to competition. When markets are stable and customer needs well defined and focused on a set of measurable performance characteristics, external integration may be accomplished by dispersing the role into the functional organization, or identifying a particular functional sub-unit to accomplish the task. When customer needs are inarticulate and wholistic, where they emphasize total product integrity, external integration is more difficult, but more essential. The development project in that context requires leadership for maintaining coherence of the product concept and driving , intensive communication and dissemination of equivocal information. In that context, merging the internal and external integrators may be an imperative of strategy. As the rest of the paper indicates, that may be the relevant context for the automobile industry of the 1980s.

<u>ii. the interaction of structure and process</u>

The three dimensions of organizational structure that we have discussed thus far - the degree of specialization, the approach to internal integration, and the mode of external integration - are closely related to one another. A choice in one dimension sets up requirements and constraints in the other two. Although one can imagine many different combinations of approach to the three requirements for development organization, in practice the relationship among the dimensions implies that we are likely to see a clustering of approaches that are internally consistent. Performance in development, and in particular the degree of product integrity, is thus likely to depend on the mix and balance among specialization and processes for internal and external integration. To understand how organization and leadership affect development performance, we need to look closely at the overall pattern, the combination of structure and process, that gives a particular organizational form its distinctive character.

Our field work in the automobile industry uncovered a wide range of mechanisms and approaches to achieving internal and external integration. Moreover, we found significant differences in the degree of specialization. The most crucial differences, however, centered on the role of the product manager, and the processes product mangers used to achieve integration.

Although there are a variety of different approaches we have found it useful to group them into two broad categories to illustrate the differences in process. The first group of firms use what we call the "lightweight" product manager system. In this system, the organization was functionally specialized (styling, product engineering, test engineering, process engineering, marketing, etc...), while a product manager was assigned to coordinate development activities through liaison representatives from each function. The presence of a product manager introduced a relatively strong form of Galbraith's lateral linkages (Galbraith 1973), but "lightweight" product managers we found had limited responsibilities in several critical respects. They had no direct access to working level people, and relatively small status and power within the organization as a whole. They had relatively little influence outside of product engineering, and only limited influence within, and they had neither direct market contact, nor concept responsibility. Their main purpose was to *coordinate.* In carrying out that purpose, they collected information on the status of work, helped the functional groups solve problems, and attempted to facilitate the achievement of overall project objectives. They played the role of internal integrator as far as coordination of information, problem solving, and communication were concerned, but played little role in external integration. External integration was usually set up to be handled by a specialized department, either within one of the broader functional subgroups (e.g. product planning group within marketing), or as a separate department.

The second group of firms used what we called the "heavyweight" product manager system. As far as internal integration was concerned the product manager had broad responsibility and influence. The product managers were usually senior in the organization, and had direct access and relatively strong influence over the working level activities within the functions. Although they often worked through liaison representatives, the liaison personnel were influential and functioned as leaders for that particular project within their functional group. Unlike the previous set up, these product managers were not only responsible for internal coordination, but also for product planning and concept development. The managers of this second group stood out in their capabilities to formulate vehicle concepts and implement their vision in a coherent effort across the organization. As such they were outstanding champions of external integration.

The differences in structure between the "lightweight" and the "heavyweight" systems were not due solely to differences in organizational structure, but were also associated with different roles for the key players and thus with differences in associated behavior and organizational processes. Heavyweight product managers do not simply perform the same tasks as the lightweights but with more influence and experience. There were instead a set of specific activities and behaviors unique to their approach, especially sharp differences in the character and nature of leadership. Heavyweight managers would commonly take on the following roles:

> *Direct market interpreter.* As external integrators, the managers cultivated direct and continuous contact with customers. They supplemented the processed market information they received from the marketing group with the "raw" market information gathered directly from existing and prospective customers. They forecasted future expectations based on a variety of clues developed from market information, and exercised market imagination.
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> *Multi-lingual translator.* Effective product managers would be "multi-lingual". They would be fluent in the language of customers, marketers, engineers and designers. A product manager who had internalized and developed a product concept from equivocal and ambiguous market information, would have to translate that concept into direct and unambiguous expressions in each of the downstream languages, in order for all of the members of the project to understand it.
>
> *Direct Engineering Manager.* In the role of creating the product and maintaining the conceptual and technical integrity of the product concept, the product manager played much the same role as the conductor of an orchestra who creates coherent music with a distinctive concept. As an engineering coordinator, the product manager often took direct action to interact with engineers at the working level. Critical components that had a decisive influence on the product's attractiveness, or that presented difficult problems from the standpoint of the product concept, were the target of the product manager's closest attention.
>
> *Concept Infuser.* Product managers in this role would do more than coordinate and referee. They guarded the concept of the product from deterioration, and infused it into the product design throughout the engineering process. They might create conflicts in

order to protect or promote the product concept. They used engineering conflicts and design problems as opportunities to communicate the product concept to working level engineers.

Compared to the "lightweight" setup which emphasizes internal coordination, the differences in role and in process in the "heavyweight" system involved a much more concerted effort at external integration. And that difference appears to be important. In the next section we show that the level of external integration is connected to product integrity. These patterns of behavior were very strongly correlated with the achievement of products with outstanding levels of integrity. Furthermore, these high levels of integrity were achieved without compromising development speed and productivity. In other words, companies with high levels of external integration consistently introduced products of high integrity in a shorter time and using fewer engineering hours than their competitors.

IV. Methodology

Our study of product development involved the collection of data, primarily between 1985 and 1988, from 29 new car development projects conducted in 20 companies located in all major car-designing regions of the 1980s: the United States (3 companies); Western Europe (9 companies), and Japan (8 companies).[6] These companies accounted for about 70 percent of worldwide car production in 1986. Furthermore, our analysis also followed the evolution of a subset of the sample through a sequence of projects that covered the time interval between 1984 and 1991. In particular, Ford Motor Company and Nissan Motors were followed in detail and are the subject of the case histories in section VI.

Sample projects exhibited significant variety, ranging over large and middle size passenger cars, small passenger cars, small vans, and micromini cars and vans. Retail prices ranged from less than $5,000 to more than $40,000 as of mid 1987. Other areas of project content that exhibited considerable variation included number of body types, ratio of common parts, technical innovativeness, and degree of supplier participation in engineering. In order to be able to use project data as general indicators of product development organizations, we adjusted the original data for these differences to the extent possible.

Another potential problem was a bias of the sample projects in terms of market success or competitiveness. Because it was extremely difficult, for reasons of competitiveness, to persuade companies to disclose project data, we had to be satisfied with the projects they provided as samples. Most, understandably, provided projects that had met with relative market success. In light of this potential bias, it may be appropriate to regard these project as comparisons of "best practices in the period."

<u>i. sources and methods</u>

Data for the study was primarily of three types: company proprietary information; publicly available information; and opinions of experts from outside the companies. Proprietary information was collected through in-depth interviews, questionnaire surveys, and internal documents. A series of

[6] For reasons of confidentiality of data, the names of neither the participating companies nor the sample projects are disclosed.

questionnaires was distributed to key project participants for each of the sample projects studied. Unstructured interviews were designed to provide a "feel" for the reality of product development and generate working hypotheses, structured interviews to examine the hypotheses. Internal documentary materials--including organization charts, product planning documents, engineering schedule data, project accounting reports, materials for internal training and education programs, and internal reports and memoranda--used in the study were verified against the interviews and questionnaires.

Statistics on product lines, product histories, and basic product specifications were publicly available through popular car magazines and regional industrial associations. In particular we used 1985 and 1987 conformance quality data available from J.D. Power and Associates. The study relied on measures of customer satisfaction published by Consumer Reports, reports by J. D. Power and Associates, and "buyer's guides" published by popular magazines, to construct indicies of product quality.

Data on the quality of design were provided by an expert panel of professional car evaluators (technical editors of car magazines and freelance critics) formed especially for this purpose. Seven professional evaluators, two from the United States, two from Europe, and three from Japan, were asked to rate the quality of product design of recently developed models at each company in terms of such criteria as concept, styling, performance, comfort, value for money, and overall design quality. Their ratings were taken as partial indicators of product development effectiveness.

ii. development performance variables

Three dimensions of product development performance were measured: engineering hours (development productivity), development lead time, and product quality.

As measured in raw form through questionnaires and interviews, engineering hours includes the time not only of engineers, but also of technicians and other administrative personnel who participated directly in the project. It does not include hours of an overhead nature (e.g., the vice president of engineering), hours spent on process engineering and tool manufacturing, hours spent on engine-transmission development (except those required to match the engine-transmission to the vehicle), and hours committed by parts suppliers or body manufacturers (except when the entire process of vehicle engineering was subcontracted). Engineering hours are thus essentially hours spent within a project on concept generation, product planning, and product engineering for vehicle (primarily body and chassis) development.

Development lead time. Development lead time (or simply lead time) refers to the time in months between the beginning of a development project and market introduction of the first version of the model.[7] In addition to concept-to-market lead time, schedule data were collected for other development phases, including concept generation, product planning, advanced engineering, product engineering, process engineering, and pilot run.

Product quality. An expert panel was employed to measure product design quality, as described above. Each of the seven experts rendered an overall evaluation of each company's models in the most recent generation as of mid 1987.[8] Evaluation criteria were concept, styling, performance, comfort, value for money, and overall evaluation. Definitions of these criteria and the scale by which they were scored are shown in Table IV.1.[9] Experts were asked to take the target customer's view as much as possible, relative to rival models, at the time of introduction. Scores were designed to be adjusted for price differences across different product segments, as well as for differences in year of introduction.[10]

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[7] Development lead time begins with the first concept study meeting or when the participants of a concept study team are appointed. As versions developed by a project are often introduced to markets sequentially by body type or geographic market, introduction of the first version (typically sedans for the domestic market) is generally regarded as the end point for lead time. Although most of the companies studied maintained their schedule records in relation to start of production (or "SOP"), start of sales was chosen as the end point for lead time in accordance with the customer-based view of product development. The present study suggests that volume production typically commences one to three months prior to market introduction.

[8] The experts were asked to evaluate 68 individual models in the same manner.

[9] In order to minimize potential biases due to regional origins of the raters, the mean of the regional averages, instead of simple averages of the seven raters, were defined as total averages of the rating for each criterion. That is, the weight assigned to each rater for calculating the total average was 1/6 for U.S. and European raters, and 1/9 for Japanese raters. This seems to be a reasonable summary, as aggregate unit car production volume by the producers studied was roughly comparable across the regions: 8 million in U.S.-Canada, 8 million in Japan, and 9 million in Western Europe in 1987. The resulting total averages were then converted to rankings for further analyses.

[10] The original overall design quality index was intended to take within-segment price differences into account by incorporating "value for money" criteria. The design quality index without the price effect was then estimated using regression analysis. Specifically, the overall evaluation was regressed on the component criteria. Regression coefficients were regarded as weights each rater attached to the criteria and were used to calculate design quality evaluations without the "value for money" component. Averages of the new evaluations were regarded as price-unadjusted indices and converted to ranking for further analyses. Thus, two summary indices of design quality, one adjusted for within-segment price effect and the other unadjusted, were developed. In practice, the adjustments

Customer satisfaction and conformance data were also used.

iii. Organization and Process

Indices in this category were constructed from multiple indicators of organization and process. Table IV.2 lists several qualitative variables (0 or 1) representing dimensions of organizational structure and process particularly relevant to internal and external integration. The indices for internal and external integration were constructed by adding up affirmative cases for these variables or their subsets. Since each organizational variable represents part of the hypothetical "ideal pattern" for successful product development, aggregated, they make up consistency, or "ideal profile," indices.[11]

have little effect; the correlation between them is 0.94.

[11] See Van de Ven and Drazin (1985) and Venkatraman (1987) for a theoretical discussion of the use of the ideal profile index in studies of organization and strategy.

Table IV.1: Evaluation Criteria in the Design Quality Survey

SCALE	5: Superior to rivals–one of the best in class 4: Better than rivals 3: Average–same as rivals 2: Worse than rivals 1: Inferior to rivals–one of the worst in class
CRITERIA	Concept. How well the total product concept fits target customer needs; total balance and consistency in all aspects of the product rather than a specific aspect; overall attractiveness of a vehicle. Styling. Aesthetic aspects of body exterior; ignore "absolute" styling sophistication and evaluate styling relative to rival products in light of target customer needs (thus a score for a minivan can be higher than that for a sports car); ignore fit and finish. Performance. How quickly, smoothly, and safely the car starts, runs, turns, and stops; measures an assessment of overall performance relative to rival products in light of target customer needs and encompasses handling, acceleration, and braking. Comfort. Degree of comfort in driver, navigator, and rear seats, including measures such as ride, noise, vibration, interior aesthetics, roominess, air conditioning, and other ergonomic aspects relative to rival products in light of target customer needs. Value for Money. Overall appraisal, which may include initial cost, resale value, maintenance costs, and operating costs; these factors as a whole may vary in importance for different types of vehicles. Overall. Overall evaluation of a product's design quality.

Source: Instruction for respondents to the design quality survey.

Table IV.2 Organizational Indeces and Variables

Internal Integration Index Variables:
Product managers exist
Product managers are responsible for wide development stages/areas
Product managers perform product planning
Product managers are responsible for layout
Product managers perform concept generation
Product managers have significant influence (formally and informally) over product engineering
Product managers maintain direct contact with working engineers
Product managers maintain direct market contact
Liaison persons have strong influence over working engineers
Product managers have strong influence outside the engineering function

External Integration Index Variables:
Concept creators have strong influence over marketing decisions
Concepts are created through cross-functional discussion under the leadership of concept creators
Concept generation and product planning stages are merged
Concept creators perform product planning
Concept creators perform layout
Simultaneous development of concept and styling
Simultaneous development of layout, styling, and engine choice
Product managers perform concept generation

V. Analytical Results

Our analytical results are divided into two sections. First, we will explore the role of external integration as a critical variable in determining the design quality of the products developed by the organizations in our sample. In the second section we adjust the quality data for differences in lead time and productivity. This allows us to examine the challenges involved in achieving a high level of development effectiveness, defined as the simultaneous achievement of high design quality, high engineering productivity and short lead times. We will test the relationship between external integration and figures of merit for development effectiveness to show the critical role of external integration in the achievement of an effective development organization. Finally, we explore the issue of nonlinearity in the achievement of development effectiveness. While our data is insufficient for a thorough analysis of this issue, our results are consistent with a nonlinear model, similar in concept to that developed in section II.3.

i. product quality and external integration

Tables V.1 through V.4 display the basic regression results for models explaining quality performance. The previous section described the procedures we used to develop the quality performance and organizational data. Since the performance data were already corrected for product characteristics (price and project content), we added only a variable measuring supplier involvement and off the shelf parts (NH in the regression) and regional dummy variables . The NH variable measures the "scope" of the project -- how much of the total engineering effort was accounted for by new parts and components, designed and engineered in-house. We include it to allow for the fact that off-the-shelf parts may constrain the design and lower its quality, while suppliers may have less expertise than the auto companies. These are, of course, empirical issues.[12]

Table V.1 illustrates various models that explain several dimensions of design quality: concept, styling, performance, comfort, value, and an overall measure. These indices are based on an expert panel, as described in section IV. A lower score represents a superior quality performance. The

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[12] For more details, please see Fujimoto (1989).

effect of the external integration index is significant at or better than the 10% level in all models. The coefficients are all negative, indicating that a higher level of the external integration index is correlated with superior design quality performance.

Throughout the subsequent analysis we focus on the overall index (NDQ-all) to capture design quality. This is the measure which most closely represents the integrity of the system since it is a holistic assessment of the product's design. The concept index (NDQ-concept) is also representative of the coherence and fit of the system, since it is defined as "how the total product concept fits target customer needs; the balance and consistency in all aspects of the product..."[13] Supporting our hypothesis that patterns of external integration are correlated with the achievement of superior product integrity, the effect of the external integration index on models of overall and concept design quality is significant at the 1% level.

Table V.2 shows models relating the external integration index to other measures of quality performance (conformance, reliability). We include a regression for NDQ - all for reference. As expected, the effect of external integration is most significant in the overall design quality measure. The effect of external integration is much weaker (and not significant at the 10% level) on conformance quality, as represented by J.D. Power and Associates data from 1985 and 1987. This is not surprising since one would expect conformance quality to be determined by a broad set of variables including effectiveness in engineering problem solving, design for manufacturability, and manufacturing capability. Conformance quality is not a function of the integration of the ensemble of problem-solving outcomes in a car's design. Rather, it is determined by how well each individual effort is executed. In other words, it is not usually a function of the aggregate, but more commonly of the weakest links.

Similarly, the TPQ indices capture the overall customer satisfaction level after purchase. They are thus a function of many factors unrelated to integration variables in the product's design effort such as plant-level quality performance variables, as well as the dealership's service record.

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[13]Please see Table IV.1.

Tables V.3 and V.4 repeat the regressions including an index for internal integration, as well as a rough measure of specialization, represented by the number of members in the project. (Since for some observations, values of the number of project members had to be imputed, we have included a project member dummy variable in the models. This acquires a value of 1 for each data point with an imputed value of project members.) The results for the External Integration Index are largely unchanged. The evidence suggests, therefore, that the External Integration Index appears to be the most significant organizational element in the models, particularly for performance variables that are closely related to the integrity of the product.

Table V.1
Regression Results on External Integration vs. NDQ Indeces

Independent Variable / Dependent Variable / Model	NDQ concept	NDQ styling	NDQ perf.	NDQ comfort	NDQ value	NDQ all
	ENDQC	ENDQS	ENDQP	ENDQC	ENDPQV	ENDQA
constant	31	20.4	28.8	30	25.3	32.3
US Company	-6.3 * (2.5)	-8.8 * (3.4)	-4.3 * (2.2)	-6.8 * (3)	-4.9 (3.4)	-7.1 * (2.6)
European Company	-8.2 † (1.9)	-9.8 † (2.6)	-9.3 † (1.6)	-8.8 † (2.2)	-5.3 * (2.5)	-7.9 † (2)
NH (Scope Index)	-14.5 # (7.7)	1 (10.6)	-11.8 # (6.7)	-16.4 # (9.2)	-11 (10.4)	-16.7 # (8.1)
External Integration Index	-2.1 † (.4)	-1.4 * (.5)	-2.1 † (.3)	-1 # (.5)	-1.6 † (.5)	-2.1 † (.4)
Sample Size	29	29	29	29	29	29
Adjusted R-squared	.6	.3	.7	.4	.2	.6
Degrees of Freedom	24	24	24	24	24	24

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

Table V.2

Regression Results on External Integration vs. Quality Indeces

Independent Variable \ Dependent Variable	NDQ all	CQ-85 JD Power	CQ-87 JD Power	TQ1	TQ2	TQ3
Model	NDQ	CQ85	CQ87	TQ1	TQ2	TQ3
constant	32.3	24.4	9.4	12.2	14.2	22.3
US Company	-7.1 * (2.6)	4.6 (3.2)	9.6 (3.4)	7.6 † (2)	5.6 # (2.9)	.1 (4.6)
European Company	-7.9 † (2)	5.6 * (2.8)	9.4 † (2.9)	-.2 (1.6)	.4 (2.3)	1.5 (3.9)
NH (Scope Index)	-16.7 # (8.1)	-20.2 * (10.6)	-3.6 (11.3)	-4.7 (6.4)	-7.3 (9.3)	-11.1 (15)
External Integration Index	-2.1 † (.4)	-1.4 (.5)	-.4 (.6)	-.7 * (.3)	-.6 (.5)	-1.3 (.7)
Sample Size	29	23	23	25	25	24
Adjusted R-squared	.6	.4	.4	.6	.3	.032
Degrees of Freedom	24	18	18	20	20	19

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

Table V.3
Regression Results on NDQ indeces

Independent Variable \ Dependent Variable	NDQ concept	NDQ styling	NDQ perf.	NDQ comfort	NDQ value	NDQ all
Model	NDQC	NDQS	NDQP	NDQC	NDPQV	NDQA
constant	24.3	25.5	27.7	25.1	34.9	31.4
US Company	-7.2 * (2.9)	-8.2 (4.2)	-4.2 (2.7)	-4.1 (3.5)	-3.4 (3.9)	-6.9 * (3.3)
European Company	-6.7 * (2.5)	-10 † (3.5)	-9.3 † (2.3)	-5.6 # (3)	-6.9 # (3.3)	-7.2 * (2.8)
NH (Scope Index)	-10.4 (7.9)	5 (11.2)	-12.1 (7.3)	-12.7 (9.8)	-15.9 (10.7)	-15.4 (9)
Internal Integration Index	.8 (.5)	-.4 (.7)	.1 (.5)	.7 (.6)	-1.1 (.7)	.2 (.6)
External Integration Index	-2.7 † (.5)	-1.3 # (.7)	-2 † (.4)	-1.2 # (.6)	-.9 (.6)	-2.2 † (.5)
# of project members	.00054 (.002)	.00043 (.0029)	.0015 (.0019)	.0019 (.0025)	-.0023 (.0027)	-.0012 (.0023)
project member dummy	1.8 (2)	2.4 (2.8)	-1.4 (1.8)	-2.2 (2.5)	-1.5 (2.7)	.9 (2.3)
Sample Size	29	29	29	29	29	29
Adjusted R-squared	0.6	0.3	0.7	0.4	.3	.5
Degrees of Freedom	21	21	21	21	21	21

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

Table V.4

Regression Results on Various Quality Indeces

Independent Variable / Dependent Variable	NDQ all	CQ-85 JD Power	CQ-87 JD Power	TQ1	TQ2	TQ3
Model	NDQ	CQ85	CQ87	TQ1	TQ2	TQ3
constant	31.4	25	7.5	12.7	19.2	19.2
US Company	-6.9 * (3.3)	5.7 (4.2)	11.9 (4.4)	7.1 (2.5)	3.3 (3.5)	1.6 (5.9)
European Company	-7.2 * (2.8)	6 (4.4)	11 (4.6)	-.5 (2.7)	-3 (3.7)	2.4 (6.2)
NH (Scope Index)	-15.4 (9)	-19.2 (11.7)	-1.4 (12.2)	-4.9 (7.1)	-9.9 (9.7)	-10.2 (16.5)
Internal Integration Index	.2 (.6)	-.035 (1)	.3 (1)	-.048 (.6)	-.7 (.8)	.2 (1.4)
External Integration Index	-2.2 † (.5)	-1.4 (.8)	-.5 (.9)	-.7 (.5)	-.3 (.7)	-1.2 (1.2)
# of project members	-.0012 (.0023)	-.002 (.0034)	-.002 (.0036)	-.000059 (.0021)	-.001 (.0029)	-.0015 (.0048)
project member dummy	.9 (2.3)	-.1 (3.6)	-1.8 (3.7)	.9 (2)	2 (2.7)	-3.6 (5)
Sample Size	29	23	23	25	25	24
Adjusted R-squared	.5	.3	.3	.6	.2	-.1
Degrees of Freedom	21	15	15	17	17	16

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

ii. the simultaneous achievement of distinctiveness, time to market and efficiency

The achievement of distinctive products with superior levels of integrity may be the most critical dimension of performance for a development organization. In a market characterized by global competitors and demanding customers, products that do not achieve distinctiveness are doomed to failure. However, if we compare two organizations, both capable of producing automobiles with distinctive and well implemented concepts, the organization that is the fastest and most efficient would have a critical advantage. That organization would be able to introduce new concepts to the market place sooner than its competitor; moreover, the higher productivity would enable it to complete a larger number of projects with the same resources (and have a more complete or fresher product line, for example). In comparing the effectiveness of the organizations in our sample, it is important that we try to capture these added dimensions of development performance in our analysis. In this section we show that the level of external integration in an organization may be critical in achieving the high performance in these multiple performance dimensions.

Fig. V.1 shows our data on the achievement of overall design quality, graphed against the external integrity index in the organization. Only producers of high volume, mass market oriented product (where speed and productivity are crucial) are represented. What the plot indicates is that the achievement of a high level of design is indeed correlated to the patterns of external integration in the organization. However, there are also clear examples of organizations that achieved a high level of design quality with very low levels of external integration. In general, these organizations tended to exhibit very strong functional specialization, and delegated the function of external integration to a separate group. In other words, while an organizational subunit was indeed given the task of achieving external integration, many of the patterns described in section III were missing. While organizations of this type were indeed able to achieve high levels of external integrity in a subset of projects, they were not able to do so in a consistent, efficient and timely manner.

To investigate this further, we created an additional measure, which attempts to capture an organization's ability to simultaneously achieve high levels of product integrity, engineering productivity, and short time to market. The logic behind the measure is the following. Suppose a firm has the capability to develop products quickly and efficiently. In order to compete, the firm will also have to achieve a high level of design quality. Low design quality will thus lead to low development performance, regardless of the level of engineering productivity or time to market achieved. As the level of design quality achieved increases, however, the organization will be increasingly able to leverage its superior time to market and productivity. A firm's performance in time to market and engineering productivity will thus essentially be amplified by its internal capabilities to produce vehicles with high levels of product integrity. This logic was reflected in a number of figures of merit we developed for the companies in our sample. The following measure Pn is representative of the set. Similar results were obtained with the other specifications.

The measure Pn was composed by first ranking the performance of the various organizations in productivity, time-to-market and overall design quality. These ranks were then transformed into scores[14], a higher score indicating superior rank. These scores were then combined into an overall figure of merit, as follows.

$$Pn = QSCORE^{n}(TMSCORE + EPSCORE)$$

where Pn is the figure of merit, QSCORE is the score based on design quality, TMSCORE is the score based on time to market, and EPSCORE is based on engineering productivity. [15]

Figures V.2 and V.3 display values of the Pn figure of merit plotted against levels of the external integration index, with n=1 and 2, respectively (P1 and P2). TablesV.5, V.6 and V.7 summarize our regression results. The correlation between P(n) and the external integration index is striking. The firms that scored highest on combined performance in product design quality, time to market and engineering productivity exhibited a common pattern that appears well captured by the External Integration Index. Moreover, the plots also indicate that firms that had achieved high

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[14]The score corresponded to the inverse rank of the organization: i.e. 29 = highest performance, 1= lowest.

[15]While this choice of functional form is arbitrary, it represents the challenges of the industry. A variety of other functional forms were also attempted, and the results were largely independent of the functional specification used, as long as the imperatives of time to market, productivity and high quality were factored in simultaneously.

levels of design quality with low levels of external integration (captured in Fig. V.1) had done so sacrificing engineering efficiency and time to market.

The patterns in Figs. V.2 and V.3 also appear distinctly nonlinear. While our evidence here is only very preliminary, the case could be made that the benefits of external integration are only captured by the firms that exhibit a relatively complete pattern. In other words, exhibiting a small subset of the mechanisms leading to effective external integration might not lead to a discernible improvement. As more of the patterns are implemented, the effectiveness and efficiency of the process might change rather sharply as the integration processes overwhelm locally optimizing behavior. The conceptual model developed in section II.3 might be a useful guide in thinking about the issue.

While our data set is by no means large enough to conclusively test these hypotheses, models NDPQ5, P1FM5, and P2FM5 provide some support. In these specifications, regressions were run on the sample after excluding both high end producers and the four top performing organizations. With the top performers out of the sample, the relationship between the external integration index and design quality, P1 or P2 figures of merit is no longer significant at any level. The implication is that the estimated relationship between external integration and product integrity is driven by the top firms that have achieved superior performance through a complete pattern of external integration efforts.

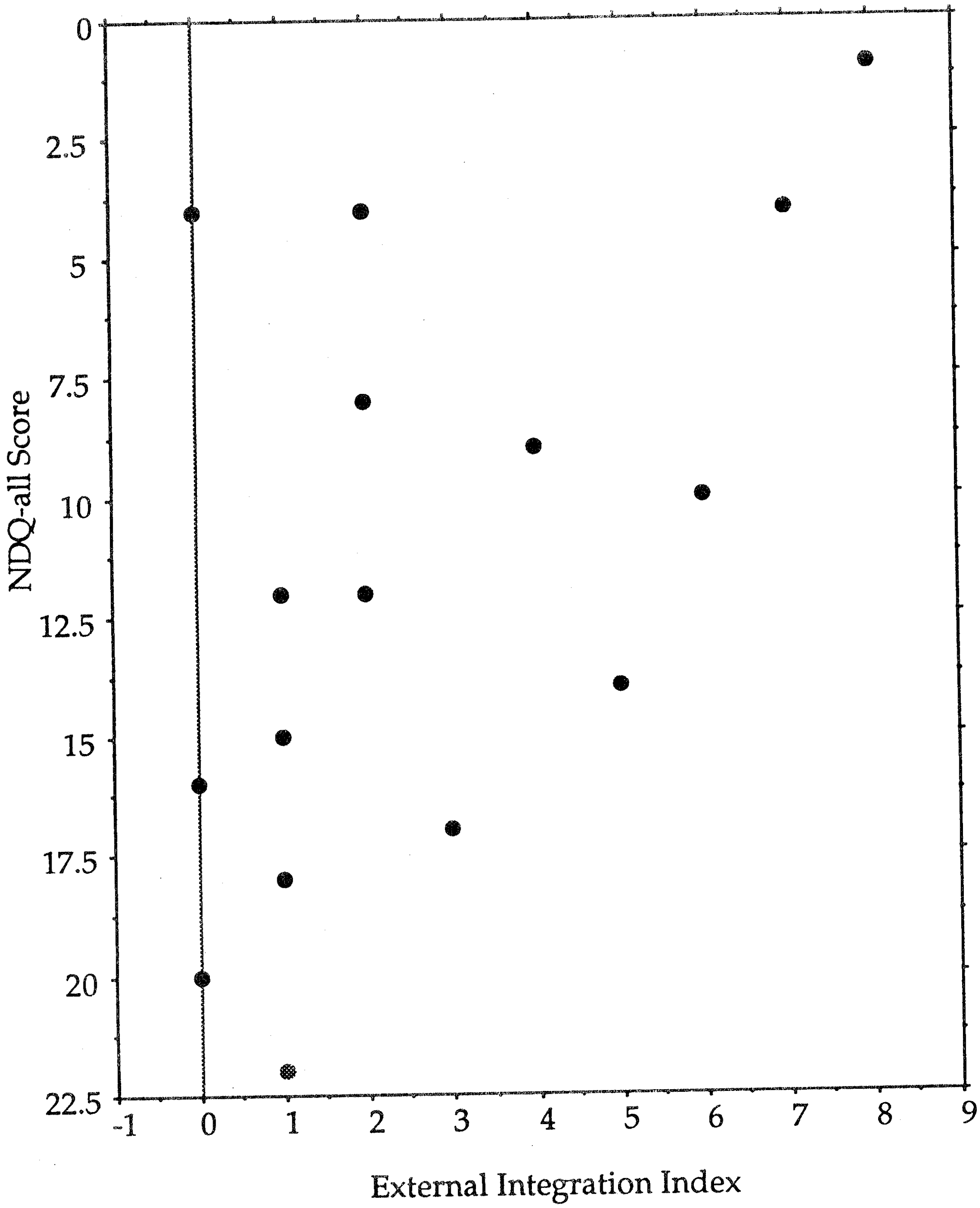

Fig. V.1: The External Integration Index vs. the NDQ-all score.

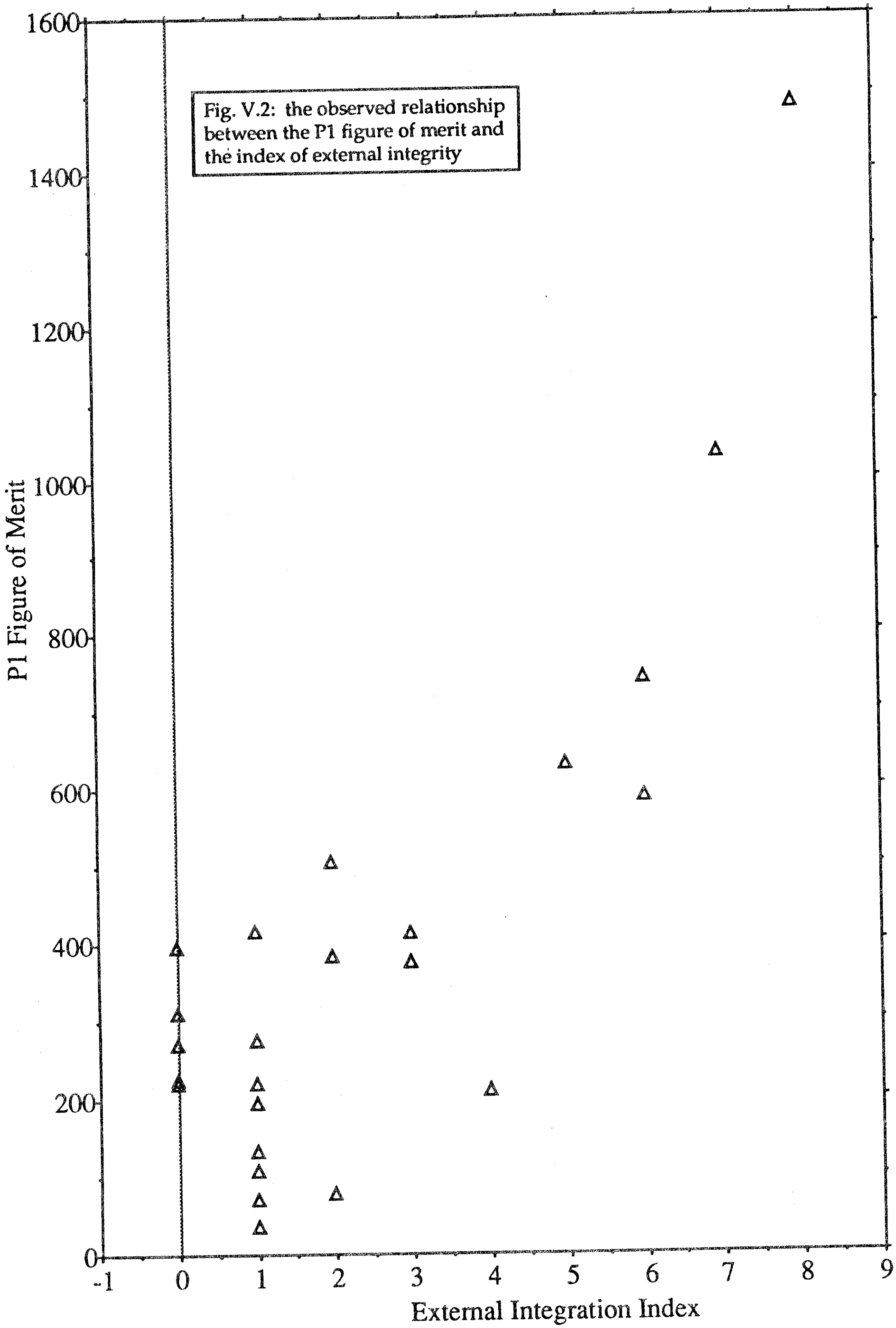
Fig. V.2: the observed relationship between the P1 figure of merit and the index of external integrity
P1 Figure of Merit
External Integration Index
1600
1400
1200
1000
800
600
400
200
0
-1
0
1
2
3
4
5
6
7
8
9

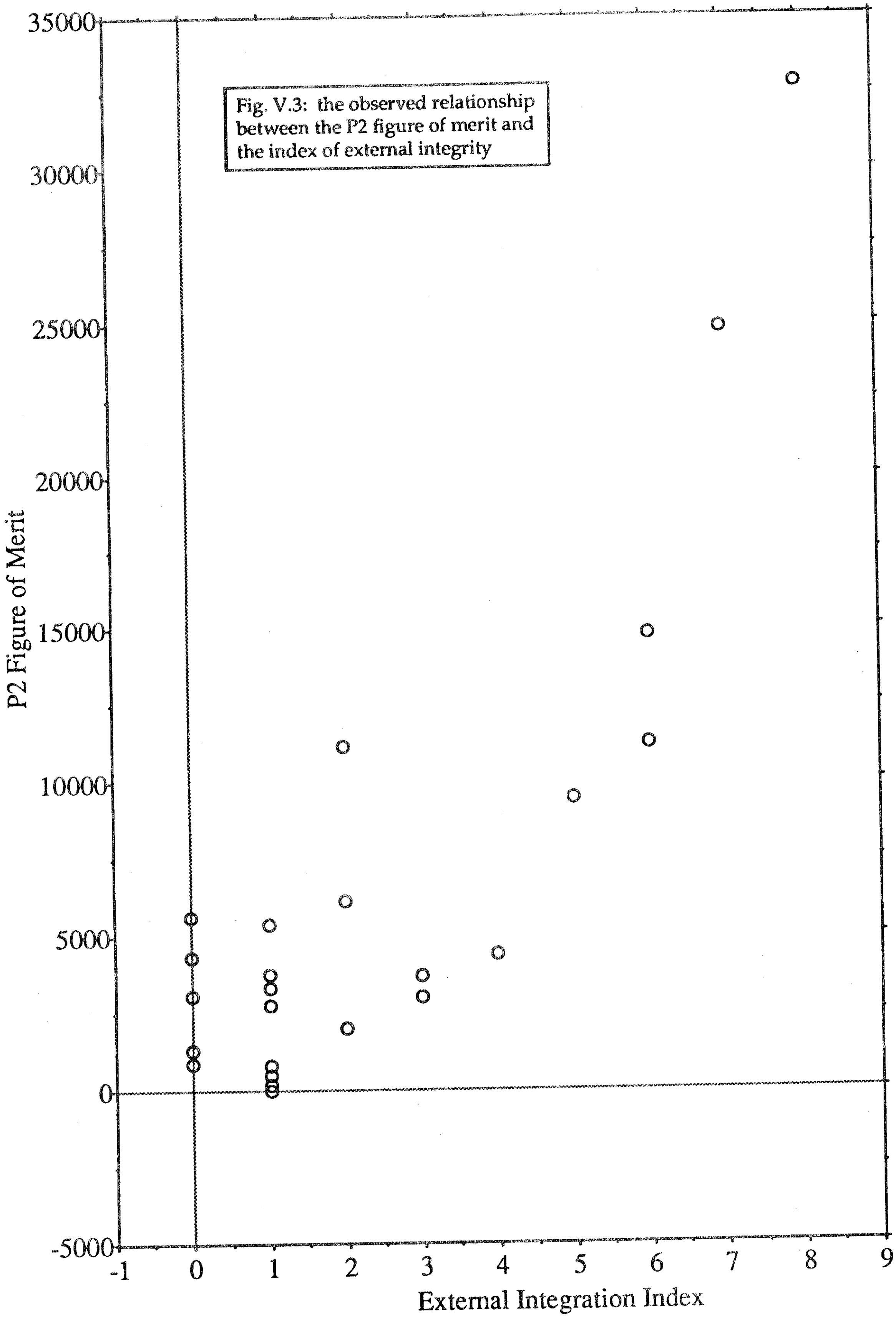
Fig. V.3: the observed relationship between the P2 figure of merit and the index of external integrity
P2 Figure of Merit
External Integration Index
35000
30000
25000
20000
15000
10000
5000
0
-5000
-1
0
1
2
3
4
5
6
7
8
9

Table V.5
Regression Results on NDQ-all (Product Integrity Index)

Independent Variable / Dependent Variable / Model	NDQ-all					
	NDQ1	NDQ2	NDQ3	NDQ4	NDPQ5	NDPQ6
constant	30.3	32.3	37.9	34.6	32.5	27.9
US Company	-7 * (2.7)	-7.1 (2.6)	-2.7 (3.3)	-7.3 * (2.6)	-6 * (2.5)	-.112 (3.12)
European Company	-7.2 † (2.5)	-7.9 (2)	-7.9 * (3.3)	-7.1 † (2.7)	-7.1 * (2.7)	-3.93 (2.52)
NH (Scope Index)	-15.4 (8.7)	-16.7 (8.1)	-26.5 * (10.90	-17.1 (8.7)	-19.2 * (8.3)	-22.8 (11.2)
Internal Integration Index	.2 (.6)		-1.1 (.6)	-.5 (.7)	-.2 (.7)	
External Integration Index	-2.2 † (.5)	-2.1 (.4)		-1.8 † (.6)	-.4 (.8)	
Complete Sample	X	X	X			X
High End Excluded				X		
High End and Top Performers Excluded					X	
Sample Size	29	29	29	25	20	29
Adjusted R-squared	0.6	0.6	0.2	0.5	0.5	0.2
Degrees of Freedom	23	24	24	19	14	25

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level

Table V.6
Regression Results on P1 Figure of Merit

Independent Variable \ Dependent Variable / Model	P1 Figure of Merit				
	P1FM1	P1FM2	P1FM3	P1FM4	P1FM5
constant	175.9	490.4	-123.3	451.8	588.6
US Company	116.1 (139.2)	92.6 (140.7)	-50.3 (153.2)	132.5 (143.9)	37 (83.1)
European Company	185.4 (127.9	81.7 (105.1)	212.6 (151.1)	107.7 (147.6)	105.4 (88.5)
NH (Scope Index)	-487.9 (447)	-680.9 (432)	-55.8 (505)	-754.5 (474.9)	-591 (274)
Internal Integration Index	39.2 (28.6)		91.7 † (27.9)	10.3 (35.9)	-8.2 (21.9)
External Integration Index	86.7 † (26.6)	107.4 † (22.4)		109.3 † (30.3)	8.7 (25.5)
Complete Sample	X	X	X		
High End Excluded				X	
High End and Top Performers Excluded					X
Sample Size	29	29	29	25	20
Adjusted R-squared	0.5	0.5	0.3	0.5	0.1
Degrees of Freedom	23	24	24	19	14

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level

Table V.7
Regression Results on P2 Figure of Merit

Independent Variable \ Dependent Variable / Model	P2 Figure of Merit				
	P2FM1	P2FM2	P2FM3	P2FM4	P2FM5
constant	-3523	2021	-12086	-131.8	4889.9
US Company	4025.8 (3184)	3611 (3168)	-737.1 (3805)	4359.4 (3436)	1761.6 (1551.6)
European Company	5574 (2927)	3745 (2368)	6531 (3751.5)	4132 (3525)	3522.7 (1652.1)
NH (Scope Index)	-3814 (10226)	-7217 (9730)	8554 (12542)	-7756 (11343)	-4590.7 (5116.5)
Internal Integration Index	691 (653)		2193 † (693)	411 (858)	-236.9 (409.1)
External Integration Index	2483 † (609.4)	2846 † (504)		2718 † (723)	297.8 (476.9)
Complete Sample	X	X	X		
High End Excluded				X	
High End and Top Performers Excluded					X
Sample Size	29	29	29	25	20
Adjusted R-squared	0.5	0.5	0.2	0.5	0.2
Degrees of Freedom	23	24	24	19	14

Note: Standard errors in parenthesis

† Statistically significant at the 1% level
* Statistically significant at the 5% level

VI. Case Studies

The analysis in the previous section focused on a crossectional data set that described a large fraction of the automobile industry during the mid to late 1980's. To supplement our crossectional analysis, we have adopted a longitudinal perspective, focusing on a few companies, and observing their evolution in some detail. The following two case summaries describe the evolution of Nissan Motors and Ford Motor Company over a time period of about ten years. The case histories reinforce the analytical insights of the previous section, in particular the critical nature of external integration processes in development effectiveness.

i. The Case of Nissan

One of the most striking examples of organizational achievement of high integration in the late 1980's and early 1990's has been Nissan. Viewed by many Japanese observers in 1985 as an ailing giant, Nissan in 1991 is recognized as a revitalized company. Company and product images recovered rapidly, and the turn-around story has been a popular topic in Japanese business journals since 1988.[16] Many–insiders and outsiders–point to fundamental changes of culture and organization, particularly in product development. The number two auto company in Japan, Nissan was, in the domestic market, associated with advanced technology. But its technological prowess was a trap. Nissan continued to rely heavily on its component technology to attract and satisfy customers, who were increasingly looking for product integrity.

New Nissan products in the early 1980's, though fully loaded with novel component technologies and high-performance gadgets, somehow lacked a coherent and distinctive message. Rated performance in the catalog was impressive, but product concepts tended to be confusing, styling was conservative, and layout was old. The entire product line possessed neither consistent identity nor clear differentiation. This weakness in product integrity, together with a weaker dealer network, historic labor problems, and lower productivity compared with Toyota, all hurt Nissan's market

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[16] See Ikari, Yoshiro. Nissan Ishiki Daikakume (Great Cultural Revolution of Nissan), Diamond, Tokyo (1987, Japanese); Shibata, Masaharu, Nani ga Nissan Jidosha wo Kaetanoka (What Changed Nissan?), PHP, Tokyo (1988, Japanese). The account which follows draws on this literature as well as interviews with managers and engineers at Nissan.

performance during the mid 1980's.[17] The crisis culminated in 1986, when the company reported its first biannual operating loss in more than thirty years. Domestic market share, once over 30 percent, was close to 20 percent and still dropping.

Product development played a leading role in Nissan's efforts at greater organizational integration, which began in the mid 1980's. Nissan product managers were traditionally coordinators within the engineering function.[18] In the early 1980's, product managers played a somewhat greater role in planning and inter-functional coordination, but external integration (concept creation) continued to be problematic. Product managers did not have clear leadership in the very early phase of product development when the product concept was still embryonic. They tended to react to sales and top management with compromises rather than take leadership in formulating a clear concept. Lacking significant direct contact with customers, they tended to be caretakers of obscure vehicle concepts (e.g., me-too styling, excessive engine variety, lack of inter-model differentiation) driven by short-term competitive pressures. Finally, communication and coordination between engineering and production was low for a Japanese company, which sometimes caused problems of design manufacturability.

Efforts to change Nissan's organization and culture began around 1985 as engineers and managers in product development sought a new development process and a new image in the minds of customers. Spurred by a sense of crisis, early informal changes focused on a new attitude towards innovation in product concepts and increased customer orientation among middle managers and working level engineers.

With the encouragement and support of a new CEO (Yutaka Kume), more formal changes followed. Managers in product development created a task force to investigate current problems at the working level and make proposals. Consensus slowly emerged for a more integrated development organization, a stronger concept creation function, and an open and customer-oriented culture. Major organizational changes implemented in 1986 and 1987 included the creation of three product management departments. Each specialized in a group of products that shared a basic product concept

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[17] For a historical comparison of Nissan and Toyota, see Cusumano (1985).

[18] For a history of Nissan's product development organization, see Ikari (1981) (1985).

and combined empowered product managers and marketing planning. The new system established product managers as external integrators who infused future customer expectations into product details. Structural changes were accompanied by efforts to change the attitudes of middle and top managers, and sales was reorganized to emphasize inter-product coordination and customer orientation.

In particular, the development process at Nissan went through a number of specific evolutions. Product managers began to take individual responsibility for each product concept. Their formal position in the organization was raised in rank and became equivalent to that of a functional head. Furthermore, they acquired strong informal influence over the marketing and manufacturing organizations. The product managers and their assistants also strengthened their activities to establish direct contact with the users, as well as professional drivers, journalists, and critics. Finally, direct interventions by program managers on working level engineers became more common.

Market results began to improve. Products changed first. Critics generally agree that Nissan models after late 1987 are characterized by distinctive vehicle concepts, a clear focus on the target market, cleaner interior-exterior styling, and a better fit between the technology and character of the vehicle. The Nissan Cedric, Bluebird, 240SX, Maxima, and 300ZX have brought the company into strong competition with Toyota and Honda for leadership in vehicle concept and styling in the Japanese domestic market.

Nissan changed in many of the ways we have discussed in this manuscript. It emphasized stronger internal-external integration, intense information exchange, the primacy of the concept creation function, and a focus on product integrity. The result, a major improvement in the distinctiveness and appeal of Nissan's products, played a critical role in Nissan's recovery and clearly illustrates how organizational change can influence market performance.

ii. The Case of Ford

In the early 1980's, the Ford Motor Company faced a dismal future: quality was far below competitive standards and market share was falling. In addition, the company's financial position was precarious and layoffs were ongoing. By the end of the decade, however, Ford had introduced a string of successful new products. Indeed, the Ford Explorer, introduced in the spring of 1990, may prove to be Ford's most successful product introduction ever. Despite the fact that it debuted in a down market, the four door, four wheel drive sport utility vehicle sold extremely well.

Behind the Explorer and other successful Ford products (such as the Lincoln Town Car, Probe, and Taurus) lay a decade of changes in Ford's management culture. A pivotal event in this process of change was the development of the Taurus, a family sedan with the styling, handling, and ride of a sophisticated European car. As a product, the Taurus offered a distinctive yet integrated package in which advanced aerodynamic styling was matched with a new chassis, independent rear suspension, and front wheel drive layout.

The Taurus was also a crucial "vehicle" for bringing about change in the development process at Ford. Traditionally, Ford's development efforts had been strongly functional in character. The development process reflected this orientation: it was schedule driven, relatively sequential in the way it organized activities, and punctuated by a series of detailed reviews that were highly proceduralized and bureaucratic. In developing the Taurus, however, Ford sought to break down barriers between functions by creating "team Taurus," the core of which included principals from all the major functions and activities involved in the creation of the new car. The team served to coordinate and integrate the development program at the senior management level, and was the first step on a long path of organizational, attitudinal, and procedural change. The team was initially headed by Lou Veraldi, at the time the director of large car programs at Ford. As the development of the Taurus proceeded, however, it became clear that integrated development, and in particular development that required much less time to complete, necessitated more than a high level core team under the direction of a single manager.

Since the Taurus, Ford has been progressing towards a more highly integrated mode of program management. Taurus' outstanding success had been achieved after many years in development and a large number of engineering hours. While the *vision* of a highly integrated organization had been implanted at Ford, much remained to be done to assure the implementation of a structure and process that could develop well integrated products consistently and efficiently. This goal required the difficult challenge of implementing new practices at all levels of the organizations, from the leaders to the working level engineers. It involved empowering the program managers to make the required decisions, and giving them the opportunity to develop the necessary skills. It also involved developing working level engineers in different departments with the capabilities to work together, to join different perspectives and cultures towards the efficient achievement of coherent results.

In order to cut lead time, improve quality, and bring products to market that were distinctive and attractive to customers, Ford launched what it called the "concept to customer" (or "C to C") process in the mid 1980's. Led by a hand-picked group of engineers and product planners, the C to C project took as its mission the creation of a new architecture for product development. Its specific focus was to create a sequence of development activities and associated milestones that would result in a 48 month lead time on major new development programs while improving product quality and creating products with attractive features and performance.

The C to C team was led by a senior experienced engineer, and its members were drawn from most of the important engineering groups as well as product planning and marketing. Through extensive interaction with senior functional managers, the group sought in the first instance to identify the overall structure of the current development process at Ford. They determined how the process actually worked, where the milestones were, and what materials were used to make decisions. The C to C team also became the focal point for significant benchmarking activities in which Ford compared itself to its major competitors and companies outside the auto industry whose success in product development was well documented. The benchmarking activities, as well as the intensive analysis of the internal process, revealed several opportunities for significant improvement. But the group also recognized the importance of establishing fundamental principles for the creation of a new development architecture. Through a series of presentations and extensive discussion within the development organization at

Ford, the group articulated and sought to create consensus around critical milestones, decision points, and criteria for decision making, as well as around patterns of responsibility and functional involvement.

Drawing in part on the recommendations of the C to C team, the Ford development organization went through a number of major changes to implement a more integrated development process. In particular, program management was formally implemented in 1987. We witnessed the evolution of Ford's development organization through the study of three projects, the 1989 Thunderbird/ Cougar, the 1988 Continental, and the 1992 Crown Victoria.

Figure VII.1 sketches the structure of the Ford development programs during early 1990. The core of the program, made up of vehicle engineering, development, planning and the controller's office was put under the direct influence of the program manager, and was completely collocated during the Crown Victoria program. Contact with the other organizations was maintained principally at two levels. The Program Steering Team (PST), led by the program manager, was responsible for overall leadership, making the most crucial system-level decisions. The PST involved managers from all of the groups listed in Figure VII.1, including manufacturing and marketing representation. Integration at lower levels of the program was insured by the Program Module Teams (PMTs), also involving multifunctional representation, each focusing on one of the different subsystems involved in the product's design.

Overall, in the three car programs studied, we noticed a considerable evolution towards a well integrated development process. The earliest emphasis was on improving the efficiency and coherence of the development process, by focusing on internal integration. The most marked improvements were found in the core team, at the center of Figure 1. The level of integration decreased somewhat as we moved away from the core, where engineers were not dedicated to the programs. The PMTs had made a very significant difference, however, provided a focus for communication, discussion, and resolution of issues surrounding a component or subsystem. However, true *working level* integration had not yet been completely achieved, as age-old differences in culture and outlook were sometimes found to clash.

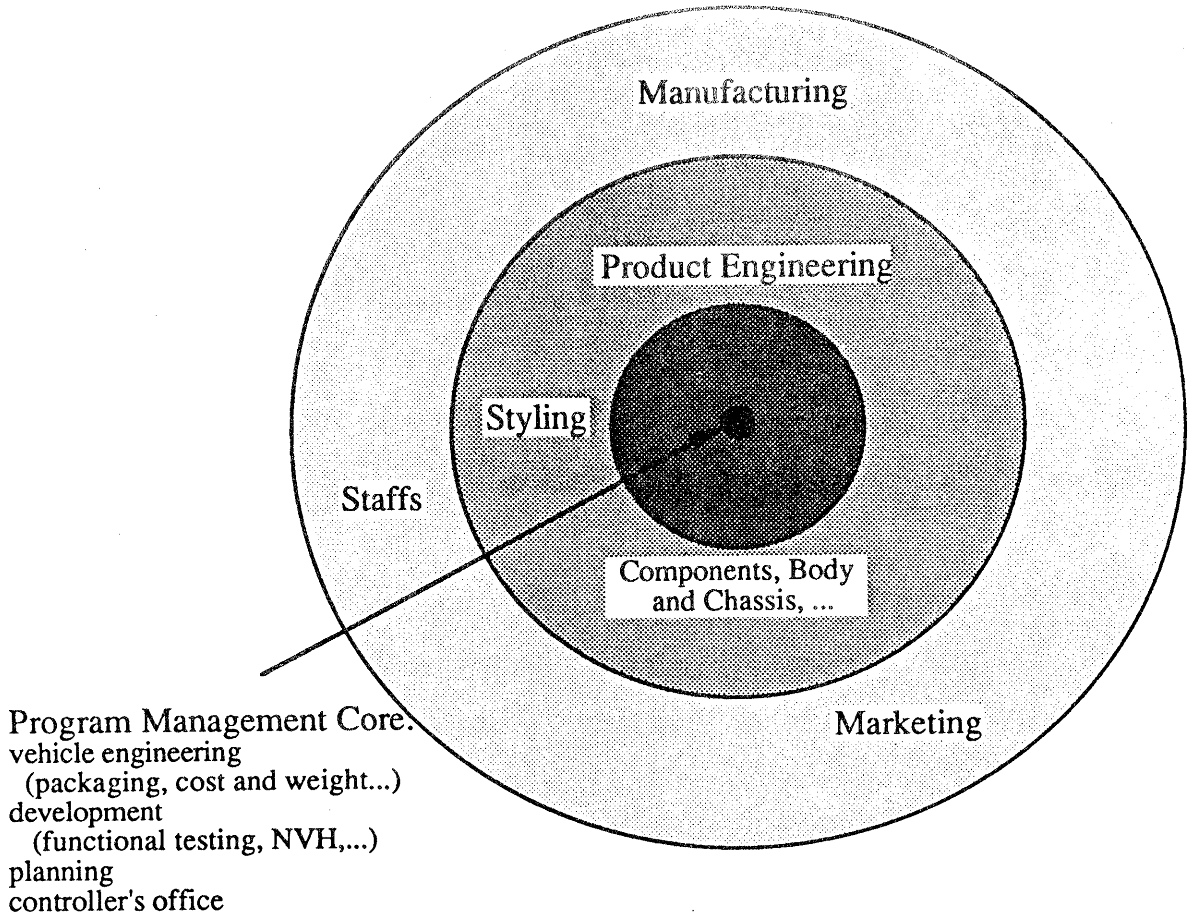

Fig. VII.1 Program structure at Ford during early 1990. Distance from the center signifies decreasing influence of the program manager.

In more recent years, the Ford organization has begun to focus on external integration processes. During some of the earlier programs, program management and the program team did not always seem fully empowered by the organization to develop their own view of what the vehicle concept was supposed to be. The early project stages involved extended negotiations between the program management team and top management, styling, and marketing. These discussions continued through a substantial part of the project, and did not always result in the creation of a precise and explicit concept. Therefore, ambiguities left in program objectives would sometimes inhibit the efficient resolution of complex multifunctional problems, sometimes contributing to project delays. By 1990, Ford had begun to target these problems, and was in the process of redefining the roles of program management and the program team to emphasize external integration processes.

Overall, the results of the Ford efforts have been quite positive. The Lincoln Continental was developed using about 25% less engineering hours than the average U.S. car program of the mid 1980's, and is a very popular car. The Crown Victoria program was one of the first to be staffed by engineers with extensive *previous* experience in integrated development projects. The engineers had thus developed the capability to work with each other and with other functions, improving the efficiency and effectiveness of their interactions. This resulted in a very well integrated and coherent program achieving impressive levels of product integrity, as shown by outstanding early market research and focus group results.

In conclusion, while a lot of progress had been made, the implementation of a relatively complete set of organizational patterns for external integration had not yet been fully achieved by late 1990. The consistency, efficiency and speed of product development, while greatly improved over previous programs, had not yet reached its full potential. However, in 1990, the evolution of Ford's development organization was still ongoing, and the near future should witness a number of additional improvements in its efficiency and effectiveness.

VIII. Conclusions

In this manuscript, we have argued that external integration is a critical dimension in a product development organization. In our data sample, which covers a very substantial portion of the projects performed in the world automobile industry over the last ten years, no other organizational variable appeared as influential in determining the ability of an organization to develop products with a high level of product integrity. Moreover, specific organizational patterns and processes for external integration appeared to be crucial in the timely and efficient achievement of superior product coherence, fit and integrity.

Our analysis has taken both crossectional and longitudinal approaches. We have examined the correlation between the existing patterns of integration in organizations and their relative development performance. Furthermore, we have studied sequences of projects in selected organizations to observe how the implementation of specific integration processes and capabilities may have led to performance improvement. In both the crossectional and longitudinal data, the importance of consistency in organizational process was underlined. The achievement of superior product integrity did not seem linked to a few specific actions or tasks. Rather, it was the combined contribution of a consistent pattern of organizational capabilities, processes and procedures that differentiated the most successful companies.

These observations leave open a number of areas for future research. For example, the existence of critical underlying level of capability for external integration should be investigated further. From our observations, a few limited efforts at external integration did not necessarily provide a clearly observable return. On the other hand, in a number of organizations, we observed that a substantial pattern of capabilities and methods provided a "critical mass" for external external integration processes. Multiple mechanisms appeared to reinforce each other and to provide the organization with the ability to develop complex products with a coherent concept, well aligned to fulfill the customer's expectations. These observations provided the motivation for the simple conceptual model described in section III.3. Additional work will be necessary to further characterize this issue.

The challenges of modern competitive environments have created an imperative to develop products with distinctive and coherent concepts faster and more efficiently than ever before. In our studies we have found a distinct pattern of organizational processes, methodologies and structures to be important in the achievement of these goals. These focus on the capability by an organization to develop a clear concept of future customer expectations and objectives, as well as on its ability to effectively translate and implement that vision throughout the multitude of individual problem solving steps that are required to design the product.

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