1 The Field-Based Framework of Industries and Firms

1.1 Purpose and Scope

This Element explores the evolution of the automobile industry and the strategies of its leading manufacturing firms between the late nineteenth century and the early twenty-first century. We focus on manufacturers of passenger cars, such as Daimler/Benz, Ford, GM, VW, Toyota and others, and offer additional descriptions of truck makers, parts suppliers, automobile dealers, and other service providers when necessary.

Although most of today's big businesses, striving for continued growth, have diversified into multiple sectors (Chandler, 1962), the world's leading firms in automobile manufacturing are heavily dependent on this single industry, its total being large in global terms (nearly 100 million units and $3 trillion per year in the late 2010s, possibly reaching 100 million units some time in the 2020s). We therefore regard these manufacturers as nearly single-business firms and analyze their competitive performance, strategies, and operations. Our exploration mainly covers the period between the 1880s (birth of internal combustion engines) and the 2010s, with some predictions about the 2020s and beyond.

1.2 The Field-Based Approach for Analyzing Industries and Firms

The framework adopted here to analyze a manufacturing industry and its firms is essentially evolutionary and bottom-up. More specifically, we regard a *manufacturing site* (e.g., factory, development facility) and a *product* (and other economic artifacts, such as processes) as our two basic units of analysis, from which we start our investigation of the automobile industry and firms from the bottom-up.

Both an industry and a firm can be seen as a collection of sites, as well as a collection of products. So, this Element opens with an analysis of these two. We then deal with the next question, that is, which characteristics of sites and products are worth emphasizing? In describing the manufacturing sites and products of the auto industry, we pay special attention to their *design* and *flows*. Let us now sketch out this design-flow view of manufacturing (details are discussed in later sections).

1.3 Design-Flow View of Manufacturing

In our design-flow view of industries, *design* refers to information about the relations among the functional and structural parameters of an artifact, such as a car or a computer (Simon, 1969; Suh, 1990). As Figure 1 illustrates, a product (e.g., an automobile) – as well as all its related artifacts, such as production

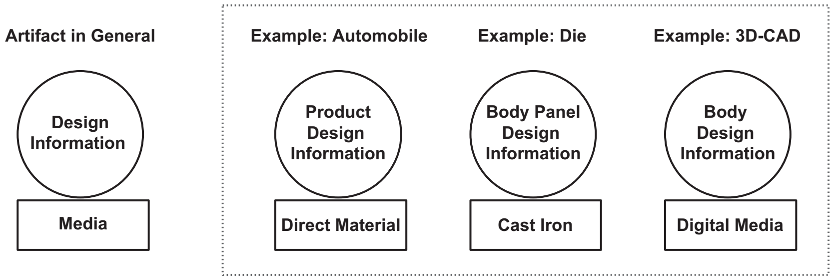

Figure 1 Productive resources as combination of value-carrying design information and its media.

equipment, jigs and dies, standard operating procedures (SOPs), workers' skills, numerical control programs, detailed engineering drawings, 3D-CAD models, prototypes, design sketches, mock-ups, product specifications, and product concept proposals – can be interpreted as a combination of design information and its media (e.g., direct materials, digital media, drafting papers), which may be called a productive resource (Penrose, 1959). We thus examine the automobile industry and firms starting from a design analysis of automobiles as products.

Then, there are *flows* of design information among productive resources. The firm's production, product development, procurement and sales activities all involve flows of design information, eventually reaching the customers or users of the product in question.

Design information is the source of value-added of a product, as well as its industry. Let us assume, for instance, that a coffee mug (its design information and medium) costs $5 and that the unit cost of its direct material (i.e., medium) is $1 per piece. Then, its value-added is $4, which is nothing but the value of the design information added to the mug. Thus, a product's design information is the source of its value-added. The same logic holds true in the case of automobiles.

It follows from this analysis that the process of *manufacturing*, including production and development, can be broadly defined as *flows of value-carrying design information among productive resources* (*and ultimately to the customers*), as indicated in Figure 2. For instance, stamping operations to manufacture a car's body panels involve flows of design information from press dies to sheet steel. A car's product development includes flows of incomplete design information from engineering drawings to prototypes and their test results, as well as from body design (3D CAD) to die design (CAM) and physical dies. Hence, its production is nothing but transfer of design information from the process (e.g., die) to the product (e.g., body panel).

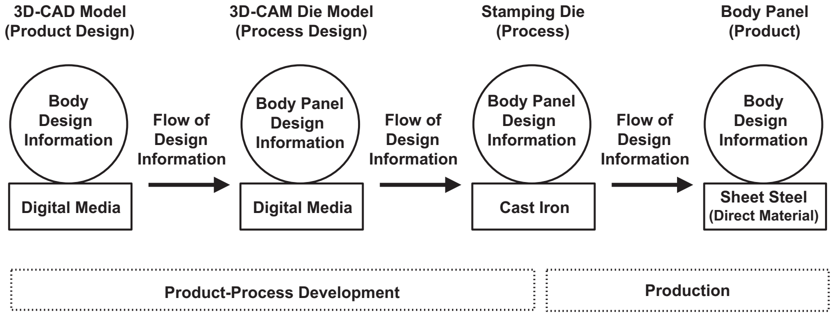

Figure 2 Manufacturing as flows of design information between productive resources (example of the automobile body).

Furthermore, to the extent that a complex artifact can be described hierarchically (Simon, 1969), we view an *industry* as total flows of value-carrying design information among *multiple hierarchies of productive resources* concerning a set of similar products, including the products' concepts, functional designs, structural designs, process designs, as well as their actual functions, structures, and processes in the physical space (Figure 3). As discussed later in the Element, these hierarchies and flows involve *transaction*, *competition,* and *complementation* among the productive resources of industries and firms.

Within this framework, a *manufacturing site*, or *genba* in Japanese, is nothing but a place, or a part of the industry, where value-carrying design information flows, or an organization of workers and other productive resources that govern or improve such flows. An industry can be seen as a set of manufacturing sites that deal with similar design information. Incidentally, this notion of "managing and improving flows of value-added in genba" is central to the so-called Toyota Production System (TPS).

Thus, in our bottom-up approach for analyzing the automobile industry and firms, our initial focus is on (1) the design characteristics of automobiles as products and (2) the flows of design information in automobile manufacturing sites. These two aspects are further discussed in Sections 2 and 3, respectively.

1.4 Product Architecture and Manufacturing Capability

Based on these preliminary observations, this Element proposes an *evolutionary framework* to analyze the automobile industry and firms that consists of (1) *organizational capability* of automobile manufacturing sites, (2) *product architecture* of the automobile, and (3) *competitive performance* of sites, firms and industries. These three components of our framework are all associated with

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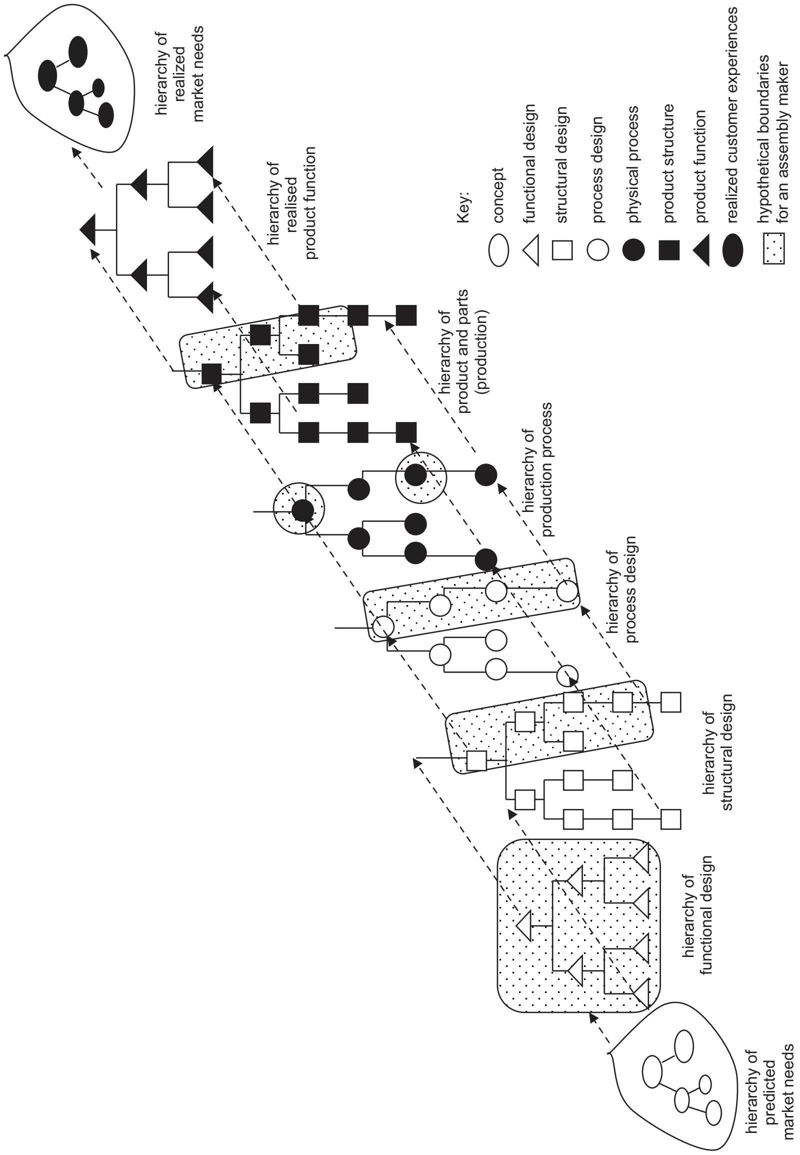

Figure 3 Industry as multiple hierarchies of design information.

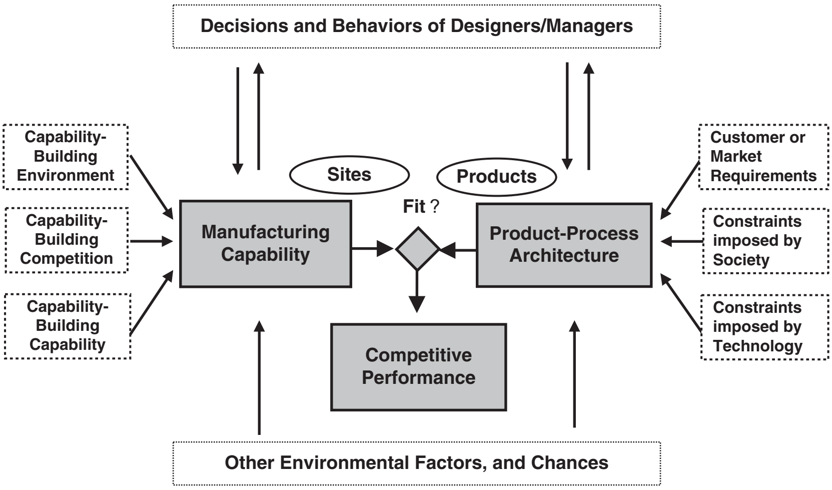

Figure 4 Design-flow view of industries: Capability, architecture, and competitiveness.

design information and its flows, which are the key concepts of our analysis (Figure 4).

Manufacturing capability: According to its definition in the routine-based view (e.g., Nelson & Winter, 1982), *manufacturing capability* is a system of organizational routines that govern the *flows* of design information to the customers both in factories and other sites. The Ford System, the modern mass-production system and TPS are prominent examples of manufacturing capabilities. TPS, for instance, is known as a manufacturing capability that consists of over 200 interrelated routines controlling the flows of value-carrying design information to the customers.

A certain type of manufacturing capability can evolve over time in a country characterized by a particular capability-building environment (see Figure 4). For example, the USA – a nation of immigrants – has tended to emphasize *division of labor*, or coordination-saving capability (e.g., standardization, modularization, specialization) whereby its firms make immediate use of incoming talent. Conversely, postwar Japan – a nation that experienced rapid economic growth and chronic labor shortage due to a lack of immigration influx – had no choice but to build collaborative (coordination-rich) capability to deal with this challenge, with long-term employment and teamwork involving multiskilled workers (Fujimoto, 1999, 2007a). Thus, the present framework assumes that history matters when it comes to the evolution of manufacturing capability.

Product process architecture: The concept of *architecture* of a product (i.e., a tradable artifact), such as an automobile, refers to the abstract aspects of its design information, or the correspondence between the functional parameters (e.g., performance specifications) and the structural parameters (e.g., shapes of the components) of the artifact in question (Ulrich, 1995). If its function–structure relation is closer to a simple one-to-one correspondence, its architecture is said to be *modular*, while if it is closer to a complex many-to-many correspondence, its architecture is *integral*. Since design activities are essentially coordination between an artifact's functional and structural elements, we may say that modular architecture is coordination-saving, whereas integral architecture is coordination-intensive. As discussed in Section 4, highly functional automobiles – smaller cars with monocoque body structures, in particular – tend to be architecturally integral, despite the fact that auto manufacturers have put in a great deal of effort to make them more modular, so as to alleviate the design workload.

An artifact's design information has two key aspects: technology and architecture. Technology refers to concrete causal relations among structures and functions, whereas architecture describes the abstract correspondence, or mapping, among them. In order to analyze the evolution of industries and firms, we usually need to investigate both technological and architectural aspects of the products in question.

Our evolutionary framework treats a product's architecture as an endogenous (rather than exogenous) variable. As shown in Figure 4, the overall architecture of a given product category (e.g., passenger cars) can be relatively modular or integral, depending upon the nature of the functional requirements that customers expect, the constraints imposed by society and governments and the physical-technical limits inherent in the product. More specifically, a product's architecture tends toward the integral and/or closed type when such requirements are stricter, since the precise optimization of design elements is necessary to cope with more severe constraints.

By contrast, when physical constraints are less severe (e.g., weight-free digital information goods), a product's architecture tends toward the modular and open type, since engineers can more easily simplify the functional–structural connections among its design elements. Although a product's *micro architecture* may be a complex composite of modular and integral areas and layers that engineers can determine, the *macro architecture* of the whole product is affected by the market and society. Thus, there is no such thing as *intrinsic architecture* for any given product category.

Competitiveness performance: Lastly, the competitive performance of manufacturing sites, products, and firms is also defined in relation to flows of design information to the customers. The *productive performance* of manufacturing sites – such as physical productivities, production and development lead times, and manufacturing quality – measures the smoothness and accuracy of the flows of design information within such sites. A product's *market performance* refers instead to its attractiveness to potential or actual customers in terms of design, price, services, and so on.

Architecture capability fit: By using the typology of architectures and capabilities, and by applying the logic of comparative advantage found in trade theories to the locations of design activities, we have elaborated a framework of *design-based comparative advantage* (Fujimoto, 2007a, 2012). This framework, relying on the axiomatic design approach (Suh, 1990), regards product design as coordination among an artifact's functional and structural parameters. Additionally, it predicts comparative advantage in design costs when a country's endowment of a certain type of manufacturing capability fits a certain industry's architectures and other design attributes. For example, coordination-intensive (i.e., integral) products are more likely to be developed economically in a coordination-rich country (i.e., a geographical area with a strong endowment of coordinative organizational capabilities).

1.5 Organization of the Element

To sum up, our field-based bottom-up framework for analyzing the evolution of the automobile industry and firms focuses on three factors that are all related to value-carrying design information and its flows: (1) *organizational capability* of manufacturing sites, which controls flows of design information inside the factories themselves; (2) *product architecture*, which captures abstract aspects of a product's design; and (3) *competitive performance*, which measures the smoothness and attractiveness of a product's design information and its flows to the customers.

Our framework is strongly interdisciplinary, since we believe genba of industries and firms to be multifaceted economic entities. As discussed in greater detail in later sections, our capability-architecture-performance (CAP) framework integrates concepts from various fields: organizational capability from strategic management and evolutionary economics (Nelson & Winter, 1982; Grant, 1991), architecture from design theory and engineering science (Ulrich, 1995), and productive performance from industry studies, technology and operations management and neo-Ricardian economics (Womack, Jones, & Roos, 1990; Clark & Fujimoto, 1991; Holweg & Pil, 2004; Fujimoto & Shiozawa, 2011–2012).

After a preliminary discussion on the evolution and strategies of manufacturing industries and firms, we use our design-flow-based framework to analyze the market and productive *competitiveness* of the automobile industry in terms of manufacturing sites, products, and firms (Section 2).

We then introduce a design analysis of the automobile as a product. We examine the automobile's *product technology*, that is, the concrete aspects of its design, including its main components (Section 3). We also look at the automobile's *product architecture*, that is, the abstract aspects of its design, focusing in particular on its integrality and modularity (Section 4).

After that, we shift our attention to design information flows at automobile manufacturing sites. We explain the automobile's manufacturing process as design information flows, including product development, purchasing, production, and sales (Section 5). We then carry out an evolutionary analysis of the coordination-rich organizational capability of Toyota, a relatively competitive automobile firm of the late twentieth century (Section 6).

We complete our evolutionary industrial analysis by dealing with the product architecture side. We explore the automobile firms' past architectural strategies from the viewpoint of the industry life cycle (Section 7).

2 Competitive Performance of Sites, Products, and Firms

2.1 Framework: Hierarchy of Competitive Performance

2.1.1 Competitiveness as the Ability to Be Selected

In order to explore competitiveness in the automobile industry and its main causes, we first need to define and reinterpret it from our design-information perspective of manufacturing. Competitive performance can be said to measure the *goodness* of product design information and its flows.

Generally speaking, industrial competitiveness is defined as a firm's performance, giving it the ability to win in a given competition. By common-sense definition, competition is a subject's effort to be selected for a certain reward under predetermined rules and/or conditions of free choice on the part of the selectors. In other words, competition is an interaction between independent selectors and selectees. When these rules and conditions do not apply, we may call the ensuing situation collusion, coercion, conflict, and so on. In this context, *competitiveness*, or competitive performance, may be defined as *a selectee's ability to be selected by selectors* under the rule of independent choice.

2.1.2 Hierarchy of Competitive Performances

It follows from this definition of competitiveness as ability to be selected that we can classify different types of competitiveness according to what the selectee is and who the selectors are. Thus, we can conceive of at least three

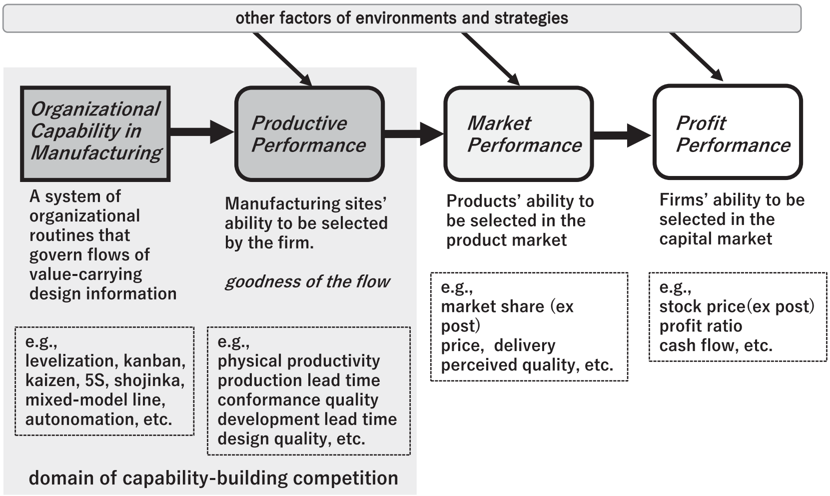

Figure 5 Capability, competitiveness, and profitability.

layers of competitive performance: (1) *profit performance*, as a firm's ability to be selected by the investors/lenders in the capital market; (2) *market performance*, as a product's ability to be selected by the customers in the product market; (3) *productive performance*, as a manufacturing site's ability to be selected by the firm as its owner (Figure 5; Fujimoto, 2007a).

More specifically, *profit performance* refers to a firm's ability to be selected in the capital market (e.g., return on sales, return on assets, return on equity), or its attractiveness as a whole in the minds of the investors. The level of *profit performance* is affected by the firm's productive and market performance, as well as by other factors, such as exchange rates, business cycles, and strategic choices.

Market performance is a product's ability to be selected in the product market, or the attractiveness of the design information embodied in the product in question in the minds of the customers. The product's ex ante market performance includes price, delivery time, and perceived quality, whereas its ex post market performance is measured by its market share. We may also call market performance *surface-level competitiveness*, as it is revealed on the surface of the market that can be observed by the customers.

Productive performance, including productivity, lead times and manufacturing quality, measures a manufacturing site's ability to be selected as a surviving facility by the firm that owns it. Thus, a firm's manufacturing sites compete to be selected by its headquarters and top managers. Since this selection is made at a level that is not visible to the customers, we may also call it *deep-level* *competitiveness*. Essentially, productive performance measures the goodness of design information flows among productive resources in the manufacturing sites.

2.1.3 Quality, Cost, Time, and Flexibility as Factors of Productive Performance

The essential aspects of productive performance include efficiency (productivity and lead times) and accuracy (quality) of design information flows across productive resources and eventually to the customers (Fujimoto, 1999).

In the case of production sites (factories), physical *productivity* is the production process's efficiency in sending design information to the product's materials (i.e., media). Given the price of production inputs, such as hourly wage rates or equipment costs, higher productivity means lower *unit cost*, which may be regarded as another efficiency-related indicator when input prices are stable and uniform across sites and over time. Likewise, *production lead time*, or time elapsed between receiving the direct materials and shipping the product, is the materials' efficiency in receiving design information from the production process. *Manufacturing quality* refers to the accuracy of design information transmission from the process to the product's materials or work in process. We can also define development productivity, development lead time, and design quality in a similar way for product development processes (Clark & Fujimoto, 1991).

Flexibility is another indicator of competitive performance, which measures the stability of the aforementioned performance aspects (e.g., productivity, unit cost, lead time, quality) vis-à-vis changes in product designs, production volumes, and other manufacturing conditions. Thus, we may identify quality, cost (productivity), time (lead time), and flexibility (QCTF) as the four main factors of productive performance.

2.1.4 An Industry's Competitive Performance

We have so far discussed competitive performance at the level of firms (profit performance), products (market performance), and sites (productive performance). What about performance at the level of a country's industry?

As already mentioned, an industry is a collection of manufacturing sites or their products, but it is not necessarily a collection of firms, which can be multi-industrial and/or multinational. Accordingly, it is not relevant to aggregate firms' profit performance at the industry level. This aggregation may however be allowed as an approximation when the firms in question can be regarded as nearly single-industry firms, as is the case with most of the major automakers.