Development of a Global Manufacturing Model in the Digital Economy – a Revolution Brought About by Virtual Engineering

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Introduction

A new manufacturing system started to become mainstream in the global manufacturing business in 2010. This is a virtual engineering environment where a 3D model combined with digital information with respect to all levels of manufacturing, development, and sales rules over the whole manufacturing business.

In the areas of product development and manufacturing, the flow of operations is as follows: planning/branding phase, initial concept design, detailed design, mass production, and sales development *(Chart 1)*. At each phase, individual engineers and specialists further develop specifications until they are finalized. Mass production is then launched, and products delivered to the market.

Conventionally, the main components of such a manufacturing process consisted of the initial consultation, planning and branding design stages, and consistency of concept and goal formulation. Specialized leaders in the areas of sales, management, planning, and product development mainly would join meetings – in the same place at the same time – to deliberate and make decisions based on previous data, market demand, and so on. Later, the focus would shift to specifics including product shape and function.

The verification at this stage also used Computer-Aided Engineering (CAE) technology, but it was mainly handled by real-world tests using prototypes. The focus was to guarantee the verification of specifications pertaining to the prototype product itself. This required both a large number of human-hours and a lengthy production schedule. Without the detailed planning phase, product design and manufacturing were impossible. Coordination with manufacturing sites on product specification development in Japan took account of manufacturing efficiency, and thus it became the foundations of Japan's manufacturing process, the source of Japan's cost-competitive, high-quality products.

The way of development is innovating within the global trend. The initial design stages of planning and branding, where the goals of basic specifications were established along with product concepts, such as 1) overall design specifications, and 2) all manufacturing processes, can be accurately verified using virtual technologies.

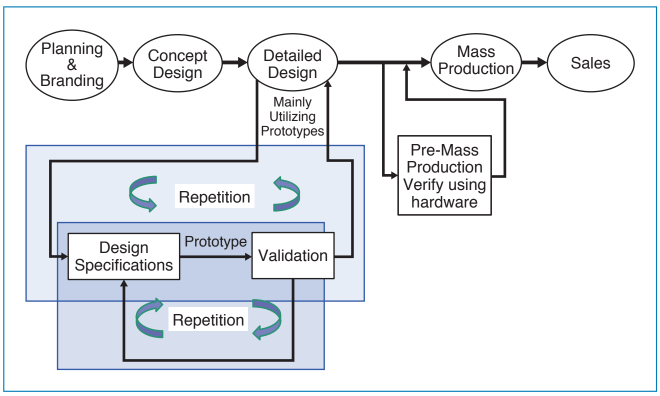
The result is a change of technology and environment where all specifications and conditions have so far been determined in the detailed design and mass production verification stages *(Chart 2)*. This is virtual engineering. The original meaning of the word "virtual" is "substantial". Thus "virtual engineering" refers to "substantial engineering".

Emergence of Virtual Engineering

As of 1990, the rapid advancement of IT began impacting production and development in the machinery manufacturing industry, particularly in the automotive sector. IT has enabled engineering development using digital technologies. Most of the

CHART 1

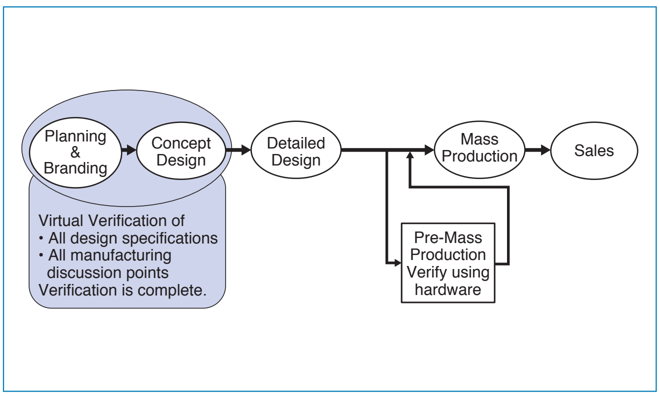
Conventional product development operations flow



Source: Mechanical Design magazine, Impact of Virtual Engineering Series, "Virtual Engineering", Vol. 63, No. 1, 2019, Nikkan Kogyo Shimbun

CHART 2

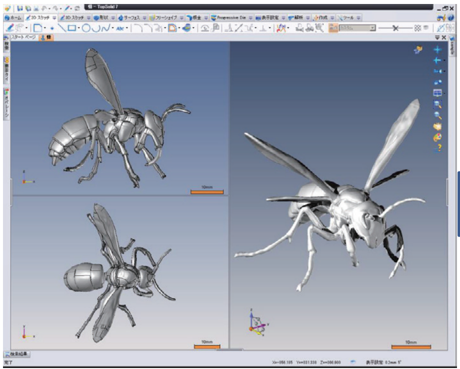
Virtual engineering product development operations flow



Source: Mechanical Design magazine, Impact of Virtual Engineering Series, "Virtual Engineering", Vol. 63, No. 1, 2019, Nikkan Kogyo Shimbun

CHART 3

Precision-cutting 3D forms

CAD Data	5-axis Machine Cutting
	

Source: Kodama Corporation materials (http://www.kodamacorp.co.jp/)

world's automotive companies have incorporated 3D Computer-Aided Design (3D CAD) systems. The 3D CAD models have led to the development of 3D drawings, a new type of design drawing using information to add a third dimension. In addition, the utilization will be a composite assembly of 3D models, and the Digital Mock-Up (DMU) which becomes a single car will be utilized.

3D CAD modelling was then applied as a 3D model for Computer-Aided Manufacturing (CAM) to directly create molds for pressed parts, casted parts and more. This helped to integrate design and manufacturing. It was also behind the shift from 2D to 3D design drawings.

3D Environment Where Products Are Crafted Precisely

Most mass production for pressing, casting, and plastic injection molding is accomplished using molds to create the desired product shape. Mold-making encompasses techniques such as cutting, grinding, and electric discharge machining using CAM 3D models. To work with 2D drawings, a new CAM 3D model for reading 2D models is created, while for 3D drawings, the 3D CAD model is directly applied. This enables the user to obtain the CAM model data, which includes the numerical control processing path, electrode models, and more. It means that the 3D shape can be manufactured precisely in accordance with the 3D design, engendering uniformity of shape and quality. The use of 3D models in designs is also on the rise in cutting, welding, and mold-making. For example, in the cutting phase, inputting a 3D model into a numerical control machine interface (I/F) program automatically generates cutting path calculations and robotic direction, so that each piece is appropriately cut and manufactured. This means a type of 3D printer that cuts 3D design shapes exactly in accordance with the designs. For instance, provided we have a 3D model of an insect as in *Chart 3*, a product can be manufactured easily using a five-axis processing machine.

Because 2D drawings cannot represent full shapes, there were different levels with quality control and shapes in technologies at manufacturing sites. On the other hand, precisely because the process allowed for the element of human skill, the differences in manufacturing site technologies impacted both quality and functionality. This worked to Japan's advantage. Japan became known for its superior manufacturing, and the quality standard of Japanese products became the goal of manufacturing the world over. When 2D drawings were prevalent, the process consisted of reading the design drawings with the input of manufacturing site technical personnel. Therefore, the manufacturing process involved more than just the information noted in the drawing. For this reason, this kind of manufacturing was considered "manufacturing similar to drawings". At present, use of 3D drawings – which fully and precisely manifest all manner of shapes – allows anyone to accurately create products in accordance with drawings. "Manufacturing and drawings are equivalent." Thus, 3D drawings offer perfect control of both product quality and functionality.

In summary, the practice of developing the shape and quality of products at the design phase started around 1990, in tandem with the development of the digital environment. This was how coordination between design and the manufacturing process began, in a sense signifying the birth of virtual engineering.

Coordination Between CAE & CAD/CAM

CAD/CAM and CAE were not linked until the 21st century, and there were separate digital environments in the CAD/CAM and CAE fields. To give some background on the CAE field, general-use CAE programs were already sold commercially in the 1960s. At that time, there was a dedicated modeling tool for making CAE models. Also, during this period there was a need for complex operation technologies including computer operations in addition to CAE analysis technologies, which necessitated training in CAE operations technologies, and CAE modeling technologies. These factors led to the development of the unique CAE digital environment. In order to utilize CAE for design study, CAE engineers were required in addition to designers. Therefore, it was difficult to synchronize the design and CAE examination in the design site where CAE engineers were not participating. In the year 2001, CAE analysis became feasible with general-use CAD systems, allowing for coordination between CAD and CAE environments. Moving forward, CAE, which had previously been separate, became a coordinated digital environment together with CAD and CAM. This is how a system that coordinated design, analysis, and manufacturing began.

At the design phase, development of functional specifications as well as manufacturing process development wielded significant impact, and at the same time the scope of design handled at the design phase expanded. Later, CAE for manufacturing development was applied in general-use CAD environments for design.

Now that 3D design drawings are employed, product features and quality are under better control. Thus, anyone can manufacture products of the same quality and features as indicated in drawings at any time.

Coordinating Between Collaborative Digital Environments

With a CAD model for a single automobile, CAE analysis on strength, rigidity, noise and vibration was first launched. This subsequently enabled analysis at the design stage for the entirety of the CAE field, including total vehicle performance and flow analysis, as it pertains to steering, and more.

Since CAE analysis technology has expanded to many fields, research began on environmental and management technologies that enable engineers in the analysis and manufacturing departments to be in sync with the design at the design stage, rather than examining all fields such as analysis and manufacturing. At this stage in the flow of operations, European car makers, IT vendors, universities, and research institutions form the basis of today's virtual engineering environment. For example, the results of conventional experiments and CAE analysis are now synchronized at the design phase. To link these with decisions on design features, specifications and production conditions, data formats were standardized, and a platform was established to coordinate CAE, CAD, and CAM data. Data-coordinated platforms were then commercialized as these systems became the de facto standard.

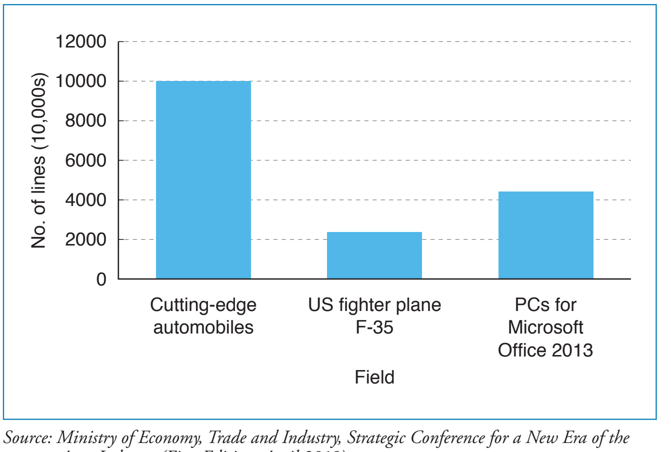
Incorporating Control Design & 3D Modeling

The software component of product development is now growing year by year. The number of software source code lines embedded in automobiles now stands at more than 100 million, compared to about one million 10 years ago. The US fighter plane F-35 had 24 million lines, while an ordinary PC has 44 million. The importance of software in vehicles truly stands out *(Chart 4)*. As software grows more complex, rendering changes in control design necessary, there is a need for control design in the common digital environment of CAD, CAM, and CAE. In the past, verification and study of the control algorithm of modules and cars, using actual hardware, has been carried out. In terms of design today, a method of verifying the behavior of the control algorithm in 3D models instead of this hardware is popular.

Time delay does not occur if there is no 3D model deformation instead of the hardware. At this rate, it is not possible to verify a highly accurate control algorithm. Therefore, deformation considers

CHART 4

Software grows increasingly complex (Comparing required numbers of programming lines)



Source: Ministry of Economy, Trade and Industry, Strategic Conference for a New Era of the Auto Industry (First Edition, April 2018)
Excerpts from public domain materials

the rigidity in CAE analysis, also by including the manufacturing tolerance of the product, and it became possible from around 2010 to control verification of higher accuracy more than using hardware in the virtual engineering environment.

Scene Model-Based Development

Automotive and airplane development involves upwards of 10,000 parts. For this reason, car manufacturers and suppliers have begun to collaborate on design. This kind of fundamental information-sharing originally involved sharing the relevant information on manufacturing by referring to drawings. Next, 2D drawings evolved into 3D ones. In response to this, scene model-based development, which is a way of developing information to exchange information including the concept of product development and user utilization scenes, began to spread to the general public around 2005, mainly in Europe. It is gradually spreading in countries around the world other than Japan. An example of scene model-based development would be a model incorporating environmental information to facilitate the study of vehicle performance in specific scenes. To achieve this, scene models encompassed not only individual product units and individual product parts but also virtual modeling of environments where the products would be used, user characteristics and so forth. In other words, scene modelling is a collection bunch of models created to examine specific areas of product performance and the environmental information required to make such determinations.

Overview of Scene Model-Based Development in Automotive Manufacturing

1) A series of models are developed based on vehicle performance and environmental modeling.
2) 3D models are used to demonstrate a wide range of complex scenes, clarifying any issues that need examination and verification.
3) Vehicle modeling, including the scenes, is shared between OEM and suppliers. Then, the system features that meet desired outcomes are written into the vehicle specifications.
(“System” here refers to combined hardware and software systems, such as braking and steering.)

Platforms Linking Development Models

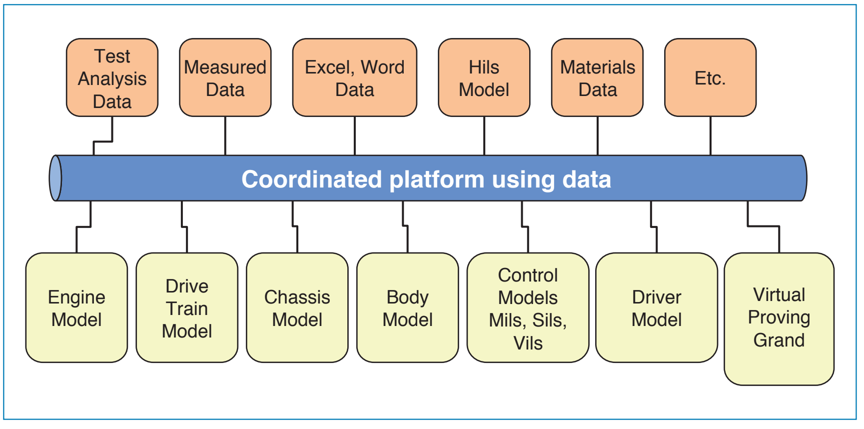
To achieve scene model-based development each of the module models must be linked so that each model works (is linked to a function) in the same way. This platform, effective for development purposes, links individual automobile parts, engine models for the various modules, chassis modules, body modules, etc. Models have also been developed to simulate various conditions including new drivers, experienced drivers, age of driver, and nationality, also linking road models to the same platform *(Chart 5)*.

Data-Sharing Flow Equals Business Flow

Suppliers who design and manufacture modules such as suspension and transmission systems link functional models to development platforms. These initiatives have led to collaboration between auto makers and suppliers. The process of working the modules between manufacturers and suppliers yields well-developed specifications for each module. Conventionally, the production of actual modules was carried out in cooperation with suppliers over the second, third, and many layers. The supplier would create each of the parts and assemble them separately, which meant that suppliers were linked to the phases of the supply chain on several levels. Under this system, a module designed by a supplier to achieve a certain function is directly linked to a platform provided by an auto manufacturer. Suppliers and auto manufacturers work together to arrive at the desired driving performance. They design the function of each module to achieve such a desired performance and this creates a scene model-based development system where all

CHART 5

Coordinated platform on development design data

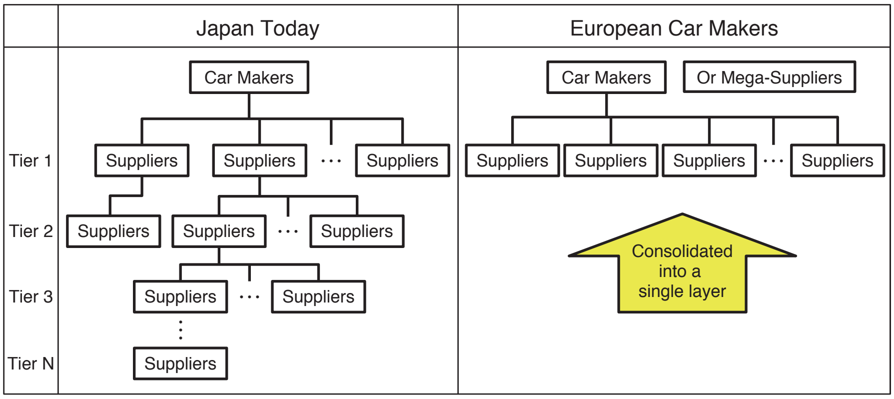


Source: Mechanical Design magazine, Impact of Virtual Engineering Series, “Platform Environments in Development and Manufacturing”, Vol. 64, No. 1, 2020, Nikkan Kogyo Shimbun the modules are independent from each other.

This system enables sharing of all kinds of information pertaining to products, including attribute information, such as mode of manufacturing, analysis conditions, control algorithms, material attributes and surface qualities, plus information from the market and users. The scope and content of the shared information subsequently expanded so that the conventional order of development and manufacturing operations (planning, overall design, detailed design, commercialization, and sales) changed. Under the new evolved business model at the stage of initial-phase planning and conceptual design, all kinds of examinations and validations involving the productions side, the sales side, as well as module suppliers, are made possible.

CHART 6

Business between consolidated OEM & suppliers



Source: Mechanical Design magazine, Impact of Virtual Engineering Series, "Platform Environments in Development and Manufacturing", Vol. 64, No. 6, 2020, Nikkan Kogyo Shimbun

Platform Businesses in Manufacturing

The current manufacturing business platform is provided by car makers or mega-suppliers. For example, the large modules used for engines or transmissions are developed primarily by mega-suppliers, in which cases mega-suppliers provide the platforms.

Only suppliers holding official contracts with mega-suppliers or car makers on development projects are permitted to join platforms. By linking modules directly with platforms, car makers or mega-suppliers are able to set up direct contracts with smaller supplies. This differs from the conventional multi-layered supply chains, resulting in a flat and single-layer business model for supply chains, similar to a platform structure *(Chart 6)*.

Suppliers working as Tier 1 with low-level supply chains would have two options: be an independent supplier without being involved in any conglomerate's supply chain or be a mega-supplier providing a development platform. This is how they would need to restructure their business model. What's more, even these small suppliers at the very back end of the supply chain would be able to become independent of the conventional suppliers who were part of a conglomerate, modeling their own data derived from their technical capacity and able to start a new business through direct contracts with auto assembling manufacturers. Originally, car makers and mega-suppliers worked with vertically-integrated business models. However, more manufacturing business platforms are making the shift to horizontal integration. In a sense, this marks the start of dramatic changes in the supply chain.

Conclusion

Conventionally, car makers handled all processes, including planning and branding, concept design, detailed design, mass production, and sales, as in *Chart 1*. Scene model-based development enabled suppliers to use their expertise independently at the detailed design phase. Further, because 3D drawings enable control of both function and quality, mass produced products of specified quality and function can be manufactured by anyone, anywhere, and they are now readily available. With 2D drawings, quality and shape are more difficult to control. Japan's superior manufacturing sector made up for this deficit, engendering unparalleled quality that set the standard for manufacturing worldwide.

With the advent of 3D drawings, however, this advantage could be lost. Though Japan has led the world in manufacturing, 3D designs have not yet been completed in Japan. For manufacturing companies around the world, the construction of a 3D design environment has become a litmus test for participation in new business models, which will affect the future outcome. Countries around the world are rapidly moving ahead to transform their new manufacturing business models. In this regard, Japan also needs to embark on a new stage of reform as soon as possible. JS

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