Manufacturing Systems and Technologies for the New Frontier

Mamoru Mitsuishi • Kanji Ueda • Fumihiko Kimura
Editors

Manufacturing Systems and Technologies for the New Frontier

The 41st CIRP Conference on Manufacturing Systems
May 26–28, 2008, Tokyo, Japan

Springer

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ISBN 978-1-84800-266-1 e-ISBN 978-1-84800-267-8

DOI 10.1007/978-1-84800-267-8

British Library Cataloguing in Publication Data
CIRP Conference on Manufacturing Systems (41st : 2008 :
Tokyo, Japan)
Manufacturing systems and technologies for the new frontier
: the 41st CIRP Conference on Manufacturing Systems, May
26-28, 2008, Tokyo, Japan
1. Manufacturing processes - Congresses
I. Title II. Mitsuishi, Mamoru III. Ueda, Kanji IV. Kimura,
F. (Fumihiko), 1945-
670
ISBN-13: 9781848002661

Library of Congress Control Number: 2008924671

Cover design: eStudio Calamar S.L., Girona, Spain

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

The 2008 CIRP Conference on Manufacturing Systems, held at the Hongo Main Campus of the University of Tokyo, Japan, marks the 41st event of the conference series since its inception in 1969. The purpose of this conference is to promote research activities in various areas of manufacturing systems through the offering of a forum for the exchange of concepts, dissemination of technological breakthroughs, and discussion of future directions.

This year, the conference program covers a wide array of topical areas including manufacturing system evaluation, manufacturing system organization, implementation and design of systems, planning, human aspects of manufacturing systems, scheduling, manufacturing system design, service engineering, and novel processes in the area of electro-physical and chemical processes, cutting, machines and forming, micro-nano technology and surfaces, and grinding. The conference includes a total of 106 technical papers that have been accepted for presentation after a rigorous peer review and revision process handled by the Program Committee. These papers were submitted by corresponding authors from 15 countries including (in descending order of paper quantity): Japan, Germany, Sweden, China and Taiwan (R.O.C.), Italy, Netherlands, Norway, Slovenia, Brazil, Denmark, Finland, France, the Philippines, Thailand, and the USA. The papers are grouped into 32 sessions. The conference is grateful for the invited speeches given by Mr. H. Yamamoto, "Driving Innovation, An Industry Case to Enhance Manufacturing Competitiveness," and by Professor T. Fujimoto, "Architecture-based Comparative Advantage in Japan and Asia." The keynote speeches on "Manufacture and Sustainable Manufacturing" by Professor E. Westkaemper, on "Challenges for the Manufacturing Enterprise to Achieve Sustainable Development" by Professor J. W. Sutherland, on “Complex Adaptive Systems (CAS) Approach to Production Systems and Organizations” by Professor L. Monostori and on “Scientific Approach to Services: What is the Design of Services?” by Professor T. Arai will be of great interest to the conference participants. The program will also be enriched by the addition of the special talk by the Past President, Professor H. Yoshikawa, which is expected at the banquet.

Our sincere appreciation goes to the International Program Committee and Local Organizing Committee members for their wonderful efforts in reviewing papers, handling papers, and preparing the technical program. We would like to thank Associate Professor N. Sugita and Ms. A. Ishihama for their technical support and secretarial assistance in making this event possible. We would also like to extend our deep appreciation to the paper authors for their excellent contributions to the conference. The authors who are willing to share their most recent and critical findings with the research community represent the dominant factor in the success of this conference. We anticipate that the conference will be an exciting event and sincerely wish that all the participants enjoy and benefit from this meeting. Finally, the organizations and companies who contributed to the financial support of the conference also deserve our great respect for this successful event.

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Driving Innovations, an industry case to enhance manufacturing competitiveness

Hironori Yamamoto

CANON ELECTRONICS INC.

Abstract

This paper gives an overview of the international position in the information and communication industry from a competitive standpoint. Canon has strength in the information technology, particularly in the field of imaging. Imaging technology is Canon's core competency. Digital technology does not replace imaging technology, rather, digital technology supplements imaging technology. With this background, this paper reviews activities at Canon to strengthen its competitive edge, mainly from technology development angle. Although the reality has multiple factors, this paper focuses on product innovation in new product development, aimed to maximize customer value. It also provides outline of processes innovation.

Keywords:

Innovative Target; Product Innovation; Process innovation

1 INTRODUCTION

An Index to measure the competitiveness of a nation is published by the Institute for Management Development (IMD), Switzerland in "World Competitiveness Yearbook" (WCY) since 1989. Between 1989 and 1993, Japan was ranked number one. Since then, Japan's competitiveness declined. In 2007, Japan was ranked number 24 in the Overall Performance, down from 16th the previous year. Among the four Competitiveness Factors, Japan maintains relatively high position in Infrastructure thanks to good accumulation from the past. Low Government Efficiency and Business Efficiency contributed to lower Overall performance. This proves insufficient efficiency of the Japanese operations in the times of highly-sophisticated information society. When one reviews the transition of the Japanese Gross Domestic Product (GDP), in 1995, the Japanese production was 71% of the United States, while in 2005, it dropped to 37% of USA. This is a reduction of 14%. This illustrates that while the Japanese domestic economy was growing mildly, Japan is falling behind relative to other economies. Globalization is in progress. Such time requires social systems that create new set of values. Innovation drives creation of new values. This paper attempts to narrow the focus to a challenge of an enterprise in driving innovation.

2 THE IT INDUSTRY AND ISSUES FOR CANON

Originally, Canon was a manufacturer of imaging products, such as cameras and copiers. However, with the development of information technology, as more and more equipment became digital and network-capable, Canon was forced to adopt to the networked environment. Canon today manufactures and sells equipment that serves as man-machine interface in the highly developed imaging information. In other words, Canon entered the information technology industry. The structure of the IT industry is described in Figure 1.

Figure 1:Existing state of the competitive edge in IT industry.

The most basic layer is science, contents form the top layer.

Network system, assembled product, device, material, and manufacturing equipment all form layers below the contents layer. USA has advantage in contents and network systems, leading introduction of new concept products and standardization activities Assembled products and devices include digital home appliance, office equipment such as copiers, semiconductors, and electronic parts where Japan maintains high competitive edge. However, Japan's strength in these layers is diminishing. Flat panel displays is an area where high growth is expected. In 2000, almost 50% was manufactured in Japan. Today, Korea and Taiwan together have grown to have 75% manufacturing share. This example illustrates the competitiveness in assembled products and devices for Japan, area that Japan used to have competitive advantage enjoy, is diminishing. It is particularly true in price competitiveness. Figure 2 summarizes the issues Japanese IT industry face. It is viewed from two angles, management/corporate environment and technology. Most issues listed in management/corporate environment have been solved over the last several years, by rigorous selection and concentration of resources to specific business area and restructuring.

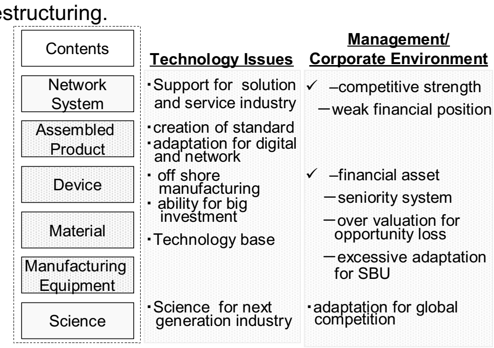

Figure 2: Issues for Japanese IT industry.

However, measures to address global competition accelerating in the IT industry are still insufficient. Among technology issues, lack of progress in technology supporting solution and service industries is a concern. Weak generation of technology coming from scientific field must be addressed. Through Management Reform since 1996, Canon removed these concerns greatly, but some issue remains.

3 CHALLENGES AT CANON

Activities at Canon to solve these management issues are described in this chapter. One of the characteristics of Canon management since its foundation is seen in the strong ties between long-term vision and management policies, embodied in its technology development. In 1996, Canon launched the “Excellent Global Corporation Plan” which promoted change from a venture company tendency placing higher priority on research and development, to enterprise-oriented tendency. The philosophy that forms the back bone of this conversion can be seen in shift from partial optimization to total optimization, shift from degree of completion to speed and quality, shift from “engineering is almighty” mentality to goal-orientated approach, and shift from revenue first to profit most. With the view of total optimization, the operation of research, manufacturing, and sales reflected lack of productivity at the manufacturing, typical of R and D oriented corporation leaving the manufacturing behind. Therefore, with the implementation of the “Excellent Global Corporation Plan,” manufacturing reform was driven under top management policy, which brought organized innovation on the manufacturing floor. Plant managers took initiative to remove ineffective practices and processes. Belt conveyor was removed, replaced by cell manufacturing system, so that the proficiency, originality and ingenuity of the workers may be brought out. Furthermore, this allowed ingenious attempt to improve productivity, a shift to more human-centric manufacturing. Factories reviewed its operation from logistics point of view. Inventory was reduced greatly. All these efforts add up to improved profitability, and made the plants more capable to cope with fluctuation. Processes went through great innovation on the manufacturing floor.

3.1 Approach towards Product Innovation

This chapter reviews technology development that took place at Canon, and describe approaches taken to gain competitive edge. As a result, Canon earned competitive advantage by possessing original technology. There are four points to consider.

(1)Processes leading to competitive advantage

(2)Important factors in setting “Innovative Target”

(3)Innovation by ongoing research and development

(4)R and D activity integrated and supported by Management mid and long-term direction

(4) is an important condition to concentrate resources driving innovation. This corresponds to technology management, linking R and D with long-term management vision. Here, (1) through (3) is explained in more detail. Business diversification that took place at Canon over the years, viewed from revenue size is described in Figure 3.

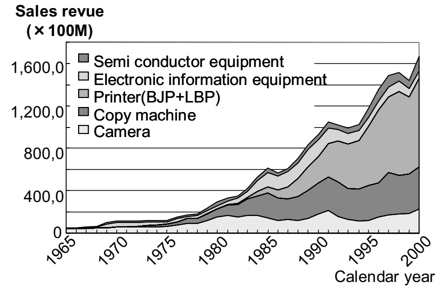

Figure 3:Concentric diversification in canon.

Canon business expanded from the single business of Camera, adding Copiers, Semiconductor equipment, and other products. Re-organizing this chart to show composition trends is shown in Figure 4, illustrating changes in the business structure.

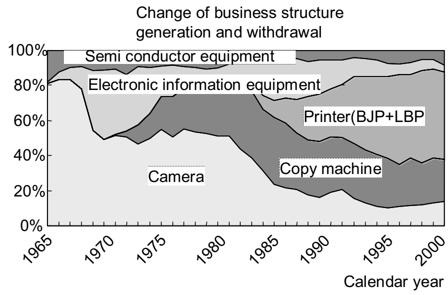

Figure 4:Concentric diversification in canon composition of each sales revenue.

One can find that it was not an easy expansion, rather, the reduction of sales, withdrawal, and creation of new business took place. Figure 5 describes processes taken to develop new product. During these processes, complex and compounding issues are broken down to individual task, which becomes a scientific or technology target. Innovation happens to solve such target. Depending on the magnitude of the target, there may be discontinuous innovation that accompanies paradigm shift, or there may be continuous innovation that may cause important differentiation to the product. Such processes allow enterprise to acquire core competency that are the source of corporate competitiveness.

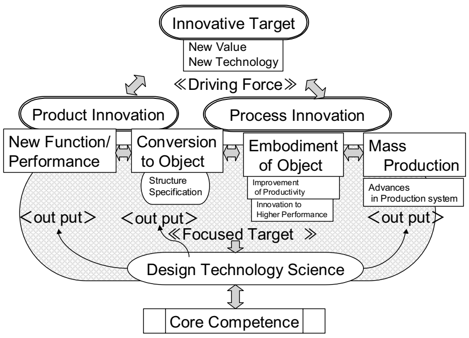

Figure 5:Innovation process and structure.

One can point out particular features of innovative target set by Canon. The first is what is called "Global niche." Market size of a product in one country is not big, but the world wide market is large. From its inception, Canon addressed the global market. Canon businesses in the Americas, Europe and Asia each accounts for about one third. The second feature is rather than conducting business within the mainstream of a technology, create an original product with original technology which is aligned to the technology trend. More specifically, Canon did not attempt to create a family of products based of digital technology. Rather, having imaging technology as Canon's core competency, Canon developed imaging products that enjoy the benefit of digital. Together with such product, Canon worked to strengthen competitiveness of the system. . The third feature is to create new value from new technology. Such new technology indicates solution to the innovative targets in the area of the first and second feature. Because they are new technology, they bring new values. New values are also the source of break through to win competitiveness. The fourth feature is to experience multiple trials. Retreat from business at an early stage minimizes loss, as the R and D investment is relatively small, and the technology itself can be saved. Data from the real market gained during such early business can be reflected to future products. Specific example at Canon includes entry to Electronic calculator and Personal Computer businesses, both closed later. However, technology acquired through such entry, and people who gained experience in developing these technology helped Canon in coping and adopting the new trend of Digital and Network in the businesses of Camera, Copier, and Printers. Figure 6 is a portfolio chart, showing value on the vertical axis, different technology on the horizontal axis.

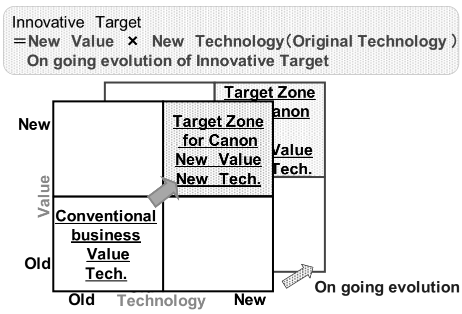

Figure 6: Innovative target.

This chart helps clarify our objective, and set the Innovative Target. Even though new value are created by existing technology, because it is based on current technology, others can easily catch up. Meanwhile, if new technology serves to create existing value, it is unlikely that the market will welcome this. Therefore, Canon created new products with values existing products could not deliver, with new technology. Innovative targets leads to competitive advantage because original value is created by original technology. Furthermore, by continuous R and D effort, evolution of original technology takes place, which elevates the strength of each original technology. This is how innovation targets are set at Canon. The structure to drive product innovation aimed for diversification is shown on Figure 7.

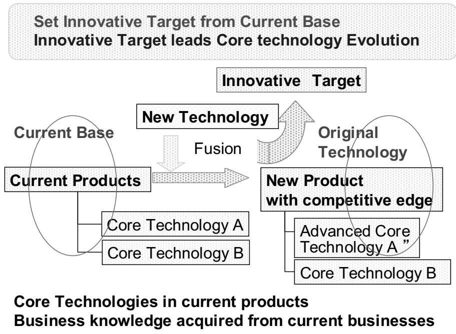

Figure 7: Processes to strengthen product competitive edge.

Core technology embodied in current product and the knowledge of the business domain form the basis to set innovative target. New technology and knowledge of the new business domain is added to consider the innovative target for diversification. Through this process, core technology the company possessed is being brushed up to become a stronger technology. Newly acquired technology and knowledge of the new domain becomes part of the core technology of the new domain.

3.2 Approach towards Process Innovation

Maintaining and enhancing competitive edge of a product is the driving force for process innovation. From technology stand point of view, the driving force is pursuit for product differentiation. Elements of differentiation can be found in improving product performance, and in reduction of cost.

When one looks at manufacturing technology from product life-cycle and its phase point of view, one can understand that different quality of technology needs to be emphasized depending on the stage.

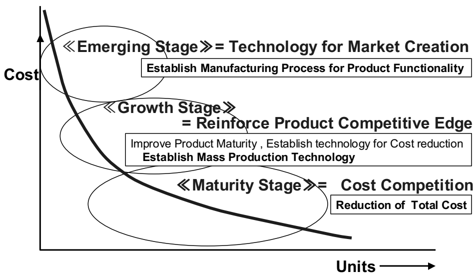

Figure 8: Correspondence between product life cycle and manufacturing technology.

During the emerging stage of new business development, as introducing the new product itself is difficult, establishment of technology elements to make this developing less difficult is given priority (establish manufacturing process.) In the growth stage, reinforcing the product competitive edge by improving maturity of the product and to reduce manufacturing cost is more important (Establish mass production technology.) In the maturity stage, in order to win the cost competition, reduction in total cost becomes important. So, at each stage of product life cycle, different driving forces seek diverse product differentiation. Thus, process innovation takes place involving most advanced knowledge and technology of the times, acquiring them interdisciplinary and concentrating them.

More specifically, here is the discussion on the case of optical industry. One example of process conversion in functionality realization and performance improvement can be found in the development of laser scanning optical system found in laser beam printers. The model is the copier, which established electro-photography process. The goal of this development is to print images from a computer, by emitting laser beam on the photoconductor drum to get dot patterns exposed.

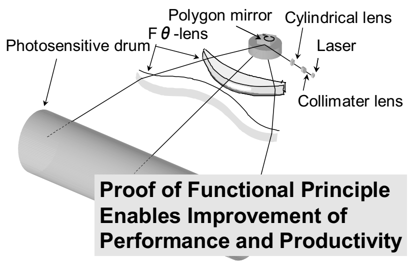

Figure 9: Optical scanning system in the LBP.

In the polygonal mirror scanning system (fig9), a toric lens was designed which dramatically relaxes accuracy requirement on the mirror rotation. In early days of development, rotation mechanism was ball bearing, material of polygon mirror was glass, and the toric lens was also made of glass. Inclusion of the toric lens from manufacturing process point of view is an improvement of the process, but it was important as it proved the functional principle of the scanning optics incorporating this special optical parts. Later, demands to improve performance, such as increase print speed, reduction of dot size, demands to reduce package size, request to lower cost were met by employing state of the art technology of the time, such as semiconductor laser, develop hydrodynamic bearing, and utilize new optical element.

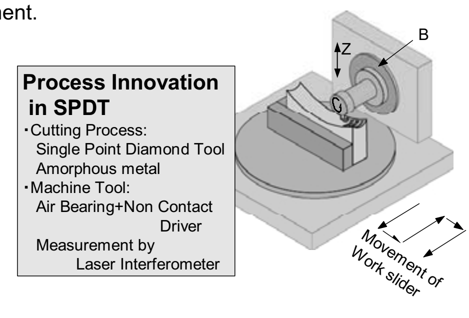

Figure 10: An example of metal molding, Toric lens application.

In particular, among the optical element, the polygon mirror, which was glass grinding and polishing process, was replaced by metal cutting work. Toric lens made by glass was replaced by plastic molding process, evolved to odd-shaped free-form aspheric lens. (fig.10) Early effort in learning single point diamond turning (SPDT) technology, which originated in the United States, helped refine manufacturing processes towards target performances in both cases of polygon mirror and metal mold of toric lens. Process innovation driven by need to introduce new functionality in a product places higher priority on realizing product functionality. In such case, applying specific technology to new products happens more predominantly, than large-scale process innovation to take place. At a later stage, when performance enhancement or cost reduction drives process innovation, transformation of material, or transformation of manufacturing technology takes place in a larger scale. Such cycle enhances competitive edge of the products, and as a result, build core competency.

4 SUMMARY

The structure of Canon product technology which has grown over the years is shown on Figure 11.

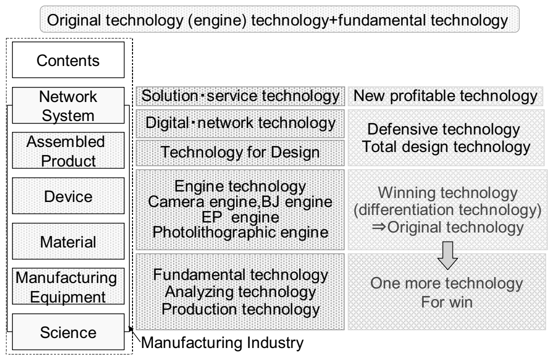

Figure 11:Technological structure of Canon.

Engine technology is positioned to win the competition. Digital and network technology, together with technology for design are positioned as defensive technology, and is systematically reinforced. More recently, the importance of fundamental technology is being recognized as technology to win. Experiments and tests of material element and other analytic approach accelerates conversion of desired function to physical state. Such approach reduces the chance of designing a product using parts with unknown character. This helps to speed up the design process and improve the design quality. Optical technology, material and process technology in the electrophographic products, inkjet process technology can only enjoy the benefit of advanced visualization and measurement techniques using super computers. In manufacturing technology too, technology regarding manufacturing equipment benefit from fundamental technology. Growth in digital technology brought effective tools. Proper use of these tools are another means to competitiveness

Architecture-based Comparative Advantage in Japan and Asia

Takahiro Fujimoto

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1 INTRODUCTION

Asia has become a global center of manufacturing during the last quarter of the 20th century. First, Japan was the only major exporter of manufacturing goods from Asia. Then, yen was rapidly appreciated after The Plaza Accord in 1985, and newly industrialized economies (NIES) such as Korea, Taiwan, Hong Kong and Singapore emerged as exporters of relatively standardized goods. Japanese manufacturing firms also started to shift their production facilities mainly in ASEAN countries.

In the 1990s, China emerged as major exporters of certain labor intensive goods. NIES also continued to expand their manufacturing bases. Japanese economy stumbled, but its trade surplus continued to be significant. America came back as a center of digital network goods and softwares. How can we explain these dynamics of manufacturing competitiveness? In this situation, after all, we may better go back to the basics of comparative advantage theory.

Generally speaking, when there is good fit between a nation's characteristics and an industry's characteristics, the industry tends to enjoy competitive advantages in that country. Ricardo's Theory of Comparative Advantage implied that "good fit" is translated into relatively high labor productivity vis-a-vis other countries (Ricardo, 1971). Neoclassicists such as Heckscher, Ohlin and Samuelson advocated that countries having larger endowment of a certain productive resource (for example, labor-rich countries) will have better fit with industries that heavily use this particular resource (for example, labor-intensive industries), assuming that productivity is identical across the countries (Hecksher, 1949; Samuelson, 1948). More recent version of competitive advantages (e.g., Porter, 1990; Cho and Moon, 2000) also follows this tradition of fit between industry and country characteristics.

In more recent years, however, various phenomena that are difficult to explain using existing theoretical frameworks alone have been emerging. These phenomena include the recent fact that Japan has been apparently surpassed by China, Korea and Taiwan in some technology-intensive products (e.g., DRAM, CD media, DVD recorder), which were assumed to be Japan's stronghold for many years.

2 EXPORT COMPETITIVENESS OF JAPAN'S INTEGRAL ARCHITECTURE PRODUCTS

Against this background, the author advocated that we need an additional framework that focuses on "fit between organizational capacity and architecture" – a version of the comparative advantage theory seen from our observations of manufacturing activities on the shop floor.

Specifically, this framework argues that Japanese manufacturing firms, facing high economic growth amid shortages of work force, materials and money, tended to engage in economically rational long-term transaction/long-term employment. As a result, they built organizational capability that emphasizes teamwork among multi-skilled workforce, or "*integrative organizational capability of manufacturing*," which raised their productivity and quality simultaneously. Toyota Production System is a typical example of such a capability (Monden, 1993; Fujimoto, 1999).

On the other hand, it was thought that there are two basic types of product-process architecture: (1) "*Integral architecture*" with complex interdependence between product functions and product structures (such as automobiles, etc.); (2) "*Modular architecture*" in which the relationship between a product's functional and structural elements have a simple and clear one-to-one correspondence (such as personal computers, etc.) (Ulrich, 1995).

It was also thought that Japan, which is a country with a high endowment of "*integrative organizational capability*" stemming from its long-term employment and long-term transaction practices, tends to have a competitive advantage in "integral architecture" products – a prediction based on our "*architecture-based comparative*" hypothesis. In other words, Japan, where coordination-oriented organizational capability has been concentrated due to its historical trajectory in the late 20th century, tends to export *coordination-intensive goods*, or products with integral architecture.

3 PRELIMINARY EMPIRICAL RESULTS

With this framework of capability-architecture matching, can this new approach to industrial competitiveness demonstrate additional explanatory power for the reality of Japan's industrial competitiveness? Although the research is still at the exploratory stage, The Manufacturing Management Research Center (MMRC) at the University of Tokyo conducted a survey analysis of selected Japanese manufacturing firms in cooperation with the Ministry of Economy, Trade and Industry (METI). The survey targeted both assembled products and processed products (chemicals, etc.), including automobiles, household appliances, electronics, parts, industrial machines, chemicals, iron and steel, fibers, and food and drink (Fujimoto and Oshika, 2006).

As the results indicate, our "integral architecture index," constructed from about a dozen of questions regarding architectural characteristics of each product surveyed, and export ratio of the product (export value/domestic production value) in question generally statistically significant positive correlations (**Figure 1**). The positive correlations were

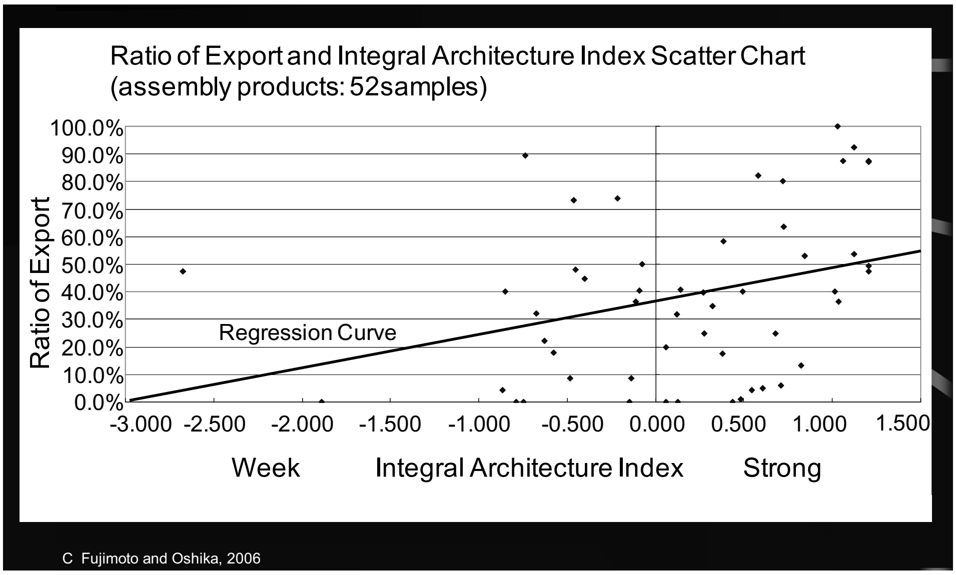

Figure 1: Ratio of export and integral architecture index (assembly products : 52 samles)

observed in both fabrication- assembly goods (e.g., machinery) and process goods (i.e., chemical). Also, the integral architecture index was positively correlated with not only export ratio, but also foreign activity ratio (export plus overseas production/domestic production), indicating that Japanese multinational firms tend to be good at integral architecture products wherever they are produced.

4 HYPOTHESES ON ARCHITECTURAL ADVANTAGE IN ASIA-PACIFIC AREA

Let's turn to architecture-based comparative advantage outside Japan. The following hypotheses are very preliminary and impressionistic ones, which are based mostly on ad-hoc empirical and historical observations of each geographical area (**Figure 2**).

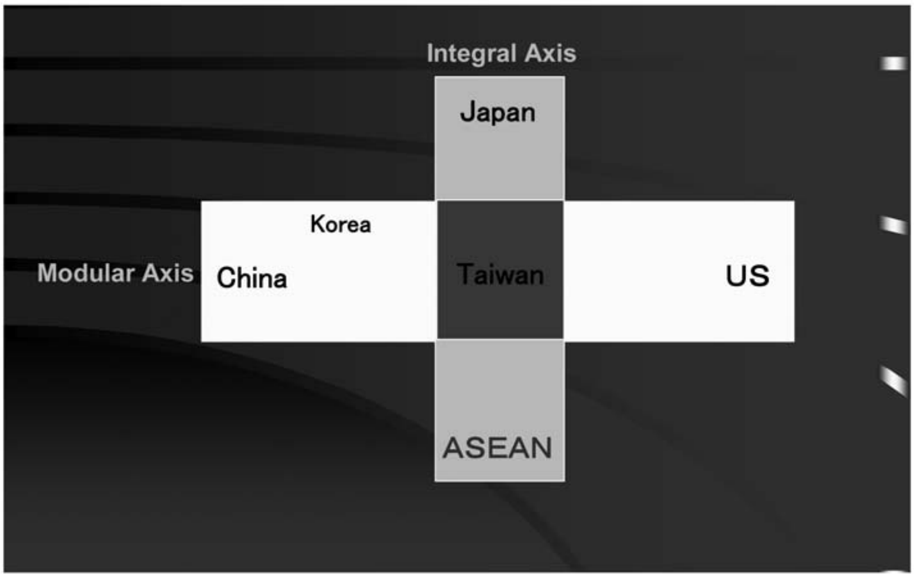

Figure 2 : Architectural gepolitics : a prediction in the pacific region

The basic logic is the same across the regions, however: Each region has its own historical path; A certain type of organizational capability tends to become concentrated in a certain region as a result of emergent capability-building process, which causes concentration of region-specific capability; Products with a certain type of product-process architecture and other characteristics tend to match better with a certain type of organizational capability, that results in relatively high productive performance (e.g., productivity, lead time, and quality).

Hypothesis on America: In a sense, America has been a country of immigrants in the past few centuries. In other words, it continued to attract human resources with industrial and technical knowledge and skills. For a society of this dynamism, it made sense to minimize coordination in order to make use of newcomers' capability as quick as possible.

As a result, American industries tended to emphasize division of labor, specialization, standardization of work, clear job demarcation, and use of market mechanism, while minimizing coordination efforts. Thus, the American System of Manufacture, throughout the 19th century, emphasized interchangeable parts and specialized equipment while minimizing coordination on the shop floor (e.g., fitter). American Mass Production System perfected this idea in the early 20th century. In the last decades of the 20th century, America rediscovered the power of a manufacturing system that economizes coordination cost—the Silicon Valley model of designing and producing digital network goods.

With this social and historical background, the framework of the architecture-based comparative advantage predicts that America-based firms tends to show comparative advantage in certain *technology-intensive modular architecture goods*.

Hypothesis on China: In the late 20th century, China, under the Communist Party regime, adopted Soviet-style national innovation system, in which industrial R&D activities were highly concentrated at the nation state level. Manufacturing firms in China were virtually equal to factories without R&D functions. The design of Chinese products tended also to lag behind that of advanced countries. Thus, when China chose an open economy path in the 1970s, many of its manufacturing firms, those in Southern coastal provinces in particular, had to acquire design information for their new products by licensing foreign technologies or copying foreign products.

For rapid catch-up of product design, many of the Chinese firms, state-owned or private, went for buying licensed or copied parts as generic modules and quickly started up new manufacturing businesses by mix-and-match of such de-facto generic components. The author calls this type of products "*quasi-open architecture*." Many of the machinery industries, such as motorcycle, truck, air conditioner, TV, and other digital consumer goods, were occupied by more than one hundred assembly makers. Copy parts themselves were also produced by hundreds of local suppliers. These firms also tended to rely on mix-and-match of standard equipment and low-wage temporary workers from low-income regions of inland China.

As a result, by the end of the 20th century, China became a major exporter of *labor-intensive modular architecture goods*. Thus, through a very different historical path, America and China became two major producers of relatively modular goods in the Pacific-rim side of the globe. This sharply contrasts with postwar Japan, which became a major exporter of integral architecture products.

Hypothesis on Korea: The most distinctive feature of the postwar Korean economy is a small number of large conglomerates, called Chaebols (e.g., Hyundai and Samsung), which somewhat resemble prewar Zaibatsu in Japan (The two share the same Chinese characters). Each Chaebol was controlled by its founder-owner and family. Because of strong top-down control by the founder-owners, Korean Chaebols tended to have strength in quick decision-making and investment on capital-intensive processes.

Thus, Korean large firms tended to have advantages in standard capital intensive goods, where mix-and-match of the latest production equipment results in competitive products, such as general purpose steels, DRAM, and CLD. In other words, Korean export power is highly concentrated in *capital-intensive modular architecture goods* produced by large firms, many of which stem from Chaebols.

Hypothesis on Taiwan: Taiwan is another significant exporter of manufacturing goods. Taiwanese economy maybe characterized as that of "competitive small country" (e.g., The Netherlands). Taiwan, because of its complicated history in the 20th century, and because of its geographical location (the intersection of America-China-Japan-ASEAN axes) has had strong economic links with the U.S., Japan, and mainland China. Taiwanese export-oriented firms tend to be good at making the most of their overseas linkages in building their organizational capabilities.

Where the products are modular and technology intensive (e.g., digital network goods), Taiwanese specialist producers tended to create networks with American firms. Where the products are integral (e.g., the automobile), Taiwanese firms tend to link themselves to the Japanese production networks. Thus, their strength resides in *versatility* of quickly moving between modular and integral architectures.

Hypothesis on ASEAN countries: As far as manufacturing competitiveness is concerned, ASEAN countries (except Singapore) have not demonstrated concentration of distinctive organizational capability. Although there is a significant degree of variety among ASEAN countries, none of them has industrial agglomeration of local firms that are technologically competitive. ASEAN countries have long functioned as production bases of the Japanese and Western multinational firms.

As such, ASEAN's manufacturing firms were mostly dependent on product designs originating from the multinational firms. Certainly, it is not realistic to foresee emergence of a cluster of ASEAN local firms with distinctive design capability in the near future. However, some of ASEAN countries, such as Thailand and Vietnam, may emerge as production bases of *labor-intensive integral architecture goods*. Their potential advantage over typical Chinese factories may be that it is easier for the former to keep multi-skilled workers with relatively low wages. China may possess a huge supply of low-wage single skilled workers, but the wage level tends to be higher and increasing for multi-skilled workers because of the volatile nature of Chinese labor market.

The key for this possible path toward integral goods is training for multi-skilled workers. In order for ASEAN economies to avoid direct competition against China, which is overwhelmingly strong in labor-intensive modular products, the former may find it beneficial to differentiate themselves from China by focusing on low-price, labor-intensive integral architecture goods. In order to produce such products competitively, it is crucial to strengthen teams of multi-skilled workers. The most effective training fields for this type of work force are, obviously, factories of Japanese firms. Thus, ASEAN firms may have a chance to become the export center of *labor-intensive integral architecture goods*, but only potentially at this point.

5 IMPLICATION FOR ODA IN ASEAN COUNTRIES

Japan's ODA to ASEAN nations have been historically significant in terms of its volume. It may need to be more strategic in the future. That is, a significant portion of Japan's ODA to ASEAN firms may be used for training of multi-skilled workers. Large scale systems and high-tech equipment may look spectacular, but it is difficult to differentiate to create distinctive manufacturing competence vis-à-vis China, a giant in modular manufacturing. The main players of such capability-building are Japanese and ASEAN manufacturing firms, but policy makers can assist their strategic activities.

Policy makers of both Japan and ASEAN may need to share a strategic vision and road map regarding manufacturing competitiveness in Asia. High technology and large systems may be favorite items for bureaucrats, but if all the countries go for such technologies, they are not necessarily the strategic solution for sustainable manufacturing competitiveness.

Asia-Pacific Area is probably the most competitive region in manufacturing. And this is the very reason why policy makers and industrialists in this region need to have a keen sense of comparative advantage. Architecture-based framework of comparative advantage may give them some additional insights. As Ricardo advocated, a country cannot be a major exporter of goods with all kinds. This principle holds true in the case of product architectures as well.

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Manufuture and Sustainable Manufacturing

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Abstract
Manufacturing is permanent on change and research requires orientations to the requirements of the future. Together with stakeholders from Manufacturing in Europe a Technology Platform – Manufuture - has been developed to formulate the strategic orientations towards the Visions of 2020 and objectives of future Research. The basic model of Manufuture has been discussed several times in the CIRC Workgroup "Paradigms" as well as in the European Manufuture Conferences. The known Model has been added by the aspects of sustainability in manufacturing to take into account the pressure for environment protection and climate. This paper gives a short summary about the way if integration of sustainability in manufacturing systems.

Keywords:
Manufacturing Systems, Sustainability, Strategies

1 INTRODUCTION

The environmental problems, caused by the consumption of natural resources and pollution in the life of technical products leed to increasing political pressure and stronger regulations for manufacturing and usage of products. Manufacturing industries are additionally under the economic pressure to compensate increasing cost and create adding value. Under these conditions it is necessary to change the paradigms from former cost orientation to competition, adding value and sustainability. Manufacturing research has the potential to develop technologies for high competitive manufacturing, adding value and sustainability by changing the orientation and the criteria of optimisation to support the structural change of Manufacturing.

2 OBJECTIVES OF SUSTAINABLE MANUFACTURING

The European Union defined the following objectives in the so called Lisbon Agenda:

- Creating more value for more (growth) and better jobs,

- Increasing the competition of European industries and and the communities in the knowledge century,

- Sustainable development of economies.

Now new scientific based studies about the climate und consequences show a dangerous development: global warming etc.

The European Technology Platform Manufuture – established to formulated the goals and strategies for the European research followed the Lisbon Agenda [2]. Like 25 others, they became the base of the European research programme (FP7). Now we have to change the objectives gain to give the environmental aspects higher priorities and reduce the consumption of energy and material under the influence of increasing costs of input for manufacturing [6].

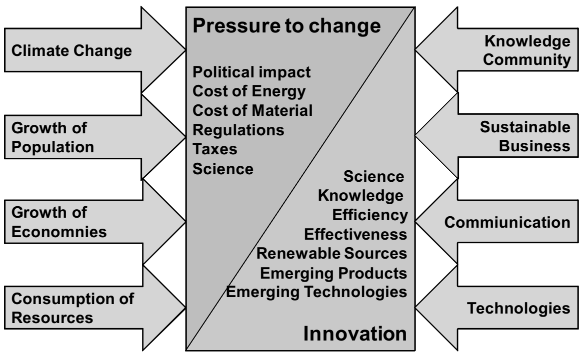

Figure 1: Pressure to change the paradigms of industrial manufacturing

Growth of population and growth of economies, which of course create more value and better life, make material and energy costly. The climate change (CO2) brings us political pressure by stronger regulations for emissions and pollution. On the other side we find the fields of innovation in material and process-technologies, the global information and communication with the electronics as drivers, the economic models and the knowledge of people which is expanding worldwide. Emerging technologies and products, renewable sources effectiveness and the efficiency of processes are needed as answers for the future of sustainable economies [3].

Manufacturing is the key area which has the potential for change [4]. But it is not only a question of research and engineering, it is even a question of business systems and activation of the human resources to implement innovation as fast as possible to change the practice from cost and profit optimisation to competition, innovation and sustainability.

Manufuture put the following objectives in the centre of the and strategic development in Europe and offers global cooperation:

Figure 2: Strategic Objectives of Manufuture

The holistic approach of the generic Manufuture model brings together the forces for change: Management, Products and Processes. A revolutionary change from tayloristic to sustainable manufacturing is required to solve the coming problems in the industrial world.

- sustainability of enterprises and business
- sustainable technologies in products and processes
- global envirionmental and social standards of work.

This can be summarised as the “New Taylor” for industrial manufacturing.

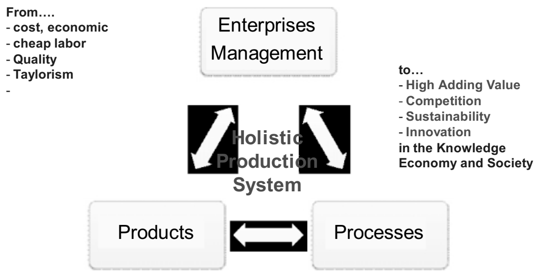

Figure 3 : The Manufure generic model – developed by CIRP

The CIRP generic model of manufacturing is a holistic view on the players of industrial development and their relations in the complex social and technical system of each enterprise. All of the players should follow a common paradigma of the future sustainable manufacturing.

3 INTEGRATION OF SUSTAINABILITY

Sustainability has many definitions and various dimensions. In the field of manufacturing, sustainability is a part of the optimisation of the overall efficiency of enterprises, products and processes. In this area Efficiency has the dimensions of economy, ecology and socials. Costs of energy or materials have an impact on the economic effectiveness. The reduction of ressources is a contribution to the economic and ecologic effectiveness.

Factories have a social dimesion. Humans influence the policy of enterprises develop products and processes and are a factor of cost. The holistic view includes the social effectiveness as part of the system.

The social effectiveness includes the skill and education and the conditions of work like ergonomic layout of workplaces, wagesystems, regulations of labor management, the cultural aspects of work and others.

The implementation of the dimensions of sustainability is possible by integration of the new paradigms in the so called holistic production systems. Production systems include the criteria of optimisation (cost, time, quality), the set of methodologies (lean, JIT, TQM,TPM etc.). Increasing ecologic or social effectiveness is a contribution to the economic effectiveness.

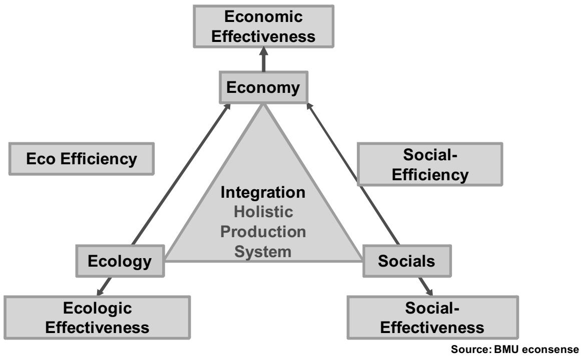

Figure 4 : Sustainability and Efficiency

The development of the basics and methodologies of holistic production systems, which have been born by Taylor [6] and which are mainly oriented to rationalisation and ecconomic efficiency have to be adapted to the requirements of future products, process - technologies and sustainability of the manufacturing system. Global standards are required in the global network of manufacturing.

4 IMPLEMENTATION OF MANUFUTURE

The Stakeholders of the Manufuture Platform defined five Pillars for the orientation of manufacturing. Taking into account the potential of new technologies and the variety of information and communication technologies in relation to industrial sectors and knowledge areas, the shown fields are parts of an overall strategy towards the development of next generation of factories.

The figure 5 shows the main fields of actions towards the European Production System for the sectors of capital intensive goods and consumer goods. Innovations in all of these action fields are contributions to European Manufacturing.

4.1 Driving force ICT for Manufacturing

We can state, that the diffusion of ICT has reached nearly all workplaces in Europe. It becomes an enabler technology for manufacturing. But ICT technologies influence even the private way of life. Basic innovations and basic research for ICT will find its way into the area of manufacturing the industrial market and are even drivers of innovation in manufacturing.

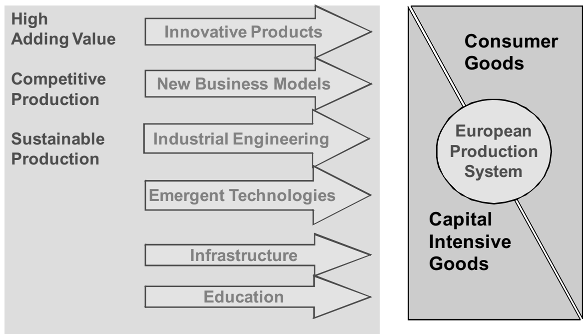

Figure 5 : Driving areas for Manufacturing development

The objectives follow the generic model of ManuFuture and objectives of High-Adding-Value and Sustainable Manufacturing. Strategic goals, targets and main visions elaborated by the ManuFuture actors follow in the next chapters. They can give a vision, which way manufacturing development should follow.

4.2 Emerging technologies

Emergent technologies are the drivers of the economic, ecologic and social effectiveness in manufacturing. The balance sheet classification covers the life cycle of products in the process chains from engineering to endof life and the öife cycle of factories from birth to Recyling. Factories are seen as komplex socio-technical products which have to be adapted to the needs of producst, markets and environment. Products meet factories in the manufacturing processes. Factories are usually elements of production networks. Their overall efficiency depends on the utilisation and the value chains. Under the aspects of sustainability the main criteria of optimisation are not only logistivcs but even the efficiency of the resources.

Manufuture defined the fields of emergent technologies, which are contributions to the overall economic, ecologic and social efficiency of both, the products and factories. The management and optimisation of the benefits (economic, ecologic and social) is one of the core areas of Research for manufacturing. This includes methodologies for engineering evaluation and management.

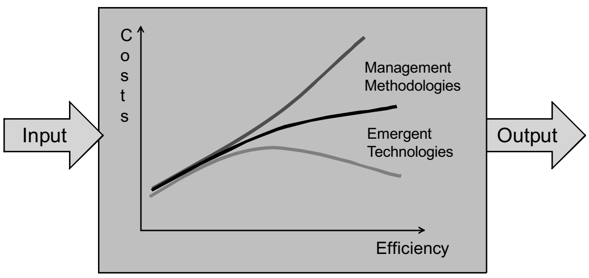

Figure 6 : Costs and Efficiency

Usually cost and efficiency have a linear and progressive relation. Industries need therefore methodologies and technologies to reduce the costs of higher efficiency. There are many examples which show, that emergent technologies have the potential to reach lower costs and at the same time higher efficiency: Dry cutting, integration of process chains, etc. They illustrate that manufacturing engineering is the key-technology of future development.

Manufacturing engineering the understanding of the holistic production systems includes the engineering of management systems, products and processes and has to use methodologies for optimization. The next figure shows the role of manufacturing engineering. More and more it becomes the goal as system-integrator of technologies from different areas: Process-technologies, materials, mechatronics, Nano-technologies or IT-methodologies to overcome existing state of the art in products processes and management.

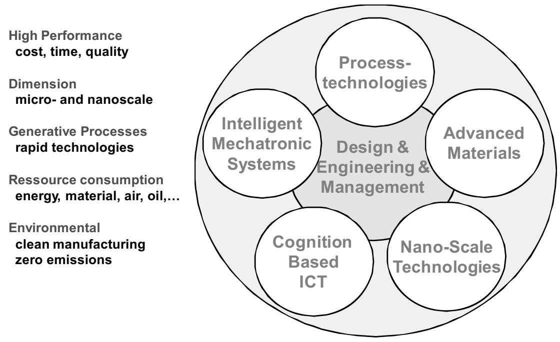

Figure 7: Development of emerging manufacturing systems

Manufacturing is on the way to overcome not only the existing limitation in performance, which was the main objective to increase economic efficiency but even in the dimensions (micro- and nano scale) to reduce the consumption of energy and material and in the consumption of resources or emissions. Following the lean-philosophy the consumption of energy and material is loss.

Technical intelligence is the long technical perspective of development toward disruptive factories

The set of methodologies of lean management defines the management system in series production [6,7]. The transformation and adaptation of these methodologies towards higher complexity, higher variants and changeable manufacturing aim at activating productivity potential in small batch production.

Lean management methodologies, which have been successfully implemented in automotive and supplier industries, are quasi standards of today's efficient manufacturing. The competitiveness under the European conditions of high wages and changing markets and technologies revealed that lean management can not reach the cost advantages in general.

The philosophy of lean mangement can easily take over the orientation of sustainable manufacturing by adding metghodolofgies of increasing the efficiencies (economic, ecologic, social) into the production system.

4.3 Survival in the turbulent environment

The development of the markets depend mainly on economic factors. In many industrial sectors cyclic fluctuations with ups and downs represent main factors of market turbulences. Manufacturing enterprises are influenced by multiple dynamic external factors concerning the products' behaviour in global markets, the strategies of competitors, the regional level of wage and reward systems including management of employee healthcare cost, regional infrastructure, the pace of technical innovations, the financial requirements of the investors and the financial constraints of operations, the robust supply of materials and components. Internal business factors such as qualification and capability of employees and the management, the demands and systems required by different customers, the utilization of resources and the capability of processes represent main influence factors as well. The enterprise environment is tough and turbulent. Only those enterprises can survive and be successful in this turbulent environment, which are robust enough and have the capability to continuous adaptations and transformations.

There is a requirement for sustainable manufacturing management supported by methods for:

- Balancing the load in mid term cyclic markets;
- Overcoming critical short term situations;
- Dynamic forecast;
- Adaptation of fix costs (dynamic systems)
- Dynamic work force models.

The strategies represent the main directions towards which research and technological development activities have to be oriented, with high priority on short term horizons.

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4.4 Road Maps for Implementation

Investment in Research, Technology and Development for Manufacturing is necessary to achieve the ambitious goals and targets of competition and sustainability in the wide area of industries. Many enterprises are fighting for survival in the turbulent markets; others are leaders in markets and effectiveness. The third area seeks the future in emerging technologies. The European Way to activate the economic potential by research for manufacturing for the wide range takes care of the sector specific situation and transsectorial synergies to push industries and accelerate the diffusion process from basic research and innovation to applicative research.

The Road Map, developed by exterts of the european manufacturing industries and research is driven by industrial/economic requirements and the need of transformation of manufacturing towards Competitive Sustainable Development. More than 80% of the proposed activities to follow visions, strategic objectives and tasks of the ManuFuture Pillars are of common interest for all industrial sectors. The authors summarised them to several transsectorial Roadmaps, unified under a comprehensive approach representing the Manufuture Vison towards the European Industrial Transformation, further on called Manufuture Workprogramme.

The prioprities of actions and research have been defined under the influence of reality. In many areas they did not follow actual academic views. Academia is still influenced by the economic orientation or by basics for technologies. The structural change from conventional manufacturing to manufacturing of the future and for sustainability including technical innovations (intelligent manufacturing even requires changes in the orientation of academic research.

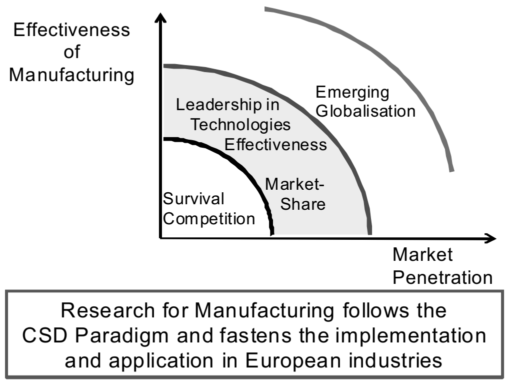

Figure 8: Transformation and Implementation

The figure shows the priorities of research following the paradigms of Manufuture and support the structural change towards the vision on manufuture: Competitive Sustainable Development (CSD).

5 SUMMARY

This paper summarized the visions and objectives of the Manufuture Technology platform in Europe. The Vision and the roadmaps for implementation follow the new paradigm of sustainable manufacturing. Sustainability can be integrated in the overall and holistic production systems. Research in Manufacturing should go ahead with the development of methodologies and intelligent technologies.

6 ACKNOWLEDGMENTS

I extend my sincere thanks to all who contributed to develop the Manufutrure Platform in Europe. Special thanks are given to my friend and CIRP colleague Franco Jovane, who startet in the CIRP Working Group paradigms and the generic model. It added the aspects of Sustainability and the visions of the factory of the future.

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Challenges for the Manufacturing Enterprise to Achieve Sustainable Development

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Abstract
Manufacturing enterprises are striving to achieve sustainability through changes in products, processes, and systems. Decision-support tools and methods are rooted not only in improving environmental aspects of manufacturing, but also in ensuring long-term productivity and social well-being. Refocused efforts on the development of sustainable technologies can further aid continuous improvement and stimulate revolutionary advancements industry-wide. Current and future challenges facing the manufacturing industry are addressed in terms of manufacturing enterprise, product life cycle design, and manufacturing processes and systems. Opportunities for future research are discussed within each of these areas.

Keywords: Sustainability; Life Cycle; Manufacturing

1 INTRODUCTION

Industry has been forced to evolve in the past in response to new regulations, technologies, and changing customer demands. At the dawn of the 21st century, there are increasing concerns about the sustainability of activities in developing nations and the industrialized world. Sustainable development calls for practices and decisions that will ensure that future generations have access to same opportunities that we presently enjoy [1]. For how long can we continue as a global society to extract natural resources, consume energy, and generate wastes with little thought for future generations? In response to growing concern for the environment, our assistance as technologists is needed to support corporate decisions related to manufacturing enterprises and product/process design all directed at helping to realize a sustainable future.

Sustainability is a globally emerging concept for that recognizes the interdependence of the economy, society, and the environment, frequently referred to as the three pillars of sustainability. Businesses are encountering increasing pressure from consumers, governments, and other organizations to address dimensions of sustainability, and increasingly, this involves more than such traditional measures of performance price and quality. Companies have begun to seriously consider product stewardship, reduction of hazardous substances, carbon footprint, energy and water consumption; and their role in society. Governments are instituting policies and companies are establishing strategies to support progress toward achieving sustainability. These policies and strategies serve as drivers for change, and many corporations have begun to critically examine their traditional practices. Manufacturers who do not evolve in response to these drivers will ultimately fall prey to global competitors who are operating under an evolving rule-set.

In particular, many recent concerns have focused on the continuing reliance on fossil fuel-based energy. Not only is accelerated use of non-renewable fuels unsustainable, but combustion results in high levels of carbon dioxide (CO_2) emissions. CO_2 has been linked to climate change, and efforts are underway to reduce its emission to the atmosphere [2]. Figure 1 shows that unless changes are made, carbon emissions will continue to increase, and in less than a century will be nearly ten-fold the current level. Industry remains a large end-use consumer of energy; in the United States it is responsible for about one-third of the total energy demand [3]. The manufacturing sector has a responsibility to reduce energy consumption as well as undertake other efforts to ensure a sustainable future.

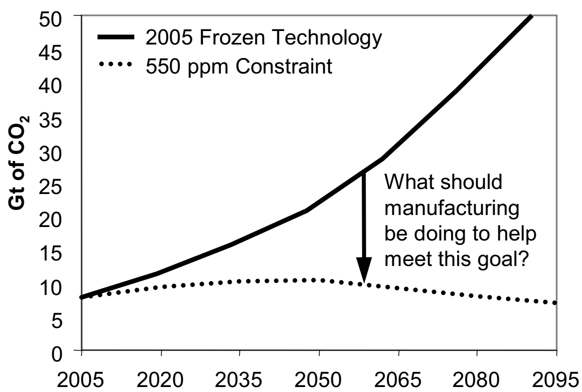

Figure 1: Carbon emissions under two scenarios: with frozen technology and with technology required to achieve 550 ppm concentration of atmospheric CO_2 [2].

This paper begins to explore some of the sustainability-related challenges associated with manufacturing. These challenges will be presented in the context of the following areas: the manufacturing enterprise, product life cycle design, and manufacturing processes and systems. As a starting point for discussion, for each area, some goals for the research community are proposed.

2 MANUFACTURING ENTERPRISES ISSUES

It is increasingly the case that companies are accountable for sustainability-related impacts outside their direct control, including the impacts of supply chain partners. Companies are more and more frequently asking how to select partners that practice sustainability principles or who are socially responsible. What motivates this interest? As one example, it is becoming ever clearer that at some point in the not-to-distant future, embedded energy or carbon of materials and products will be taxed, regulated, or otherwise valued as part of costs. As a guide for supply chain-related decisions, it is believed the following issues must be addressed:

Standard measures for evaluating sustainability performance. As has been noted, corporations have much experience in considering such traditional metrics as cost, quality, and time to delivery in making supplier decisions. There is growing interest in the use of environmental metrics to describe corporate performance, and ISO 14000 certification represents an important first step in standardizing the methods by which all companies approach environmental sustainability. The Global Reporting Initiative has improved sustainability reporting through efforts aimed at standardization and transparency [4]. However, even for companies aware of their corporate-wide environmental footprint, it is very difficult to disaggregate this environmental information based on the materials, components, and products that they may produce. Standard eco-measures for products and processes are needed. In terms of societal sustainability, ISO 26000 is still several years away from being released. Still, it seems likely that formulating socio-measures of performance at the product/process level will be even more challenging than developing eco-measures.

Method for integrating the sustainability-related impacts of all the contributions to a product from a supply chain. Manufacturers create products using components/materials obtained from suppliers and through value-added operations performed on components and materials. Assuming that eco- and socio-measures of performance can be defined and quantified for each component, at issue is how to integrate these measures for the product. Hutchins and Sutherland [5] have discussed this issue and proposed a scheme that weights supplier performance measures by the economic value the supplier-delivered component contributes to the product; the scheme also incorporates the value-weighted performance of the manufacturer itself.

Development of EOUP (end-of-use product) management strategies and associated logistics. As corporations contemplate a future where used products are recovered and returned for recycling and remanufacturing, increased attention must be given to tracking the "inventory" and status of products that are currently being used. Moreover, consideration must be given to the best manner to recover and transport these EOUPs for subsequent processing [6].

The foregoing discussion highlights the fact that there are significant technical challenges that must be addressed to establish meaningful measures of sustainability performance as well as a method for the integration of these measures. An emerging paradigm shift in the notion of how used products are managed will drive many enterprise changes, and will require increased use of life cycle thinking to ensure that any action taken is not counter-productive. It should be evident that the record-keeping associated with such ventures will be significant.

3 PRODUCT DESIGN ISSUES

Products should be designed to respond to the needs of consumers. In the 21st century, the challenge of sustainability suggests that designers must also factor the environment and broader social interests into their decisions. It is now well recognized that designers should consider the entire product life cycle in this decision-making process.

Can we continue to tolerate a situation where waste is "designed into" products? Where manufacturing processes consume vast amounts of energy and materials and produce waste of all forms? Where used products are disposed with little regard to potential environmental impact and value lost? The traditional life cycle includes materials extraction and processing, manufacturing, distribution, use, and end-of-life stages. End-of-life for many products means disposal/ landfilling. Figure 2 suggests a product life cycle to which we should aspire. Green design is employed to reduce environmental impacts across the life cycle, green manufacturing processes are used that require little energy and emit zero wastes, and preventative maintenance is employed to extend product life. The figure shows EOUPs being recovered for reuse, remanufacturing, and recycling.

3.1 Life cycle assessment

Any meaningful progress in terms of product design that promotes sustainability will require a life cycle assessment (LCA). A research challenge associated with this category is

Improvement of LCA methods and software tools. This challenge includes progress on identifying appropriate allocation schemes, guidelines for performing streamlined LCAs, and improved data quality. Gaps are present within existing tools and these must be identified and filled (e.g., not enough manufacturing process-specific information). Not enough is known about the uncertainties and risks embedded within LCA methods and data, and thus on the reliability of the methods themselves. Methods and data are needed for both environmental LCAs and societal LCAs.

As noted previously, weighting of various impacts requires consideration of trade-off analysis methods to simultaneously consider economic, social, and environmental issues.

3.2 Material selection

Material selection is a key element of design, and thus will have a significant effect on sustainability. Guidelines have been developed for the selection of materials [7] [8]. They often are general and do not provide the necessary specificity that designers require.

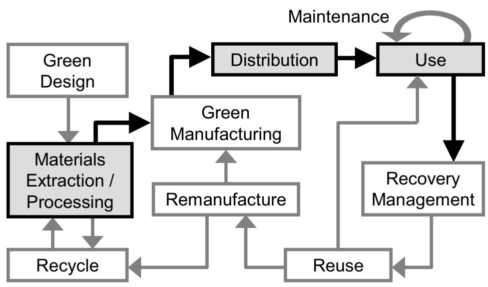

Figure 2: Product life cycle incorporating green design and manufacturing and used product recovery management.

Table 1: Embedded (processing) energy estimates of selected engineering materials (MJ/kg), adapted from [9].

Material	MJ/kg
Aluminum, virgin (recycled)	191 (8.1)
Float glass	15.9
Polypropylene	64.0
Steel, virgin (recycled)	32.0 (10.1)

The following is offered as a research challenge in the area of material selection:

Development of improved materials data for a variety of metrics. Some data are available on the environmental characteristics of materials, but the quality of these data may be suspect, and much property-related data is missing (e.g., energy consumed, waste produced, and water used per unit mass; recyclability; and biodegradability). Considerable progress is needed to tie materials level issues to such societal level issues as education, healthcare, and equity.

Furthermore, the sparse data that are available may be misleading. Table 1 provides estimates of embodied energy for several engineering materials; the values do not include manufacturing energy requirements. The table reveals large energy benefits associated with recycled aluminum and steel and suggests that aluminum is a superior alternative to steel. However, it must be remembered that the embedded energy of a recycled aluminum product must also reflect the significant energy required to process the virgin aluminum.

3.3 Design for the environment

Design for the environment (DFE) encompasses strategies and techniques aimed at reducing environmental impacts through such efforts as extending product life, reducing use-stage environmental burdens, and facilitating post-use recovery, reuse, recycling, and remanufacturing. Research challenges related to DFE include the following:

Increased emphasis on modular design. This philosophy calls for modular, upgradeable platforms that reduce impacts through integration of recovered end-of-use components. Modules should be defined across platforms and product generations, and yet not limit design flexibility. Much work is needed in the general area of design modularity; improved knowledge of returning component availability and condition is also required. Modularity offers a significant manufacturing benefit and supports mass customization. Of course, as in all design-related decisions, modular design should be guided based on life cycle assessment knowledge.

Renewed attention to product dematerialization and service-oriented products. Environmental impact is virtually proportional to the amount of material in many products, e.g., fuel consumption of an automobile is proportional to its mass. Dematerialization calls for the development of products that employ less total material in meeting consumer needs. Methods for dematerialization include more efficient product designs, better materials, and transitioning from a tangible (material-based) product to a service (an intangible product) [10]. While efforts have been underway for decades to develop more material efficient product designs, the concept of integrated product-service systems that have a high service content is more recent phenomenon and is only beginning to receive attention from the research community.

Of course, the research challenges identified represent only two DFE issues, and many others exist. The principle of sustainability embraces societal issues, thus an analogous companion to DFE would be the philosophy of Design for Society. Presumably, DFS would be focused on developing integrated product-service systems that in addition to satisfying consumer needs, also address broader societal concerns. The creation of products for the developing world using appropriate technology is one example of DFS.

4 MANUFACTURING PROCESSES AND SYSTEMS ISSUES

Across their life cycles, products consume large levels of resources and produce substantial wastes. An automobile consumes nearly 1 TJ of energy across its life cycle [11]. While most of this energy is associated with vehicle use, about 125 MJ is expended in materials processing and manufacturing – and this happens over a relatively short time period. Williams [12] reported the majority of the life cycle energy associated with a desktop computer is attributable to manufacturing (81%). Clearly, manufacturing processes have a significant eco-footprint that requires attention.

In an era of increased attention to recycling and remanufacturing, more focus should be directed at the processes employed for these activities. Important challenges related to the manufacturing of virgin and used products exist and these challenges may be classified based on whether they are associated with virgin products (manufacturing processes) or used products (recovery processes). Systems-oriented challenges are also present for both classes. The text below presents some thoughts on the challenges associated with these two classes.

4.1 Manufacturing processes

Our goal for manufacturing processes should be to establish processes that consume very little energy and produce zero or near-zero waste. Moreover, in support of product and process design efforts, information on existing and proposed manufacturing processes needs to be available that relates process inputs to environmental impacts. The following challenges are proposed:

Establish improved information on the environmental impacts of existing manufacturing processes and explore new technological concepts for greener operations. In support of product and process design, and life cycle assessment, the environmental impacts (resources consumed and wastes produced) by manufacturing need to be better quantified. Where good data exists, it is often aggregated and difficult to allocate to a single operation. New processes and technologies need to be established that avoid the traps (and wastes) of traditional operations; for example, we need to identify techniques for eliminating material removal operations, perhaps via additive operations.

Development of systems that can accommodate the use of mixed manufactured and remanufactured components. As we consider manufacturing systems of the future, it may be that both manufacturing and remanufacturing operations are housed in the same facility. Manufacturing processes will produce virgin components and remanufacturing operations will process used components, perhaps with both flows of components flowing into products. Clearly, such a situation will require the development of new approaches to manufacturing system design and operations to accommodate the significant differences between manufacturing and remanufacturing.

4.2 Recovery processes

Recovery processes are essentially those processes used to transform a used product into a component or material that can be re-integrated into a product. In essence, recovery processes include dismantling, sorting, remanufacturing, and recycling operations. Proposed research challenges associated with recovery processes include:

Development of recovery process knowledge and technologies. Improved knowledge is required for all steps in the processing of a used product into either a refurbished component or material that can be formed into a component. This includes inspection, dismantling, sortation, purification, remanufacturing, and recycling processes. At issue is acquiring fundamental insights into the physics of the operations, with particular emphasis placed on the understanding how environmental impacts depend on process inputs. One key challenge is identifying, based upon inspection, whether to recycle or remanufacture a used product, early during the recovery process before additional costly activities are undertaken. A continuing concern will be to develop effective recycling and remanufacturing processes.

Establishment of better manufacturing systems for recycling and remanufacturing. At a systems level, methods are needed that are less labor intensive and more flexible. For example, it would be ideal if dismantling facilities could disassemble a diverse variety of products.

As a general comment, while much work has been performed to characterize manufacturing operations and improve their performance, little of this work has been directed at environment-related issues. Many issues remain to be investigated.

5 SUMMARY AND CONCLUSIONS

Many individuals now believe that we are entering a sustainability revolution, and this revolution will present us with many issues to be addressed. The manufacturing research community needs to recognize that sustainability issues need to be addressed and critically examine all elements of the processes and systems for which we are responsible – what should we be doing to help achieve sustainable development? As a starting point for discussions, this paper has proposed several challenges for the manufacturing enterprise that we should consider as we contemplate the future:

- Standard measures for evaluating sustainability performance.
- Method for integrating the sustainability-related impacts of all the contributions to a product from a supply chain.
- EOUP management strategies and associated logistics.
- LCA methods and software tools.
- Improved materials data for a variety of metrics.
- Emphasis on modular design.
- Product dematerialization and in particular, service-oriented products.
- Information on the environmental impacts of existing manufacturing processes and new technological concepts for greener operations.
- Systems that can accommodate the use of mixed manufactured and remanufactured components.
- Recovery process knowledge and technologies.
- Better manufacturing systems for recycling and remanufacturing.

Additional interaction on these and other issues is welcomed and needed. After all, the stakes are high. Unless appropriate actions are taken, we run the risk of jeopardizing our future.

6 ACKNOWLEDGEMENTS

The authors gratefully acknowledge support from the National Science Foundation through the Sustainable Futures IGERT project (under Grant No. DGE 0333401).

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Complex Adaptive Systems (CAS) Approach to Production Systems and Organisations

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Abstract

Theoretical study of complex systems receives more and more attention as most sciences broaden their perspectives. First, the paper overviews a few important complexity approaches, then it argues that complex adaptive systems (CASs) are especially important for production control research. As examples, firstly, a CAS based scheduling mechanism is described in which agents apply reinforcement learning to handle complex production control tasks, secondly, a semi-formal model of production networks is given combining stochastic processes, graph or network theory, and CASs. Further research issues are also highlighted.

Keywords:
Modelling, Production, Complexity, Adaptive Agents

1 INTRODUCTION

Growing complexity is one of the most significant characteristics of today's manufacturing, which is manifested not only in manufacturing systems, but also the products to be manufactured, in the processes, and the company structures [1]. The systems operate in a *changing environment* rife with *uncertainty*.

The need to be able to measure the complexity of a system, structure or problem and to obtain quantitative relations for complexity arises in more and more sciences: besides computer science and engineering, the traditional branches of mathematics, physics, chemistry, biology and social sciences are also confronted more and more frequently with this problem [2].

Complex Adaptive Systems (CASs) represent a relatively new theory, with the goal to study the structures and dynamics of systems and the question, how the adaptability of systems creates complexity [3], [4]. A CAS can be considered as a multi-agent system, where a major part of the environment of any given adaptive agent consists of other adaptive agents.

The main aim of the paper is to illustrate the appropriateness of the CAS approach for modelling different levels of production systems and organisations. Firstly, classical complexity measures are shortly surveyed, followed by enumerating some attempts to characterise the complexity in the manufacturing domain. The CAS approach is described shortly in Chapter 3, followed by chapters focusing on two different levels of the production hierarchy, namely the shop floor level and the level of the production networks. A CAS-based adaptive distributed production control is illustrated in Chapter 4, where the scheduling problem is formulated as a Markov decision process (MDP), and a three-level learning procedure is introduced. Chapter 5 gives a semi-formal model of production networks, combining stochastic processes, graph or network theory, and CASs. Further research issues conclude the paper.

2 COMPLEXITY AND ITS MEASURES

The meaning of the word "complexity" is vague, ambiguous, no universal, precise (e.g., formal) definition exists accordingly. Yet, there are approaches, especially in mathematics and computer science, which aim at defining special forms of complexity. In this section we provide a brief overview of some important classical complexity approaches.

2.1 Classical complexity measures

Since Alan Turing introduced his mathematical machines (viz., the Turing-machines) in the 1930s, they have become a fundamental tool for analyzing algorithms and problems. According to the theory of computational complexity, complexity is measured by the quantity of computational resources made use of by a particular task. Several complexity measures are known which are associated with algorithms [2], e.g., time-complexity, space-complexity and, for distributed systems, communication-complexity. Regarding the complexity of problems, the two most important classes of problems are P and NP. By definition, a P-problem is a decision problem that can be solved by a deterministic Turing machine in polynomial time. An NP-problem can be solved by a nondeterministic Turing machine in polynomial time. Roughly, problems in P are "easy" problems, while problems in NP are "hard" ones. Naturally, this classification is a simplification. We know that any P-problem is also an NP-problem. However, the question, whenever P = NP, is currently the most important problem of computational complexity theory.

Information complexity, viz. entropy, tries to measure the randomness or disorder of objects. This approach was suggested by Claude Shannon who in 1948 introduced entropy to communication theory [5]. Entropy provides a measure of the amount of information associated with the occurrence of given states. This is of key importance in information- and code-theory, however, can also be applied to measure other complex systems, e.g., graphs or networks.