Klaus Ruth
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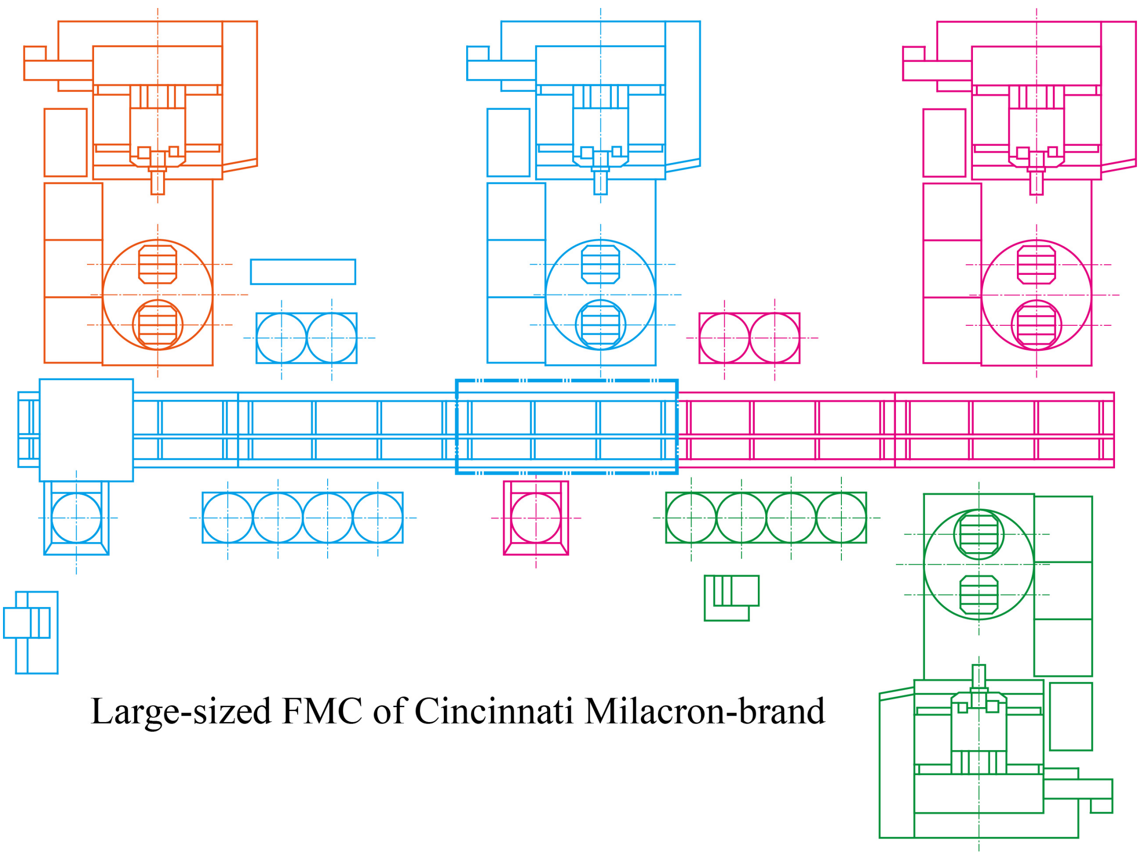
Flexible-Intelligent and Smart Factory Systems



Large-sized FMC of Cincinnati Milacron-brand

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Klaus Ruth, Yoshimi Ito

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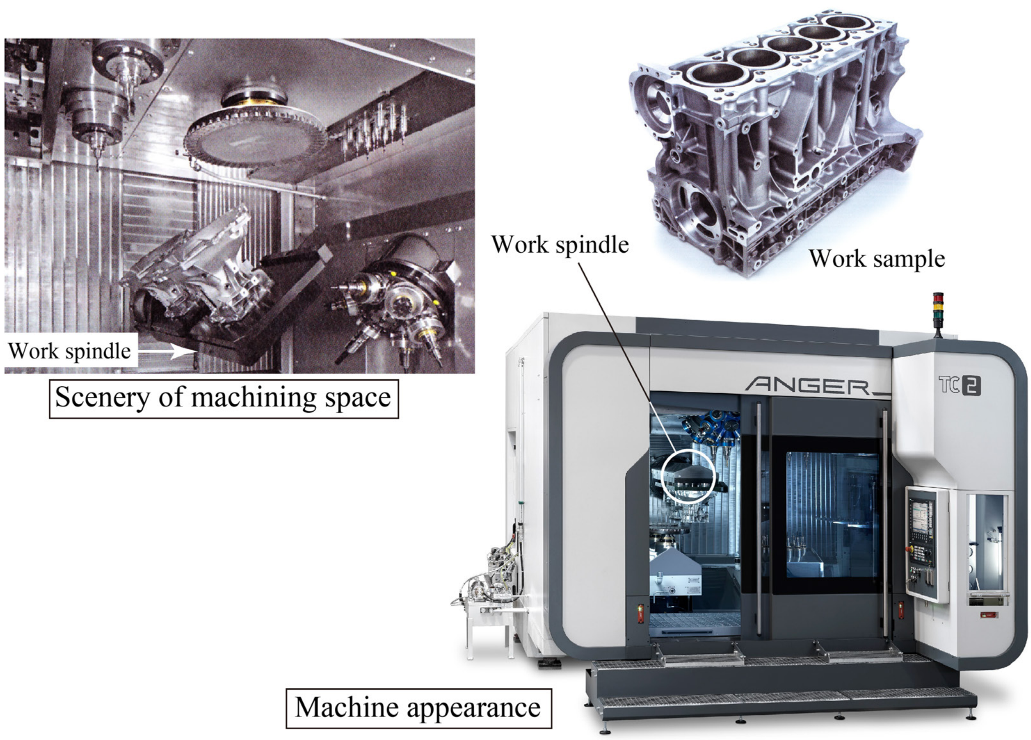
Layout Design of FMS and Convertibility to CPS Module



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Preface

The production activity is, in principle, a synergy of the design and manufacture, and generally speaking, the manufacturing system ranges from machining, through assembly, to the product inspection. Obviously, the fundamental issue is to generate a group of the parts (components) for a product, of which the human society requires. Reportedly, there have been various kinds and types in the machining system depending upon the technological, economic and social environments of each nation and region across the whole world. In general, we can classify the machining system by both the variety of part kinds possible to processing and the processing volume of each part kind, as exemplified, for example, “Much Variation in Part Kinds and Less Volume Machining for Each Part”, i.e. in short “Much Variation and Less Volume Machining”.

As reported elsewhere, the machining system ranges roughly from the production cell and transfer line to FMS (Flexible Machining System) including agile type, and in the industrial nation, primary concerns are FMS and its variants. Importantly, with the advance of CIM (Computer-Integrated Manufacturing), and also the information and communication network, it is at present natural to regard the machining system as one of the core functions within a concept of the “*Flexible and Intelligent Factory*”, exactly calling “FCIPS (*Flexible Computer-Integrated Production Structure*)”. Paraphrasing, FCIPS consists of CIM, information communication network, and also of FMS, where CIM can facilitate information processing for the design and manufacture of the product, production control and enterprise management. In addition, FMS is modular-designed, where FMC (Flexible Machining Cell) plays the role of the basic module. Importantly, FCIPS was conceptualised in the 1990s; however, on that occasion FCIPS was far from fruition, because CIM, and also the information and communication technology were immature.

Although FCIPS and its variants are in the leading position at present, geminately, a recent upheaval in the production activity is the smart factory, which is one of the flagship projects within the “Industrie 4.0” Programme initiated by the German Government in the beginning of 2010s. In fact, the smart factory consists of “Cloud Computing”, “Information Communication Network” and the “CPS (Cyber Physical Systems) Module”, and can be characterised by its autonomous function, where the CPS module is called “Fog Computing or Edge” in certain cases. For ease of comparative understanding, both FCIPS and the smart factory can be represented with the “Human-mimetic Model”, which consists of the “Brain (CIM and Cloud Computing)”, “Nervous System (Information Communication Network)” and “Limbs and Tools (FMC and CPS Module)”.

As widely discoursed, the smart factory is now the utmost hot topic in the production activity, and people in general concerns believe that the smart factory is excellent and very innovative, and that we have never had such a concept so far as exemplified in nearly all discourses, discussions and suggestions being carried out in Japan. As a result, it is very difficult to find the report, which discusses the technological inheritance between FCIPS and the smart factory.

On the basis of our long-standing experiences, the production system has been advanced, deployed and improved by positively applying its technological and human resources so far accumulated to successors. Obviously, it is very rare case that a new production system is to be in reality without any relationships to those being in practice. We must be thus aware of the necessity and inevitability to conduct, at least, the comparative investigation into FCIPS and the smart factory, extremely focusing on the convertibility of FCIPS to the smart factory. In such a comparative investigation, one of the primary concerns is the growing importance of the “Manufacturing Culture”, because some variants in FCIPS and the smart factory aim at the “Virtual Concentration of Production Bases” across the whole world, which is a “MUST” in the era of the localised globalisation. In fact, a group of either FMCs or CPS modules should be distributed within a wider region or across the whole world in the virtual concentration of the production bases in full consideration of the culture- and mindset environments in the objective realm. In short, the manufacturing culture is a synergy of the production technology and the industrial sociology.

In due course, this book describes first the fundamental knowledge about, and also present and future perspectives of FCIPS, and then discusses the concept of the smart factory together with its case studies. In addition, for ease of understanding FCIPS is detailed and visualised quickly by using the "Production Morphology", i.e. life history of the product. The book discusses furthermore the convertibility of FMC for "One-off Production" in FCIPS into the CPS module in the smart factory, and suggests the research and engineering subjects to be conducted here after.

In short, the book can thus contribute duly for people both in the academia and in the industry to plan the valuable research and engineering development to a large extent.

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Yokohama, Japan Yoshimi Ito

1st December, 2018

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Chapter 1 Fundamentals of Production Systems

Abstract Of quick notes, the "*Flexible and Intelligent Factory System*", exactly calling *FCIPS* (Flexible Computer-Integrated Production Structure), and its variants are in the leading position of the production system of wider scope at present, and can facilitate the production activities in the industrial nation to a large extent. In contrast, a recent upheaval in the production activity is the *smart factory*, which is one of the flagship projects within the *"Industrie 4.0" Programme* initiated by the German Government; however, nearly all discourses, discussions and suggestions of the smart factory have been carried out without any considerations of FCIPS (refer to Preface for details).

This chapter describes first the definition of and fundamental knowledge about FCIPS, and then its present and future perspectives, extremely suggesting its wider availability for various production activities in the localised globalisation area, e.g. in the form of the "*Virtual Concentration of Production Bases*". In addition, for ease of understanding, FCIPS is detailed and visualised quickly by using the "*Production Morphology (Life History of Product)*". Obviously, FCIPS can be facilitated considerably by the manufacturing culture and we see the same story in the smart factory. It is furthermore notable that the authors assert the similarity of both the concepts in FCIPS and smart factory, and duly suggest the better convertibility of *FMC* (Flexible Manufacturing Cell; Small-sized *FMS*) for one-off production into the *CPS* (Cyber Physical Systems) module in the smart factory.

1. 1 Introduction

Up to the late 1970s, it was enough to discuss the production activity with narrower scope, i.e. a production system, which is a combination of the design office and manufacturing system of manual-intensive type within a factory. For example, the machining system, one of the sub-systems of the manufacturing system, consisted of a group of traditional machine tools and its inputs were the part drawing, raw and semi-finished materials and machining schedule. In addition, the worker played the role of material transportation and information delivery.

With the advent of the computer control for the production activity, the manufacturing system became employed DNC (Direct Numerical Control), which is a forerunning system of *FMS* (Flexible Manufacturing System) [1] and since the beginning of 1980s, *FMS* was prevailed in the factory floor, where the automatised facilities played very important roles on behalf of the worker. Furthermore, *FMS* has been closely integrated both the computing and information communication technologies. Thus, it is better to understand and call the production activity with wider scope such as a "*Flexible and Intelligent Factory System*", exactly naming an *FCIPS* (Flexible Computer-Integrated Production Structure, Ito 1991 and 1993). By it, we may define definitely the production activity, and also avoid the misunderstanding of the corresponding terminologies in the year 2000 and beyond.

Although some simplified variants of FCIPS are in leading position in the industrial nations at present, we must use various production systems depending upon the technological, economic and social environments of each nation. Of course, the nation being industrialised may benefit considerably by the production system of manual-intensive type, and such a system should be employed even in the industrial nation in certain cases. This is because the human society requires of various products in accordance with its environments. As a result, we must learn the overall view of the production system as will be described in Chapter 2.

In short, FCIPS consists of *CIM* (Computer-integrated Manufacturing), information communication network and *FMS* as shown in Fig. 1.1. More

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[1] To differentiate FMS for machining, i.e. "Flexible Machining System", which is the leading topic within this book, from *FMS* in general, the acronym of "Flexible Manufacturing System" is represented by the italic like *FMS* to avoid unnecessary confusions and redundancy. Of note, FMS includes FMC (Flexible Machining Cell), FML (Flexible Machining Line), and FTL (Flexible Transfer Line) [refer to Chapters 2 and 3].

specifically, CIM can mainly process the leading three information, i.e. those related to "Engineering Design and Manufacture of Product", "Production Control Management" and "Enterprise Management" [2], and in nearly all cases, *FMS* is designed by the modular principle, in which the basic module is, in general, *FMC* (Flexible Manufacturing Cell) possible to distribute within a certain region, e.g. either within an industrial estate or across the whole world (see Appendix). In fact, FCIPS may facilitate the production activity in the era of localised globalisation to a larger extent.

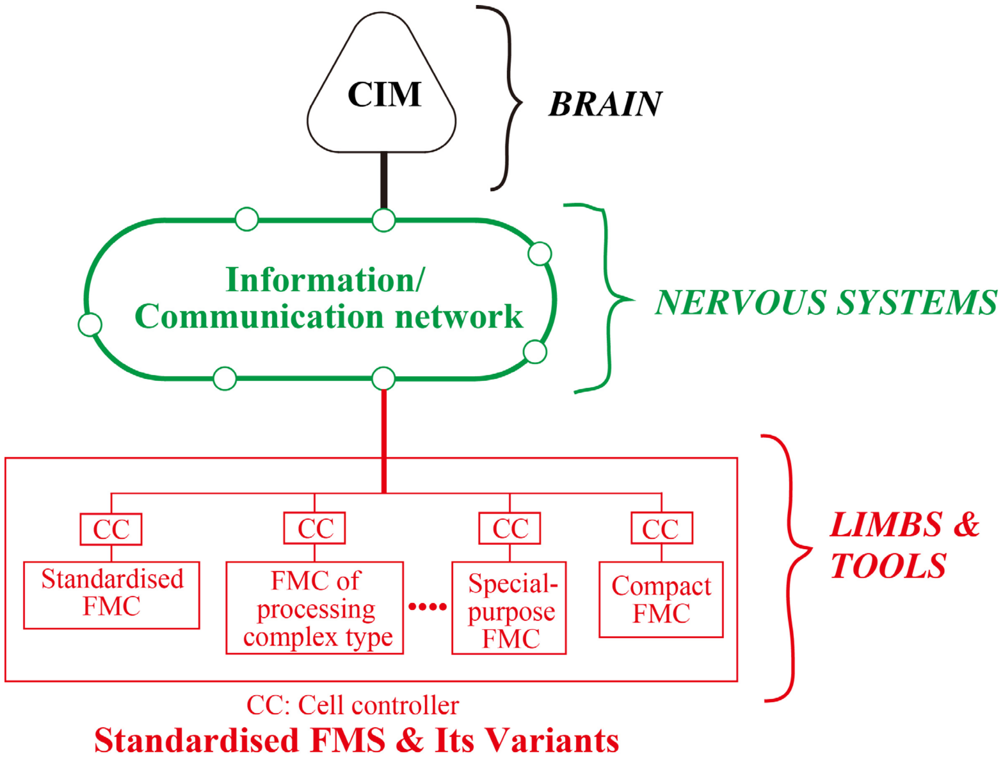

Fig. 1.1 Concept of FCIPS

For the ease of understanding FCIPS, it is convenient to model FCIPS by the human being, i.e. CIM, information communication network and *FMS* being likely "Brain", "Nervous system" and "Limbs and Tools", respec-

[2] In fact, CIM consists mainly of CAD (Computer-Aided Design), CAPP (Computer-Aided Process Planning), CAOP (Computer-Aided Operational Planning) or CAM (Computer-Aided Manufacturing), MRP (Material Requirement Planning or Material Resources Planning), SCM (Supply Chain Management) and so on.

tively. Importantly, FCIPS should be in healthy condition by fusing satisfactorily these three as like as human being. More importantly, we cannot create the product without having the “Limbs and Tools”, even when the “Brain and Nervous system” can work very well.

In retrospect, FCIPS was conceptualised in 1990s on the basis of the achievement obtained from the predictive research into the “Production Environments in the Year 2000 and beyond”. Such a predictive research was carried out by the leading industrial nations as shown in Table 1.1, and up to 2010s, FCIPS in full version remains in the concept stage and is far from the practical use. This is because both the computing and information communication technologies have been immature up to today (Ito, 1993).

Countries	Organisations	Projects
UK	Engineering Council IEE Royal Society of Arts UK Government	20/20 Vision Next Generation Manufacturing Enterprise Tomorrow’s Company Programme 20/15 Vision
USA	National Research Council (Chairperson: Prof. Bollinger)	Visionary Manufacturing Challenges for 2020
Germany	Forschungzentrum Karlsruhe/ German Federal Government	Produktion 2000
Japan	Science Council of Japan	Research Guide for Production Science and Technology in Beginning of 21st Century

Table 1.1 Predictive researches into desirable production systems around 2020 - conducted in 1990s

In this context, an interesting trial is an “*Agent Platform*” for the production monitoring and control systems. Importantly, the agent implements interfaces to different communication standards, because in industrial applications, a product monitoring and control system has to connect to new plants by providing modern protocols as well as historically grown plants supporting only rudimentary communication facilities. More importantly, Daimler-Chrysler Bremen has been said to run one of the first promising applications of the agent platform to the machining cell for cylinder heads and other engine parts in C-type car. In fact, C-type car started its production at the beginning of 2007, and it has been reported to obtain excellent results concerning capacity utilisation and smoothed production (Sauer and Sutschet, 2006).

More specifically, in the motorcar industry, there are many isolated stand-alone information systems to various extents as follows. The agent can connect efficiently and effectively these one another.

(1) Production monitoring and control, and supervisory and data acquisition.
(2) Quality management and feedback of inspection results.
(3) Alarming, maintenance and repair according to facilities' status.
(4) Order control, sequence setup, material control and provision.
(5) Worker information system.
(6) Body and object identification, localisation and tracking systems.
(7) Short-time simulation.
(8) Plan ring of new equipment "digital factory", ramp-up until full output.

As will be clear from the above, the immaturity in the information communication network technology was one of the obstacles to be a whole FCIPS in fruition.

With both the advent of cloud computing and the advance of information communication technology, the concept of the "*Smart Factory*" has, as widely known, proposed within the *"Industrie 4.0"* Programme of Germany as one of the flagship projects, and in due course, we can observe a considerable number of the smart factories in practice. Nearly all discourses have asserted that the smart factory is innovative, and will become the leading production facility.

It is however worth suggesting herein that the smart factory appears as to be one of the variants of FCIPS, provided that the system reinforces extremely its "*Autonomous Function*", and also improves its applicability to the "*One-off Production (with Keen Manufacturing Cost)*" as will be discussed in detail later.

As can be readily seen, we must first understand the production activity in general concerns, and then its wide sphere ranging from the enterprise management to the grass-root like skills in the factory floor. It is thus necessary and inevitable to understand the whole matters of the production activity by using the hierarchical classification method. As will be clear from the following, the production activity can be, for example in machining, hierarchically represented in the order of "Factory location planning - FCIPS - FMS - FMC - Machine tools - Machining space - Attachment, cutting tools and raw materials".

1.2 Overall View of FCIPS

In discussing FCIPS at present, we must first consider its surrounding environments for the technological, economic and social aspects to a large extent, and also the hidden core technology within it. Nevertheless, we pay a little attention to its social aspects like the factory location planning, culture- and mindset-issues of indigenous region, effects of localised globalisation and so on as shown in Fig. 1.2. These can be interpreted as the circumference conditions, and in short, some of such professional areas are being established under the aegis of the "*Manufacturing Culture*". Obviously, these circumference issues are very important, because FCIPS should generate the product necessary to the human society (Ito and Ruth, 2006).

In contrast, the hidden core technology is far beyond the knowledge about the system layout and system component. More specifically, the system layout in machining depends to certain extent upon the process planning and tool layout design, in which the grass root-like knowledge plays the very important role such as exemplified in Fig. 1.3. In Fig. 1.3, the reverse turn top (cylindrical turning) is closely related to whether we can use the one-chucking operation with the innovative tooling or not, i.e. cost reduction by avoiding either hand-off or re-chucking operation.

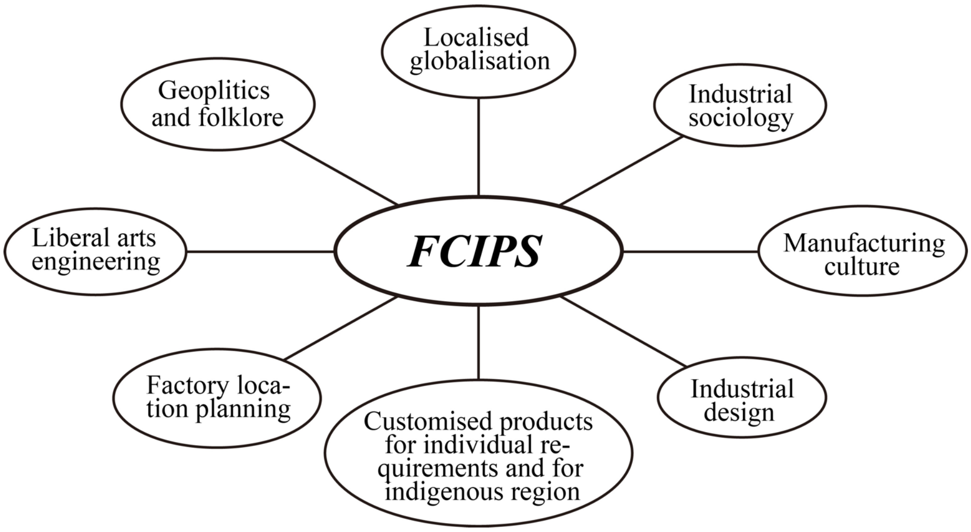

Fig. 1.2 Outer environments of FCIPS

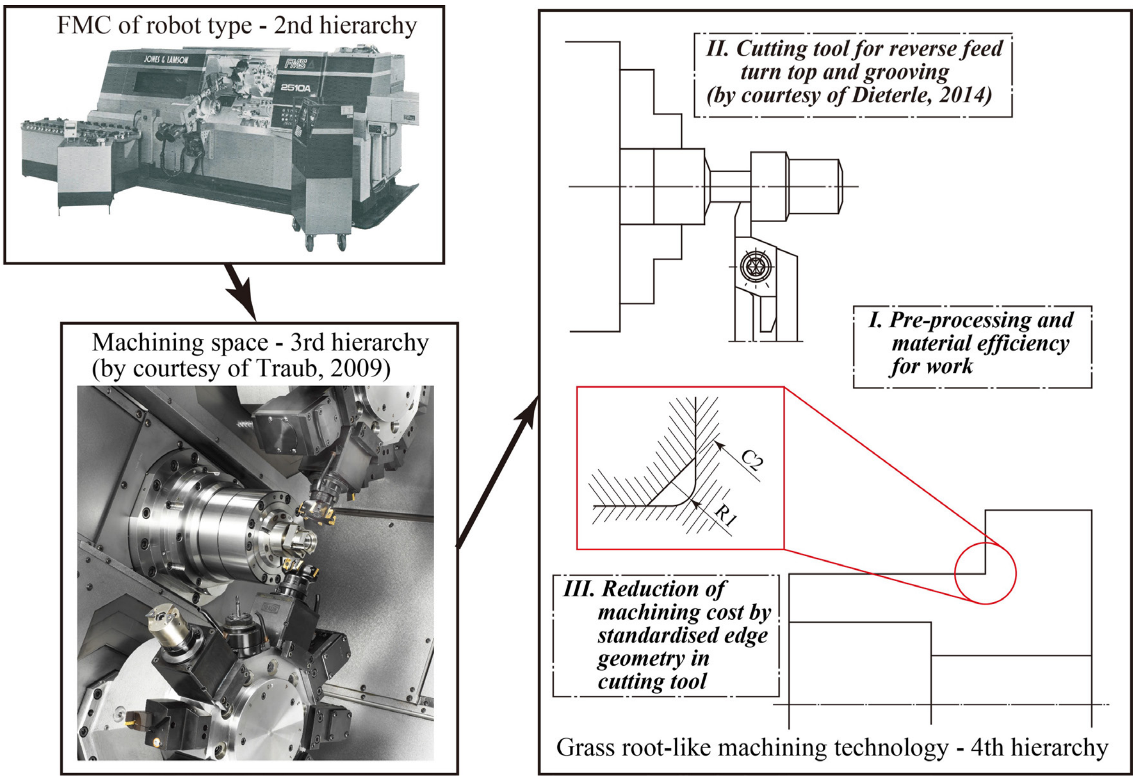

Fig. 1.3 Hierarchical structure within FCIPS
- Necessary technologies in the lowest layer

As can be seen from Figs. 1.2 and 1.3, we must first understand the wider realm of the production activity, necessities of interdisciplinary knowledge ranging from the production technology and production control, through management of organisational structure, to the liberal arts engineering and industrial sociology. Obviously, we face a very acute shortage of human resources, who can manage all the activities mentioned above. In consideration of the extreme importance of the "Limbs and Tools" in the production activity, it is desirable, at least, to foster the mature production engineer with the ability of the layout design of the system and also having certain knowledge about the manufacturing culture.

Secondly, the major determinants in FCIPS are the "Material and Information Flows" within it as will be delved into details in Chapter 3. In the material flow, a leading issue is whether the material flow is discrete or continuous. In the former, the material to be processed is transferred from the processing to succeeding stations stepwise, i.e. "Point-to-Point", whereas in the latter the material is transferred between both the points without any interruption, i.e. "Flow Type (Process Type)".

We can observe the discrete type in nearly all manufacturing industries, and flow type, for example, in the food, petroleum refining and cosmetics industries [3]. Of course, we can observe the mixing type as exemplified by manufacturing for the cutting tool insert. Furthermore, such material and information flows must extend to the sister companies, subsidiaries and subcontractors, e.g. those related to the supply chain. Importantly, both the discrete and flow types differ definitely each other in many respects, e.g. design principle, system configuration, system components, characteristic features and so on.

Finally, FCIPS is a synergy of hardware, software and information communication network. Importantly, the hardware ranges from the system configuration (layout), through system component and its attachment, to the processing tools, whereas the software ranges from the supply chain and enterprise management, through production control, to factory floor control and surveillance.

Summarising, there are a considerable number of the variants in FCIPS de-

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[3] This book deals with only FCIPS of discrete type and its variants, because we need the very different knowledge when describing, discoursing and discussing FCIPS of flow type.

pending upon the connecting pattern between CIM and *FMS*. As a typical example, a CIM controls a group of general purpose-oriented *FMSs*, which can conduct machining, assembly and product inspection (central control style). In contrast, several CIMs control a group of special purpose-oriented *FMSs* (distributed control style), provided that each CIM has autonomous functions. In addition, we must be aware that the characteristic feature of CIM depends upon the system configuration of *FMS* to some extent, and *FMS* can be characterised by a group of the basic modules, i.e. *FMCs*, and also by their combinations possible.

1.3 Production Morphology and Its Hierarchical Structure

There are various models to represent the production activity, and in addition to FCIPS, another simple and representative model is the "*Production Morphology*" as shown in Fig. 1.4 [4]. This production morphology is for the discrete type, and as can be readily seen, describes the product life, which starts from either market survey or order placement of the client, and then terminates at the disposal of the product. In many respects, FCIPS and the production morphology are very convenient to discuss the production activity. It is thus worth discussing the correlation between these two models. Although not guaranteeing the one-to-one relation, in short, CIM and *FMS* correspond with the production morphology across the whole, and the manufacturing and remanufacturing procedures, respectively. Obviously, we may use either FCIPS or the production morphology depending upon the facing issue. Importantly, each procedure within Fig. 1.4 can be detailed, and for example, Fig.1.5 shows more detailed flow of the design procedure. Paraphrasing, it is better to understand the production morphology in consideration of its hierarchical structure. In fact, the "Production of Part Drawing" in the design procedure can be further detailed as shown in Fig. 1.6. In Fig. 1.6, the "Data Base for

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[4] Within this book, the "Production" is defined by the British way, i.e. Production = Design + Manufacture

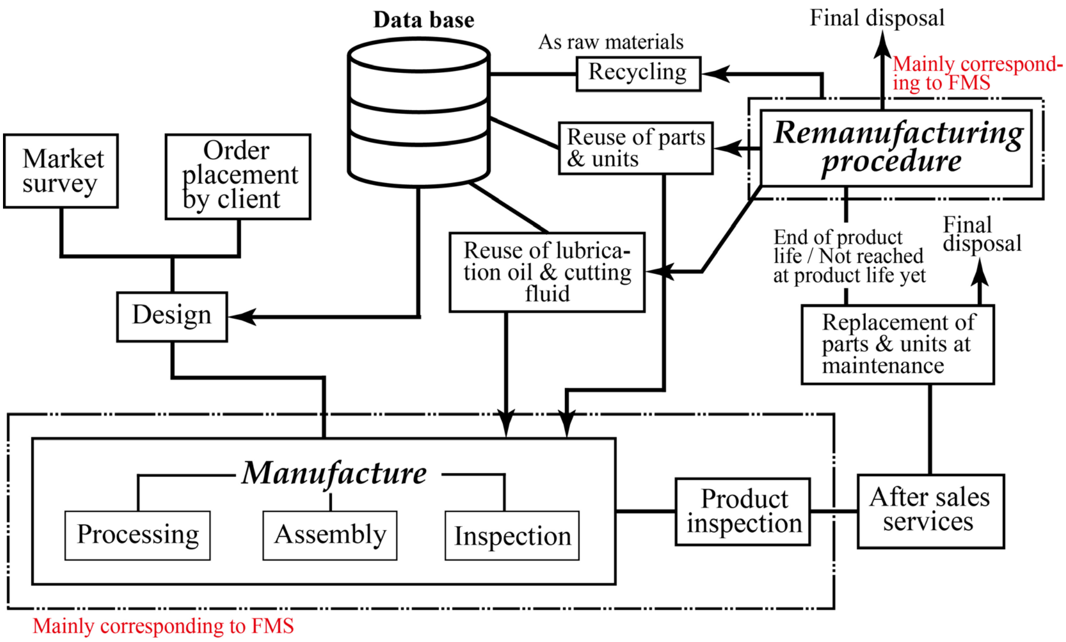


Fig. 1.4 Concept of production morphology

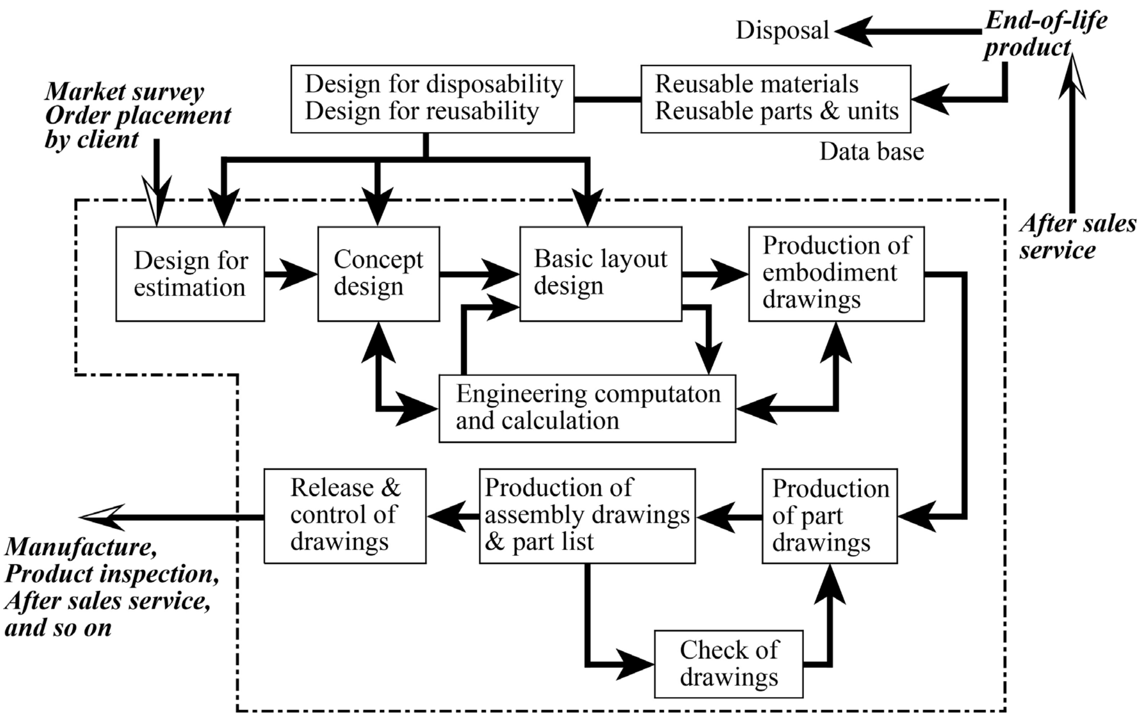


Fig. 1.5 Simplified design flow

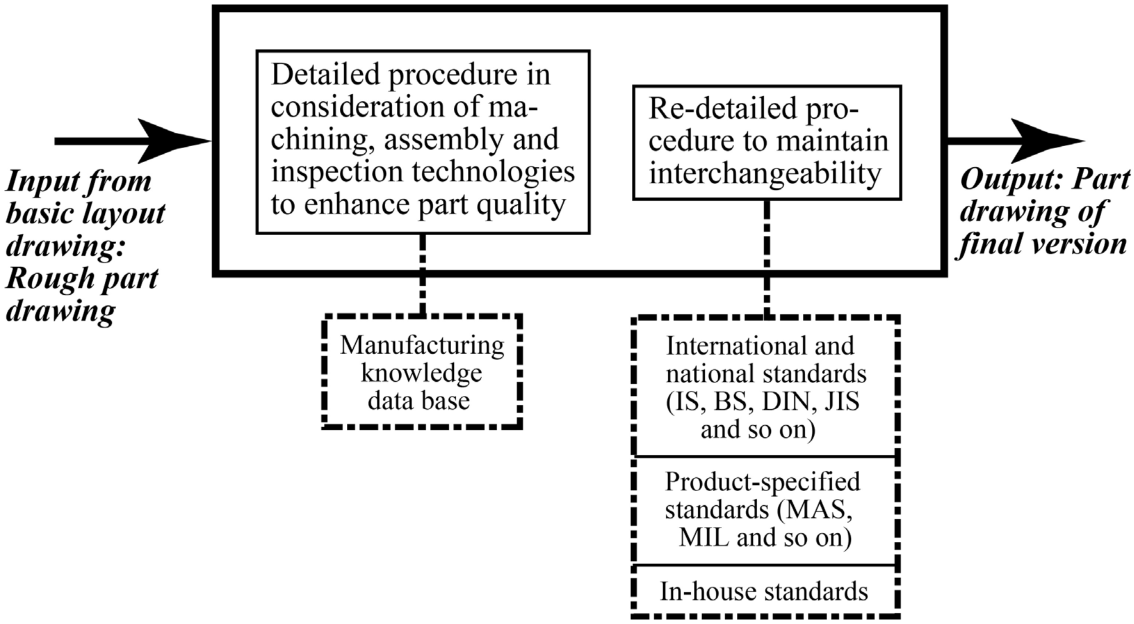


Fig. 1.6 Production procedure of part drawing

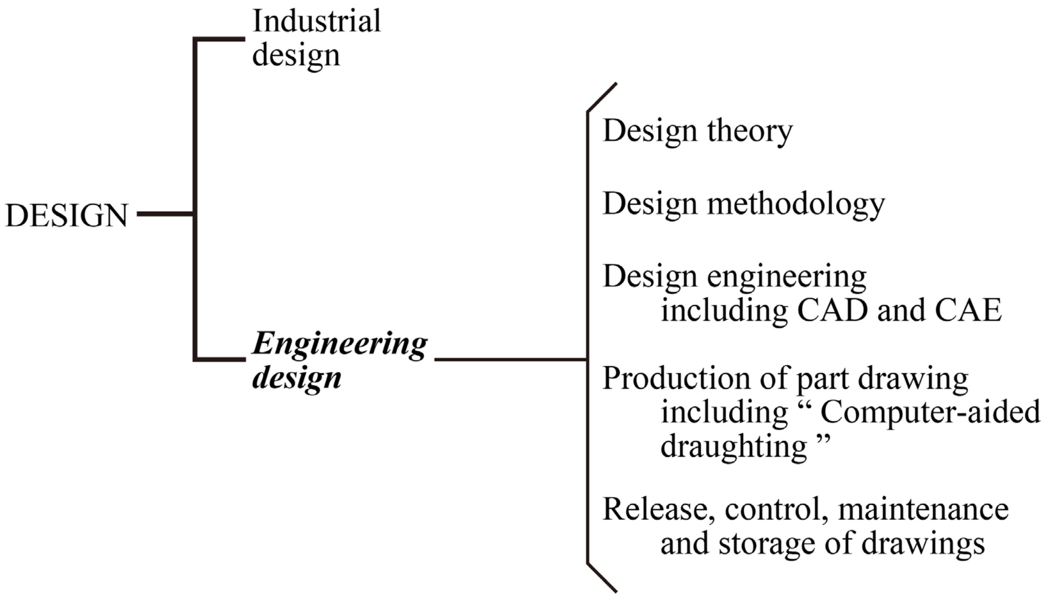


Fig. 1.7 Classification of engineering design

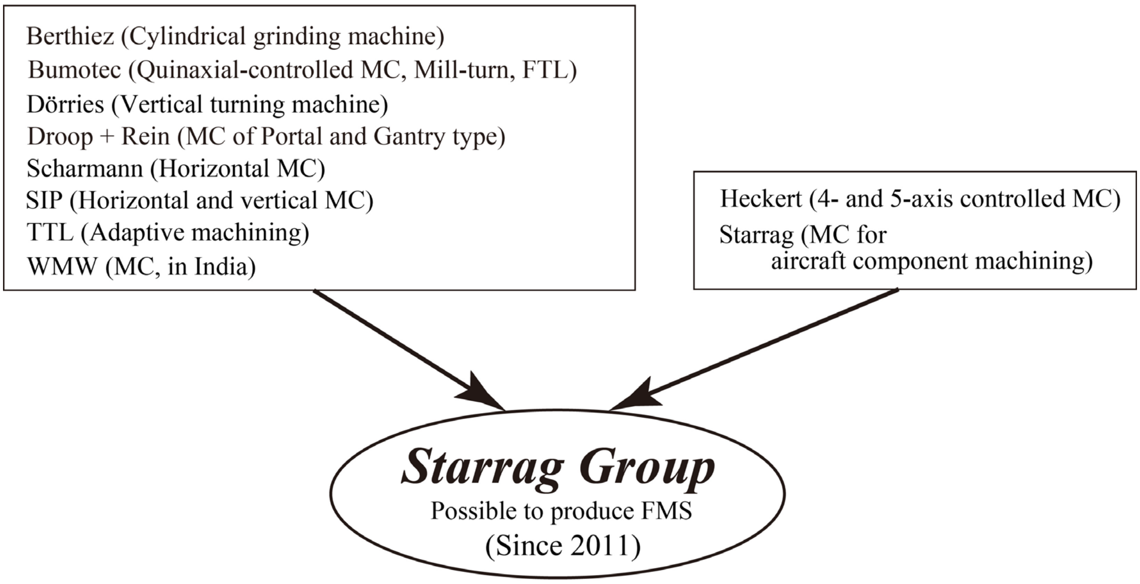
Manufacturing Knowledge” involves the grass root-like machining technology shown already in Fig. 1.3, and in addition, the part drawing is one of input information for CAPP. CAPP is one of the leading functions within the production control management within CIM. Of note, we can

classify the design by another viewpoint regarding what is the essential work to be carried out, and Fig. 1.7 is one of such classifications ranging from the design theory to the release and control of drawings.
As will be clear from the above, FCIPS can be characterised by the stressed procedure within the production morphology, resulting in the differing system configuration and concerns. For example, FMS for machining differs considerable from that for assembly.

1.4 Localised Globalisation, Virtual Concentration of Production Bases and Manufacturing Culture

With the advance of the localised globalisation, the merger of the corporations increases to reinforce the market competitiveness, and such an organisation can facilitate the "*Virtual Concentration of Production Bases*". Actually, we can now point out three representative cases, i.e. DMG Mori, Friendship and Starrag Groups within the machine tool industry. Of these, Friendship Group and Starrag Group can be characterised by their organisational structure based on Asian and Europe regions, respectively. For example, Starrag Group consists of Starrag, Berthiez, Heckert, Scharmann, SIP and so on, and deploys the product on the basis of each company's characteristic features as shown in Fig. 1.8.
Obviously, such a merger must pay the special attention to the "*Divisions of Work in Product Deployment*" and "Time Difference Overcoming Production" to enhance the beneficial features. More specifically, we must delve into the desirable system configuration, even when employing FCIPS with widely distributed *FMCs* across the whole world. Importantly, FCIPS should be designed in full consideration of the differing culture and mindset aspect of each region including the qualification of the worker. In this context, Tables 1.2 (a) and (b) summarise the additional engineering design specifications for flexible manufacturing applicable to each region within Asia, which was obtained from the on-the-spot investigation conducted by one of the authors (Ito) so far. The system designer should

consider these specifications in addition to the fundamental ones together with the kind of the objective product.



Agglomeration: Mainly within Europe

Fig. 1.8 A representative conglomerate in machine tool manufacturing

(a)

Countries and Region	Product- and production-related	Worker-related	Facility-related and factory environments	Remarks
India	Assurance of product quality Reinforcement of production control	Lower educational qualification Cheap labour cost	Unstable electricity supply (Installation of in-house electric power plant) Anti-dust remedies from the outside of factory	Awareness improvement of worker in differing cleanness between factory and home
Malaysia	——	Relatively high NC utilisation technology	——	——
Philippines	Assurance of product quality	Automatisation in consideration of cultivation of human resources	Unstable electricity supply	Machine tool industry being immature
Thailand	Assurance of product quality Quality adjustment to be compatible with regional environments Reduction of work-in-progress Weighing MRP	——	Necessity for responding various manufacturing requirements due to vigorous deployment of Japanese transplants	Outstanding utlisation technology within TL only

MRP: Material Resources Planning

(b)

Countries and Region	Product- and production-related	Worker-related	Facility-related and factory environments	Remarks
Korea	——	Relatively cheap labour cost, although not being in high work efficiency	Ease of machine operation for worker	Specified to FTL
P. R. of China	Assurance of product quality	——	Unstable electricity supply	——
Singapore	Assurance of product quality Reduction of manufacturing cost	——	Incorporation of maintenance free function for high humidity	Prevalence of various and wide-range manufacturing requirements
Taiwan	Fluctuation in productivity	Shortage of skilled workers	Poor ability for large investment	

FTL: Flexible Transfer Line

Table 1.2 Differing design attributes for flexible manufacturing in Asian area - in late 1990s: **a** In case of being industrialised nations. **b** In case of nations recently industrialised

Safety and security in smart manufacturing and product for people and environments - Including protection for unauthorised access to data and information
Necessities of socio-technical approaches in design of smart factory
Socio-technical approaches to work organisation and CPD together with taking care of worker' s health and comfortable life style
Training and "Workplace-based CPD" - Promotion of best pracitice networks and digital learning techniques
Regulatory framework - Law and legislation in business
Resource efficiency - Raw materials and energy

CPD: Continuing Professional Development

Table 1.3 Research and engineering development subjects in relation to manufacturing culture

In many respects, we can benefit considerably from the manufacturing culture in discussing and suggesting something definite in the production activity for the localised globalisation era. For example, the "acatech (National Academy of Science and Engineering)" has suggested a flagship project entitled “Work Organisation and Work Design in Digital Industrial Age”, in which primary concerns are as follows (acatech, April 2013) [5].

(1) The worker should manage open and virtual platform, and also extensive human-machine and human-system interactions.
(2) “MUST” is an interdisciplinary approach expecting the holistic effects, for example, by a group consisting of “Engineer + IT expert + Psychologist + Ergonomist + Social and occupational scientist + --”.

In short, the “acatech” suggests the individual research and engineering development subjects as shown in Table 1.3, and from these, we may understand the importance of the manufacturing culture.

1.5 Comparison of Concepts between FCIPS and Smart Factory

The “acatech” has suggested both the key terms and the sentences to represent the concept of the smart factory as shown in Table 1.4 (acatech, April 2013). In general senses, it is possible to draw the schematic view of the smart factory by combining these key terms and sentences (Ito, 1988); however, the “acatech” has not shown any such concept drawings.

Against to this context, we may have a clue by comparing the concept of FCIPS in detail with those in Table 1.4. In short, Fig. 1.9 is a comparative illustration for the concept of FCIPS with that of the smart factory including again the human-mimetic model. For ease of understanding, in the right of Fig. 1.9, we display the hierarchical structure in the information processing together with the computer system, and detail furthermore the information to be processed at each hierarchy within the smart factory and FCIPS. In contrast, in the “Limbs and Tools”, the dire necessity is to concert both the material and information flows, and in due course, a facing issue is to what extent the cell controller should manage information processing in consideration of the material flow (see Fig. 3.4).

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[5] “acatech” is the organisational structure for promoting the “Industrie 4.0 Programme”.

Factory concept compatible with IoT (Internet of Things) and IoS (Internet of Services) environments

Factory concept applicable to Small- and Medium-sized Enterprises

Autonomously controllable CPS (Cyber Physical Systems) modules consisting of smart machines, storage systems and other manufacturing facilities with excellent information communication function

Capability of producing smart product (individual requirement-oriented product)

Mass-customization

Factory concept consisting of two leading networks: Vertical network is a synergy of computer, information and communication network, production facilities, transportation devices and so on within a factory as a whole. Horizontal network is a chain-like organisational structure among a group of factories within an enterprise, other manufacturing enterprises, other service companies and so on

Note: The core of network is called "End-to-end engineering" , i.e. production morphology not including "Re-manufacturing"

Table 1.4 Representative key terms and sentences for smart factory within Industrie 4.0 (based on publicised information by acatech)

As can be seen from Fig. 1.9, it is natural and reasonable to assert the good agreement between both the concepts, and we may conclude that the smart factory is one of the variants of FCIPS, apart from that FCIPS has, in nature, certain difficulty in application to the one-off production.

More specifically, the smart factory is, in principle, designed to be only applicable to the "*One-off Production with Keen Processing Cost*", where the keen cost is equivalent to or less than that obtainable from the "*Less Variation and Large Volume Production*". In contrast, FCIPS covers all the production patterns and the one-off production within FCIPS does not care anything related to the reduction of the processing cost, but should finish the product and component with the highest quality even when the batch size is "*One*". In this context, we must be furthermore aware that the smart factory has been discoursed and discussed by placing main stress on cloud computing and information communication (Brains and Nervous systems), but not on the factory floor (Limbs and Tools).

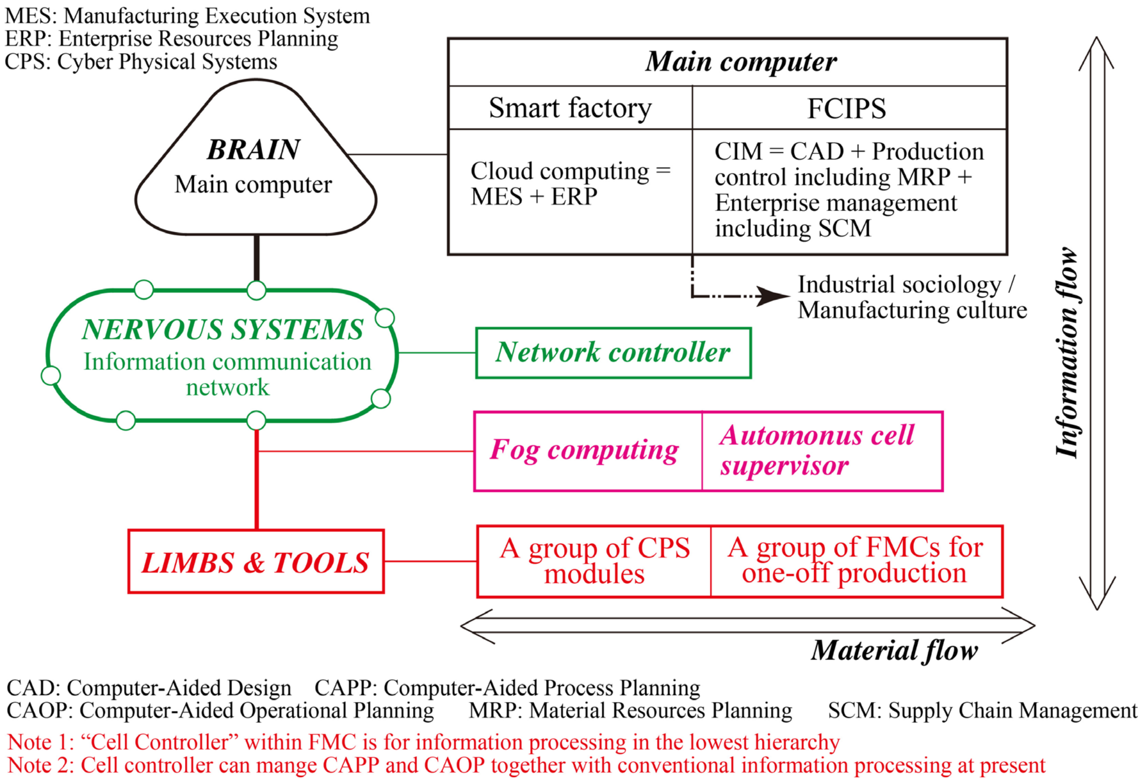

Fig. 1.9 Concepts of both FCIPS and smart factory - Their human-mimetic models

Of special notes, Figs. 1.10 (a) and (b) show the concept of FCIPS in detail, and as can be seen, FCIPS can be characterised by (1) CIM with human-intelligence-based function, (2) a group of *FMCs* with autonomous function, e.g. either "Auction" or "Task Broker" type, (3) *FMCs* of widely distributed allocation type, and (4) simultaneous material and information flows by the data tag (Ito, 1993).

To this end, it is worth suggesting that there are, as shown already in Fig. 1.9, differing terms in the smart factory from those in the production technology, and such differing terms result in misunderstanding and confusion of the smart factory to some extent. For example, the "Mass Customization" is, dare to say, wrong term in the production technology, but the one-off production is correct. Nevertheless, the smart factory in practice can provide us with the valuable knowledge regarding cloud computing and information communication technology, and thus some case studies will be described in Chapter 5. Obviously, such the knowledge is

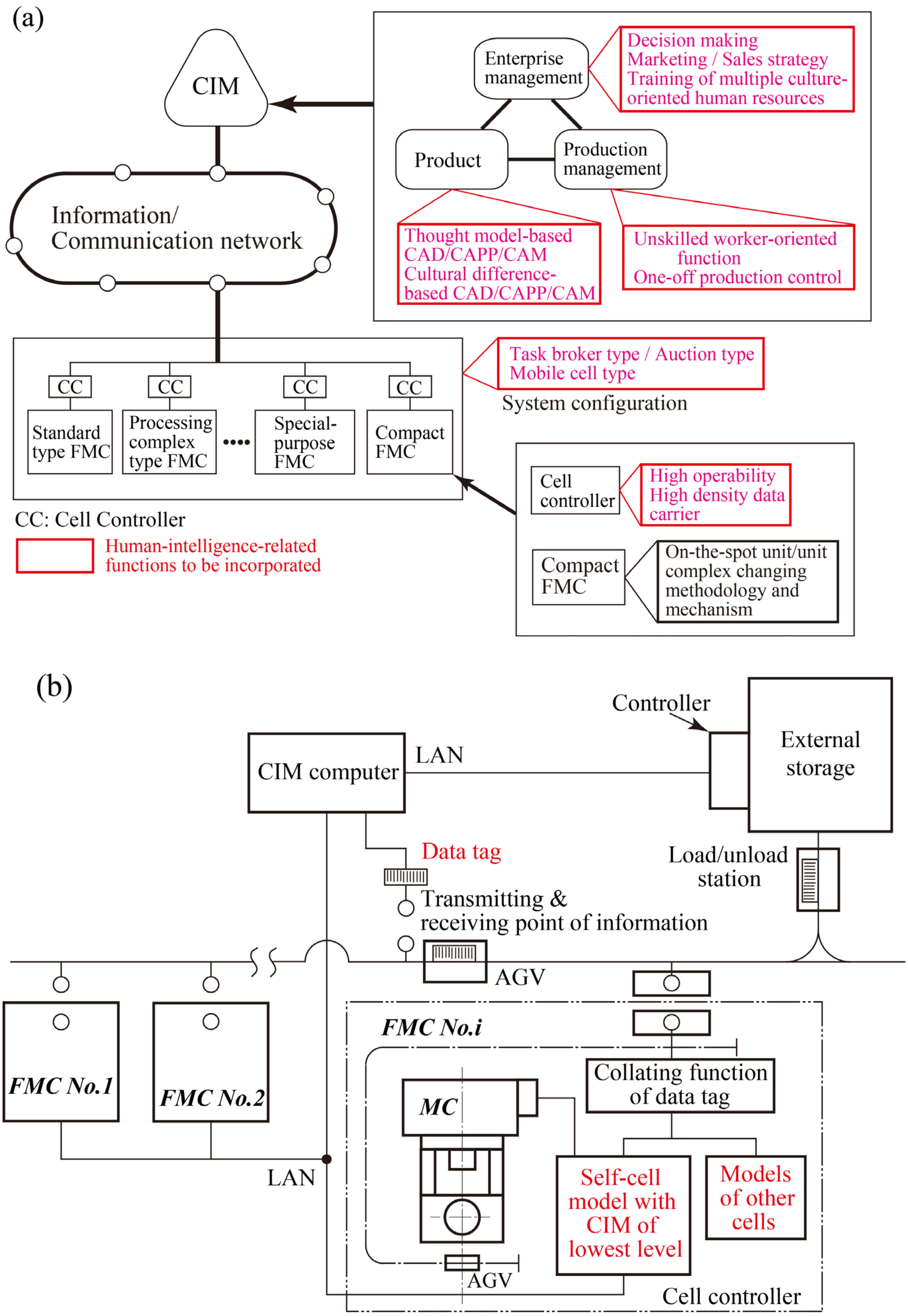

Fig. 1.10 Concept of FCIPS in detail: **a** System configuration - FMC either auction- or task broker-like type. **b** Cell controller and information processing

also very helpful to understand the essential features of CIM.

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Chapter 2 General Concerns in Manufacturing Systems of Discrete Type

Abstract A product is to be in reality by integrating a group of parts, and thus the kernel of FCIPS is, needles to say, the manufacturing system (Limbs and Tools). The manufacturing system consists, in principle, of processing, assembly and inspection procedures. In discussing the production activity, thus, it is extremely important to place the stress on the processing system. To suggest first the importance of understanding the hierarchical structure in the production system, Chapter 2 demonstrates (1) the differing aspects between the machining and assembly systems, and also between *FMCs* for metal cutting and metalworking. In contrast, we may suggest the configuration similarities between *FMCs* for machining and assembly.

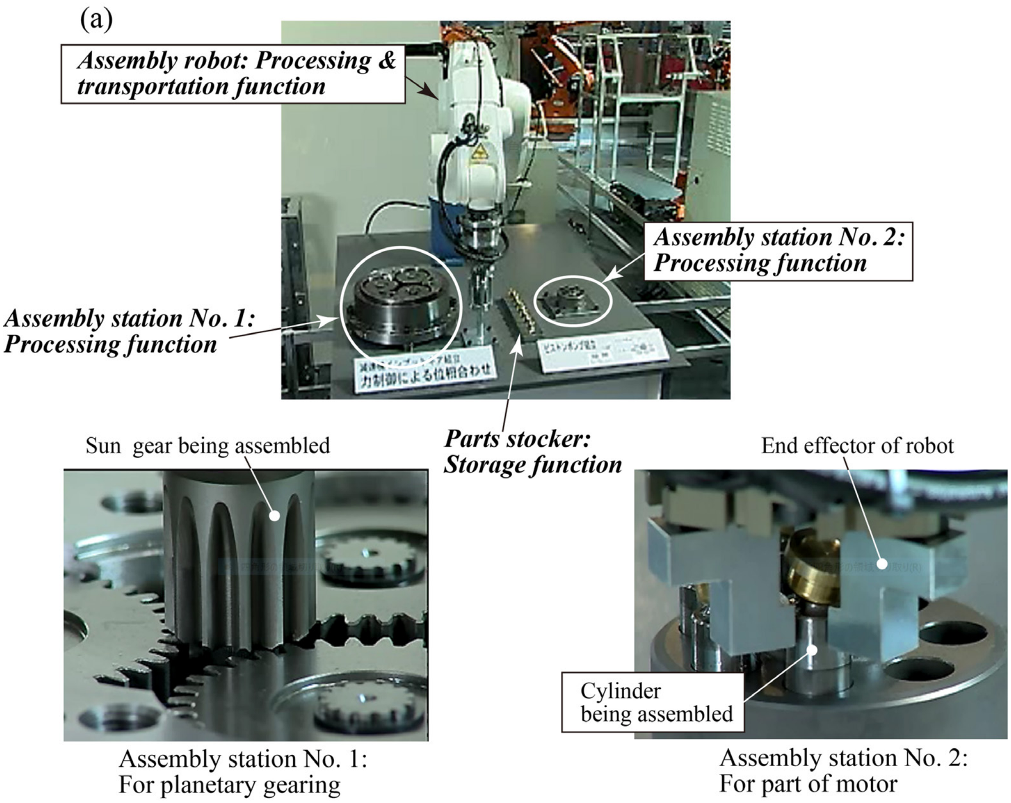
Although we can use various processing methods, the major is part machining, and then to clarify the characteristic features of the machining system, Chapter 2 describes (2) a classification of the machining system in consideration of the production pattern (mode) like "*Much Variation and Small Volume Production*", (3) some representatives ranging from the production cell and transfer line to FMC and NC transfer line, and also (4) the input and output for both the material and information flows in the machining systems.

2.1 First-hand View of Manufacturing Systems

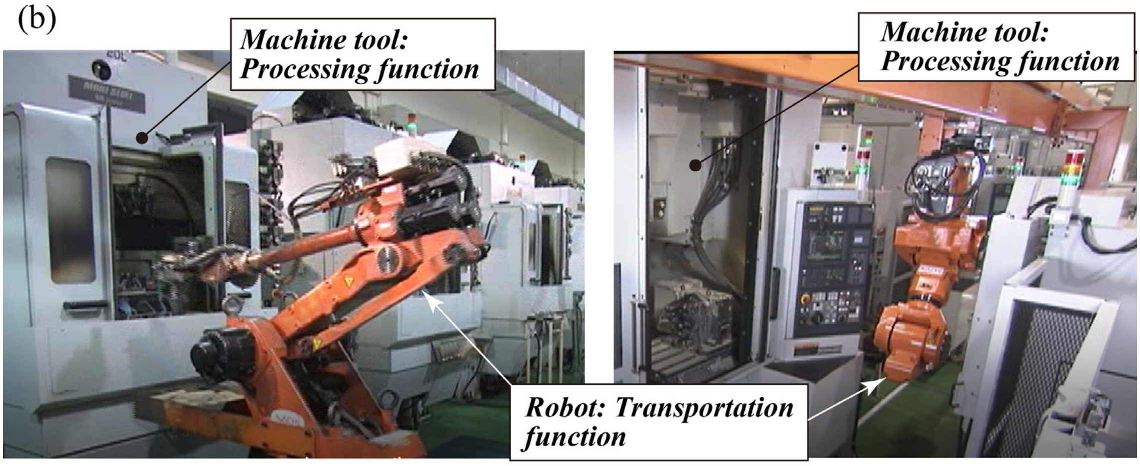
We need various products to maintain and advance our human society, and the product is to be in reality in accordance with the requirements of the society. Obviously, the "Limbs and Tools" within FCIPS is very important to generate the product, and when changing the viewpoint to the production morphology, we must at first eye the manufacturing procedure. Actually, we must launch out to the generation of a group of the parts (components) and then assemble them into the product. While processing and assembling a group of the parts, we must also inspect on demand the quality of the part and unit, and of course the product itself.

Apart from the remanufacturing procedures, let us now discuss the manufacturing procedure shown already in Fig. 1.4. In this context, we must mind that the primary concern in remanufacturing is the disintegration of the product at its end of life or disposal, but not processing the part.

In principle, there are somewhat differing appearance and features among the processing, assembly and product inspection systems; however, on the contrary, these systems have similar configurations, although the core processing function differs considerably one another. In addition, these systems are integrated into the large-sized system in part or as a whole. It is thus notable that the rudimental and further necessary knowledge can be obtained by investigating in detail the system for processing.



(b)



Short-range travelling robot of floor type　　Long-range tavelling robot of overhead type

Fig. 2.1 FMCs for assembly and machining: **a** Assembly of hydraulic motor with planetary gearing. **b** Robots for work loading and unloading (by courtesy of Fujikoshi, 2017)

For ease of understanding, Figs. 2.1 (a) and (b) show the typical *FMCs* for assembly and machining, i.e. typical processing methods in manufacturing, together with their core functions, which will be discussed later. In fact, we cannot observe the apparent differences in the cell layout or configuration, apart from the machines for processing function. In FMC for machining, the NC turning machine and articulated robot can facilitate the machining and transportation functions, respectively. In contrast, the articulated robot can facilitate the assembly function in *FMC* for assembly remaining other functions as similar as those in machining. A crucial problem is thus to understand the differing roles of the robot between for the transportation device and for the assembly machine.

Even when placing the stress on the processing procedure, we must consider furthermore various methods being employed. Roughly saying, the processing method can be classified into “Metal Removal Processing”, “Metal Non-removal Processing” and “Additive Processing” like 3D printing. Importantly, the latter two supply often their products to metal removal processing as raw or semi-finished materials.

Figures 2.2 (a) and (b) illustrate the overall views for metal removal processing and non-removal processing by using the hierarchical classifica-

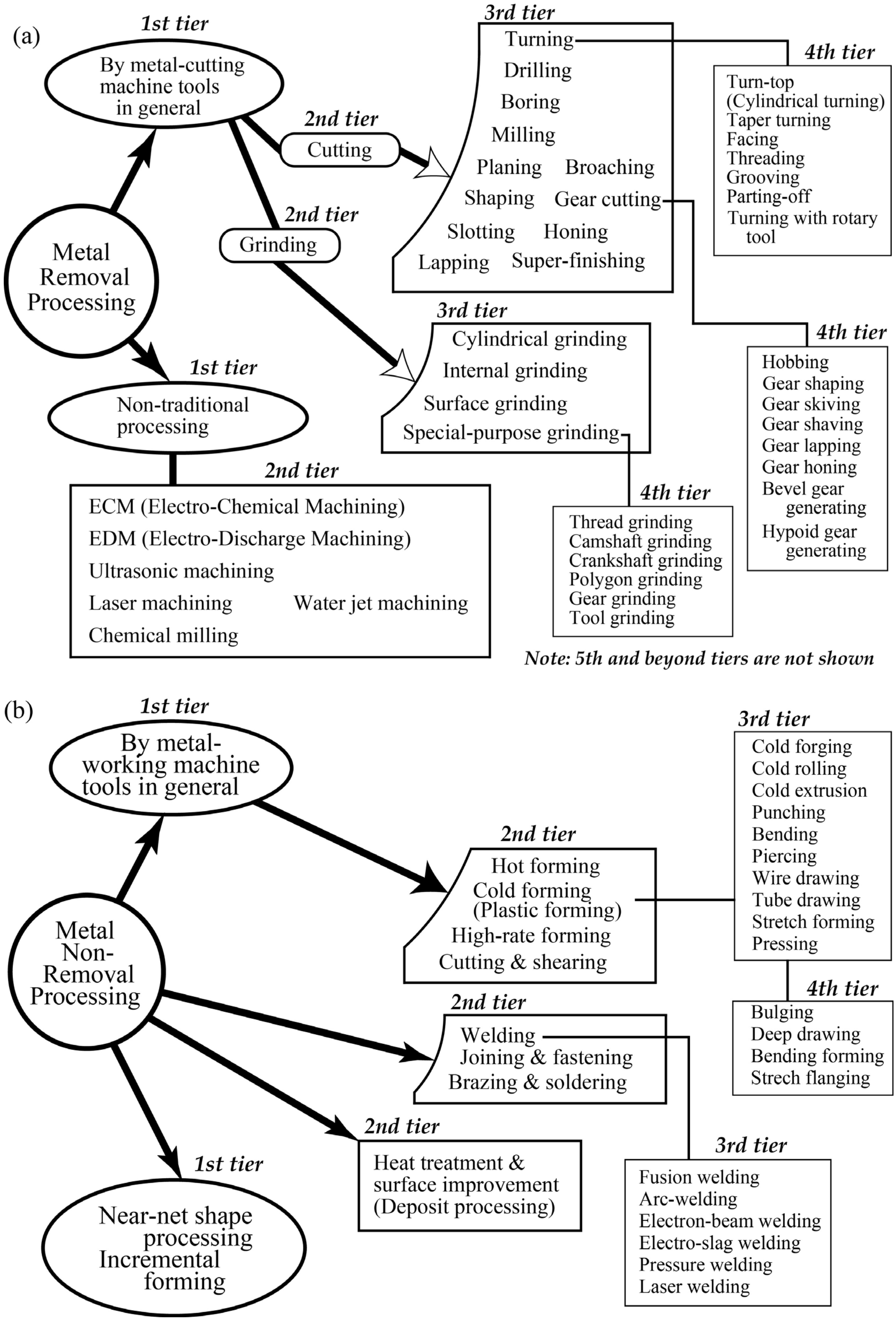


Fig. 2.2 Hierarchical classification for representative metal processing: **a** For removal type. **b** For non-removal type

tion, respectively. In many respects, such a classification method is very convenient when carrying out the necessary discussion as already verified elsewhere (Ito and Matsumura, 2017).

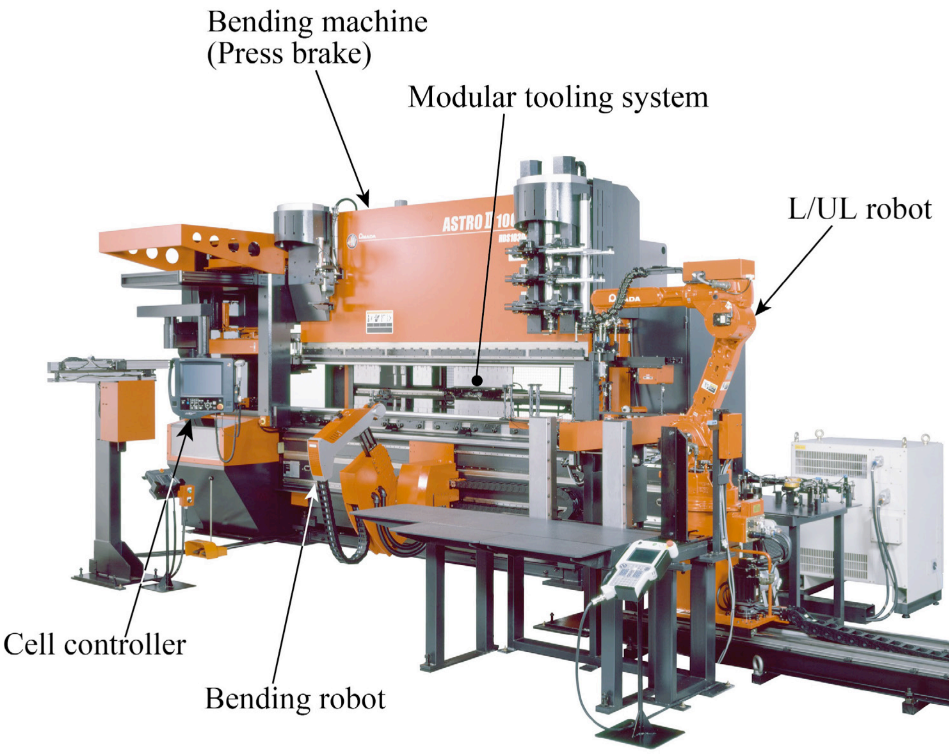


Fig. 2.3 FMC for sheet metal bending (by courtesy of Amada, 2010)

Figure 2.3 shows an *FMC* of robot type for metalworking in the 2000s. More specifically, *FMC* for bending, i.e. one of the metal non-removal processing methods, and the core machine is the press brake (bending machine) of Amada-brand (Type ASTRO II -100NT). As can be seen from Fig. 2.3, *FMC* has the functions of ATC (Automatic Tool Changer), automatic gripper changer for bending robot and automatic hand changer for L/UL (Load and Unload) robot. As a result, this *FMC* is applicable to the batch production, although we believe so far that the metalworking is available for the "*Less Variation and Large Volume Production*".
Importantly, the cell configuration and function are as similar as those shown already in Fig. 2.1 (b), apart from the machines for processing

function. In short, the machines are the NC turning machine for machining and NC press brake for metalworking.
It is furthermore very interesting that in the sheet metal bending, the operator must handle skillfully the raw sheet metal in accordance with the deformation procedure called “Flower Patterns”, and the bending robot can replace such human skills. In short, we can benefit within (1) high-precision and high-speed stable bending, (2) higher operability by reducing set-up time and (3) user-friendly functions in operation from *FMC* shown in Fig. 2.3.

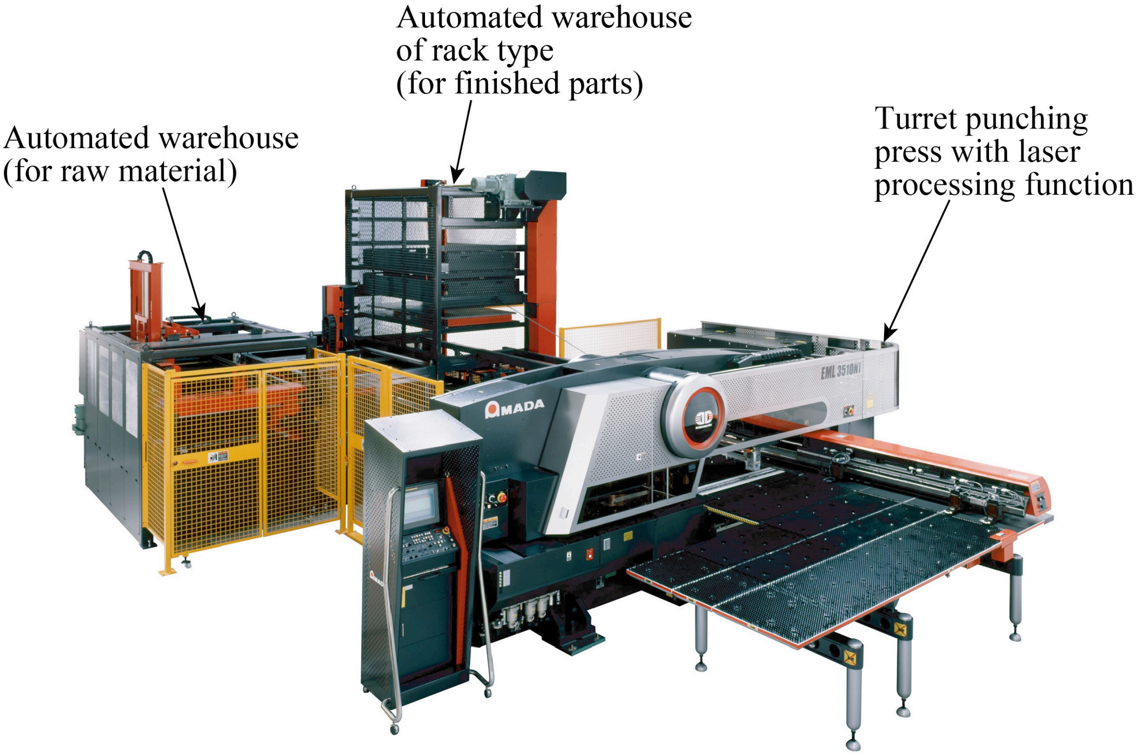


Fig. 2.4 FMC for sheet metal processing (by courtesy of Amada, 2010)

For further convenience to the reader, Fig. 2.4 shows also *FMC* for sheet metal processing for various kinds and large-fluctuation volume production, the characteristic features of which are as follows.

(1) The turret punching press is capable of punching the small-sized hole with pre-determined shape, and also of laser cutting for the large-sized hole with free curve. In addition, the machine can carry out forming

and tapping.

(2) Punching can be performed by the direct drive using the twin-servo motor, resulting in the higher-speed movement of the punching head. This technology has been already employed in the NC metal-cutting machine tool more than 20 years ago.

To this end, it is again worth suggesting that FMC for machining is fundamental in the whole system layout including system components, and also in functions to be facilitated across the whole production system especially related to material processing. Thus, we will discuss the machining system hereafter.

2.2 Fundamentals for Machining Systems

As will be clear from Section 2.3, there are a considerable number of the kinds and types in the machining system. It is however worth emphasising that the cell for machining is the utmost basic configuration, and at present primary concern is FMC for machining. Paraphrasing, it is recommendable to understand and discuss the fundamentals of the machining system by placing the stress on FMC.

Figure 2.5 illustrates thus the layout and configuration of a machining cell, i.e. large-sized FMC, together with the necessary and inevitable information, i.e. five basic functions, and also inputs to and outputs from the cell.

Importantly, FMC should consist of the leading five functions, i.e. "Machining", "Transportation", "Storage", "Maintenance and Daily Inspection" and "Control and surveillance" functions, which are with either the manual ways or automatisation. Of these, it is desirable that the transportation is, in principle, of "One-direction Flow" type apart from that by the robot. In addition, the cell controller deals with the control, surveillance and supervision function, which is the lowest hierarchy within CIM.

We must also be aware of both the input and the output are in close tie with the "Material and Information Flows" within the cell. More specifically, the raw material, part drawing and short-term production planning are input and duly the finished part and production achievements are output. Actually, CIM and cell controller deal with all the necessary information within the cell, and at issue is the "*Division of Work in Information Processing*" between CIM and the cell controller.

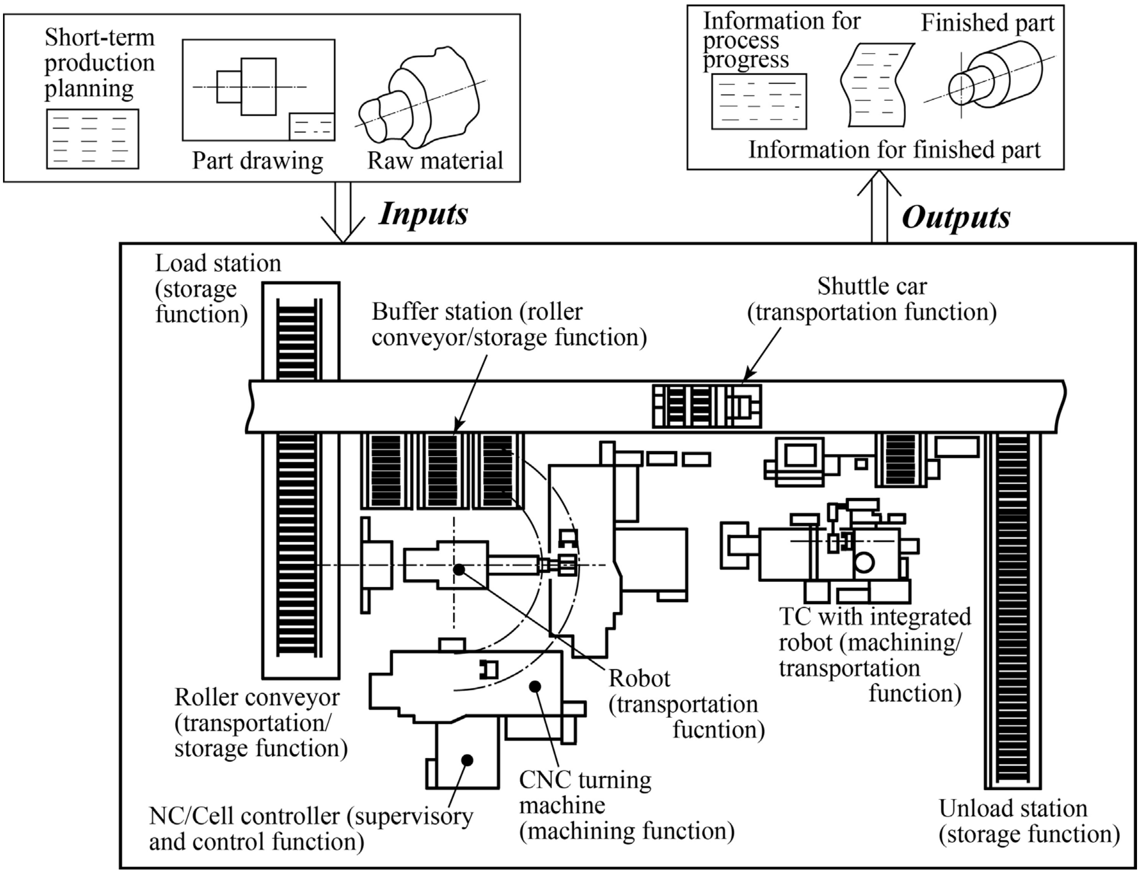


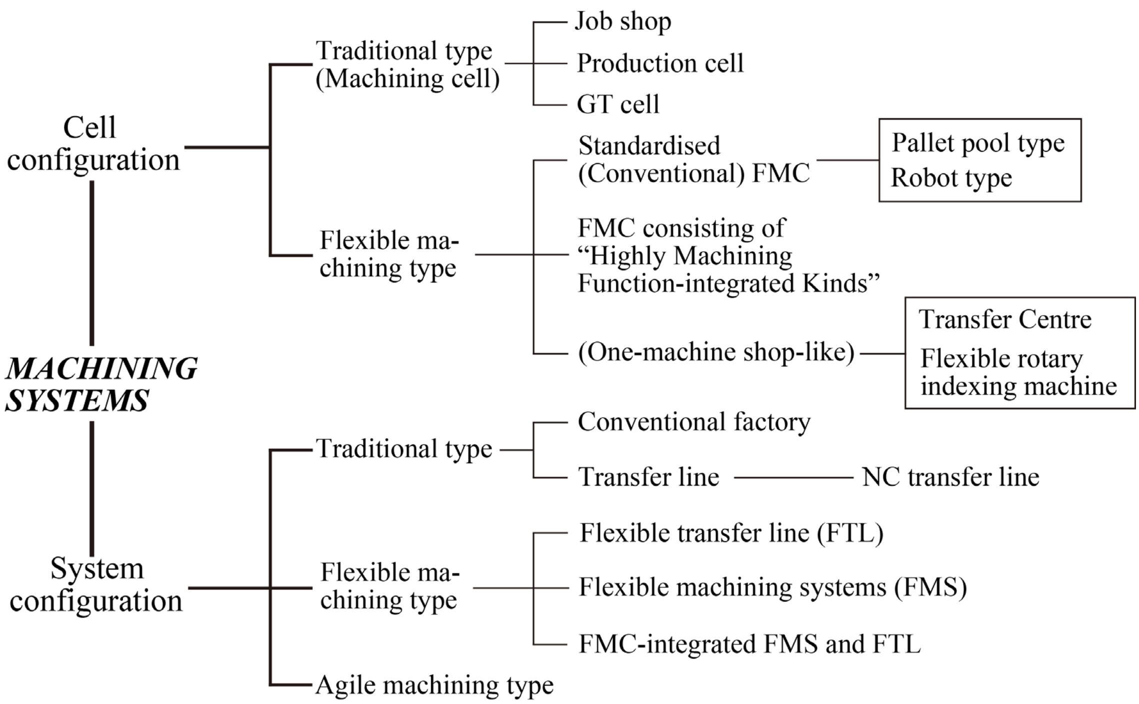
Fig. 2.5 Five fundamental functions, inputs and outputs in machining cell

Having in mind these fundamentals, FMC should be designed in full consideration of the functional and performance specifications of the objective product, parts of which should be machined at present and in the very near future. With the enhancement of the product itself, the machining method of its parts could be changed, and in due course, a kind of the machine tool disappears and a new kind could be in practical use. As a result, the machining system could be varied to some extent. Against this

context, the innovation in the machining system induces duly certain changes in the product.
As widely known from the past, it is thus the vital rule that the machining system should be designed in consideration of the close tie among the product, its production pattern (mode), system configuration and system control method including manual operation (see Section 6.6).

2.3 Classification of Machining Systems

In general, we can classify the machining system into the two leading configurations, i.e. cell and system such as shown in Fig. 2.6, and of these, FMC, FMS including the "*Agile Machining System*" and FTL (Flexible Transfer Line) are in leading position nowadays.



Note: Within machining systems with wider scope, there are several variants depending upon linking pattern with CIM and information communication network

Fig. 2.6 Classification of machining systems

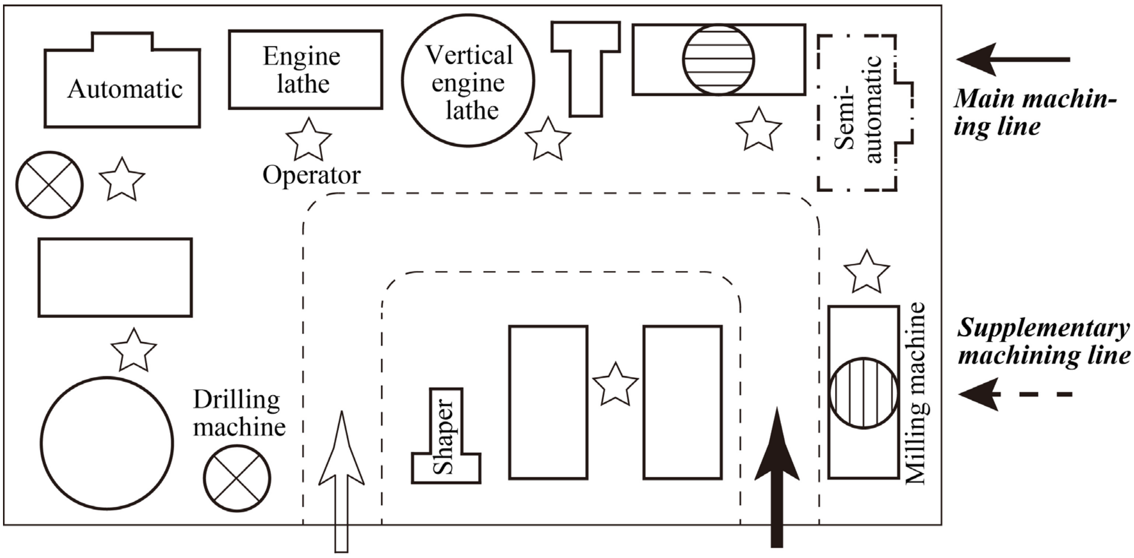
It is however notable that the NC TL (NC Transfer Line), a successor of the traditional TL (Transfer Line), is economically very effective in the "*Less*

Variation (Large batch size) and Large Volume Production". In short, we can assert the much more economical superiority of the NC TL than FTL even now on the basis of our long-standing experiences, although restricting the machining flexibility to some extent.

Admitting that the flexible and agile machining systems including the cell are at present in leading position in the industrial nations, the traditional machining cell and system also play important roles in the being industrialised nation. More importantly, one of the utmost advanced flexible machining cells, e.g. "*Transfer Centre*", is originated from the traditional cell and system. We must thus have certain knowledge about the traditional machining cell and particularly about TL.

In the era of the traditional machine tool, i.e. in the year 1970 and before, we used to install the machining cell, which is for the "*Much Variation (small batch size) and Small Volume Production*", and which can be apparently classified into the "*Job Shop*", "*GT (Group Technology) Cell*" and "*Production Cell*". In addition, these are compatible with the machining facility especially for SME (Small- and Medium-sized Enterprises). These three appear however as to be very similar, and thus we have not had the necessary and definite definitions for these three so far. For example, Fig. 2.7 shows a job shop with rationalised material flow, and also for the factory of SME (Torihara, 1966). Against this context, Fig. 2.8 shows a GT cell for SME, in which all the parts to be machined should be classified into several part families by using GT (*Group Technology*), and this GT cell aims at the rationalisation in machining and transportation (Merchant, 1976). Importantly, the part family should be determined on the basis of the similarity of machining methods and sequence, i.e. GT for process planning and tool layout planning. More importantly, GT cell aims at the economic efficiency as same as that obtainable from the less variation and large volume production.

By comparing those shown in Figs. 2.7 and 2.8, we may understand the difficulty in identifying the differing features within them. Dare to say, we may differentiate these three as follows.



Note: Both the gates for inputs can be used for outputs depending upon material flow

Fig. 2.7 Job shop-like machining cell with rationalised material flow (by Torihara, 1966)

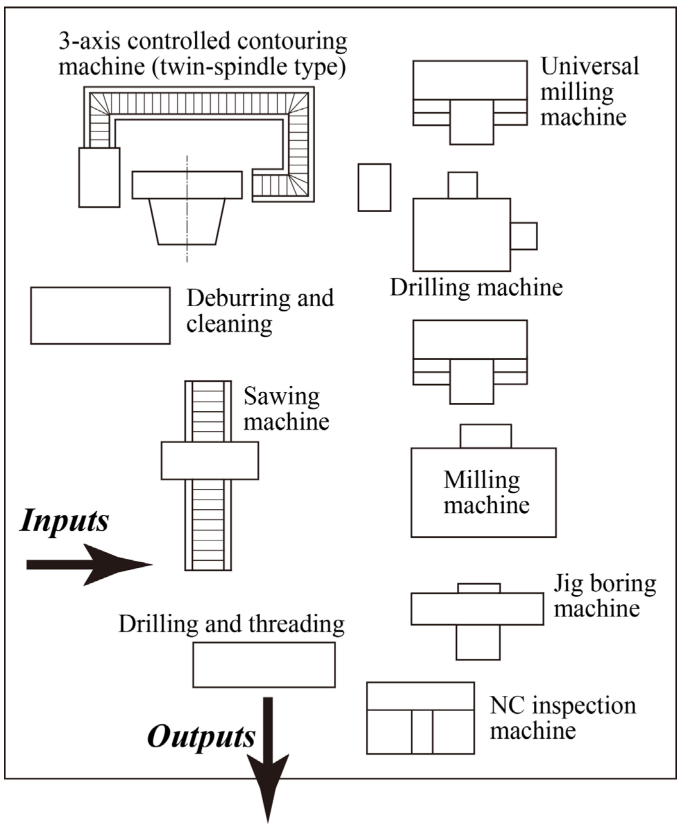


Fig. 2.8 GT cell in 1970s (proposed by Allen and introduced by Merchant)

(1) Job shop consists of a group of various kinds of the machine tool, which are chosen in consideration of the expectable order placement.
(2) GT cell consists of several groups of machine tools and each group can be facilitated by a certain number of the same kinds. The grouping principle is based on GT theory extremely placing the stress on the machining process planning.
(3) There are various definitions for the production cell. For example, a variant of the job shop is regarded as a production cell when the material flow within the job shop is rationalised. In addition, someone asserts that GT cell itself is one of the production cells.
(4) With the advent of NC technology of first generation, we faced much more difficulties to differentiate correctly the job shop, GT cell and production cell than ever before. This is because NC machine tool has the flexibility in its machining function and capability to some extent. For example, GT technology was not so effective as compared with that in the era of traditional machine tool.
(5) In this context, Fig. 2.9 shows a large-sized factory for machining the aeroplane components, which is of a group of GT cells and of DNC type. In fact, each cell consists of a considerable number of the same kinds, because of the larger production volume and longer machining time of the part. Paraphrasing, each cell can be regarded as a machine as a whole in Fig. 2.8. Herein, DNC is one of the pre-concepts for FMS.

Fig. 2.10 shows an advanced job shop being on work, and as can be readily seen, there are no obvious differences between those in Figs. 2.7 and 2.10, apart from the installation of MCs (Machining Centres) and NC machine tools instead of the traditional machine tools [1].

Although there remains something to be seen, the machining cell is vital and very important in designing and using the production system in general as already exemplified in Fig. 2.5. Importantly, we sublimated the machining cell up to FMC by incorporating NC and computing technology,

[1] Figs. 2.9 and 2.10 are produced on the basis of on-the-spot investigation by one of authors (Ito).

and FMC is dominant in the production activity at present. Furthermore,

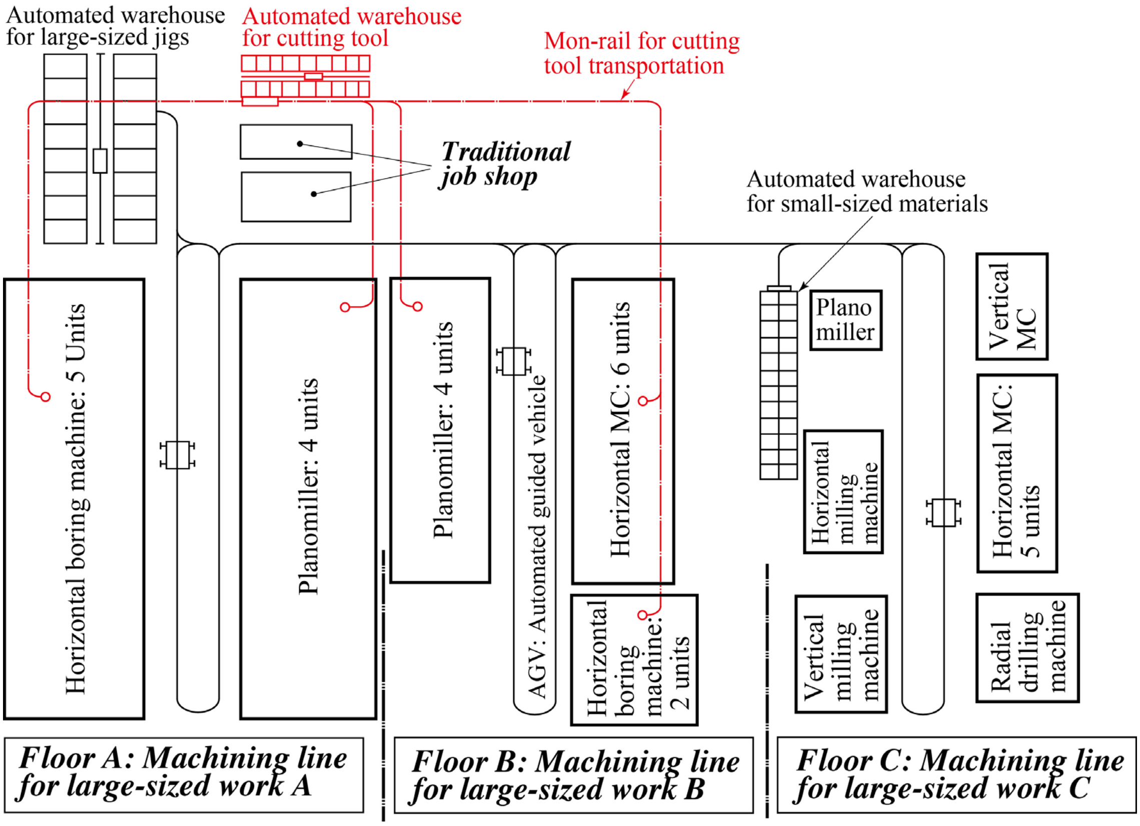


Fig. 2.9 A variant of GT cell - Aeroplane component machining system (simplified and modified system installed at MBB Augsburg plant)

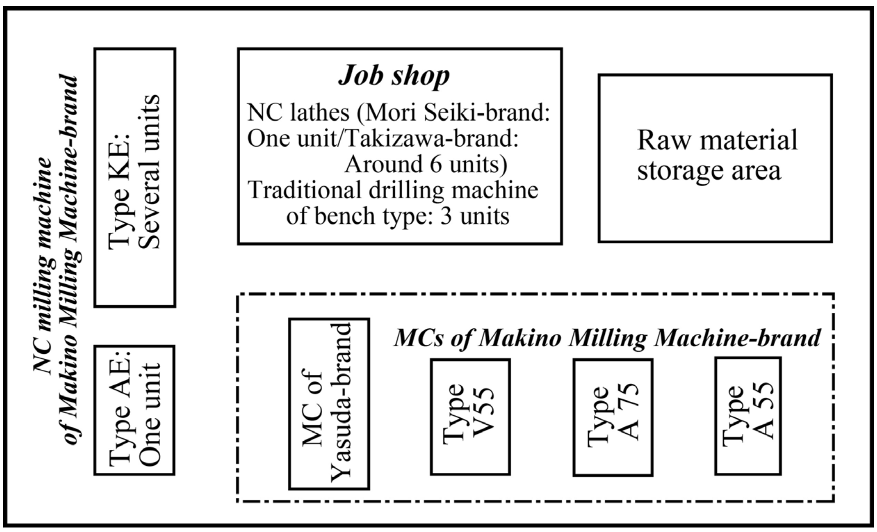


Fig. 2.10 Production cell involving job shop - Installed by Eba Machinery at Nomura-Haiphong Industrial Zone around 2005

the large-sized system is often modular-designed by integrating a group of FMCs as will be detailed in Chapter 3.

2.4 Resurrection of Design Principle of TL and Implicit Technological Inheritance of Automatic Turret Lathe - "MQB (Platform Method)"

In discussing the machining system, we must pay the special attention to the importance of the traditional machining cell as mentioned in the preceding Section, and as similar as the machining cell, TL is also very important, because its design principle has recently been resurrected in the design of the "*Transfer Centre*". More specifically, FTL and the transfer centre should be, in general, designed by the modular principle, which is the utmost characteristic feature in the design of TL, and reported already elsewhere, the transfer centre can be extremely characterised by the design method of MQB (die Modularer QuerBaukasten; Platform), i.e. one of the variants of the modular design (see Chapter 3).

In retrospect, TL was developed extremely for the less variation and large volume production in the motorcar industry in the 1950s, so that we were able to reduce considerably the renewal cost of the machining facilities, when we conducted the model changes of the car [2]. Obviously, one of the remedies to such requirements is to employ the modular design, which is extremely applicable to the user-oriented machining system. After then, TL has been developed to FTL in accordance with the changing production pattern, and FTL is one of the very conventional facilities nowadays (Ito, 2008).

Admitting the importance of FTL, in the classification shown in Fig. 2.6, one of enchant kinds is the transfer centre, which is the utmost advanced FTL of compactly cubic type. It is thus necessary to understand the developing history of FTL, and also the characteristic features of the

[2] The modular design was called "Building Block System" (in German, die Baukasten Systeme) up to 1970s.

transfer centre. Of special note, Fig. 2.11 shows the developing history of FTL and identifies its variants, which are being in practical use even in the year 2010 and beyond. Thus, Fig. 2.11 can be regarded as one of the classification systems of FTL.

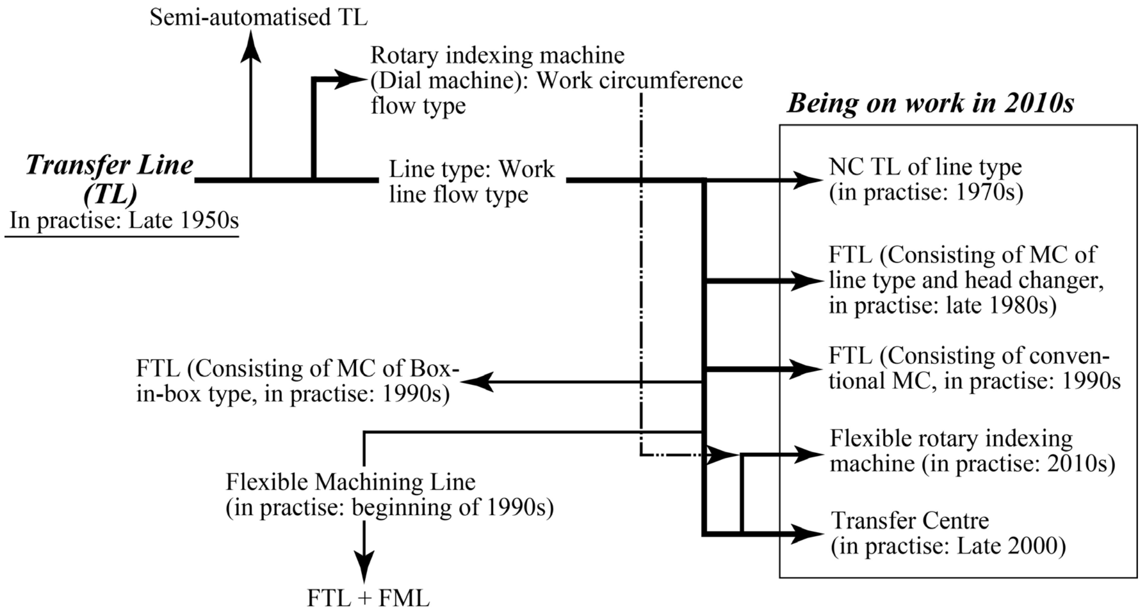
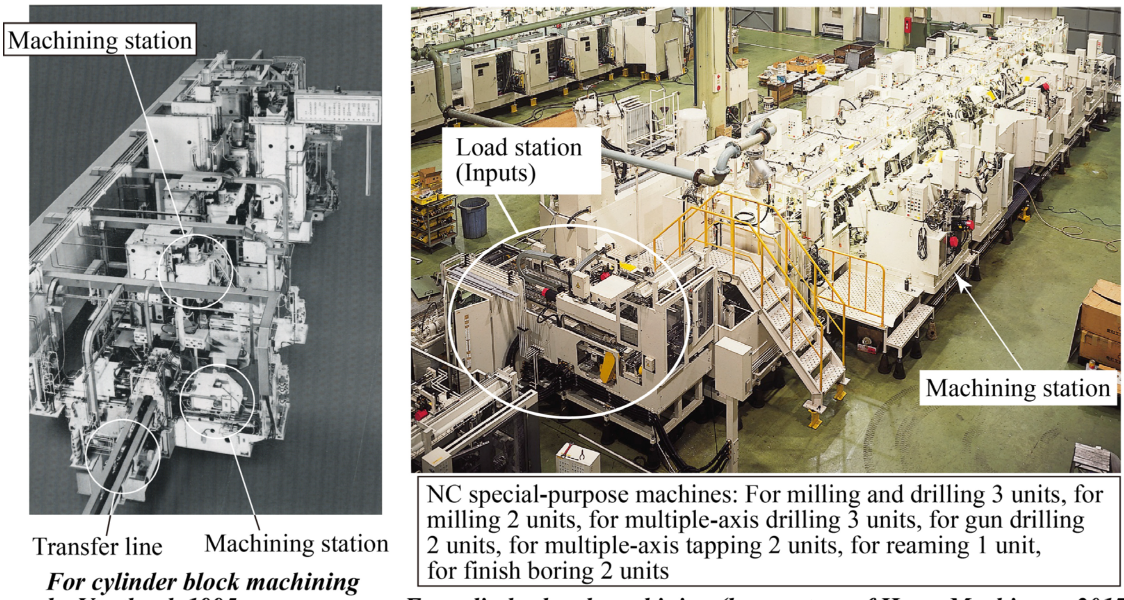


Fig. 2.11 Classification and development history of TL and FTL

Figure 2.12 shows an NC TL being on work together with comparing it to the traditional TL. As can be readily seen, the line configuration is very similar in both TL and NC TL; however, the machining station in NC TL is replaced to NC special-purpose machine tool from the traditional one in TL, i.e. traditional special-purpose machine tool. In short, there are three types in the traditional TL, i.e. TL of line flow, TL of rotary indexing type (dial machine) and TL of way type, and as will be discussed in Chapter 3, we have resurrected the transfer centre from these traditional types.

At present, the transfer centre is applicable to the "*Considerable Variation and Variable Volume Production*", but not to "A Kind of Production" and "One-off Production". It is thus desirable that we will establish the transfer centre to be applicable to the one-off production together with facilitating the "On-the-Spot Interchangeability of Modules" at the user's factory.



For cylinder block machining by Vogtland, 1995

For cylinder head machining (by courtesy of Howa Machinery, 2017)

Fig. 2.12 Traditional TL and modernised NC TL

Obviously, we can talk a similar story in the case of the machining cell, in which the NC machine tool play the role of the core machining function in certain cases as shown in Fig. 2.10. In addition, the standardised FMC has been prevailed instead of the machining cell even in SME as will be discussed in Chapter 3, and the machining function in such FMCs consists, in general, of MC and TC (Turning Centre).

We must thus eye the technological inheritance in MC and TC from the traditional machine tool to deepen and to widen our understanding for the machining system. Fig. 2.13 illustrates a developing history of TC from the traditional turning machine, and as can be seen, there are three noteworthy technologies, which are now employed within MC and TC as follows (Ito, 1994).

(1) Tool post of unit type, which is modular-designed, and can be interpreted a forerunning trials of the “Platform”, i.e. formation of user-oriented machining space.
(2) Employment of turret head, which is a common structural component in TC nowadays.

(3) "*Turret-over-spindle*" configuration in automatic turret lathe of Cleveland-brand (in case of Monforts-brand, "Turret-under-Spindle"). The travelling turret bar of pentagon shape (with turret head) is placed at the right above position of the main spindle, so that we can solve the "Hot Spindle-Cold Turret Problem" in the conventional turret lathe. In short, this remedy in the structural configuration results in the main spindle with preferable thermal stability, and then sublimates to "*Spindle-over-Spindle*" configuration, i.e. twin-spindle configuration in MC later (see Fig. 3.18).

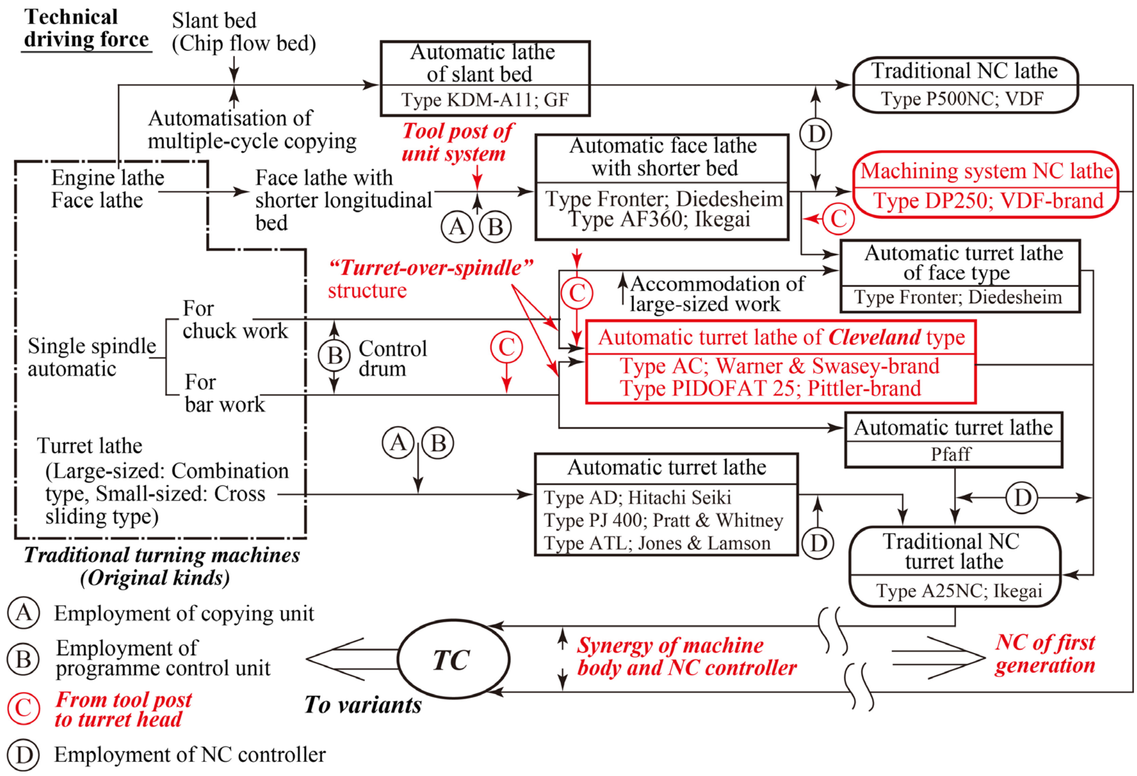


Fig. 2.13 Development to TC from traditional turning machines

More specifically, in Fig. 2.13 the "Machining System NC Lathe" of VDF-brand (Type DP250) contributed to the advance of the modular design in TC to a large extent, and in due course, the automatic turret lathe of Cleveland type stimulated considerably the contrivance of TC of twin-spindle type.

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Chapter 3 Basic Knowledge about and Layout Design for Flexible Machining Systems

Abstract We must use various machining systems depending upon technological, economic and social environments in the nation and region across the whole world, and within the industrial nation, FMS (Flexible Machining System) and its variants like FMC (Flexible Machining Cell) and FTL (Flexible Transfer Line) have been prevailed. Importantly, FMC and both FMC-integrated FMS and FTL are growing their importance almost daily, whereas we must modify the design guide for FMS and concerns so far used in consideration of their present and near future perspectives. In fact, the traditional design guide becomes obsolete with the advance of FMC.

This chapter describes first the definition of FMS after classifying the applicable area of FMS and its variants at present, and then shows some representative FMCs especially placing the stress on the (defacto) standardised FMC, and also FTLs in consideration of its importance within the motorcar industry. In this context, it appears that FMC for one-off production is available for the CPS module in the smart factory, provided that the cell controller should be contrived something necessary.

In consideration that both FMC and FMS are modular-designed to be facilitated the flexibility, expandability and redundancy, the basic knowledge about the design for FMC is also stated. It is furthermore important to enhance FMC by incorporating the function-integrated kinds in the machine tool, and thus a quick note for such kinds is given, where the transfer centre, i.e. a forerunning trial of such kinds, is discussed.

3.1 Applicable Ranges of FMS and Its Variants When Considering Production Patterns

In the 1980s, FMS became the leading machining facility within the large-sized enterprise, and from the viewpoint of the total production capability within a nation, SME (Small- and Medium Sized Enterprise) was compelled to install FMS in order to leverage its machining capability with that of the large-sized enterprise. As can be imagined, SME could not afford to fulfill such a requirement because of the poor investment capacity. Importantly, we need such a leverage even now especially in the motorcar industry, where a group of subsidiaries and subcontractors, i.e. those in general of SMEs, can support the production activity of the parent company to a large extent through the supply chain. More importantly, a group of subsidiaries and subcontractors is of hierarchical structure, e.g. ranging from 1st to 3rd tires, and thus there are considerable difficulties to install FMS within them much more than our thoughts.

In retrospect, to solve such an installation problem of FMS on that occasion, FMC was developed (MITI, 1983). Paraphrasing, FMC is very handy with keen purchasing price and running cost, and even SME can install it without any difficulties. In due course, we can obtain the amazing economical benefit as similar as that of FMS by installing FMC. As a result, FMC has mushroomed and for the time being is dominant.

Since the 1980s, FMS has been duly deployed to various ways to respond properly to the changing machining requirement of the society, i.e. FMC, large-sized FMC, FTL, FML (Flexible Machining Line) and FMS. Importantly, primary concerns are FMC for stand-alone operation, and also FMC-integrated FMS and FTL at present [1]. In short, we can now manage nearly all the machining requirements by using FMC and FMC-integrated system, apart from the one-off production.

To understand such trends, Fig. 3.1 illustrates the applicable range of each variant of FMS by indicating obviously the production pattern, i.e. "*One-off Production*", "*A kind of Production*", "*Much Variation (small batch size) and Small Volume Production*", "*Medium Variation and medium Volume Production*", and "*Less Variation and Large Volume Production*".

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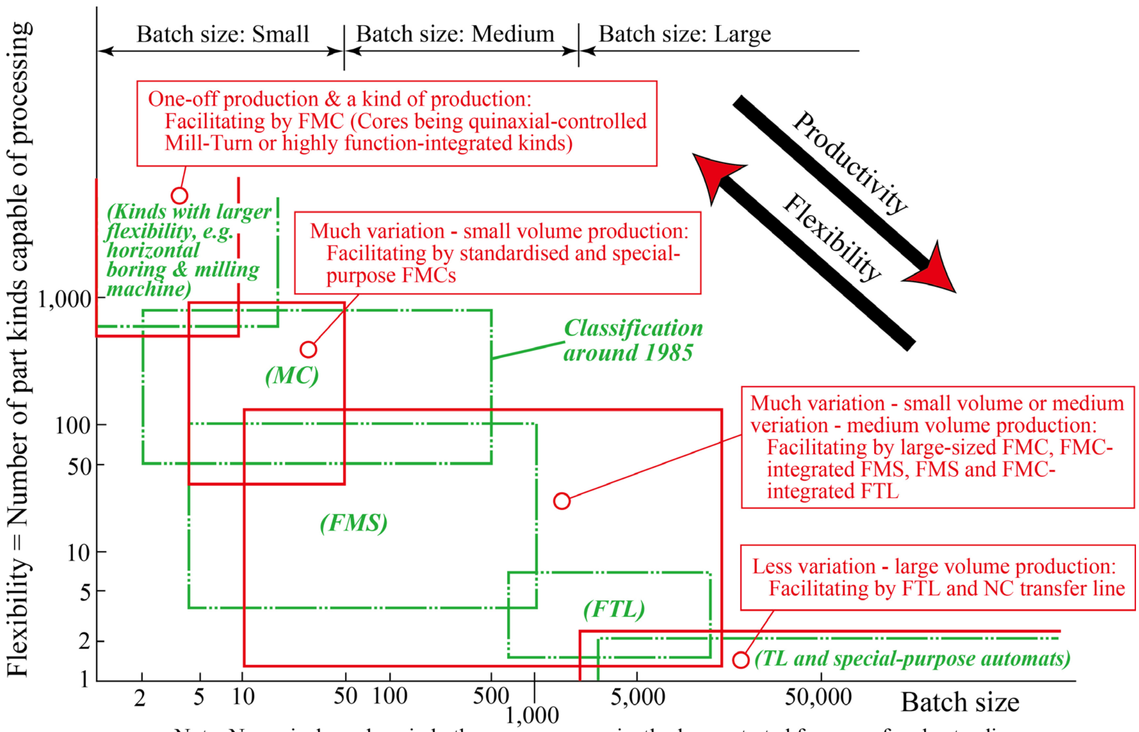
[1] FML was proposed by Fritz Werner, and can be characterised by its flexibility and machining capability, which are in mid-way between FTL and FMS.

In this context, it is worth suggesting that FMC is, in general, available for up to a kind of production, but not for the one-off production.

Importantly, Fig. 3.1 is a modification of the proposal by Klahorst around 1980. He proposed the classification for the flexible manufacturing system by using both the indexes, i.e. flexibility (manageable variation of part kinds) and batch size, as shown together in Fig. 3.1 by the green line and letter, which was on the strength of the classification proposed by Kearney & Trecker. More importantly, it is worth suggesting that his proposal is very reliable as verified by many engineers and elsewhere [2, 3].



Note: Numerical numbers in both axes are conveniently demonstrated for ease of understanding (suggested by Klahorst around 1985)

Fig. 3.1 Classification of flexible machining systems in 2010s

In due course, we have already established the design guide for FMS and

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[2] If necessary, we can add furthermore the following production patterns, i.e. "Considerable Variation and Variable Volume Production" and "Client's Order Responding Production".

[3] Warnecke introduced the proposal of Klahorst on the occasion of KAIST Seminar held at March, 1982 (Seoul) within his topic entitled "Tendencies for Improvement of Productivity in Manufacturing Industry – A Survey".

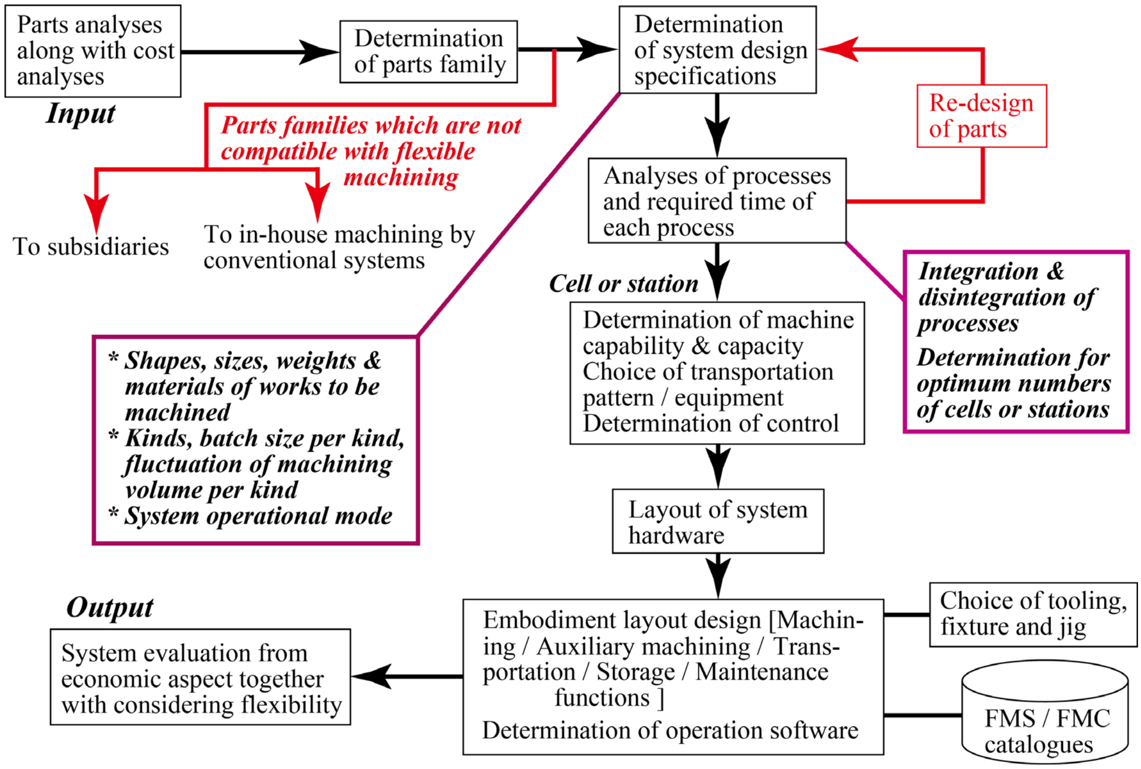


Fig. 3.2 Traditional system design flow for flexible machining

Leading attributes		Auxiliary attributes
Traditional	Newly arisen	
Kinds and types of objective products Production volume and production pattern Allowable production cost and delivery term Required product quality	Compatibility with localised globalisation Virtual concentration System concepts: Quality assurance-oriented Skill-based or facility-relied on	Rate of automatisation Compactness of system Factory location Social infrastructure Human resources available Supply chain available Real concentrations possible and so on

Table 3.1 System design attributes in general

concerns to large extent, and Fig. 3.2 reproduces a design flow starting from the part analyses including the processing schedule, through the determinations of system specifications, layout design and the preparation of operational software, to the system evaluation. In the system design, it is first important to specify the system design attributes in general as shown in Table 3.1. Actually, we must consider myriad attributes and superiority order among attributes in accordance with the manufacturing requirements including designer's philosophy and preference, technologies available, corporate culture, installation region of system, and so on.

Then, primary concern is the determination of the system configuration, which is closely related to the five fundamental functions as exemplified in Fig. 2.5 and system components facilitating the due function. Thus, Table 3.2 shows such functions together with the available system components for each function and also the determinants of the system configuration. Importantly, these system components should have furthermore the following functionalities.

Fundamental system functions Corresponding system components	Determinants of system configurations
Machining Metal-cutting machine tools	Kinds of machine tools: Traditional NC machine tools, MC, TC, Mill-turn and "Highly Function-integrated Kinds" Division of machining processes: Pre-, main- and post-machining / Which of three must be incorporated within the system
Transportation Conveyor, Linear motor, Overhead crane, Robots, Rail-guided vehicle, Mono-rail, Stacker crane, AGV	Combination of material flow patterns and corresponding facilities Transportation objectives: Raw material, semi-finished work, tools, jigs and fixtures, end effector of robot / Which must be automatically transferred within the system
Storage Automated warehouse, APC, Load & unload station, Buffer, Waiting station, Detour branch in transportation	Allocation: Concentric or distribution type / Central or peripheral Layout design: How to combine warehouses, converted portions of transportation line, load / unload station and buffer areas, Configurations of load / unload station Objectives to be contained: Raw materilas, finished parts, tools, jigs and fixtures, end effector of robot and so on / Which must be contained
Others Surveillance devices, In-process sensor and so on	Whether the measuring and inspection stations or cells are incorporated within the system or not Kinds of specified stations or cells: For measuring and inspection, washing, simple assembly, heat treatment and so on

Note: AGV: Automated guided vehicle APC: Automatic pallet changer
Division of machining processes: In full terms, "Division of Work in Machining Processes"

Table 3.2 Determinants of system configurations

(1) Flexibility.

(2) Leverage of functionalities and performances to cost.

(3) Higher modularity for ease of integration to system and wider

procurability.

(4) Ease of renewal and better disposability.

(5) Higher operability.

(6) Ease of inspection and maintenance.

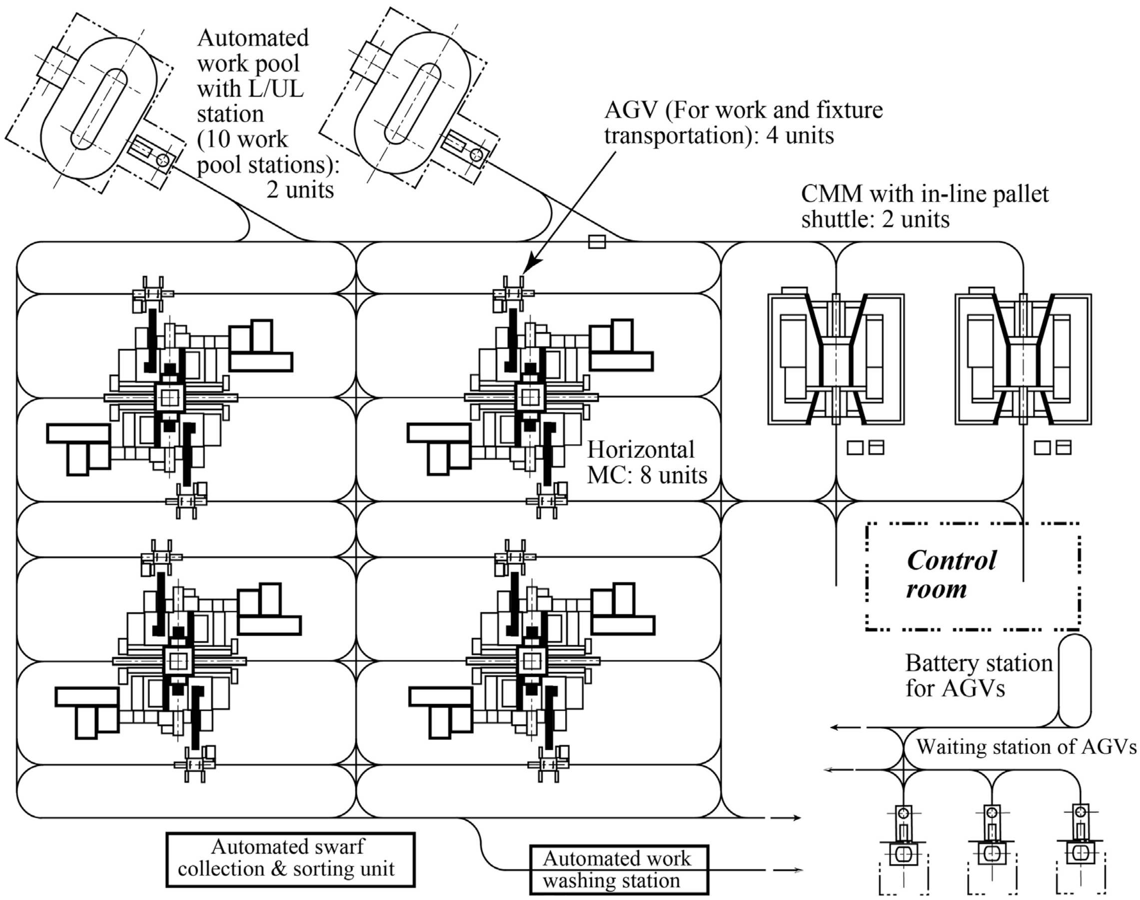


Fig. 3.3 System configuration of FMS to be installed at Vought Co. - For machining aeroplane components

To deepen the understanding to such the design guide, Fig. 3.3 shows a plan of the basic layout for FMS, which was produced by Cincinnati Milacron with price of 10 Mil. US$, to be installed in Dallas Plant of Vought Aerospace in 1984, and aimed at machining the aeroplane components, i.e. aft components of B-1B bomber. From Fig. 3.3, we can assimilate concretely the roles of determinants shown in Table 3.2 in the configuration of the basic layout. Actually, at issue is the kind of core machine tools, and equally we must discuss the auxiliary facilities and devices such as work preparation station, washing stand, work turn-over device and CMM (Coordinate Measuring Machine), which are necessary to form the system in accordance with the machining requirements. In general, such facilities like CMM and washing station are not provided to the system apart from the special case like FMS for ordnance manufacturing (FMS Magazine, 1983).

It is however notable that such a design flow and determinants for system configuration render, at present, useless by the upheaval of the following new waves, and thus we must investigate a new design guide as will be discussed in the following Sections.

(1) We must revise the design flow following the "Determination of System Design Specifications" in consideration that FMC and FMC-integrated system have recently been in leading position. As a result, for example, the procedure for "*Integration and Disintegration of Processes*" is not so important nowadays.

(2) With growing importance of the "*Highly Function-integrated Kinds*" in the machine tool, the "Re-design of Parts" procedure in the design flow renders useless (see Section 3.4). This is because nearly all machining requirements can be carried out, for example, by the mill-turn, which is one of the function-integrated kinds being prevailed.

To this end, it emphasises that the system evaluation extremely related to the "*Flexibility*" is at burning issue.

3.2 Definition of FMS

When discussing this issue, it is very helpful to refer to the definition of FMS proposed by Weck (1974). He eyed the utmost characteristic feature of FMS in the material and information flows, i.e. simultaneous supply of both the material and information necessary to process the material at any stations within the system, to eliminate completely the idle time, e.g. waiting time. This definition is very valuable and may be called "*Same Time - Same Place Principle*" as shown in Fig. 3.4.

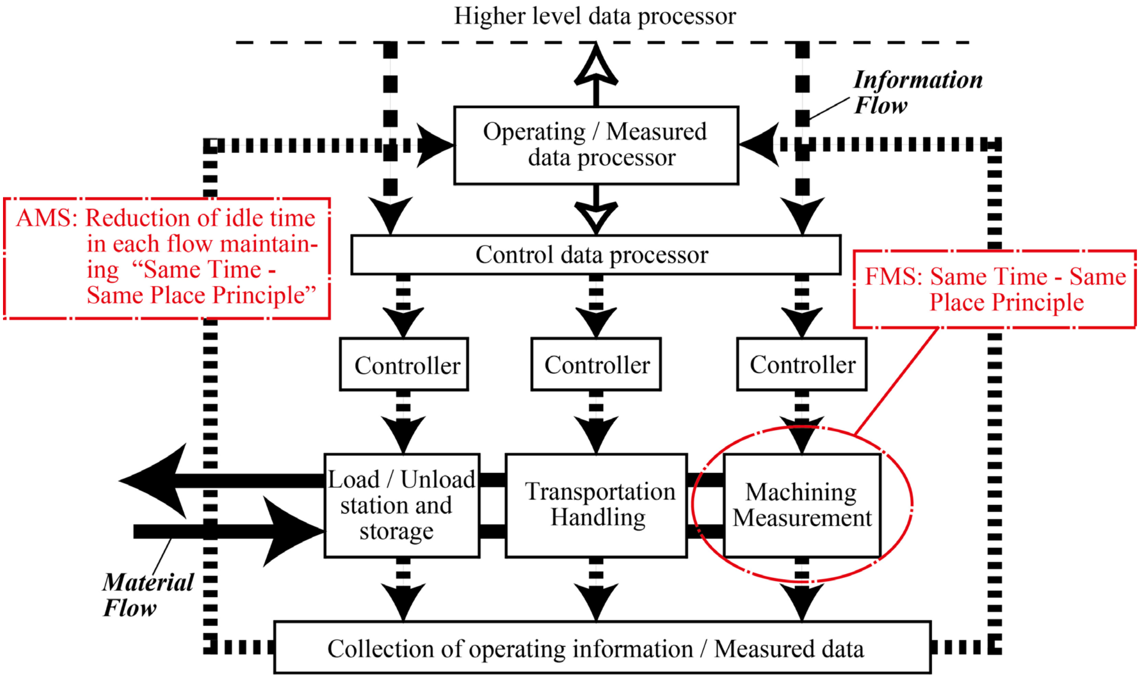


Fig. 3.4 Definitions of FMS and AMS

As can be readily seen, such a characteristic feature can be accommodated by using the computerised control, and in AMS (Agile Manufacturing System), it may be asserted that the idle time in each flow can be reduced as far as possible by maintaining the same time - same place principle as shown also in Fig. 3.4. Obviously, the definition of Weck is available not only for FMS including FTL, but also for FMC including FMC-integrated system.

Importantly, we may identify the material flow as a horizontal integration through value networks (physical space), and also the information flow as a vertical integration and networked manufacturing systems (cyber space) in the smart factory concept. In short, FMC may be regarded as a CPS module, provided that FMC is available for one-off production.

3.3 Present Perspectives for Flexible Machining Systems

As will be clear from the above, we must place the stress on FMC, and also on both FMC-integrated FMS and FTL in discussing the flexible machining system at present. As will be discussed later, it is natural that both FMS and FMC are designed by using the modular principle, and as literally shown, FMC can facilitate the basic module in designing FMC-integrated system.

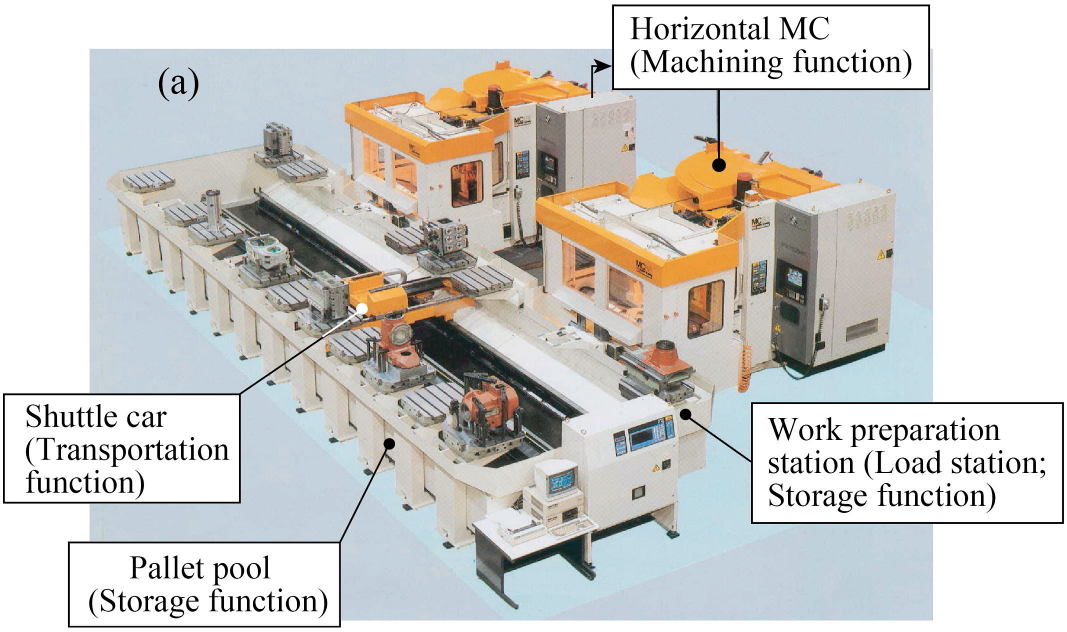
3.3.1 FMC and FMC-integrated FMS

On the occasion of the first stage of the development in the 1980s, there were two types of FMC, i.e. FMCs of pallet pool and robot types, depending upon their core machining functions. In short, the former consisting of MC is for the box-like work, whereas the latter consisting of NC turning machine or TC is for axial-symmetrical work.

Since then, these two have been widely employed as shown in Figs. 3.5 (a) and (b), and also Figs. 3.6 (a) and (b) in the form of time-series like representation. For example, Fig. 3.6 (a) shows an FMC of robot type in the 1980s, and its characteristic features are, as can be seen, to integrate compactly the work handling robot within a machine as a whole, and also to employ the modular design so as to suit the customer's specific needs with expandability. With the advance of the cell component and related technologies, FMC has had much more functionality and higher performance than ever before; however, we can say that there are no significant differences in the dimensional and performance specifications between both FMCs shown in Figs. 3.6 (a) and (b).

Importantly, nowadays we can regard these as (defacto) standardised FMCs for stand-alone operation or basic modules for FMC-integrated system, i.e. large-sized FMC, FMS and FTL, and more importantly there are several variants as shown in Fig. 3.7 depending upon the system component, by which each variant can be characterised. Of special note, it emphasises that the standardised FMC and its variant have been mushroomed within SME as expected by its original idea.

Within the context of variants, it is very interesting that we have at present multifarious specified types with continuously diversifying the machining requirements of the human society as will be noted below.



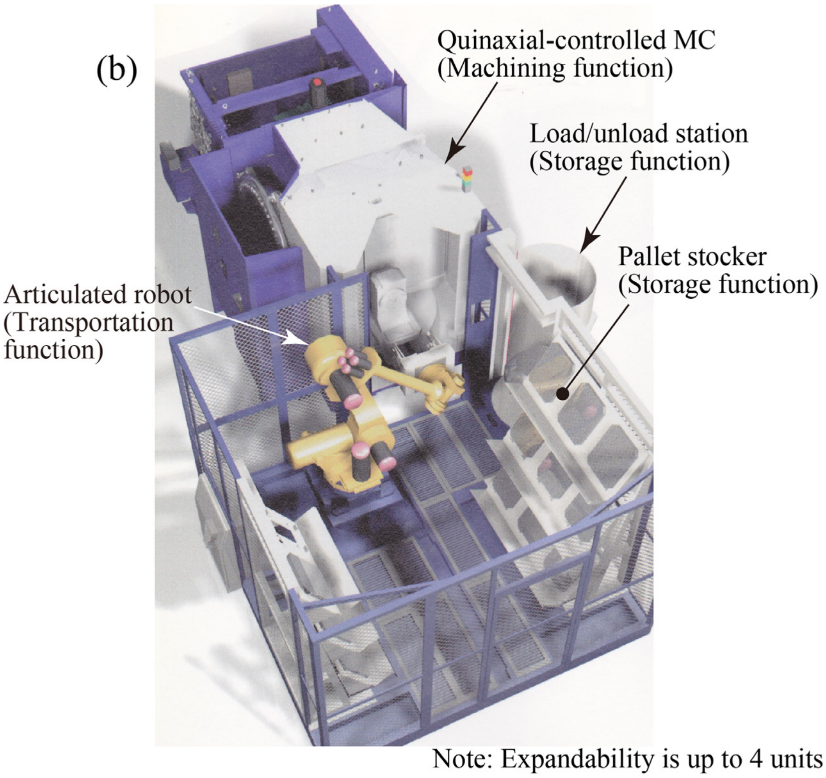


Fig. 3.5 FMC of pallet pool type: **a** Expandable type of Makino-brand, late 1980s. **b** Type μMMC (by courtesy of Makino Milling Machine, 2016)

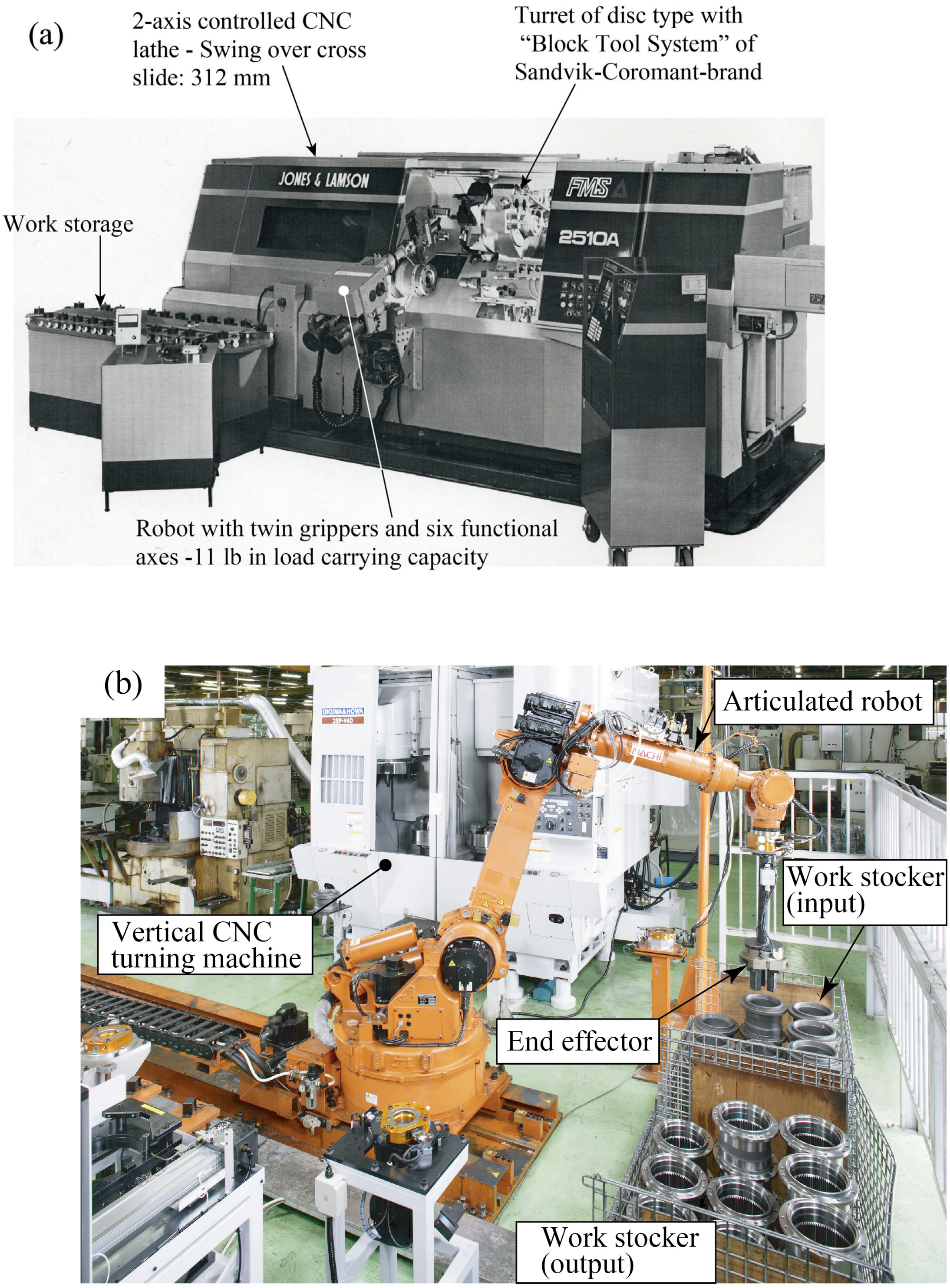


Fig. 3.6 FMC of robot type: **a** Front-located robot type - Type FMS 2510A, Jones & Lamson-brand, in 1980s. **b** Front allocated travelling type (by courtesy of Fujikoshi, 2010)

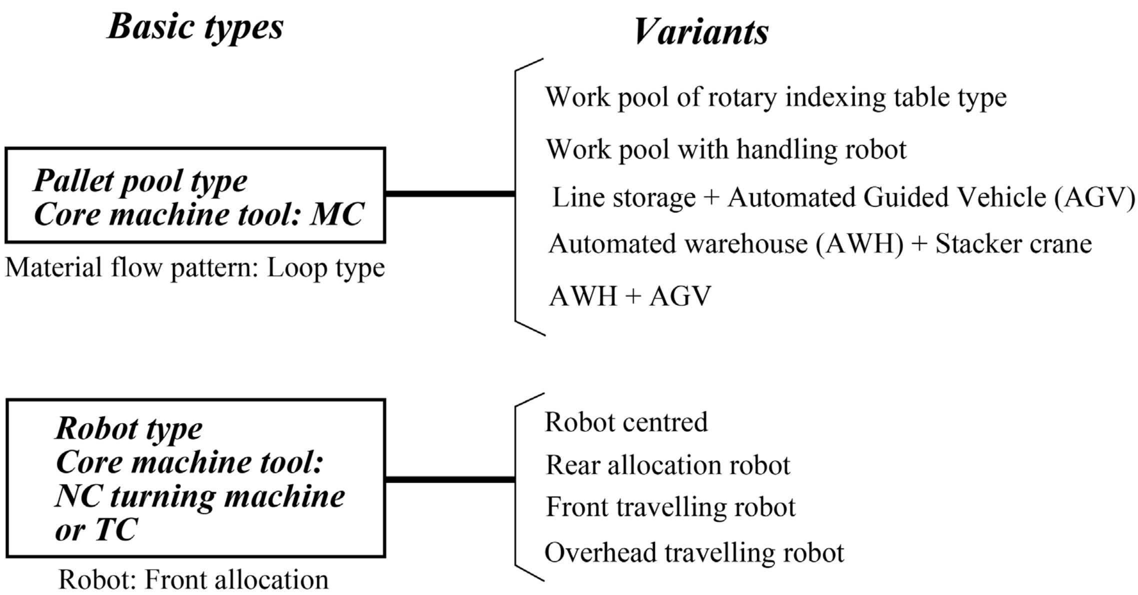
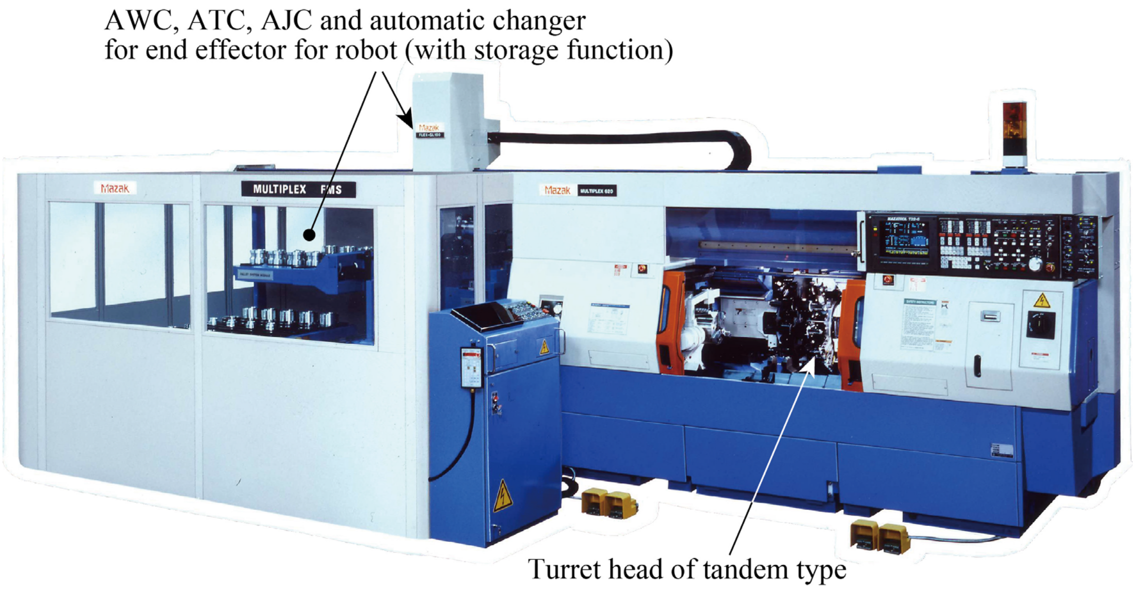


Fig. 3.7 Variants of standardised FMCs

Figure 3.8 shows a further variation in FMC of overhead travelling robot type. This FMC has been on market since 2000, and can be characterised by TC of twin-spindle and tandem turret head type, resulting in much more flexibility in machining than our expectation as follows.

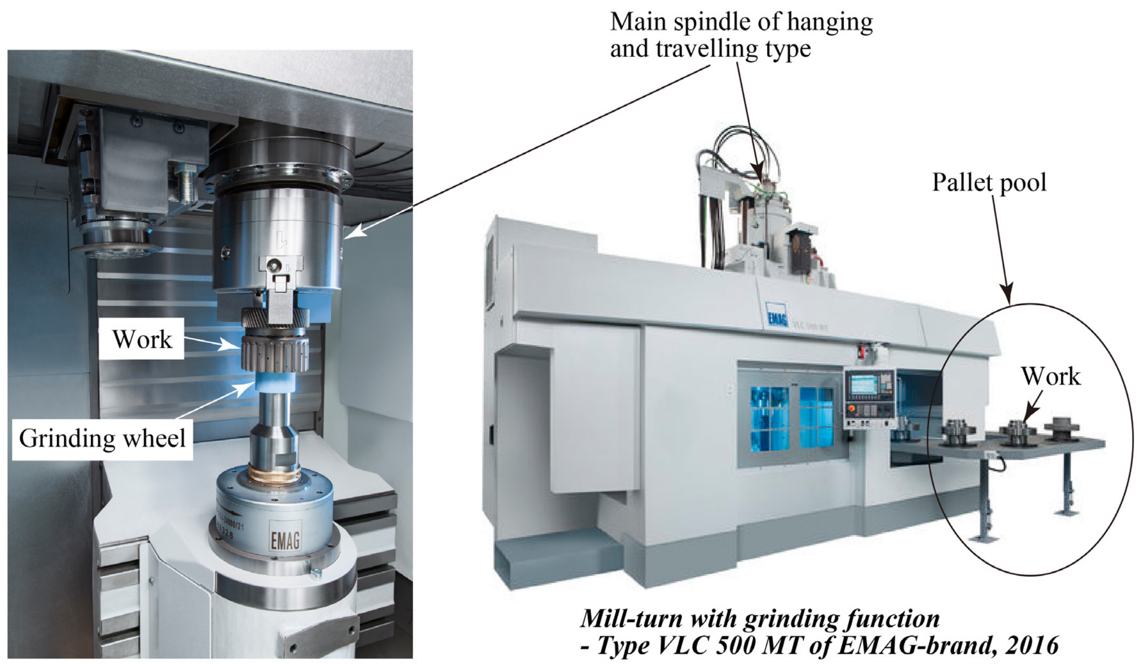
(1) Continuous machining by concerting first and second main spindles.
(2) Simultaneously different machining by each main spindle.
(3) High accuracy machining for the slender work by synchronous driving for both main spindles. Such a driving method is for avoiding unfavourable torsion in the work caused by the differing driving torque between both spindles as like as that in the car wheel lathe.

In general, it appears that FMC is of fully automatised system; however, we need the direct control and surveillance by the mature operator in very special machining. Fig. 3.9 shows an FMC enabling the better accessibility of the operator to the cell by allocating the comfortable working space at the front of the machine. Of special note, this FMC consists of the mill-turn with grinding function, and as can be seen from the left of Fig. 3.9, the main spindle is of travelling and hanging type to achieve the higher machining accuracy by one-chucking operation.



Work specifications in maximum: 200 mm in dia. × 120 mm in length
AWC: Automatic Work Changer ATC: Automatic Tool Changer AJC: Automatic Jaw Changer

Fig. 3.8 A variant of FMC of robot type - Core machine: TC
(Type MULTIPLEX620, by courtesy of Yamazaki Mazak, 2012)



Mill-turn with grinding function
- Type VLC 500 MT of EMAG-brand, 2016

Machining space of GC - Type VLC 100 G
(by courtesy of EMAG, 2013)

Fig. 3.9 FMC of pallet pool type for higher accuracy machining with easy accessibility for operator

Fig. 3.10 FMC for gear manufacturing
(by courtesy of Waldrich Coburg, 2013)

In many respects, we can benefit by installing the standardised FMC and its variants to a large extent; however, we need, in certain cases, special purpose-oriented FMC in consideration of the complexity in the form-generating movement in the machining function. For example, Fig. 3.10 is of pallet pool type for cutting the large-sized internal gear, which is the component of the window power generator, and being on work at Siemens (Waldrich Coburg-brand). More specifically, this FMC is consists of 2 units of MCs of portal type, in which the cross-rail is of hydrostatic guideway to absorb the impact-like load caused by gear cutting, and can conduct turning, drilling, milling and hobbing (Waldrich Coburg, 2013).
As can be easily imagined, we may produce various FMC-integrated FMS, provided that we can pre-determine a group of FMCs with standardised type, its variants and special-purpose type, i.e. a group of basic modules with wide variety. In short, Starrag Group displays its product deployment ranging from FMS for one-off production to that for a less variation and

large volume production, and these FMSs are modular-designed, in which the basic module is either MC or FMC.

In addition, Yamazaki Mazak demonstrates FMC-integrated FMS in its product deployment by extremely placing the stress on the economic benefit and step-wise skill improvement of the operator. In short, this FMS can be specified as follows.

(1) The basic module consists of one unit of machine, one unit of pallet pool allowable to contain 6 pallets, one unit of load/unload station.

(2) FMS is of line flow type and consists of up to 16 units of machines, one unit of stacker crane, one unit of pallet pool allowable to contain 240 pallets in maximum, and 8 units of load/unload stations.

In the meanwhile, the motorcar industry is the utmost leading user for flexible machining, and thus FTL has been widely employed, where the basic module is a machine as a whole like MC of line type, i.e. FTL of conventional type. In fact, FMC-integrated FTL was once employed, but after then not so prevailed as will be discussed below.

Against this context, it is notable and remarkable that FMC for one-off production is recently in fruition by contriving a new cell controller, but not the machining function. Could be, this is one of the remedies to reinforce the marketability of FMC. As widely known, FMC is very handy and easy for practical use immediately after installation without any teething trouble, resulting in a lucrative product for the machine tool manufacturer.

Okuma has supplied a standardised FMC of robot type shown in Fig. 3.11 to Sandvik Coromant at 2016 to machine the boring bar with both the "*On-demand Manufacturing*" and also "*One-off Production*". The machining function is cored by the mill-turn (Type: MULTUS U3000), which is a synergy of TC and MC, and furthermore reinforced by the quick tool changing, flexibility in tool layout and interchangeability of the collet chuck. Within this cell, the robot loads and unloads the work, changes the collet chuck and centre, and also serves the lower turret head and external ATC for expanding the allowable capacity of the cutting tool. Importantly, Table 3.3 delineates the functionalities of the cell controller, and within them, the utmost characteristic feature is a function related to production planning, which is in-house made by Sandvik Coromant (Okuma, 2017).

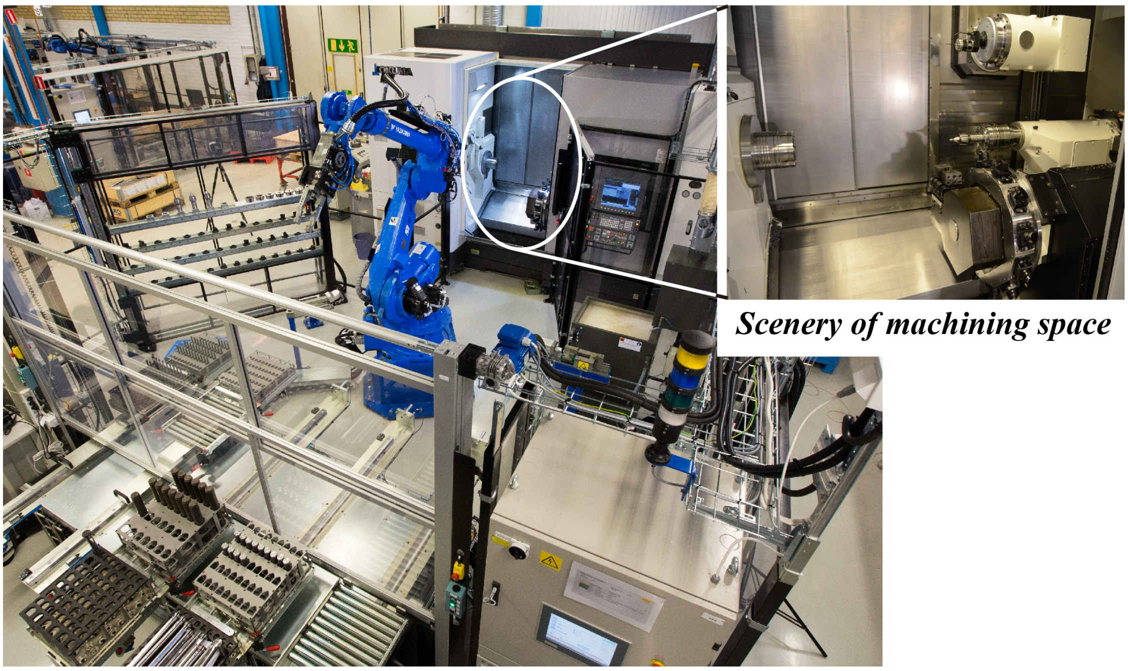


Fig. 3.11 FMC for “One-off Production”
(by courtesy of Sandvik Coromant and Okuma, 2017)

CNC interface to display machining state, machine conditions and so on
Exchange of NC programme accroding to machining requirements Custom tool management software enabling communication with external tool magazine
CNC-held library accessible via network connection to data for tool, centre and collet chuck from Okuma controller
TAP system: Interface with operator Direct generation of parameters for robot and NC programme from three-dimensional model of work Cognitive function for collet chuck, centre and cutting tool being on work

Characteristic feature of cell controller:
Custom software solution for seamless dialogue among machine itself, robot of Yasukawa-brand and Sandvik Coromant’ s production planning system (TAP system)

Table 3.3 Outlines of cell controller in FMC for “One-off Production”
installed at Sandvik Coromant

More specifically, production planning can especially facilitate the generation of the NC programme and robot control information from three-dimensional model of the work. We used to manage such a function by CIM, and Fig. 3.12 summarises the functionalities for FMC of standardised type shown in Fig. 3.5 (b). In general, the cell controller for the standardised FMC can manage, for example, the following.

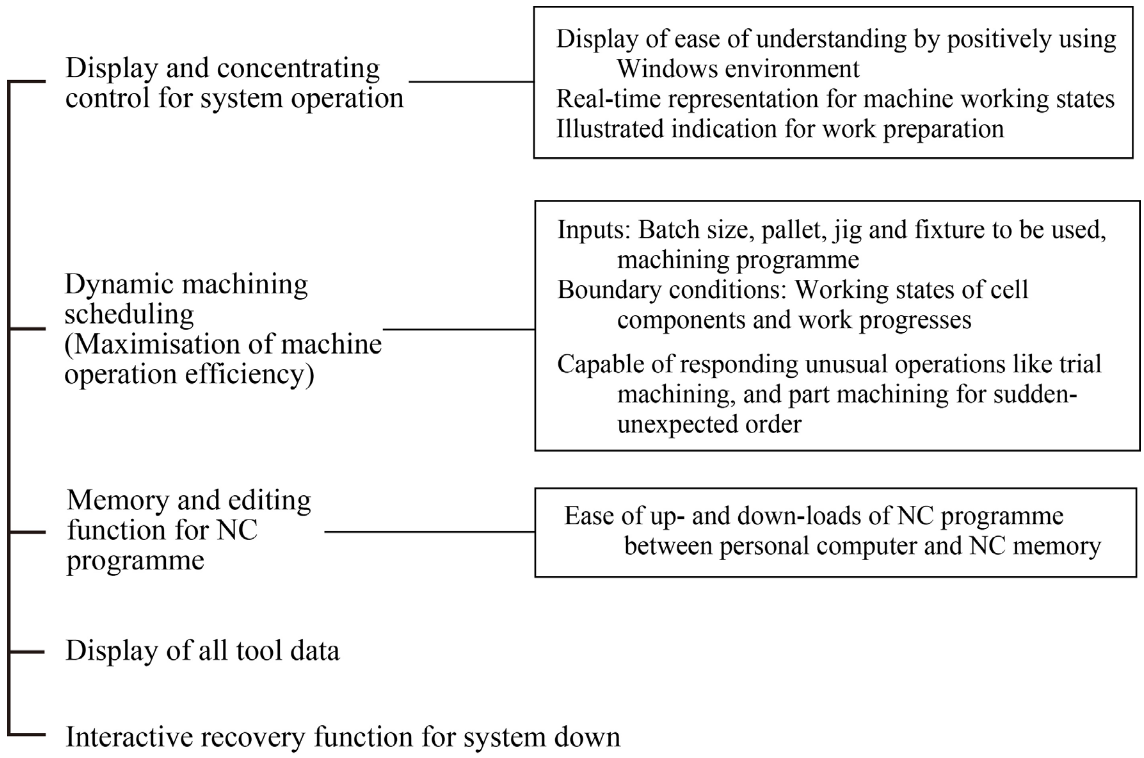


Fig. 3.12 Example of functionalities in cell controller for FMC of pallet pool type

(1) Surveillance for healthy condition of cell and cell components.
(2) Display of production control data.
(3) Long-distant consultancy and services.
(4) Generation of NC programme and machining simulation based on part drawing.
(5) In certain cases, interactive functions with worker by handy display, e.g. indication for work preparation and remedies indication in general.

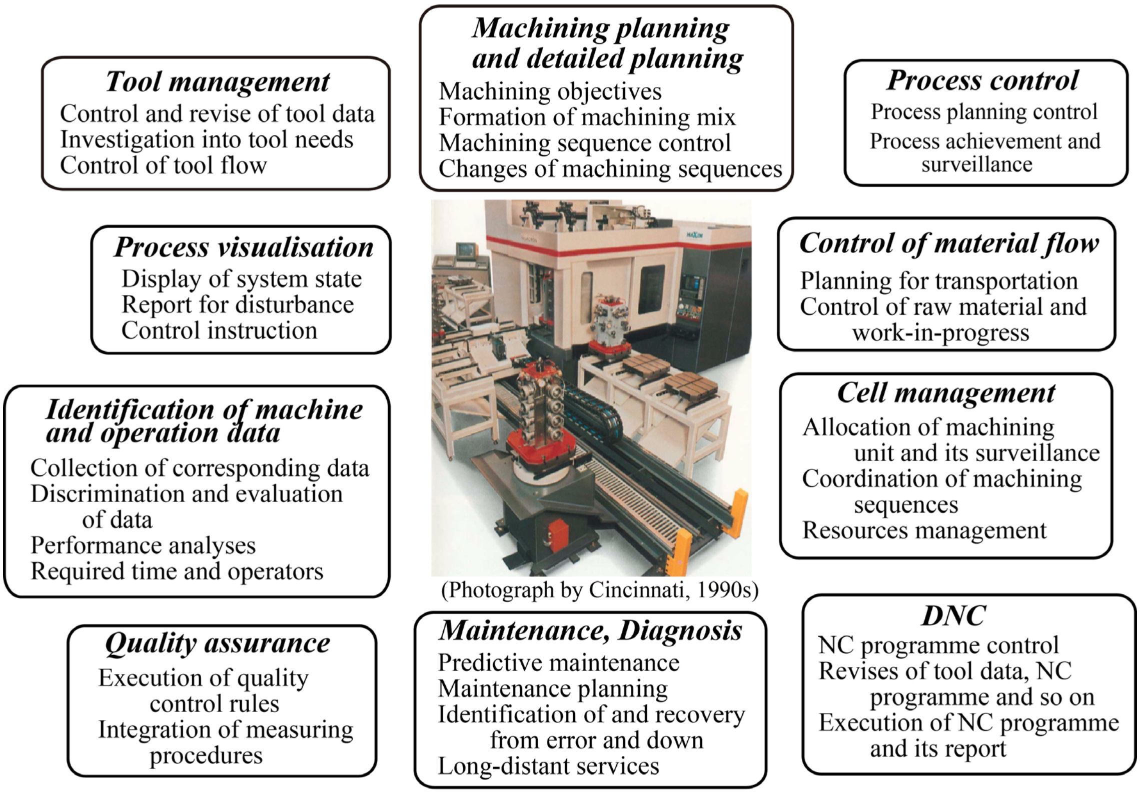


Fig. 3.13 Functionalities of FMS controller in general concerns (by Uhlmann, 2008)

(6) If necessary, integration of CAD/CAM with CNC by virtual machine. This aims at the optimisation of the machining processes and also the realisation of paperless machining.

In contrast, CIM deals with, in general, such process scheduling, work planning and optimisation of machining processes. For the sake of further understanding, Fig. 3.13 reproduces the functionalities of FMS controller in general concerns [4], and as will be clear again, we necessitate the simplification of the functionalities depending upon the machining objectives and also in consideration of the division of work between CIM and the controller for either FMS or FMC.

To this end, we may assert that FMC for the one-off production may be converted into a CPS module in the smart factory proposed by the "Industrie 4.0" Project in various aspects as will be clear from the above.

[4] Apart from the photograph, Fig. 3.13 is based on the handouts publicised on web by Professor Uhlmann of Technische Universität Berlin under the title of Flexible Fertigungssysteme in 2008.

3.3.2 FTL and FMC-integrated FTL

As already shown in Fig. 2.11, we can observe various machining lines in practice. Although TL and NC transfer line were once employed by the electric motor and lock sewing machine industries in the past, the major user of TL was the motorcar industry. With the changing production patterns, i.e. those from the "*Less variation and Large Volume Production*" to the medium variation and medium volume production, the old-fashioned FTL became the major machining facilities in the motorcar industry. At present, we have a new horizon, i.e. "*Considerable Variation and Various Volume Production*" in the motorcar industry, and thus we have contrived FTL of new fashion like FML of Fritz Werner-brand. Simultaneously, we have modernised the old-fashioned FTL to the conventional FTL by enhancing its machining capability in consideration of the current machining requirements.

As a result, both the conventional and new-fashioned FTLs are in practice in the motorcar industry, and importantly such FTLs are gradually going to be replaced by the "*Transfer Centre*" to respond to the "*Much Variation and Less Volume Production*".

For example, Mitsubishi Heavy Industries has shipped an FTL for cylinder block machining to the USA in the 2000s, which is for the considerable variation and various volume production, to respond to the recent machining requirements of the motorcar industry (Konishi and Sugano, 2005). In fact, this FTL is a synergy of FTL for rough machining and NC transfer line for finish machining, which was later replaced by FTL for finish machining (Fujimura et al, 2006).

In this context, it is notable that FTL for rough machining appears to be newly fashioned by contriving MC and transportation equipment as follows.

(1) The high productivity-oriented MC (Type M-CM4A), which is suitable for rough and conventional machining by the dimensional and performance specifications shown in Table 3.4, was duly developed to machine the power train parts made of aluminum alloy and cast iron.

(2) FTL can manage five different part families by dividing its line into a considerable number of the GT cell-like entities, in which a couple of MCs with the same specifications are installed. As a result, FTL has certain redundancy when an MC is down, and thus can continue its due work, although the machining capacity reduces to some extent.
(3) In addition, the high-speed gantry loader of overhead type can randomly transfer the work to each MC across a whole entity, in order to reinforce the redundancy in machining. Of note, the work is in the sequential flow and cannot take over the preceding work in the old-fashioned FTL.

Travelling ranges along X, Y and Z axes: 700 × 610 × 650 mm in max.
Travelling speed along X, Y and Z axes: 50 m/min in max.
Rotational angle around B axis: 360 deg.
Rotational speed of main spindle: 12,000 rev/min in max.
Tapered hole of main spindle: BBT 40
Output of main motor: 15/11/7.5 (10 min/30min/con.) kW
Number of tools in ATC: 24
Design allowance for MTBF: 5,000 hrs.
Remarks: Main spindle of cartridge type, Ease of maintenance by placing insentively devices for pressurised oil and air, lubrication, and cutting fluid at rear space of machine

Table 3.4 Dimensional and performance specifications of MC of high productivity-oriented type

In retrospect, primary concern in the motorcar industry was FTL consisting of MC of line type and one-direction flow of the work, i.e. old fashioned-FTL, although FMC-integrated FTL was employed in part, for example, that of Diedesheim-brand and installed within Opel (Zeh and Frank, 1984, see Fig. 4.7).

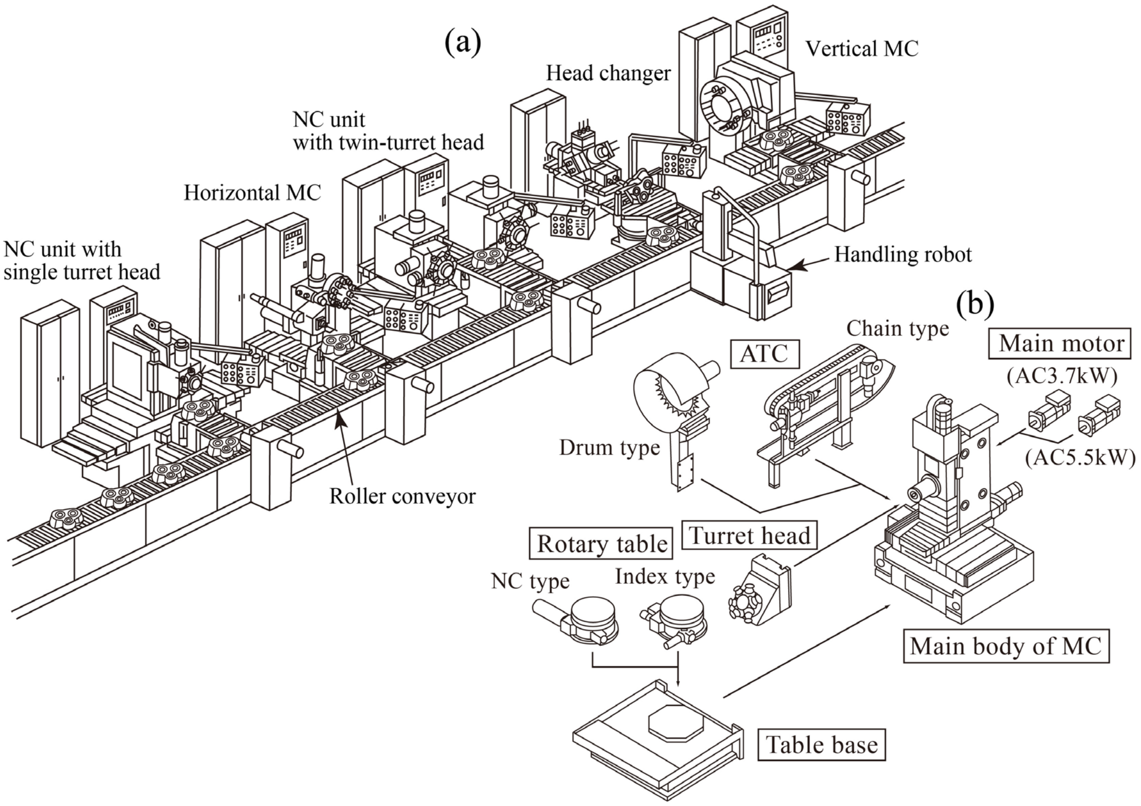


Fig. 3.14 Old fashioned-FTL and modular design in MC of line type: **a** FTL for machining cylinder head, cylinder block, mission case and so on (by courtesy of Toyama, 1990s). **b** Modules in MC of line type (Type NF1-H 1990, by courtesy of Fujikoshi)

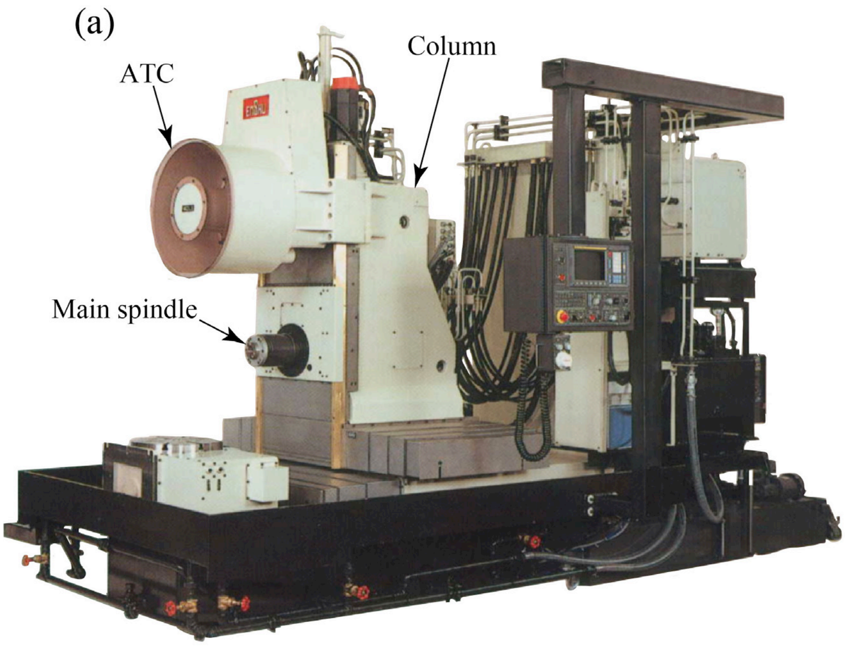
Figure 3.14 reproduces the typical old-fashioned FTL together with MC of line type, both of which are modular-designed. More specifically, this FTL is for machining the cylinder block, cylinder head and so on, and consists of the head changer, MC of line type and NC unit with turret head. As shown together in Fig. 3.14, MC of line type can vary its structural configuration by changing the combination of the basic modules, i.e. turret head or ATC, output power of main motor and types of the rotary table, while maintaining the main body and table base in constant. In short, such a structural design aims only at variations in the machining space, one of the variants in the fundamental modular design of hierarchical type, i.e. "*Platform Type (MQB)*", and is recently being prevailed (Ito, 2017, see Appendix of this volume).

Figure 3.15 shows the conventional FTL of Komatsu NTC-brand, and for

Fig. 3.15 FTL for cylinder block machining
(by courtesy of Komatsu NTC, 2017)

machining the parts of the power train and driving mechanism. In addition, Figs. 3.16 (a) and (b) show MC of line type in the past and at present, and there are, of course, the improvement in the performance specifications, but no essential differences in form-generating movement between these MCs. More specifically, MC of line type has been prevailed, and can be characterised by its form-generating movement, which is definitely concentrated to the column branch within a main body structure, i.e. that conventionally called MC of column travelling type, as can be seen from Fig. 3.14.

Because of a wide variety in the machining requirements, FTL has been apparently diversified as already shown in Fig. 2.11; however, we need to detail further such a diversification depending upon the kind of the machine tool. From Fig. 2.11, there are, at least, three different configurations in FTL, i.e. those facilitating by (1) MC of line type, (2) conventional MC for economisation, and (3) higher-cutting speed MC of box-in-box structure like the "Type Specht 500 of Hüller-Hille-Brand" (Schnier, et al, 1998).



Travelling ranges along X, Y and Z axes: 500 mm

Cutting feed: 1 ~ 1,500 mm/min

Quick feed: 60,000 mm/min

Main spindle rotational speed (BT40):
40 ~ 12,000 rev/min in max.

Working space of table: 400 mm in dia.

Maximum allowable work weight: 650 kg

Number of allowable tools: 24

Output of main motor: 11 kW

Fig. 3.16 MC of line type (by courtesy of Enshu): **a** Structural configuretion - Type HMC40-LS, 1993. **b** Appearance, dimensional and performance specifications of machine - Type GE40H, 2017

Meanwhile, Fig. 3.17 illustrates the structural configuration of MC with “Box-in-Box” structure and also travelling column. In this case, the moving components like the quill and spindle head are made of light alloy, and driven by the linear motor, so that MC can realise the higher-speed movement with stable condition. In addition, the saddle is light-weighted structure by using the monocoque configuration.

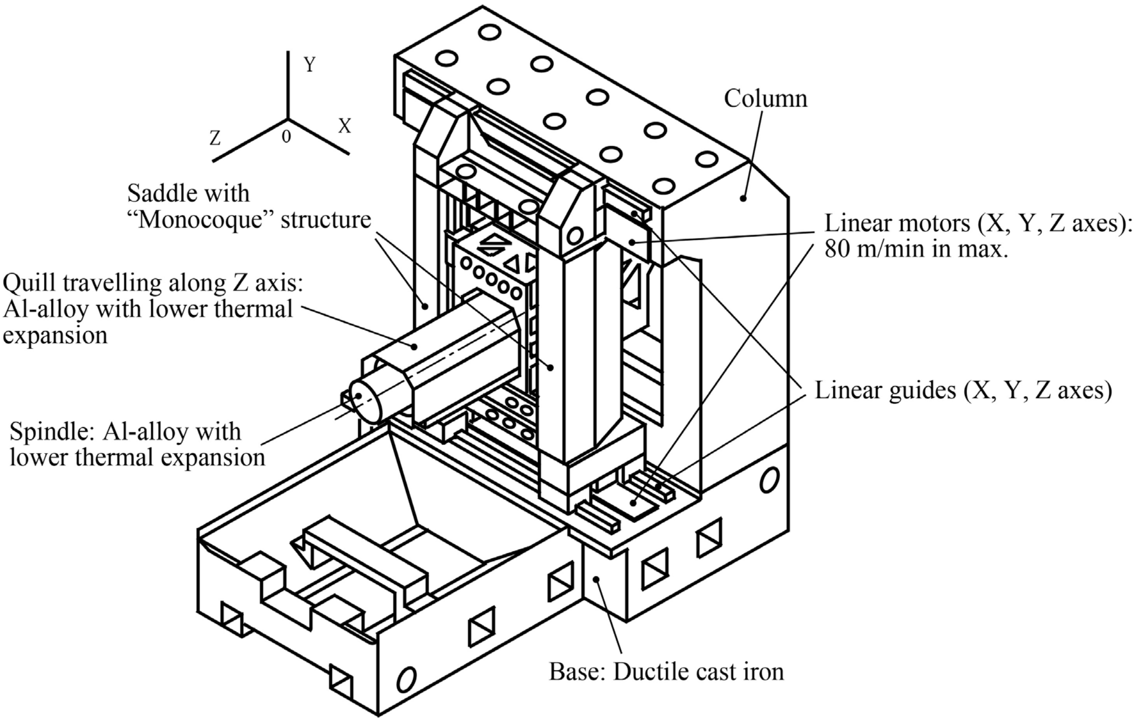


Fig. 3.17 MC with "Box-in-Box" structure - Type Linear M of Toyoda Iron Work-brand, 1990s

Of special note for understanding the marketing strategy of the machine tool manufacturer to the motorcar industry, it is worth introducing the product deployment of Fritz Werner in the 1990s. In fact, Fritz Werner supplied FML, FMS and FMC by integrating the basic modules, which range from MCs of three types, i.e. (1) MC of line type, (2) MC of twin-spindle type and (3) single-spindle MC with multiple-axis head changing function, to the special-purpose machine, roller conveyor, rail-guided AGV and gantry robot. Fig. 3.18 shows an FMC of twin type, in which MC of vertically allocated twin-spindle (spindle-over-spindle) type is employed to allow heavy duty machining.

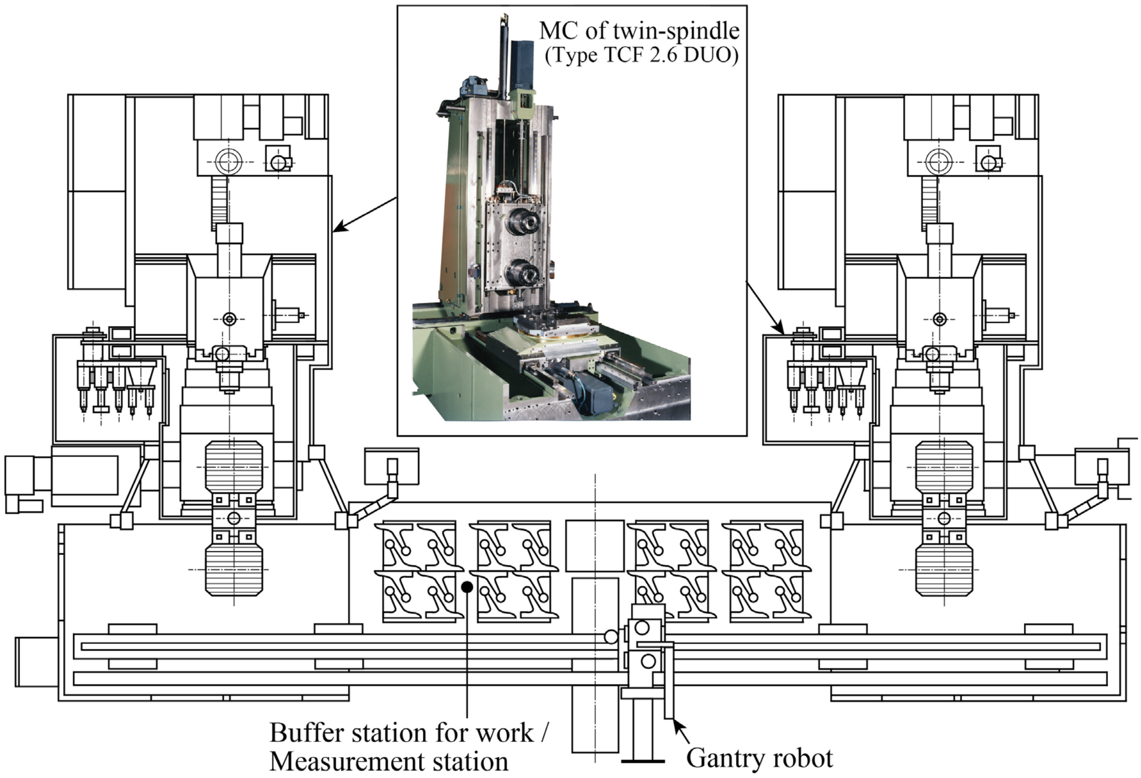


Fig. 3.18 FMC of twin-type consisting of MC of twin-spindle type (by courtesy of Hammer of Fritz Werner, 1993)

As will be clear from Fig. 3.1, in general, FMC is suitable for much variation and small volume production; however, this FMC is for “*Less Variation and Large Volume Production*”, and concretely saying, for machining the rocker arm of four kinds with 400 thousands parts per year (cycle time: 1.2 ~ 1.8 min). Importantly, even FMC may convert its applicable area by replacing the core machine, and in certain cases, such a conversion is in fruition by contriving the software for the cell controller.

3.4 Fundamentals in Layout Design

We need now to establish a new layout design guide on the basis of those shown already in Fig. 3.2, Tables 3.1 and 3.2, and also in consideration of the present and near future perspectives of flexible machining. For example, FMC and FMC-integrated system have been in the leading position, and in this context, we must again confirm the following determinants in the layout design beforehand (see also Fig. A.4 in Appendix).

(1) Close tie among three leading attributes, i.e. "*Cell Configuration* (layout and cell components)", "*Machining Objectives*" and "*Machining Pattern*", and if possible, including furthermore "Allowable Cost and Delivery Time".

(2) Although FMC and FMC-integrated system are now dominant to respond to the machining patterns related to the "*One-off Production*", "*A Kind of Production*" and "*Much Variation and Less Volume Production*", in certain cases we must be aware that the cell configuration should be compatible with the "Medium Variation and Medium Volume Production" and "Less Variation and Large Volume Production" (see Fig. 3.1).

(3) Five fundamental functions for cell, and cell components facilitating each function. In short, FMC and FMS consist of machining, transportation, storage, maintenance, and also surveillance and control functions as already, for example, shown in Fig. 2.5. Of these, the control function is software-oriented, the lower hierarchy within CIM, and can be facilitated by the cell controller. In fact, the hardware aspect of the controller is the transducer for in-process measurement of system operating conditions, whereas at burning issue in software aspect is to establish the cell model, so that the "*Autonomous Function*" will be in fruition.

(4) "*Division of Work in Machining Function*" in consideration of the corresponding kind in the machine tool, which can determine the cell configuration to large extent. For example, the machining function can be classified into pre-machining, main-machining and post-machining, or rough machining and finish machining, although such a classification has become obsolete according to the advent of the "*Highly Function-integrated Kinds*" like the mill-turn.

(5) Flow pattern of the material within FMC, i.e., "*Inner Material Flow*", and also between FMCs, i.e. "*Outer Material Flow*". More specifically, we must differentiate and concert the inner and outer material flows in

designing the transportation and warehouse functions, especially in the FMC-integrated system. In this context, we must pay special attention to it that the kind and type in the system component are dominant in forming the system configuration extremely including the flow pattern of the materials within the system.

(6) All the flexible machining systems should be, in principle, designed by the modular method, in which either system component or FMC plays the role of the basic module. By employing the modular design, we can provide the flexible machining system with "*Flexibility*", "*Expandability*" and "*Redundancy*". As literally shown, FMC-integrated system is of modular design, in which FMC is the basic module.

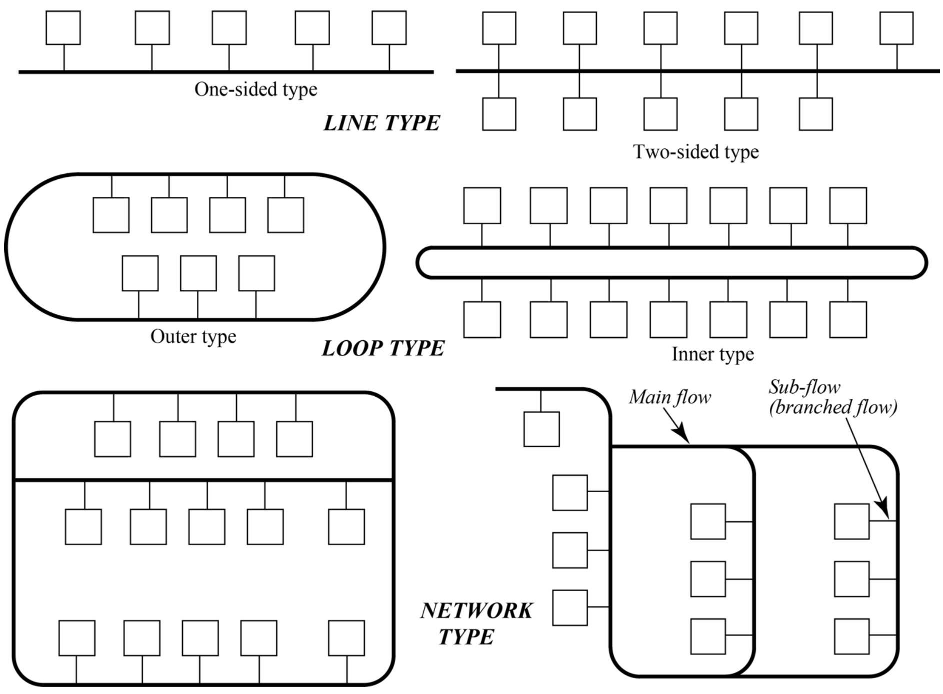


Fig. 3.19 Three representative patterns in material flow

In consideration of the fundamentals in the layout design mentioned above, we will discuss the system component and concerns in detail in the succeeding chapter. In short, a root cause of difficulties lies in to what extent we must standardise the design guide for the system layout, and as reported elsewhere, at least, we must be aware of the material flow pattern, and also of the essential features in the modular design.

Figure 3.19 illustrates three representative patterns and their variants in the material flow. In general, there are no rules regarding which of the three patterns should be employed; however, the line type is often employed by FTL, because the tact time is dominant design factor.

In the design, one of the primary concerns is to guarantee the "*Flexibility in Transportation*", e.g. ease of leap-flog transportation, and such a flexibility can be automatically facilitated when the basic module is FMC, because FMC has its own internal transportation function. Against this context, we must provide the sub-flow (branched flow) line, when the basic module is the machine tool as a whole without buffer like APC (Automatic Pallet Changer) as will be discussed in Section 4.2.

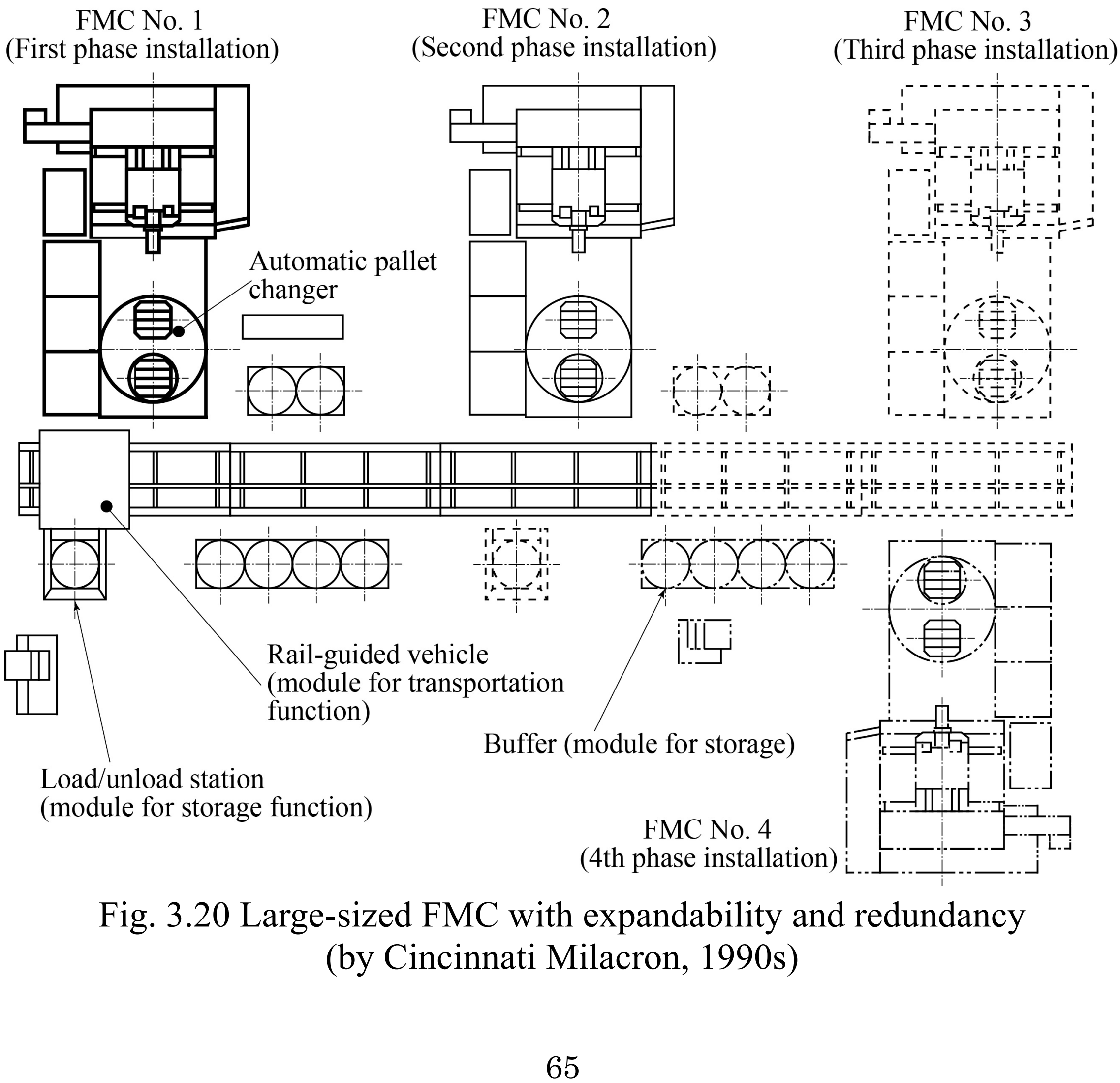


Fig. 3.20 Large-sized FMC with expandability and redundancy
(by Cincinnati Milacron, 1990s)

Figure 3.20 shows a typical example of the modular design in FMS, in which the basic module is FMC, and the core machine in FMC is MC. FMC itself can thus conduct various machining methods to some extent (*Flexibility*). As can be furthermore seen from Fig. 3.20, with the increase of the order placement, we can reinforce the productivity by furthermore installing another FMC (*Expandability*), and after installing two FMCs, we can run the system even when one FMC is down (*Redundancy*).

Obviously, an FMC will enhance its variation in the machining method much more by replacing MC with, for example, the mill-turn than our expectation (Much Flexibility). In addition, we can provide FMC with the redundancy by employing MC of twin-spindle type, which plays a similar role as FMC of twin-core machine type (see Fig. 3.18).

Machine Hardware	Step-by-Step Software Implementation	Software Features
STAGE 1: Stand-alone Machine Single machine, Manual pallet load/unload	Basic Machine Software plus Options	Tool monitor (life, uses, load) Tool life (scaling, life test) Auto datum (auto power down) Spindle probe (broken tool detect) Adaptive control Progarm leap Extensive library routines High speed tapping Feed/speed override inhibit Unmanned operation Continuous sequence monitor
STAGE 2: Multi-pallet system Up to 4 machines Up to 15 pallets per machine	+ Multi-pallet Software + Control Upgrade	Machine controlled transport Pallet order queuing 2 programs per pallet 1st Op/2nd Op machining Dedicated load/unload point Pallet offsets per pallet Pallets grouped to machine Unmanned operation
STAGE 3: Independent Car Control Up to 15 devices (Machines or load/unload stations) Up to 63 pallets serving all devices Dedicated load/unload stations	Communication Software and Hardware + ICC Software and Hardware ICC: Independent Car Control	Keyboard and screen Pool of static pallets Queue of load/unload pallets Queue of machine pallets Pallets not zoned to machines Editing of allowed machines Editing of allowed laod/unload Unmanned operation Workplan of one machine operation Pallet offsets per pallet Program per pallet
STAGE 4: Scheduling and Transport Executor Up to 15 machines including non-machining stations Up to 63 pallets serving all stations	+ SATE Interfaces + Multi-User; Multi-Tasking, Compouter Running SATE Software SATE: Scheduling & Transport Executor	Host to machine communications link Menu driven Simultaneous multiple orders Monitor of machine tooling Multiple parts per fixture DNC Pallet tracking Simulation Tool management Management information Links to CIM environment
STAGE 5: Multi-Cell System Multiple cells integrated Data transferred through cells External facilities shared between cells	+ Multi-Cell Software	Two or more cell hosts Common link to tool setter Common link to MRP II Common link to CAM Possibility of access to any cell

Table 3.5 Software of modular type for cell controller
(by KTM of UK, in 1980s)

Against this context, we must discuss the corresponding modular system in the software. In retrospect, KTM of UK produced and merchandised the software for FMC of modular type in the middle of 1980s, and thus to deepen the further understanding, Table 3.5 reproduces to what extent the modular design was applied. More specifically, the software of modular type is applicable to the cell and its variants ranging from the stand-alone machine, through machine with multiple pallets, to FMCs.

Obviously, with the advance of CIM and information communication network, and also the emergence of cloud computing, at issue is the "*Division of Work*" between the central computer and cell controller. In short, such issues result in (1) the re-consideration of the software of modular type and also (2) the further investigation into the necessary and inevitable functionalities of the cell controller in very near future by taking into consideration the segmental knowledge about the cell controller in general (see Figs. 3.12 and 3.13) and those for one-off production" (see Table 3.3).

The essential features of the cell controller are the unmanned administration, diagnosis and reporting, and as widely known, the basic necessity is to grasp correctly the healthy condition of and on-going processes within the cell without the intervention of the worker. Thus, a root cause of difficulties lies in the enhancement of the in-process measurement including the signal transmission and processing.

Figure 3.21 illustrates nearly all physical and chemical properties in the system component and cell, and as can be seen, we must detect a huge number of information regarding (1) shape, size and surface quality of the work being machined, (2) setting accuracies of the work, and also of cutting and grinding tools, (3) wear and breakage condition of the cutting and grinding tools, (4) temperature and vibration in machine-attachment-tool-work system, (5) cutting and grinding forces and (6) healthy condition of cell and its components while machining the work [5].

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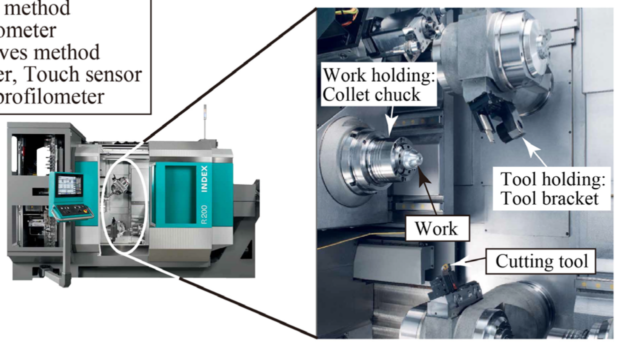
[5] The in-process measurement belongs one of the big professional realms in the production, and thus please refer to some suitable books, when facing something necessary to know it in detail.

Quality of finished parts

Monitoring objectives	*Available sensors*
Accuracies for shape, dimensions and surface quality	Friction roller method Laser interferometer Ultrasonic waves method Air micrometer, Touch sensor Stylus-based profilometer

Preparatory conditions of work and tool

Monitoring objectives	*Available sensors*
Work preparation Work mounting and tool holding conditions and their deformation Dynamic balance, precession and run-out of rotating tool	Positive stopper Air micrometer Strain gauge CCD camera Acceleration pick-up



Cutting and grinding states

Monitoring objectives	*Available sensors*
Cutting & grinding forces Cutting temperature Tool wear and breakage Loading of grinding wheel Swarf pattern	Strain gauge, CCD camera Vibration pick-up, AE sensor, Piezoelectric cell Current transformer of motor Heat flux sensor, Infrared sensor Ultrasonic waves transducer

Healthy condition of machine body

Monitoring objectives	*Available sensors*
Level alignment of foundation, Structural deformation Temperature distribution Noise & vibration Deterioration of cutting fluid	Level, Strain gauge Thermocouple Thermocamera Vibration pick-up Condenser microphone

Fig. 3.21 Various objectives and sensors for in-process measurement while machining (machine photograph: by courtesy of Index)

Return on Investment (Profitability)		
Cost reduction derived from rationalisation effects	Benefit obtainable from increase of sales and production volumes	Cost reduction derived from compatibility with new manufacturing requirements
Flexible automatised processing, for example - Automatised supplies of work, tool, and information - Change of manufacturing objective without any replenishment time - Processing by self-operational control and process surveillance Reduction of work-in-progress and backlog Small expenditure for manufacturing control Automatisation of quality assurance	Shorter delivery time - Quick response to order fluctuation - Quickly launching out new objectives - Quality improvement	

Table 3. 6 Determinants for investment calculation in FMS (by Uhlmann, 2008) [6]

To this end, it is worth suggesting that we must consider the economic

[6] Table 3.6 is reproduced from the handouts publicised on web by Professor Uhlmann of Technische Universität Berlin under the title of Flexible Fertigungssysteme in 2008.

aspects, e.g. installation and renewal costs of FMS, and economic benefits in consideration of system flexibility, in the layout design to a large extent. For example, Uhlmann suggested a qualitative guide for evaluating the economic effects of FMS as shown in Table 3.6. In short, he asserted that the return of investment can be determined by the three leading factors, i.e. (1) cost reduction derived from the rationalisation, (2) benefits obtainable from the increase of sales and production volumes, and (3) cost reduction derived from the compatibility with new manufacturing requirements.

Admitting the importance of the economic evaluation of FMS and concerns, we must recognise the poor activities in the academic research into and engineering development for the evaluation method applicable to practice. In fact, we can find very few achievements in the economic evaluation of the modular design for the machine tool and quantitative evaluation in the system flexibility, which give some clues, but are far from the completion (see Chapter 6). Of note, Kersten et al (2009) proposed an idea for evaluating the economic benefits of the modular design on the strength of "Costs-by-Cause" concept. In fact, they tried to estimate the direct costs for inventory and quality controls, and also indirect costs with special respect to engineering, product variety, delivery time and so on. As can be readily imagined, their proposal is far from completion, but very interesting. Actually, against the common sense that the mill-turn with milling head is superior to other types, Traub asserts the outstanding economisation of a mill-turn without milling head, which is produced on the basis of the platform, and facilitated with the multiple turret heads of the same specifications for the machining space.

Importantly, Ito et al (1985) proposed an idea of the "*Flexibility Evaluation Vector*", which is a space vector and can represent the "System Flexibility" and "Characteristic Feature of System Configuration" by the "Absolute Value (Magnitude of Vector)" and "Directional Cosine", respectively (see Chapter 6 of this volume).

3.5 Future Perspectives for Flexible Machining Systems

In consideration of the present perspective, there is two-pronged way in the developing direction of FMC in very near future, i.e. standardised and special-purpose FMCs. Importantly, the machining function in the standardised FMC should be much more enhanced by the function-integrated kinds than ever before, so that FMC is of compactly cubic for the rationalisation of the cell layout and also for the ease of handling in operation. In due course, the large-sized FMC and FMC-integrated system will accelerate the modular design concept by using such FMCs. In addition, it is worth suggesting that FMC with function-integrated kinds in the machine tool may be suitable for the CPS module in the smart factory, because of its "*One-machine Shop*"-like configuration and functionality, by which we may expect a better connectivity with the information communication network and cloud computing through fog computing, i.e. advanced cell controller.

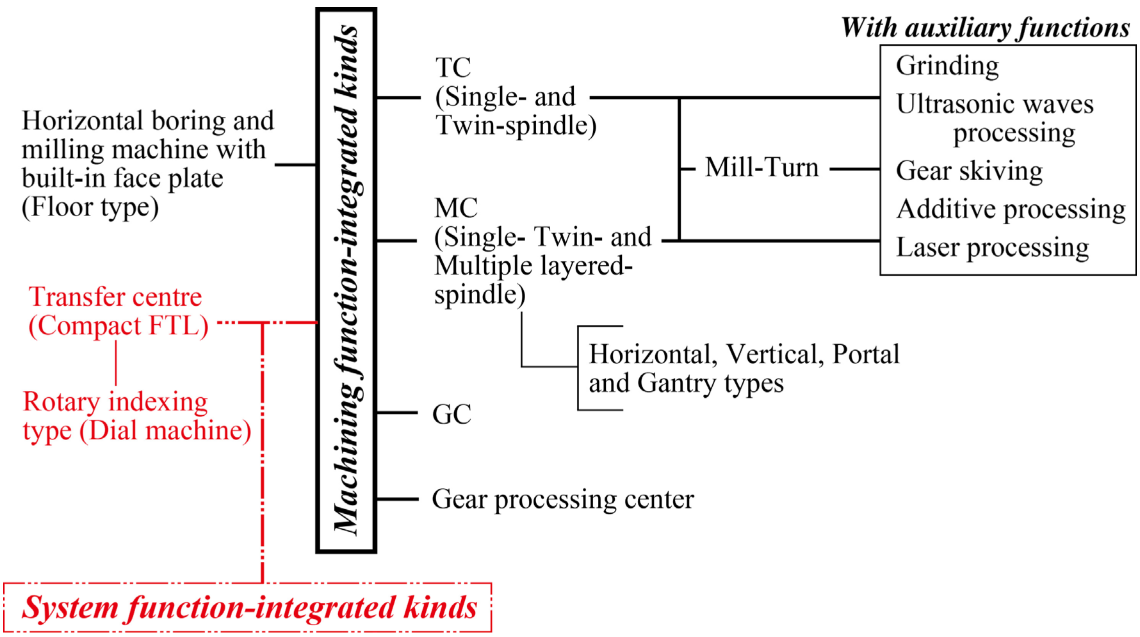


Fig. 3.22 A classification of "Function-integrated Kinds" in 2010s

Figure 3.22 summarises the present perspectives of the "*Function-integrat-*

ed Kinds", which can be classified into two types, i.e. "*Highly Machining Function-integrated*" and "*System Function-integrated*" types. Of these, the former is at facing issue, and in retrospect, TC and MC is the first stage of the integration of the machining function. As widely known, the mill-turn, which is a synergy of TC and MC, has gradually prevailed, and in addition, TC and MC reinforce their machining variation by incorporating the grinding, laser processing, ultrasonic machining, gear

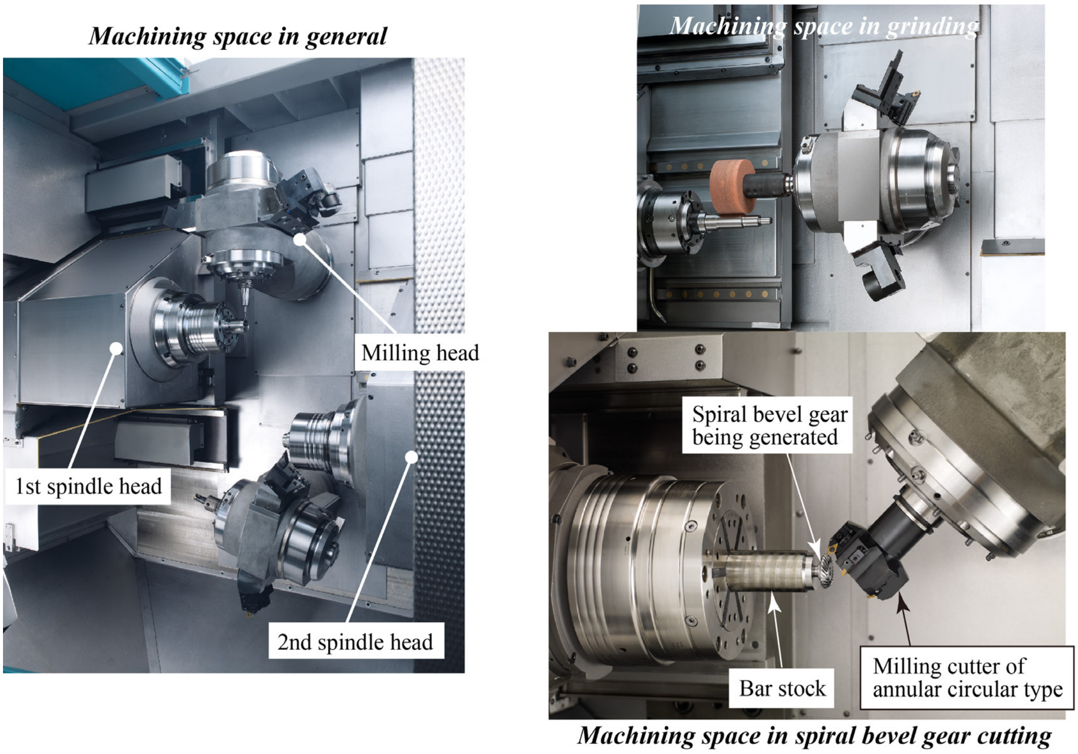


Fig. 3.23 Machining spaces in mill-turn - Directing quickly to "One-machine Shop" (R Series, by courtesy of Index, 2016)

cutting and additive processing, i.e. 3D printing. Fig. 3.23 shows TC of twin-spindle type of Index-brand, which is with grinding and gear cutting functions, resulting in high integration of the machining methods. In this context, we must mind that the horizontal boring and milling machine becomes obsolete, although it has the wider flexibility in machining by nature.

From the viewpoint of the suitability for FMC in very near future, it is recommendable to establish a kind, which is a synergy of the highly machining function-integrated and system function-integrated types. As can be seen from Fig. 3.22, however, the latter is far from completion apart from the "*Transfer Centre*" as will be discussed later.

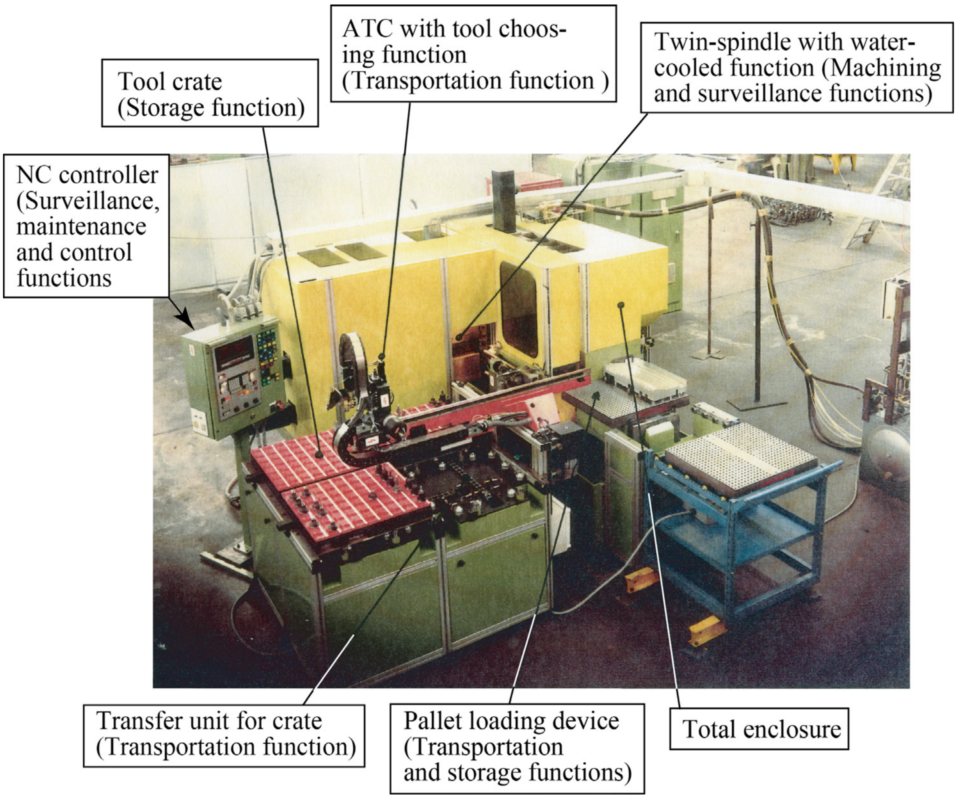


Fig. 3.24 System-function integrated MC of twin-spindle type
(Type AUTOMAX I, by courtesy of MPM Co.)

Of course, we tried to develop such a system function-integrated type as shown in Fig. 3.24, which was produced by MPM (Marwin Precision Machine) and installed within the Preston Factory of British Aerospace. As can be seen, all the five fundamental functions for an FMC are facilitated within a whole machine-like space, although MC is kernel of the machining function, and it is notable that the main spindle has a function of the in-process measurement for the tool damage by integrating the piezo-electric transducer at the spindle nose (Ito, 2008) [7]. It is however regrettable that such a machine was not accepted by the user since then,

[7] Tsugami merchandised the system function–integrated type (Type MA) in 1982.

because it is not so economised. Instead of the system function-integrated type, TC of twin-spindle type is prevailing, because it can carry out the hand-off work.

Now let us discuss the present perspectives of the "*Transfer Centre*" in consideration of its origin in TL as mentioned beforehand. In short, there are the three types depending upon the original types in TL, i.e. those originating from (1) the head changer within TL of line flow, (2) special-purpose machine of wing type and (3) rotary indexing machine (dial machine). In certain cases, these transfer centres maintain their original appearances, and importantly they are applicable to the "*Much Variation and Small Volume Production*" being on progress in the motorcar industry.

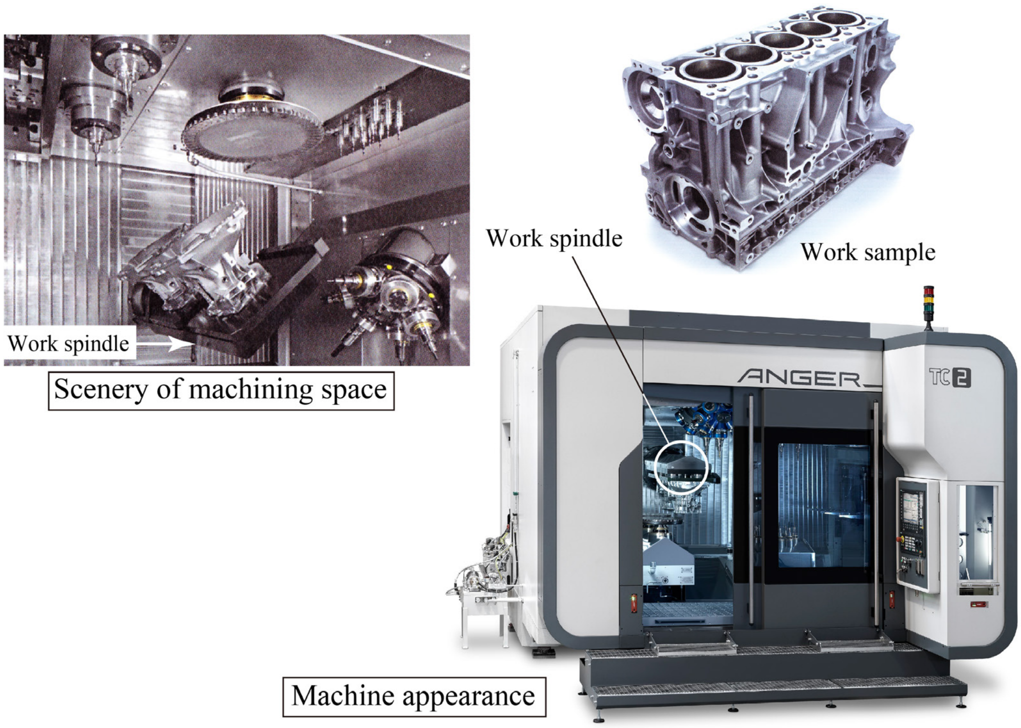


Fig. 3.25 Transfer centre and its machining space
(by courtesy of ANGER)

Figure 3.25 shows the utmost representative transfer centre of ANGER-brand, which can be characterised by its work spindle capable of travelling within the 3-dimensional machining space, and which is of

system function-integrated type with limited integration of the machining function. More specifically, the form-generating movement can be carried out by the combination of the work spindle and a considerable number of the cutting tools with various kinds and types, i.e. those mounted on turret head, tool cassette, single-spindle head and multiple-axis spindle head, which are placed around the work spindle.
It is furthermore worth suggesting that the transfer centre of ANGER-brand has machining capacity equivalent to that carried out by MCs of 2 ~ 5 units. Actually, this transfer centre may replace, for example, FTL shown in Fig. 3.26, which was designed in full consideration of the compatibility with Chinese market.

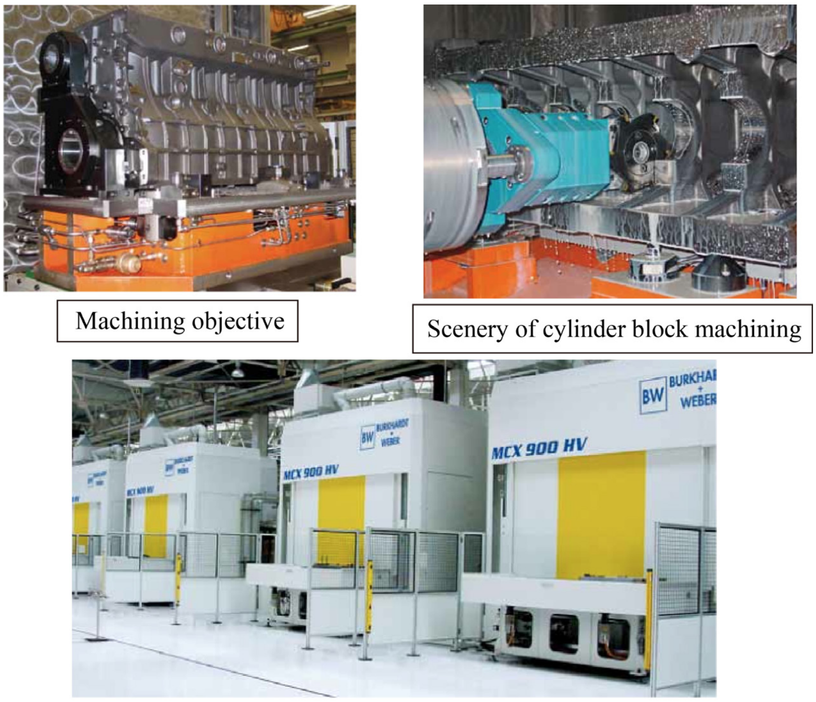


Fig. 3.26 FTL for machining parts of diesel engine
(Burkhardt + Weber, around 2010)

In fact, this FTL consists of (1) 5 units of horizontal MCs of heavy duty type (main spindle speed in maximum: 10,000 rev/min, main motor: 37 kW) and (2) one unit of MC with swivelling head type, and in due course, is capable of machining the cylinder block and cylinder head equivalent to

6,000 units of the diesel engine per year. For the sake of further understanding, the machining scenery of the cylinder block is also shown in Fig. 3.26 (Burkhardt + Weber, 2011).

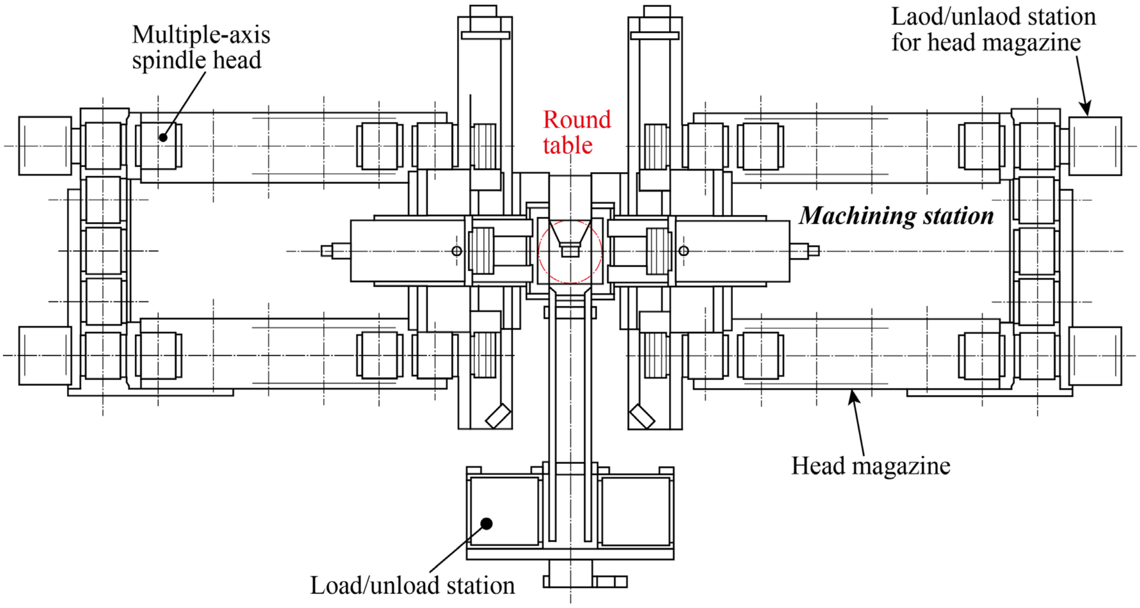
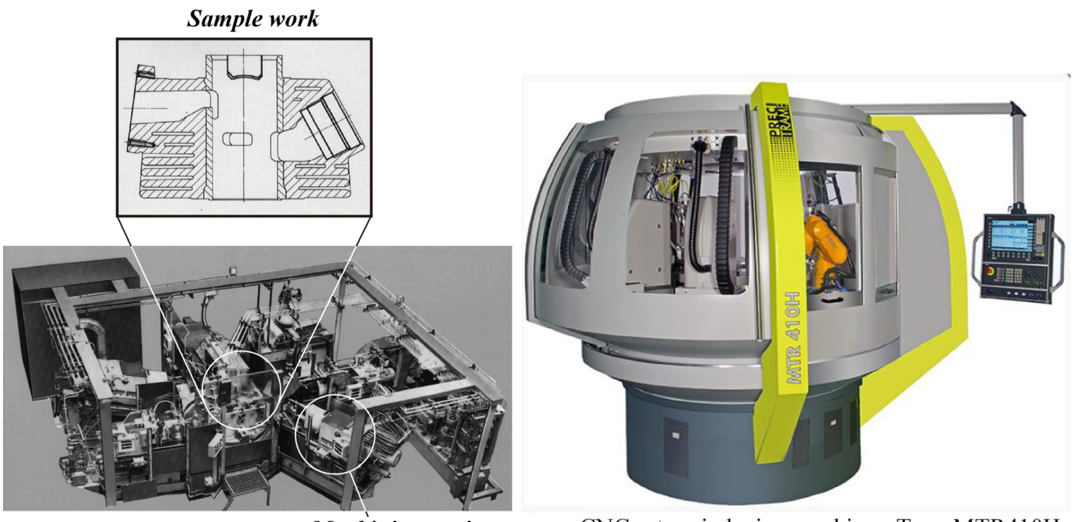


Fig. 3.27 FMC of head changer type for machining differential gear box (by Burkhard + Weber, 1970s)

Although the appearance of the transfer centre of ANGER-brand differs from the head changer, we may assert that this transfer centre is originated from the head changer as shown in Fig. 3.27, and also MC of head indexing type (see Chapter 4). Admitting that the work is mounted on the table in stationary condition and the head with cutting tool is transferred in accordance with the machining requirement in the head changer shown in Fig. 3.27, the transfer centre is designed by the similar principle used in the head changer. In contrast, we must be aware that the head changer is not cubic configuration, and applicable only to the less variation and large volume production.

In retrospect, we used to design the cell configuration in flat type as exemplified by the head changer shown in Fig. 3.27; however, to use the factory floor more efficiently than ever before and to reduce the tax for fixed assets, the cubic type becomes very popular now as exemplified by the transfer centre. Of note, in the flat and cubic types, all the system components are allocated on the two-dimensional space and within three-dimensional space, respectively. Obviously, the flat type is obsolete now and the cubic type is very common, although having not been stated in the design guide of FMC.

Figure 3.28 shows the transfer centre of Precitrame Machines-brand (Commercial name: CNC Rotary Transfer Machine) together with the rotary indexing machine in the 1960s. As can be seen, this transfer centre has the very similar appearance in the past, whereas it has modernised the capability of the machining function by the modular unit, e.g. those for milling, turning, drilling, tapping and grinding, and in certain cases, capable of integrating the small-size assembly robot. This transfer centre is thus a synergy of the system function-integrated and processing (machining and assembly) function-integrated types.



Traditional rotary indexing machine - Vogtland-brand, 1995

CNC rotary indexing machine - Type MTR410H, PRECITRAME MACHINE-brand, 2013

Fig. 3.28 Transfer centre based on traditional rotary indexing machine

In addition to these, Fig. 3.29 shows another special type, which is originated from the rotary indexing TL of wing type, and the system function-integrated type with limited integration of the machining function.

In fact, this transfer centre has been merchandised by Icon (Commercial name: Multiple-station MC, Type Icon 6-250), and more specifically, appears to be compactly integrated MCs of 4 units. In addition, each MC plays the role of each machining station, where simultaneous five-face processing is capable. In addition it is very interesting that the machining station is quick-changeable modular design and expandable up to eight 3-axis controlled machining units (Swiss Quality Production, 2011).

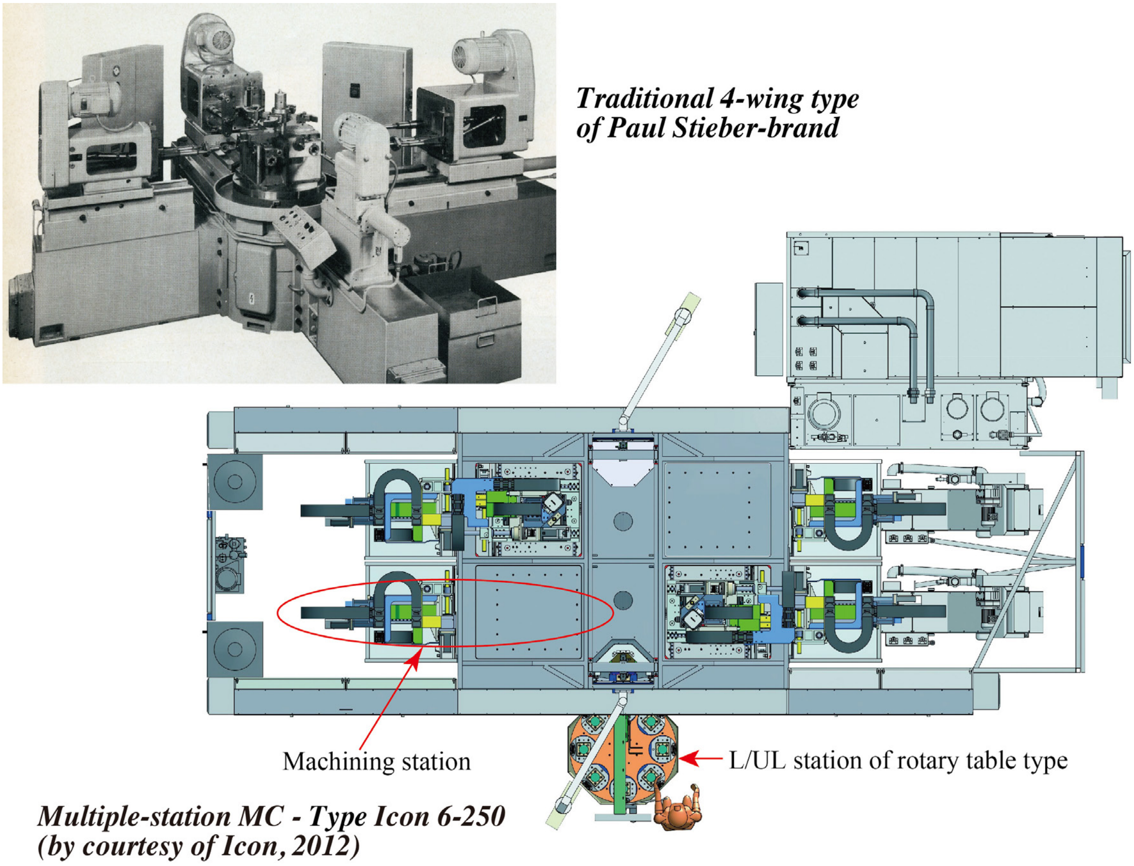


Fig. 3.29 Transfer centre based on traditional TL of wing type

To this end, Fig. 3.30 reproduces a valuable forerunning trial for the transfer centre of Tönshoff-brand, which is a variant of TL of rotary indexing type called "*Trunnion Type*". As can be seen from Fig. 3.29, it implies that FMC consisting of the trunnion type is one of the forebears of that of Icon-brand. More specifically, this FMC can facilitate two- or three-direction machining by indexing the drum at every 4, 5 or 6 stations, and is capable of multiple-point cutting, multiple-axis machining, threading, grooving, facing, milling and so on.

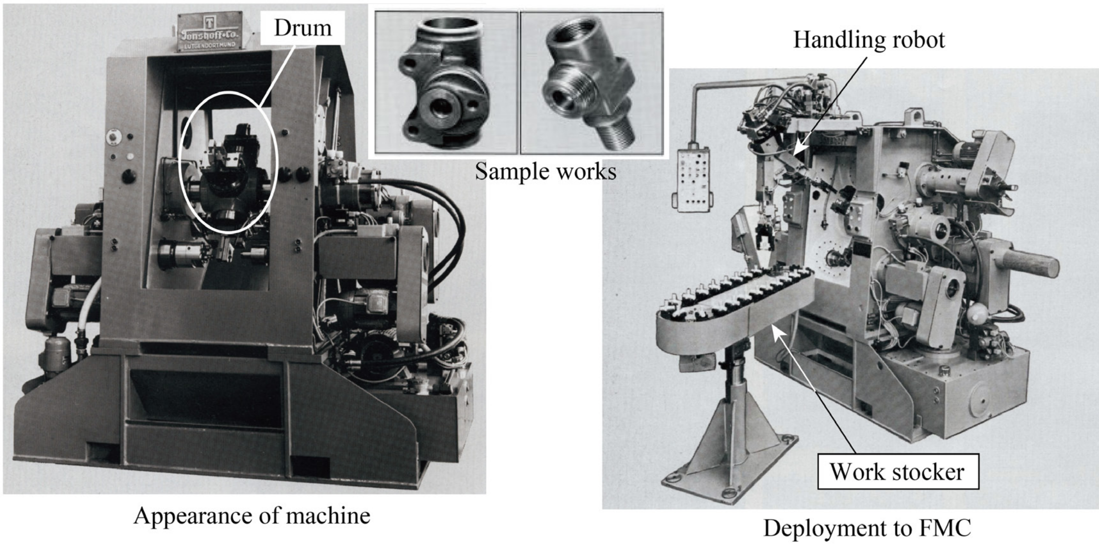


Fig. 3.30 FMC based on “Trunnion Type” of Tönshoff-brand
- A variant in TL of rotary indexing type, 1984

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Chapter 4 System and Cell Components for Flexible Machining

Abstract In the system design, there are two ways, i.e. top-down and bottom-up methods. In general, we used to design the system by the bottom-up method, in which we can purchase widely the system components necessary from the market through the supply chain, and we are capable of integrating them into a system or cell in accordance with the design specifications. In the very rare case, we design the system in a top-down manner, although we need to develop some new system components, if necessary.
Importantly, in both methods, primary concern is the modular design, and thus this chapter describes the system components generally available for flexible machining in consideration of the determinants for the system configuration and layout. In this context, the chapter places the stress on the system components for machining, transportation and storage, and for ease of understanding delineates their classifications in the form of first-hand view, and gives a quick note for each component. In addition, the system component for main machining is explicated in detail considering its present and near future perspective, and it is notable that the chapter clarifies to what extent FMC, FMS and FTL can be characterised by the system component for main machining together with pre- and post-machining.

4.1 System and Cell Components for Machining

In the 1990s and before, the main machining procedure in FMCs and FMSs was facilitated with CNC turning machine, TC, MC and their variants. In contrast, the pre- and post-machining procedures were facilitated with such machines like traditional NC sawing machine and NC milling machine to process the raw material, and also with the special-purpose kinds like the traditional NC fine boring machine and NC grinding machine, respectively. Importantly, FTL has been positioned differently in part from FMC and FMS, and often consist of MC of line type, head changer, special-purpose NC unit and so on.

As reported elsewhere, NC machine tools have launched out to a new horizon with the advent of the mill-turn, which is a synergy of TC and MC, in the 2000 and beyond. Fig. 4.1 shows a classification of machine tools in general around 2010, and we can observe several interesting trends as follows:

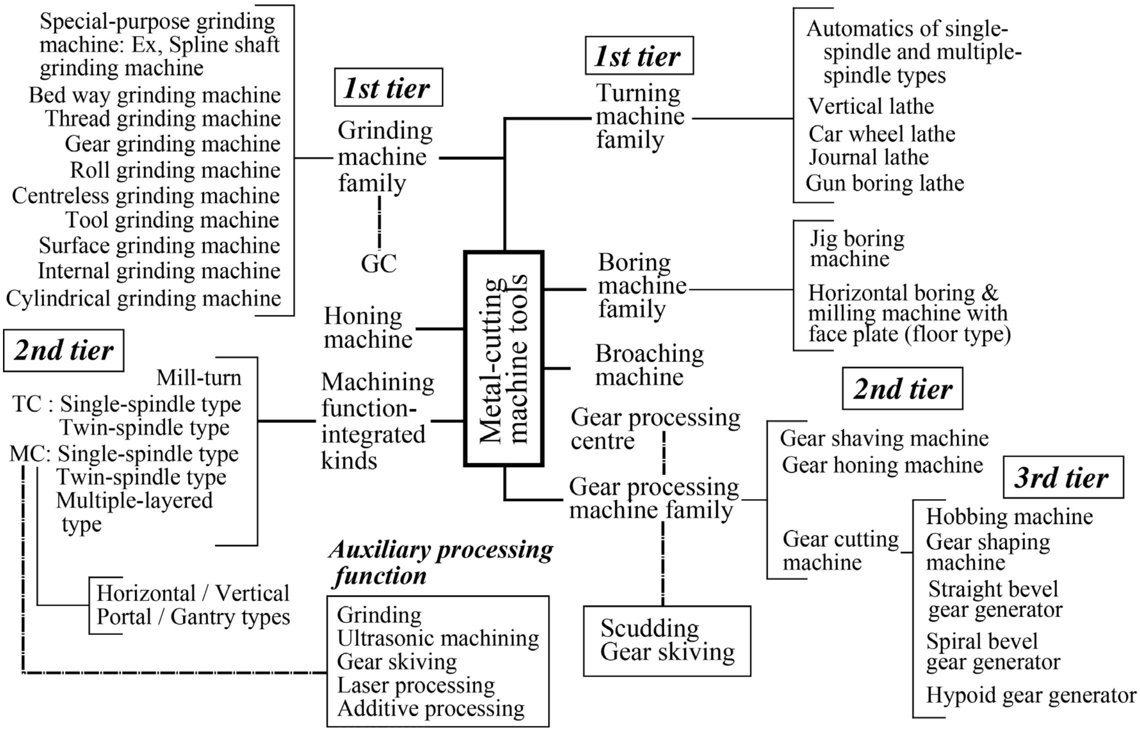


Fig. 4.1 Machine tool classification by structural configuration in 2010s

(1) Following TC and MC, the grinding machine and gear production machine families have directed into the integration to establish GC (Grinding Centre) and the “Gear Production Centre”.

(2) TC and MC have been reinforced their form-generating function by further auxiliary processing functions such as grinding, ultrasonic machining, gear cutting, laser processing and additive processing (see

Fig. 3.22).

(3) As exemplified by the mill-turn of advanced type shown in Fig. 3. 23, we have accelerated the development of the "*Function-integrated Kind*", and raise duly a fruitful result in the transfer centre as already mentioned in Section 3.4.

Importantly, these innovation and contrivance result in the density integration of various machining methods and system functions within a kind as a whole, and render the division of work in machining procedures useless, because a machine may behave like a town factory, i.e. "*One-machine Shop*". In due course, we must expect considerable changes in the system and cell configuration in flexible machining. For example, there are no necessities, at least, to consider the post-machining procedure, because we may expect to incorporate it within the main machining procedure hereafter.

As will be clear from the above, we must be always aware of the present and near future perspectives in the machine tool technology and objective requirements of flexible machining, which are often a trigger to contrive a new kind. In this context, the motorcar and aeroplane industries are the greatest users in the massive consumption and in the demand with the highest machining accuracy, respectively.

It is thus necessary to conduct the predictive research into the future perspective of the needs of the machine tool especially in both the motorcar and the aeroplane industries. Actually, we can have an interesting report of the interview investigation conducted by JMTBA (Japan Machine Tool Builders' Association) in June 2005. The report described the following future perspectives in the motorcar industry, especially placing the main stress on the machine tool and manufacturing system.

(1) A remarkable changing trend is the shortening of the product life, resulting in the reduction of production volume per each car type. For example, the engine manufacturing line capable of machining 20,000 units per year should be changed to that for 5,000 units per year.

(2) It is desirable that the manufacturing line can cope with the "Shorter

Installation Time", "Higher Flexibility", "Maintenance-free" and "Ease of Operation (Higher operability)".
(3) Major requirements for the machine tool are the "Ease of swarf disposal" and "Compact type".
Table 4.1 shows furthermore a report publicised by MANTYS in 2003, where the future perspective in general concern is stated together with clarifying the driving force [1].

Driving force	***Changes in machine tools***
"Near net shape" metal forming Increase of welded structures	Elimination of rough cutting and hole drilling Reduction of routing monobloc components
Increase of plastics and metal matrix materials	Contrivance in tooling requirements
Positive use of "Information Technology"	Increased level of machine tool system, diagnostics and data acquisition Interfacing of machine tool system with CAD/CAM/VR
Shortening of product development time	Demand for multiple-function machine tools
Reduction of in-house machining by introducing "OEMs" and by out-sourcing "Tier 1"	Emphasis on FTL
Lower volume vehicle production	Agile approach to metal cutting Manned lean manufacturing in Eastern Europe

Table 4.1 Prediction for changes in machine tools (by MANTYS, 2003)

In the following, thus, we will discuss the kind of machine tool, which is, in principle, available for the main machining procedure in the standardised FMC, special-purpose FMC and FTL. In this context, we can choose some leading kinds from Fig. 4.1, which are suitable for flexible machining as shown in Fig. 4.2. In due course, an extremely new horizon is to employ

[1] MANTYS is the abbreviation of the Project Name, "Thematic Network on Manufacturing Technologies", which has been supported by the European Commission Growth Programme and launched out at September, 2001.

the "Function-integrated Kinds" such as "Transfer Centre" and mill-turn, which can be regarded as a "*Dexterous Machine*". Paraphrasing, FMC can be gradually facilitated by the function-integrated kinds, resulting in a "*One-machine Shop*" (see Section 3.4) [2].

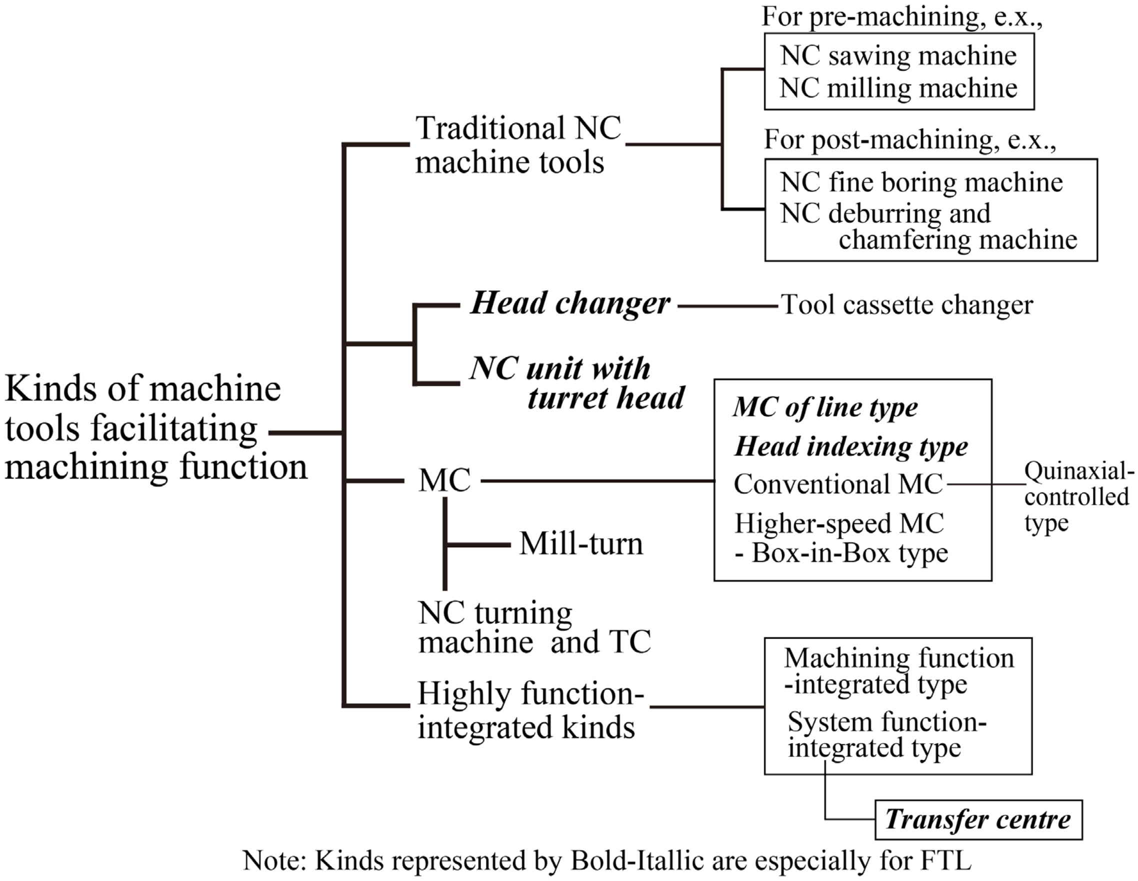


Fig. 4.2 Kinds of machine tools facilitating machining function in FMC and FTL

In addition, it is desirable to extend our discussion to the "*Linkage Diagramme within Machining Space*" as suggested elsewhere, if possible, not remaining within the territories of the core machine and cell configuration. This is because "the more versatile an integration of machining methods, the more difficult is its application". Paraphrasing, with the further advance of the function-integrated kinds, we need to actively apply the grass root-like knowledge about the factory floor, and

[2] Regarding the future perspective, refer to Section 3.4. In this chapter, the fundamental knowledge will be stated in details.

one of the remedies is the linkage diagramme within machining space. Fig. 4.3 reproduces thus an example in the case of drilling (Ito and Matsumura, 2017).

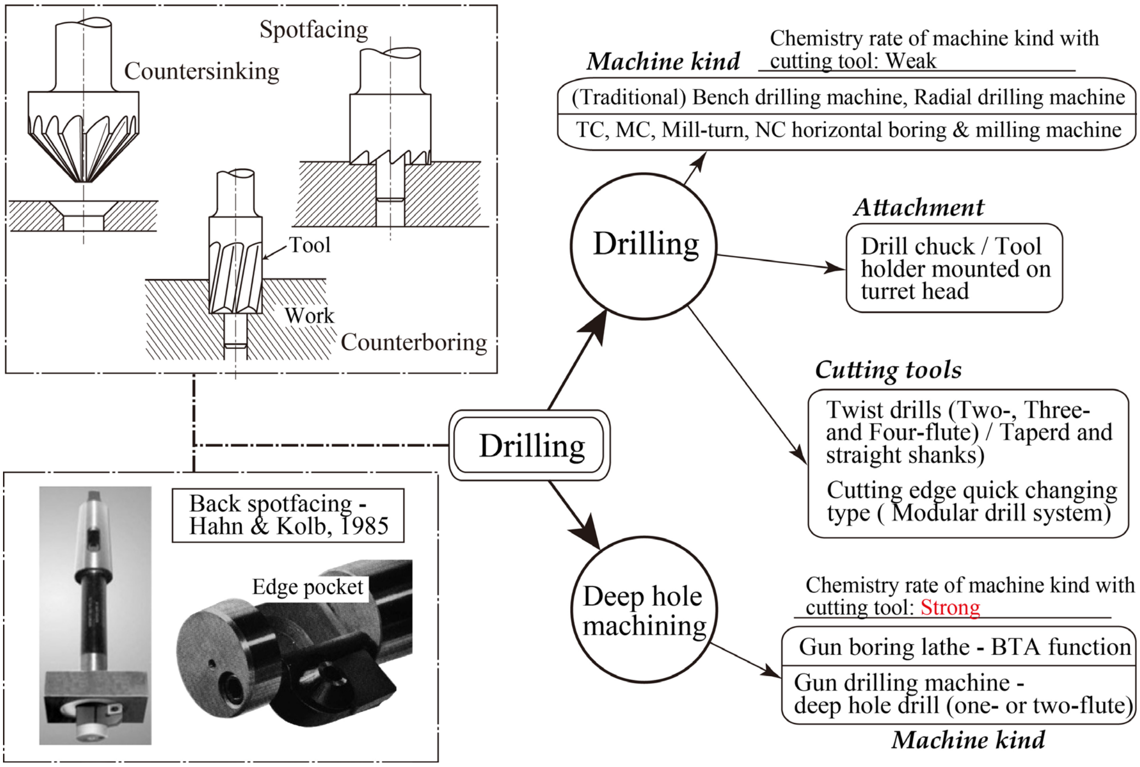


Fig. 4.3 Linkage diagramme ranging from machining method to structural configuration entities - Drilling

4.1.1 Kinds of Machine Tools for Standardised FMC

In general, the machining function in the standardised FMC consists of NC turning machine, TC, or MC as already mentioned in Chapter 3. With increasing much more variety in the machining requirements than ever before, advanced TC and MC, e.g. MCs with auxiliary function as shown at the top-right in Fig. 3.22, become primary concern. In certain case, it is very interesting that the standardised FMC consists of the mill-turn, which is applicable to FMC for "*One-off Production*" as already mentioned in Chapter 3. The mill-turn is a synergy of MC and TC, and thus very convenient for the core machine of FMC, although it is expensive.

Fig. 4.4 Quinaxial-controlled MC with grinding function - Type RXP 500
(by courtesy of Röders, 2013)

Table size: 250 mm (Trunnion type)
Spindle rotational speed (max): 42,000 rev/min
Output of main motor: 14 kW
Linear movement: Linear motor with linear guide
Capability of on-machine measurement by touch probe
With jig-grinding function for mould die of artificial teeth

Table 4.2 Dimensional and performance specifications of MC
(Type RXP 500DS of Röders-brand)

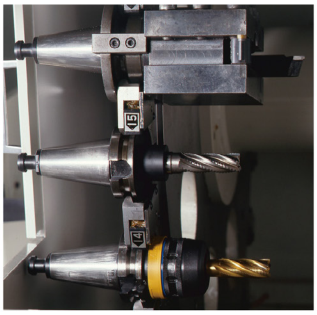
Figure 4.4 is an exemplification of the quinaxial-controlled MC with grinding function, which is of Röders-brand (Type RXP 500) and capable of finishing, for example, the die for the artificial teeth as shown together in Fig. 4.4. Table 4.2 shows its dimensional and performance specifications to deepen the related knowledge.

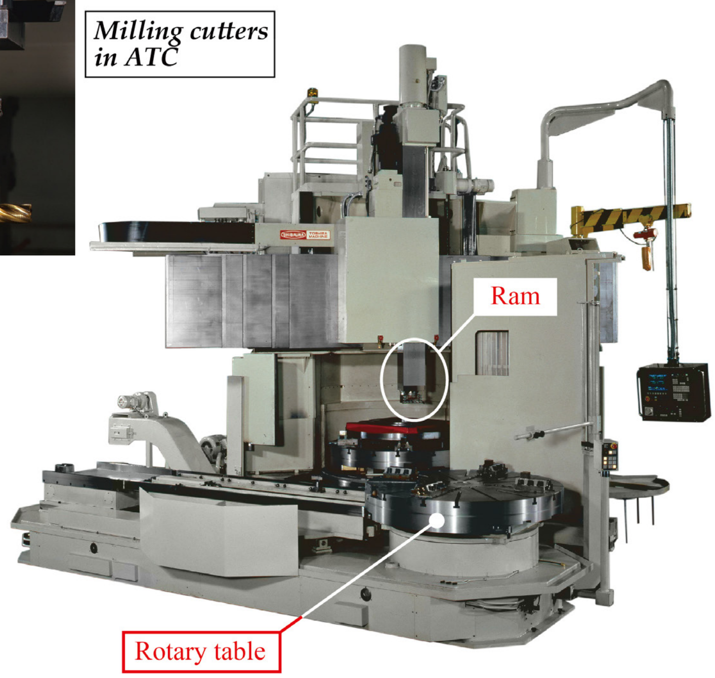
As can be readily seen from Fig. 3.1, the quinaxial-controlled MC is applicable to the core of FMC for the "*A Kind of Production*". In short, FMC with quinaxial-controlled MC is very attractive to the motorcar industry to enhance the market competitiveness of its product, and also to produce the component for the prototype in very near future. Importantly, we have now two-pronged representative quinaxial-controlled MCs. One is of trunnion type, in which the work is mounted on the rotary table supported by the trunnion, and the other is of tilting head type, which can give A- and C-axes movements by the main spindle. As can be easily imagined, either the work or the main spindle can position much more var-

Fig. 4.5 A typical configuration of "Mill-Turn" - Type MULTUS B300 (by courtesy of Okuma, 2004)

ious postures than those in 3-axis controlled MC. We can thus handle the work with much more complex shape such as an aeroplane component as compared with the motorcar component.

Figure 4.5 shows a mill-turn, and as will be clear from Fig. 4.4, this mill-turn can be characterised by the milling head of tilting type, although there are various mill-turns without the milling head, but with a considerable number of the turret heads only.
Conceptually, the quinaxial-controlled MC may be converted into the mill-turn by providing the table with continuous rotating function. For example, MC can machine the work as like as the vertical turning machine when the main spindle is in still stand and the table rotates continuously. Of course, we can produce the mill-turn on the basis of TC without any difficulties. In fact, TC may machine the work by using the milling cutter when the turret contains the driving mechanism of the tool shank.





Type TMC-10B

Table diameter: 1,000 mm
Ram stroke: 630 mm
Allowable maximum cutting force of ram: 3,500 kgf
Allowable maximum torque for milling: 70 kgf-m
Rotational speed range for milling: 20 ~ 1,000 rev/min
Output of motor for milling : 7.5 kW
Allowable maximum mounting weight in case of turning: 7,000 kgf
Allowable maximum torque for table: 1,080 kgf-m
Rotating speed range of table: 4 ~ 315 rev/min
Output of motor for table driving: 30 kW

Fig. 4.6 Integration of milling function to vertical TC
(Type TMC, around 2005, by courtesy of Toshiba Machine Mfg.)

In principle, we can have higher probability to produce the mill-turn on the basis of TC than the quinaxial-controlled MC. A similar integration of the machining method is available for the vertical turning machine as shown in Fig. 4.6, which is capable of milling by the driving mechanism integrated

within the ram. Of note, the vertical turning machine plays a core role in FMC for machining the engine component of the aeroplane.
In very near future, we can expect the enhancement of FMC by employing the highly function-integrated kinds, which are being in trial or in partly practice as already shown in Fig. 3.22. In fact, we have now two kinds: one aims at the integration of various machining methods within a machine tool as a whole, and the other tries such an integration for the system functions. The former and the latter can be called "*Machining Function-integrated Kind*" and "*System Function-integrated Kind*", respectively, and as exemplified by the transfer centre, the latter becomes practical use in part in the motorcar industry.

4.1.2 Kinds of Machine Tools for FTL

As already shown in Figs. 2.11 and 2.12, the motorcar industry has employed in part NC TL even in 2010 and beyond, and thus we must consider the kinds of the machine tool ranging from NC special-purpose machine tool, through MC of line type and standardised MC, to head changer and transfer centre, when designing FTL.
Within FTL context, MC of line type has been and is the core of machining as shown in Figs. 3. 14, 3.15 and 3.26, because of its less width along the transfer line, resulting in the reduction of tact time. Obviously, we need to install a few machining units or cells to conduct finish machining, i.e. post-machining, like the fine boring machine as exemplified those of Mitsubishi Heavy Industries-brand (see Chapter 3). To deepen the understanding, Fig.3.16 showed already the time series-like changes of MC of line type together with the dimensional and performance specifications at present.
Supposedly, FTL of line type has a shortage in the flexibility for transportation when connecting MC of line type by using the conveyor, because such a device cannot do leap-flog-like transportation. In the current FTL, thus, we employ often the shuttle car, travelling robot and gantry crane of overhead type to enhance the flexibility for transportation to some

extent.

Of special notes, FTL is the utmost leading manufacturing facility for the motorcar industry at present, and thus we can estimate the production capability of the enterprise when we will be able to obtain the details of FTL. Obviously, the dimensional and performance specifications of FTL are, in general, company's confidentiality. For example, we cannot obtain the details of those shown in Figs. 3.15 and 3.26; however, it appears that the head changer and MC of head indexing type render useless with the advance of the MC of line type especially in the tool layout and tools available. Could be, MC of line type is being provided with the tool cassette, which plays similar role as a head changer.

Within this context, we may expect a new horizon in FMC-integrated FTL by replacing FMC with the transfer centre. Concretely saying, an innovative FTL is to be in reality by connecting a group of the transfer centres with the outer transportation line together with reinforcing the flexibility for machining.

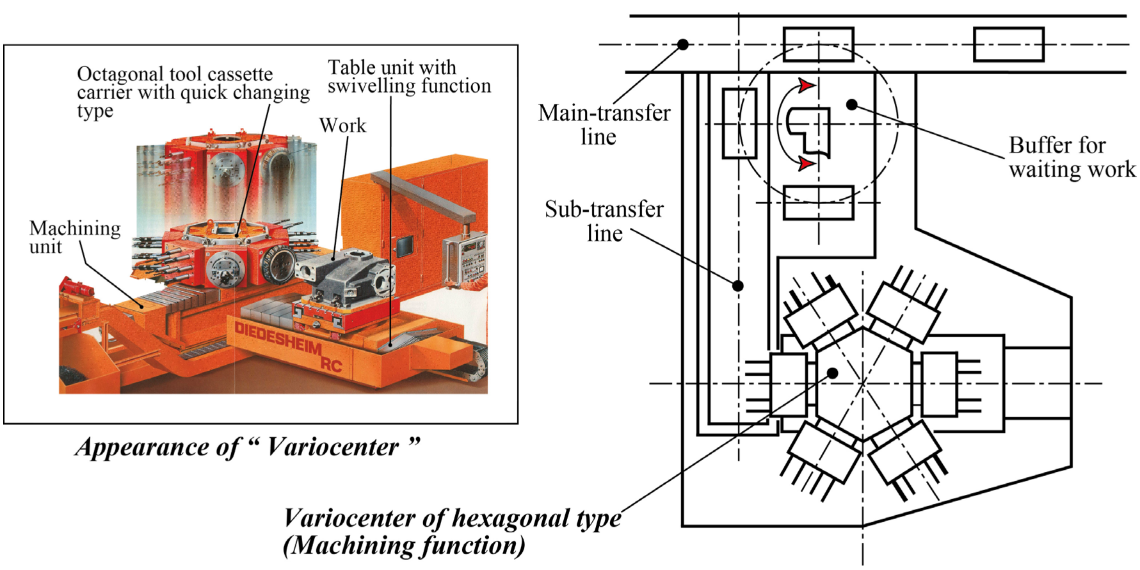


Fig. 4.7 Basic module for FMC-integrated FTL (Diedesheim-brand, 1980s)

In retrospect, Opel once employed the FMC-integrated FTL of Diedesheim-brand, which was with the branched transportation line, and in which FMC consisted of a variant of head changer and work stocker. As a result, this FTL guarantees great flexibilities in machining, transportation and storage, and thus is highly esteemed, whereas it needs wider installation space and is very costly. Fig. 4.7 reproduces the structural configuration of FMC, i.e. basic module, and as can be seen, the core of FMC is a synergy of head changer and head indexing unit, which is called “Variocenter” and can be characterised as follows.

(1) The turret head, i.e. tool cassette carrier, is of either hexagon or octagon, of quick changing type and should be mounted all the tools, which can, in principle, facilitate all the machining requirements for an objective work.

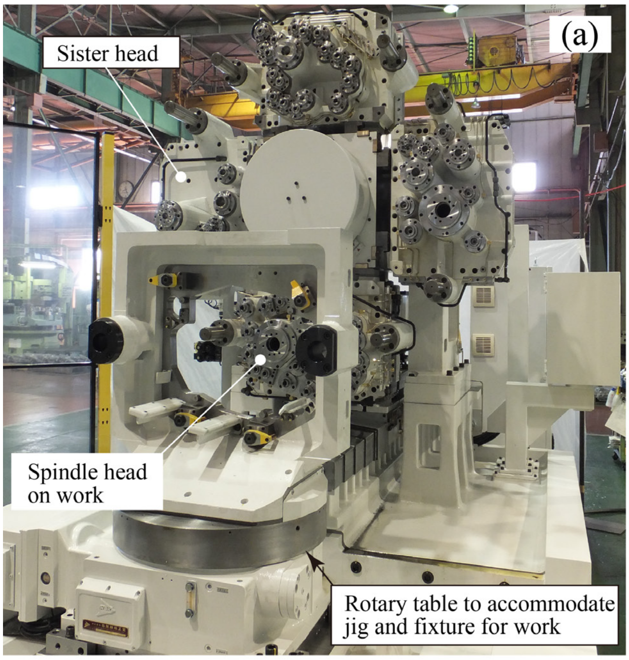
(2) The tool cassette carrier and work are transported by the overhead travelling crane and AGV travelling on the floor, respectively.

In short, “Variocenter” is of compact sub-module with versatile machining functions and capabilities, and flexible accessibility to the outer transportation system, resulting in high compatibility with FMC-integrated FMS.

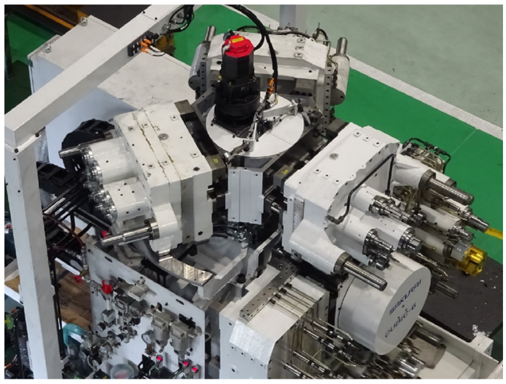
Although reducing the necessity of the head changer and MC of head indexing type, in certain cases we need the head changer of advanced type like the transfer centre. Fig. 4.8 (a) shows such an advanced head changer, which is, in principle, of 4 indexing-turret head type, and also compactly cubic type. As can be seen from Fig. 4.8 (a), this head changer can be characterised by the following.

(1) The machining capacity is equal to that carried out by 3 ~ 4 units of conventional MC, and can be reinforced by installing furthermore the head magazine at the column top. In contrast, the versatility for the machining objective is limited within the narrower scope like the family of transmission.

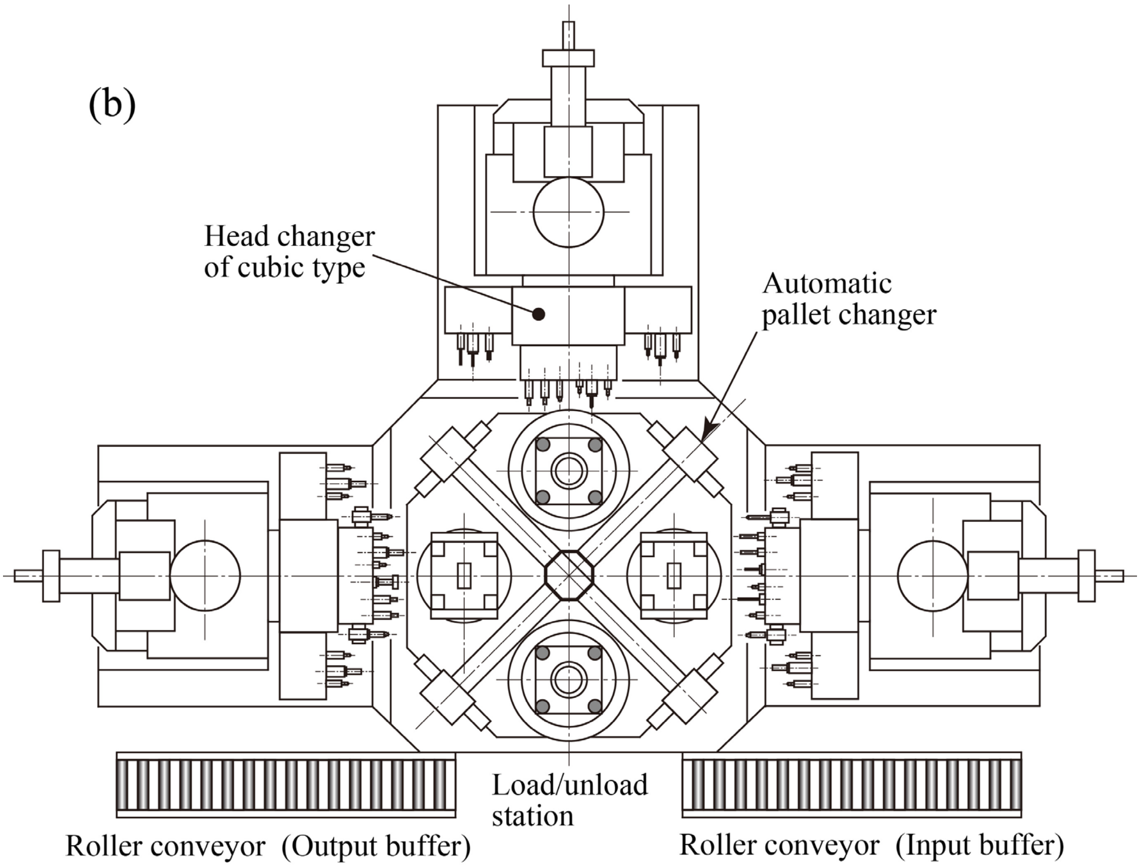
(2) The “Swarf-to-Swarf” time is 4.5 sec., even though the spindle head is made of Al alloy and 300 kg in maximum weight together with tooling.



Spindle head travelling type by feed unit: Type Cubic 4


A variant with head magazine

Travelling range of spindle head: 550 mm in max.
Guideway width of spindle head: 450 mm
Output and rotational speed of main motor:
7.5 kW and 2,000 rev/min in max.
Size of spindle head: 400 × 500 mm



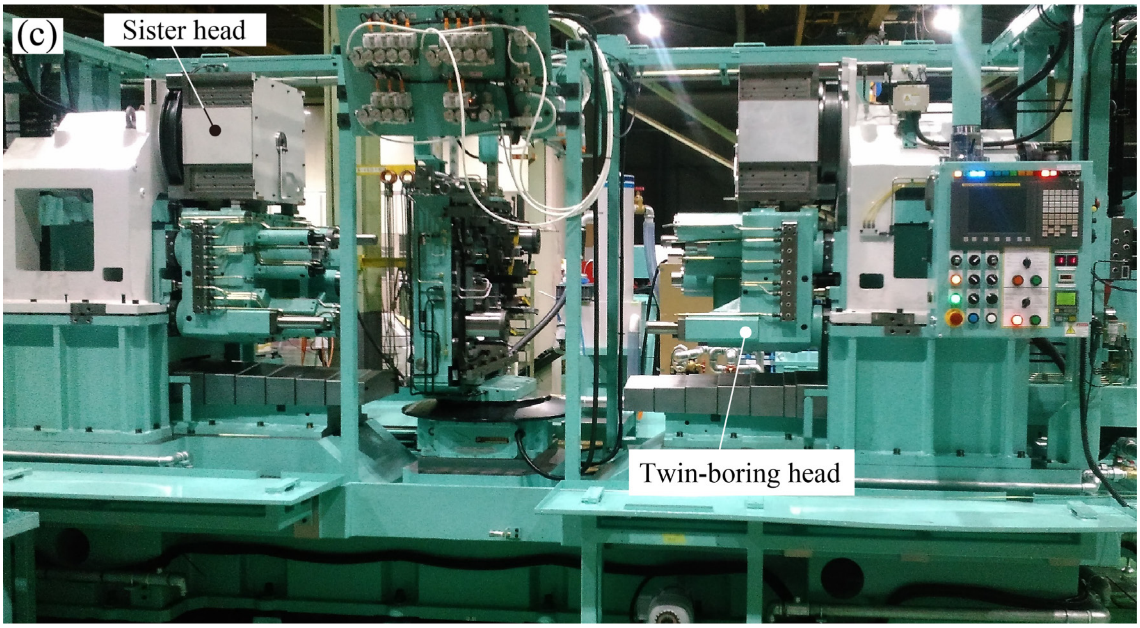


Fig. 4.8 An advanced head changer and its variants: **a** Basic configuration of compactly cubic type. **b** FMC of T type-like machine allocation. **c** Deployment to fine boring machine (by courtesy of Sakurai, 2017)

(3) At the machining space, the spindle head can be connected to the power unit with the simple rotational indexing and travelling movements.

(4) Wide expandability to variants ranging from FMC to the fine boring machine for post-machining.

For example, Fig. 4.8 (b) shows an FMC, in which three head changers are of T-like allocation around APC (Automatic Pallet Changer), and which has the machining capacity equivalent to that carried out by 10 units of the conventional MC. Obviously, we can produce a compact FTL, where this FMC is of basic module. In addition, Fig. 4.8 (c) shows a fine boring machine for post-machining, and as will be clear, the machine can be characterised by facilitating the sister head together with maintaining the higher machining accuracy.

Importantly, Fig. 4.9 shows furthermore MC of gantry type, which is of Nicolás Correa-brand (Type FOX), and which is with head changing mechanism and temperature control function. The head changer is very similar to that employed in the planomiller in the past. Although being not so popular, we need FMC cored by MC of gantry type for the large-sized, heavy and unwieldy work to some extent.

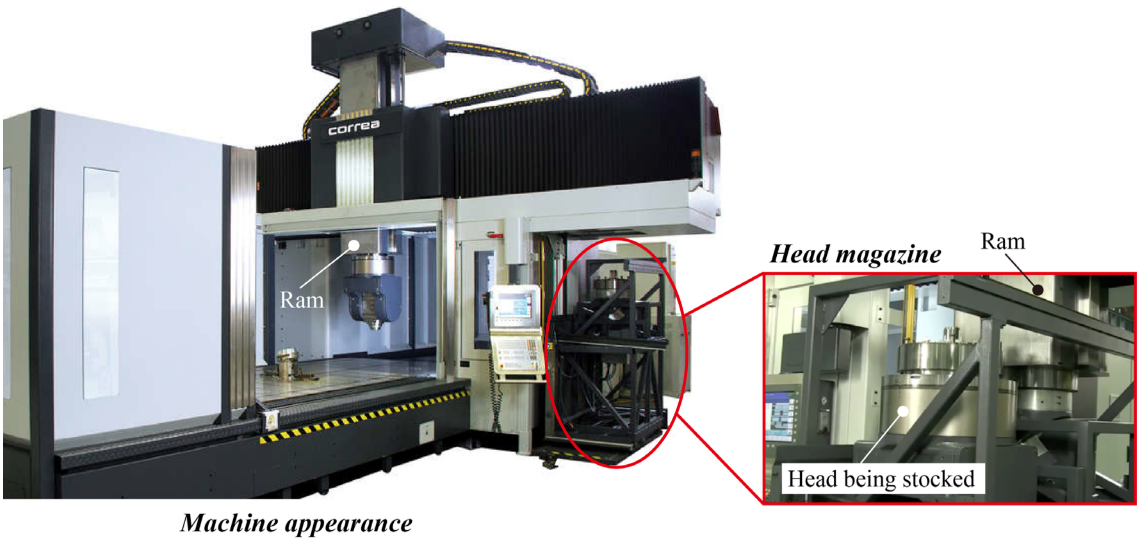


Fig. 4.9 MC of gantry type with head changer (by Nicolás Correa, 2017)

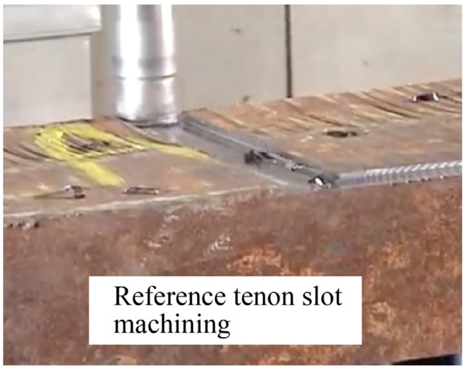
4.1.3 Kinds of Machine Tools for Pre-machining and Special-purpose Machining

Admitting that TC and MC may cover, in nearly all the cases, the necessary post-machining procedure, we need still some kinds for pre-machining. This is because the work should be pre-machined the reference and location faces and concerns in order to its secure-handed fixing with allowable locating accuracy. In addition, we must cut the raw material in consideration of the material efficiency. In this context, we may use two remedies: one is to convert second-handed MC into such machining, and the other is to employ, for example, the utmost advanced milling machine and sawing machine.

Importantly, it is desirable to employ the utmost advanced kind even in pre-machining with the increasing importance of flexible machining with the higher accuracy and heavy-duty cutting. Obviously, such a performance of flexible machining depends extremely upon the finishing quality of the reference and locating faces, which results in the higher positioning accuracy and sure-handed clamping rigidity of the work. Of special note, we must furthermore be aware of what is pre-processing for the raw material of the work as well as pre-machining of the work.

In pre-machining, it is, more or less, preferable to carry out the heavy-duty cutting in the cases of cast and forged raw materials, and in general, we employ the milling machine of bed type such as shown in Fig. 4.10, which is of Jiuh-Yeh Precision Machinery-brand, and can be characterised as follows.

Type VH 650B
(by Jiuh-Yeh Precision Machinery-brand, 2017)



Machining sceneries
by East Coast Magnets in India

Fig. 4.10 Milling machine of bed type available for pre-machining to produce references for work positioning and clamping

(1) Main spindle of plural type, i.e. combination of vertical and horizontal spindles.
(2) Main body structure and main spindle are made of Meehanite cast iron and Cr-Mo steel, respectively.
(3) Slideways are Turcite-coated.
(4) Ease of conversion from manual into CNC operation.

Fig. 4.11 Typical sawing machines (by courtesy of Amada Holdings, 2017)

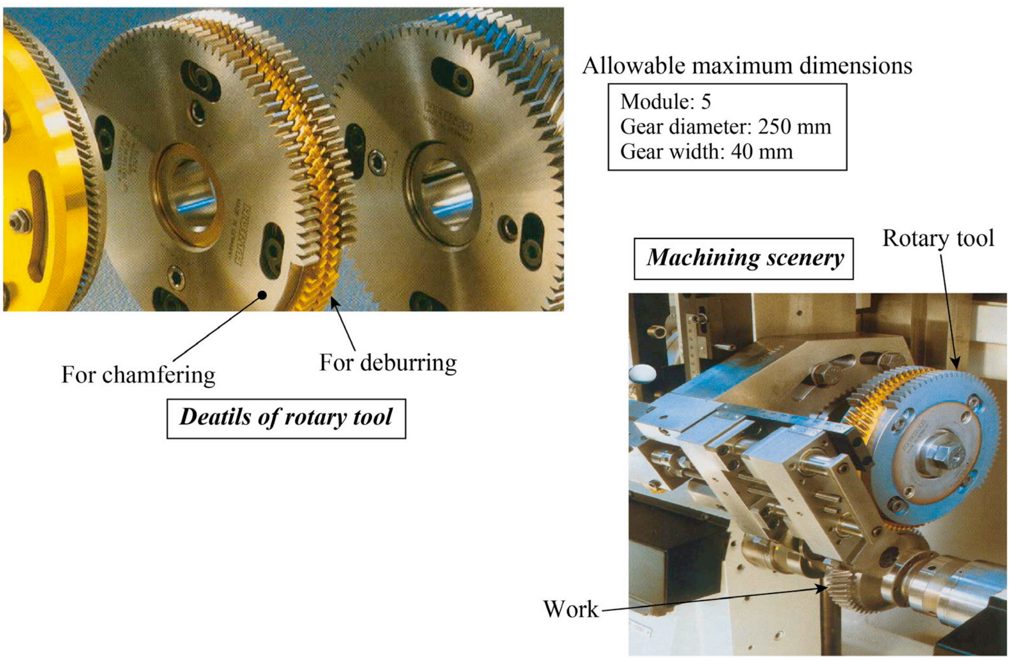


Fig. 4.12 Rotary chamfering and deburring - Type ZEA, Hurth-brand, 1999

As can be seen from the above, the milling machine shown in Fig. 4.10

appears as to be over-performance from the traditional viewpoint for pre-machining in FMS and concerns; however, it is nowadays mandatory to employ such a machine.
In accordance with the same idea mentioned above, Fig. 4.11 shows the advanced sawing machine, which can be classified into two types depending upon the saw configuration, i.e. either circular saw or band saw. Of course, we can benefit considerably by facilitating CNC resulting in the considerable improvement of the material efficiency.
To this end, Fig. 4.12 shows the gear chamfering and deburring machine. In FMC for gear production, such a procedure is not involved in the cell configuration, and regarded, in general, as post-machining as well as gear lapping.

4.2 System and Cell Components for Transportation

Figure 4.13 is a classification of the transportation machines and devices, and these should be divided into those for short-range and long-range transportation (see Figs. 3.5, 3.9, 3.14, 3.18 and 3.30). In this context, we must be aware that the gantry robot (gantry loader) is often used for the long-range transportation, and that AGV (Automated Guided Vehicle) of floor travelling type is non-railed in certain cases.
Obviously, the long-range transportation is at issue in designing FMS and FTL. As mentioned elsewhere, these systems are, in general, of modular configuration by using FMC as a basic module, and thus each FMC should be interconnected with others by using the facility for long-range transportation, for example, the conveyor, gantry loader and AGV.
In this context, it is crucial to decide which facility shall be employed in consideration of the "*Flexibility in Transportation*" without any sub-transfer lines (see Fig. 4.7). Needles to say, the gantry loader is superior to the roller conveyor, although the transportation flexibility in both the facilities is limited, and thus Figs. 4.14 (a) and (b) show these two facilities to ease further understanding.

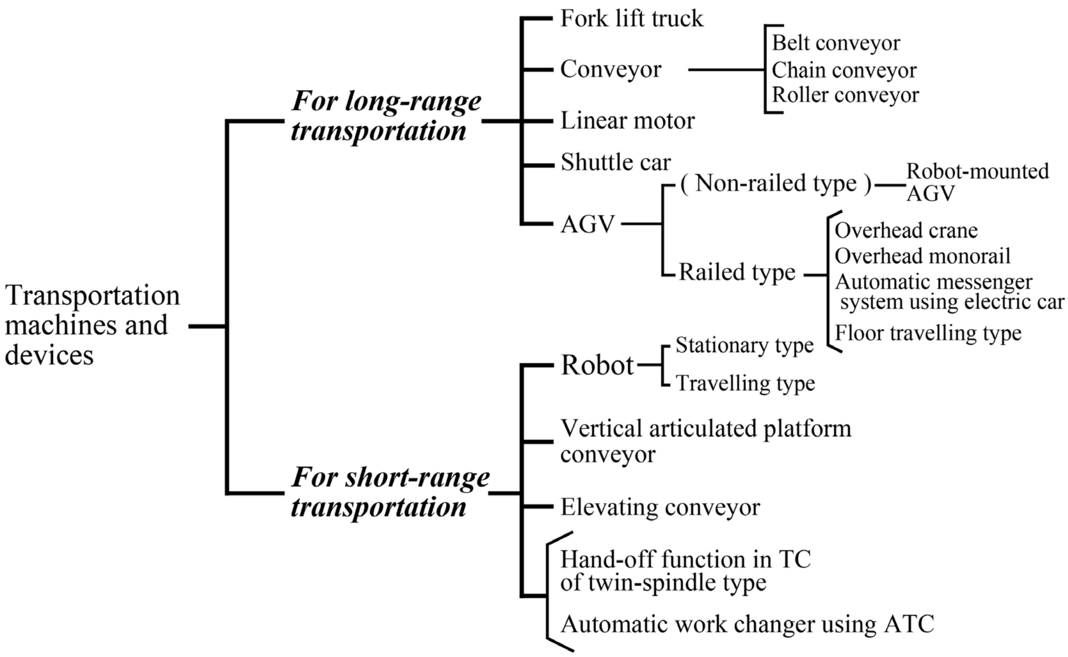


Fig. 4.13 Classification for transportation machines and devices

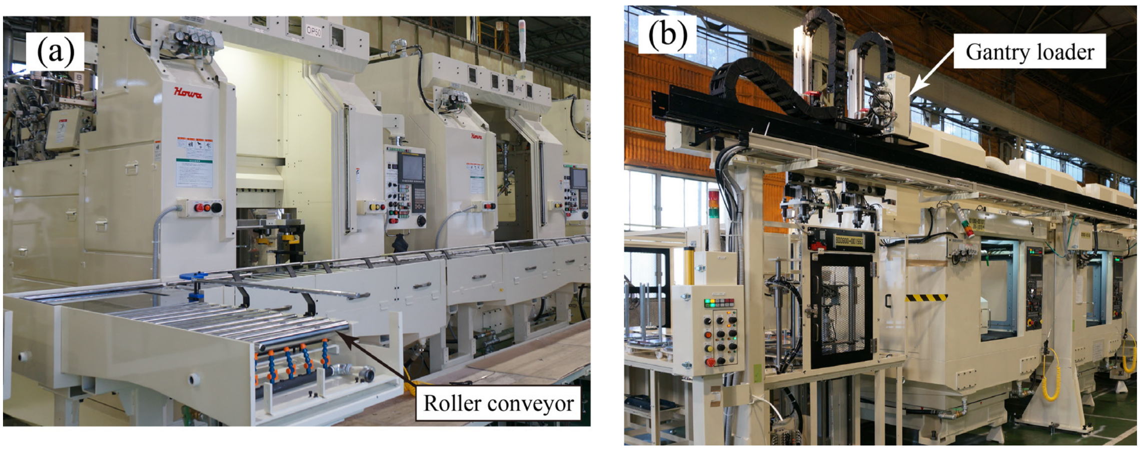


Fig. 4.14 Long-range transportation in FMS: **a** Roller conveyor type. **b** Gantry loader type (by courtesy of Howa Machinery)

In due course, the more growing importance of FMC, the more necessity is to contrive the facility for the short-range transportation, i.e. internal transportation device within cell. As can be readily seen, the robot is a representative for such a transportation machine since the first phase development of flexible manufacturing in the late 1970. After then, the vertical articulated platform conveyor and elevating conveyor have become popular with the growing importance of the compact and cubic-like FMC. It is furthermore very interesting that the twin-spindle, main spindle of travelling type and ATC can facilitate the internal transportation device with the advance of the structural design of the core machine tools especially in the case of TC (see Fig. 3.23). In TC of twin-spindle type, the second main spindle has a function of longitudinal travelling and thus is capable of carrying out the "*Hand-off Operation*". In fact, the work can be first held by the first main spindle, and then grasped by the second main spindle, if necessary, while machining the work.

	Gantry loader	***Industrial robot***
Adavntages	Heavy payload allowable Good connectivity with others Good watching capability while loading, unloading and machining procedures Highest accessibility to machine tools One loader can handle two machine tools, if necessary	Higher flexibility in transportation Availability without any constraints in machine structure Capability of tower-like connection with others
Disadvantages	Larger installation space Higher investment Necessity for automatised opening to access machining space	Needs for own control systems Limitation in work weight Double-gripper is not usual Not accessible while machining Costly safe guard for robot movement space Necessity for automatised opening to access machining space

Table 4.3 Comparison of characteristic features between gantry loader and industrial robot (by Wollnack, 2008)

It is worth suggesting that we must arrange some valuable data to conduct the rational decision in the transportation design. For example, Table 4.3 shows a comparison for characteristic features between the gantry loader and the industrial robot [3].

For the sake of further understanding, the robot and AGV will be quickly noted in the following.

4.2.1 Robots

Figure 4.15 illustrates again a large-sized FMC, which consists of the robot-centred cell, TC with integrated handling robot (see Fig. 2.5), long-range transportation system (roller conveyor and shuttle car) and buffer station. In the robot-centred cell, the robot of polar co-ordinate type is for the internal transportation among the buffer station and two NC turning machines.

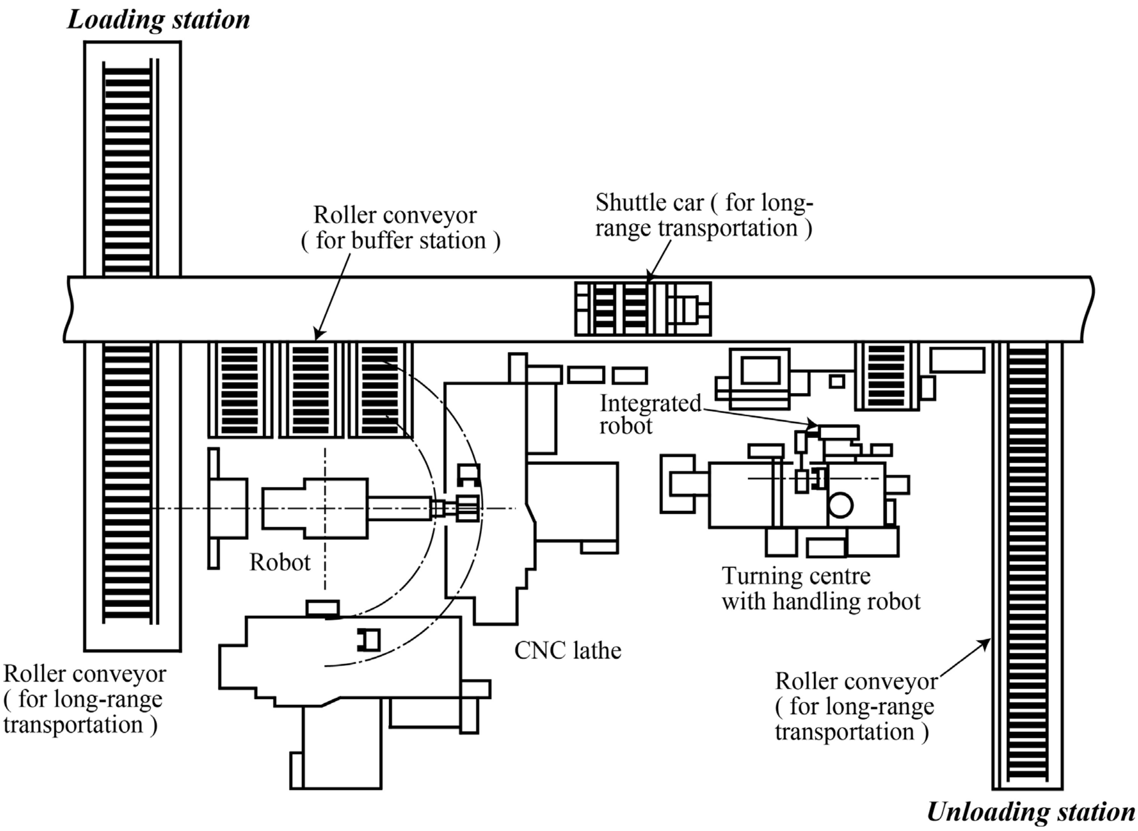


Fig. 4.15 Large-sized FMC and roles of robots

As will be clear from the above, there are various types of robots, e.g.

[3] Table 4.3 is produced from the handouts publicised on web by Dr. Wollnack of Technische Universität Hamburg-Harburg under the title of " Flexible Fertigungssysteme " in 2008.

Cartesian, cylindrical, polar and multiple-articulated types. In addition, these can be classified into the stationary, linear travelling, polar moving and so on. Paraphrasing, the robots of linear travelling, integrated within TC (see Fig. 3.6) and independent allocation types are very popular in FMC. In the travelling type, for example, the robot is allocated on the floor including the gantry type (see Fig. 3.18), and also on the overhead of the machine (see Figs. 2.1, 3.8 and 3.9). In the independent allocation type, the robot is allocated at the centre of the cell, front or rear of the machine (see Figs. 3.5 and 3.6).

Having in mind the versatility for the robot application in FMS and concerns, it is worth suggesting that the travelling robot is, in general, for the short-range transportation. In contrast, Fig. 4.16 shows a travelling robot for relatively long-range transportation, i.e. in fact that for FMS.

Fig. 4.16 Relatively long-range travelling robot for FMS
(by courtesy of Howa Machinery)

4.2.2 AGV

With the narrower scope, AGV (Automated Guided Vehicle) is not of rail-guided type, but of non-railed type in the most cases (see Figs. 3.3 and 3.20), although we need often the guide path in AGV of non-railed type. AGV can be classified on the basis of various attributes such as (1) guiding principle, (2) steering system of wheel, and (3) transfer method of mounted materials. As a result, we have a wide allowance in choosing AGV system depending upon the transportation specifications.

Figure 4.17 shows two classification systems based on the guiding principle and transfer method of mounted materials. In addition, Fig. 4.18 reproduces an AGV in the past together with showing the automatic messenger system with electric car for cutting tool transfer and L/UL (Load/Unload) station as a temporary work stocker. As can be seen, AGV itself has not changed so much as compared with those of today, which will be shown later.

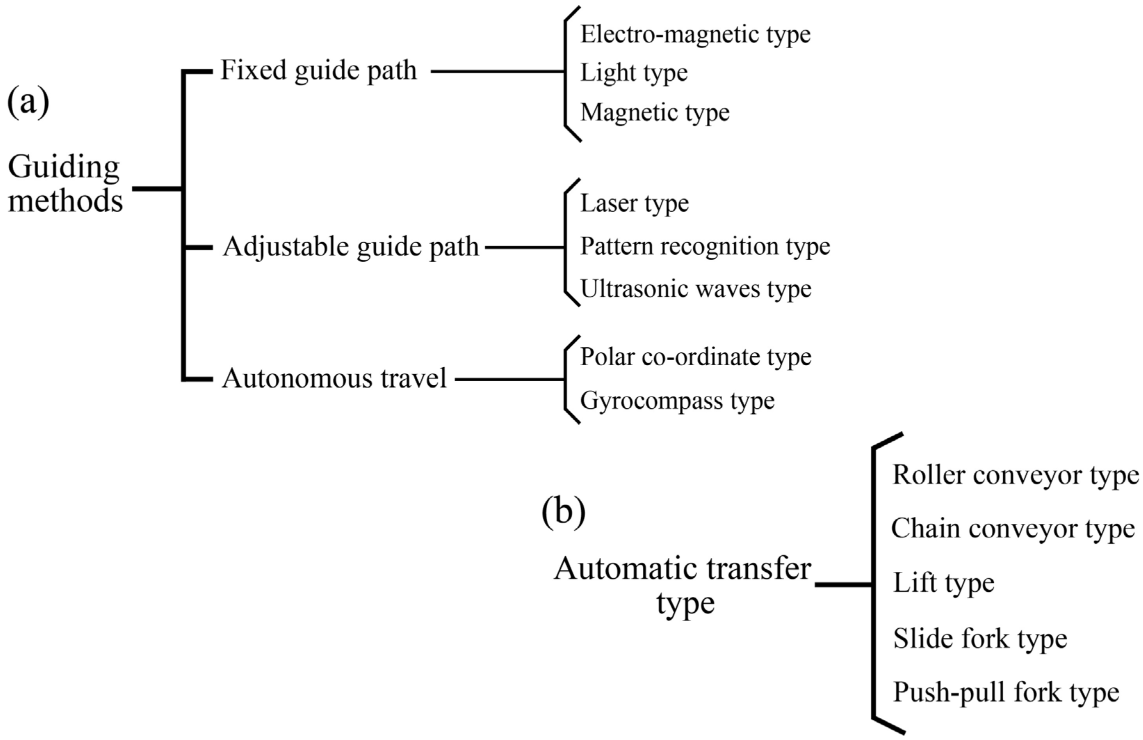


Fig. 4.17 Two examples of classification system for AGV: **a** Guiding methods. **b** Material transfer equipment

In general, AGV consists of (1) travelling system, (2) onboard controller,

(3) battery, (4) safety measures, (5) transfer equipment and (6) fine positioning function. Of these, the safety measures are very important because AGV is used often with the intermediation of the system operator. Within AGV context, at issue is the communication device with the AGV traffic controller, and in general we use the optical, inductive radio and radio type. The information to be communicated are, at least, (1) the requirements for material transportation, (2) blocking control and (3) malfunction states.

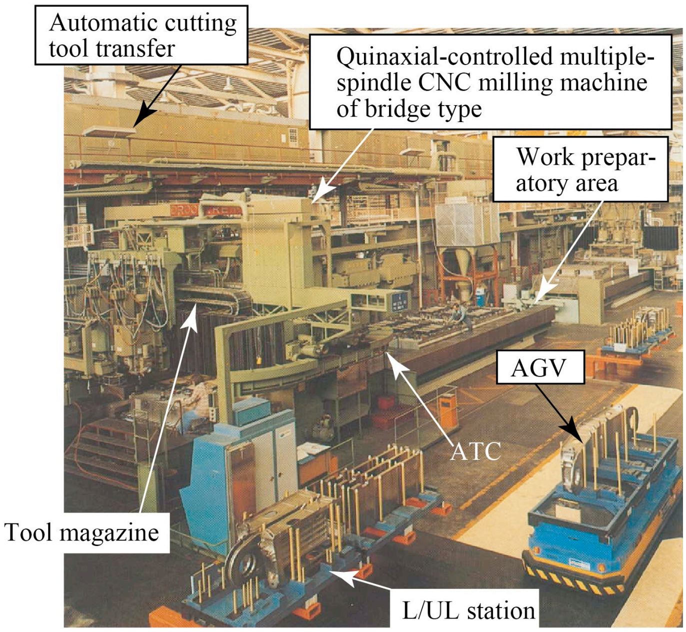
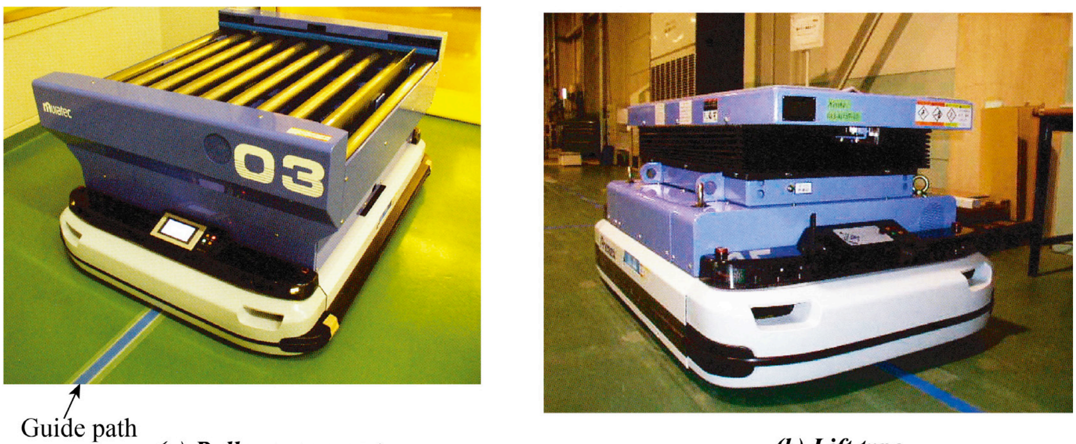


Fig. 4.18 AGV travelling factory floor
(by Messerschmitt-Bölkow-Blohm, 1985)



(a) Roller conveyor type *(b) Lift type*

Fig. 4.19 Two representative AGVs
(by courtesy of Murata Machinery, 2010)

Figure 4.19 shows a basic structural unit of the representative AGV in the 2000s, and this is of magnetic guiding method, with 60 m/min in maximum speed while travelling linear guide path, and can positioned within ±10 mm. In addition, AGV can travel to forward, reverse and lateral directions, and also spin-turn. As can be readily seen, we can produce various AGV by mounting the different material transfer unit, such as robot, lifting and roller conveyor types.

4.3 System and Cell Components for Storage

We can actualise the storage function in FMS and concerns by using various equipment and devices, e.g. station and stand, and also warehouse, and thus the unified classification of such facilities is not easy. Importantly, in the case of the storage facilities, we must consider the system size, e.g. either large-sized FMS or FMC, as similar to those for transportation machine and device.

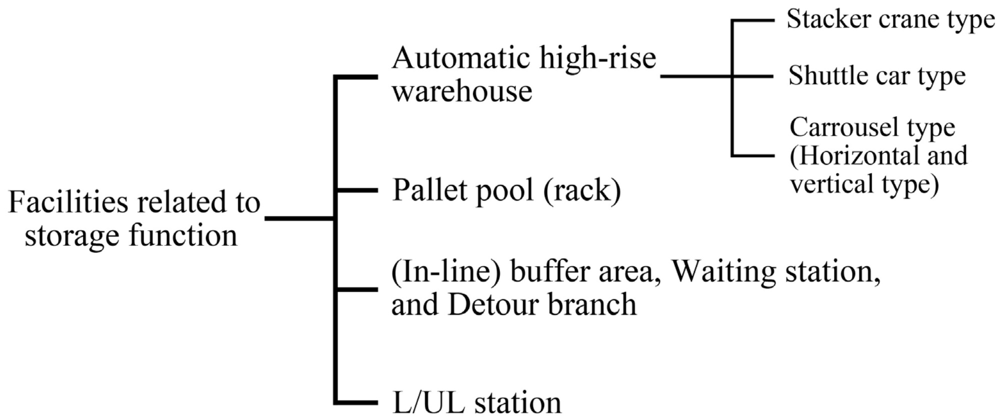


Fig. 4.20 A classification system of storage facilities

Figure 4.20 summarises some representative facilities for the storage. For example, the automatic high-rise warehouse and buffer area are for large-sized FMS and compact FMC, respectively. In fact, the storage function of FMC is, in the most cases, designed by using the buffer area, L/UL station, small-sized pallet pool (pallet stocker) and APCs (Automatic Pallet Changers), and in part the rack of carrousel type.

Figures 4.21 (a), (b) and (c) show various APCs and as will be clear, the pallet pool varies depending upon machining requirements of FMC. Paraphrasing, various APCs are in practical use by combining the basic configurations in the pallet pool and pallet changing mechanism as shown in Table 4.4.

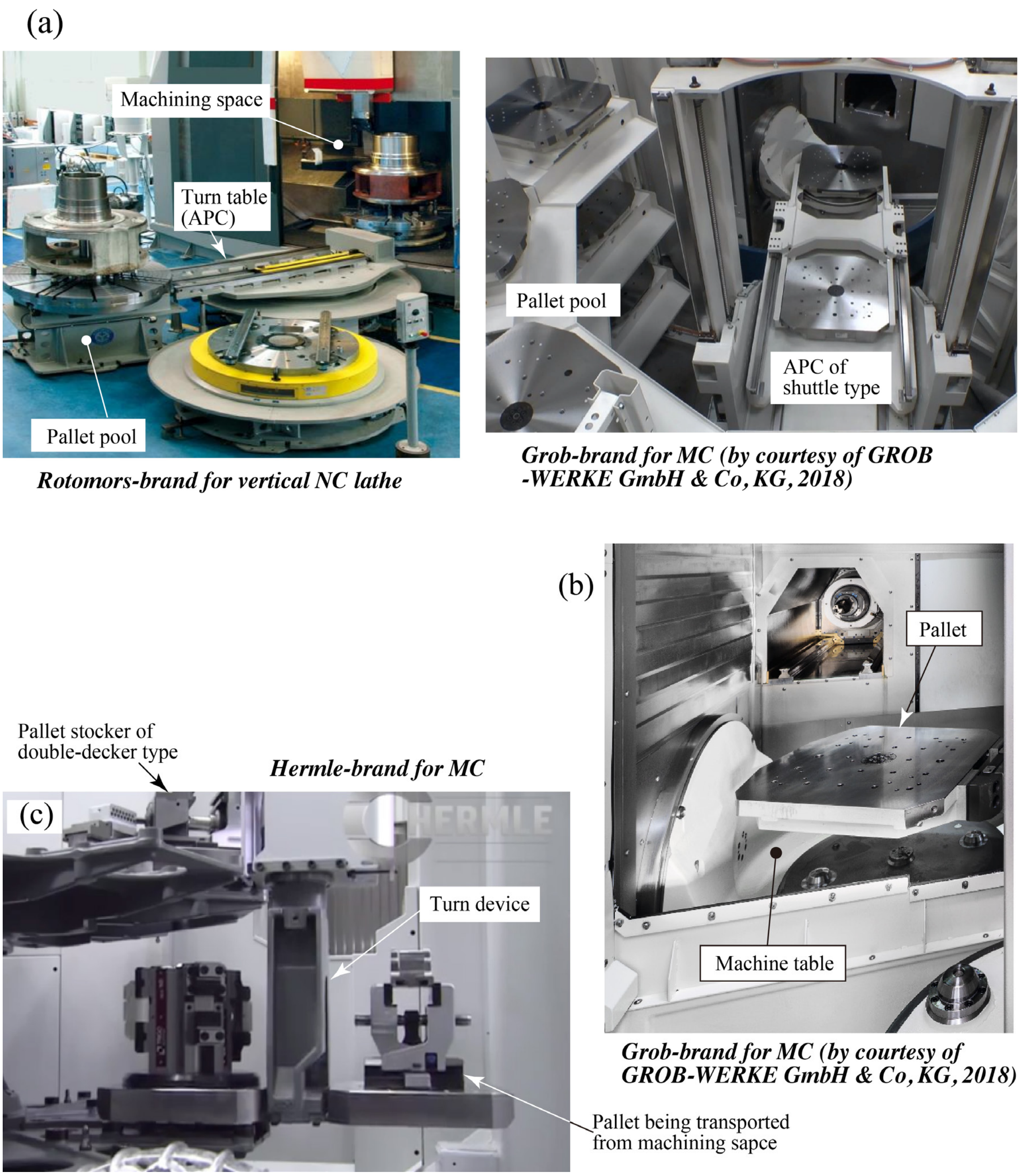


Fig. 4.21 Various configurations in APC: **a** Turn table of shuttle type. **b** Lifting turn table type. **c** Turn device of overhead travelling type for MC

Pallet pool

Type	Variation
Circular table type	mono-layer
	Double-decker
Circulating oval table type	
Linear arrangement table type	
Crescent arrange-ment type	Flat storage
	Cubic storage

Changing mechanism

Type	Variation
Lifting turn table type	
Turn table with shuttle type	one-direction
	Two-direction
	Polar movement
Hanging turn device of tarvelling type	

Table 4.4 Various APCs obtainable by combining various configurations in pallet pool and pallet changing mechanism

In the case of the large-sized FMC, FMS and FTL, the automated warehouse has been prevailed, and notwithstanding its variation in the type, e.g. high-rise, carrousel, and pallet pool types, the basic element is “Rack”, and as can be imagined, nearly all storage facilities are modular-designed. It is furthermore very interesting that the automated warehouse can be classified into (1) cubic (building rack or unit rack), (2) rotating rack (vertical, horizontal carrousel or horizontal multiple-story carrousel) and (3) travelling rack types, resulting in the difficulties to establish the classification system.

More specifically, in a representative automatic warehouse, e.g. the commercial name being “Uni-shuttle HP” of Murata Machinery-brand, the in- and out-let capacity is 3,000 piece (package, bucket, cassette and so on) per hour in maximum, the shuttle car can handle the transportation of the piece, and the travelling speed of the shuttle is 400 m/min. In addition, the warehouse has a considerable flexibility by providing the plural vertical conveyors and storage area for various usages. Fig. 4.22 shows the inside view of an automatic warehouse, by which we can understand the important role of the shuttle car and vertical conveyor.

To this end, it is worth suggesting that the tool magazine within ATC plays also the role of the storage function especially in the case of the stand-alone type, but not integrated within the main structure of TC and MC. In such a case, it is better to classify the tool magazine such as shown in Fig. 4.23.

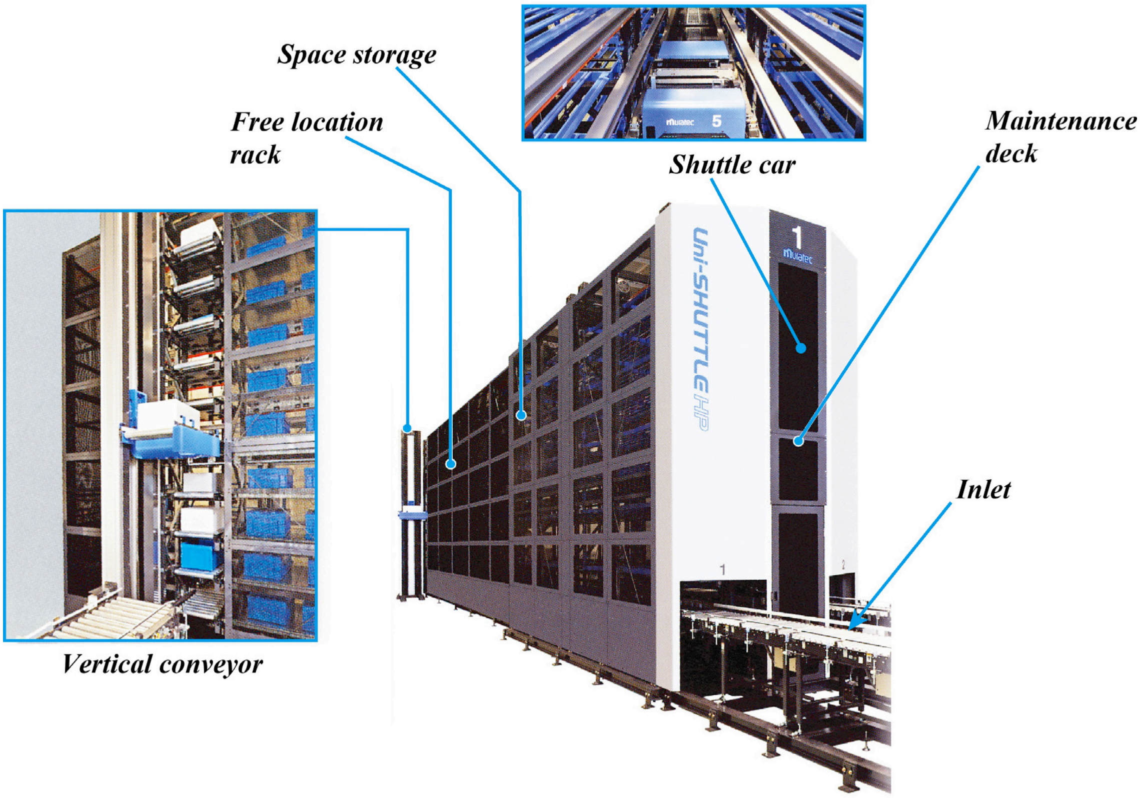


Fig. 4.22 An example of automated warehouse
(by courtesy of Murata Machinery, 2010)

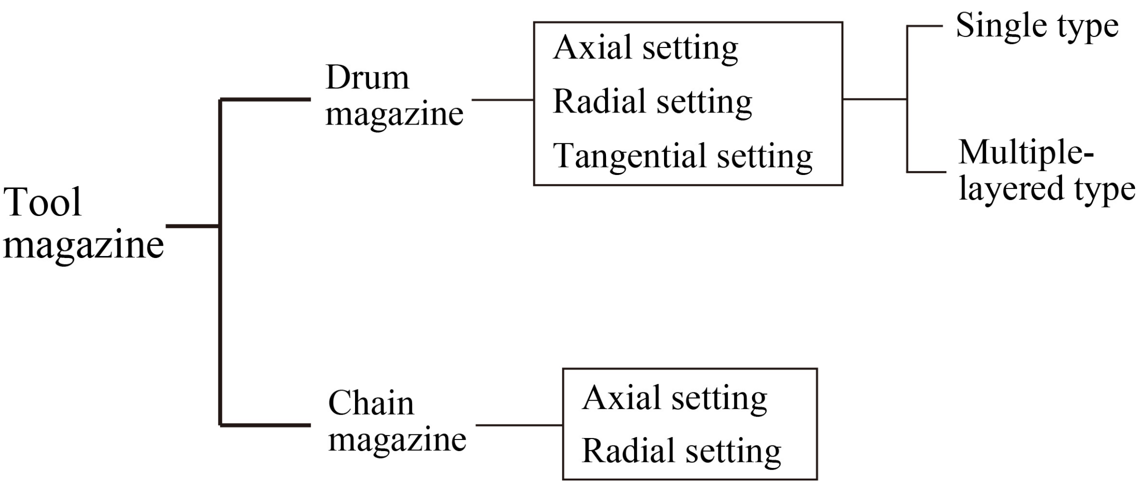


Fig. 4.23 Classification of tool magazine configuration

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Chapter 5 Case Studies on Smart Factory
- To verify Convertibility of FMC for One-off Production into CPS Module in Smart Factory

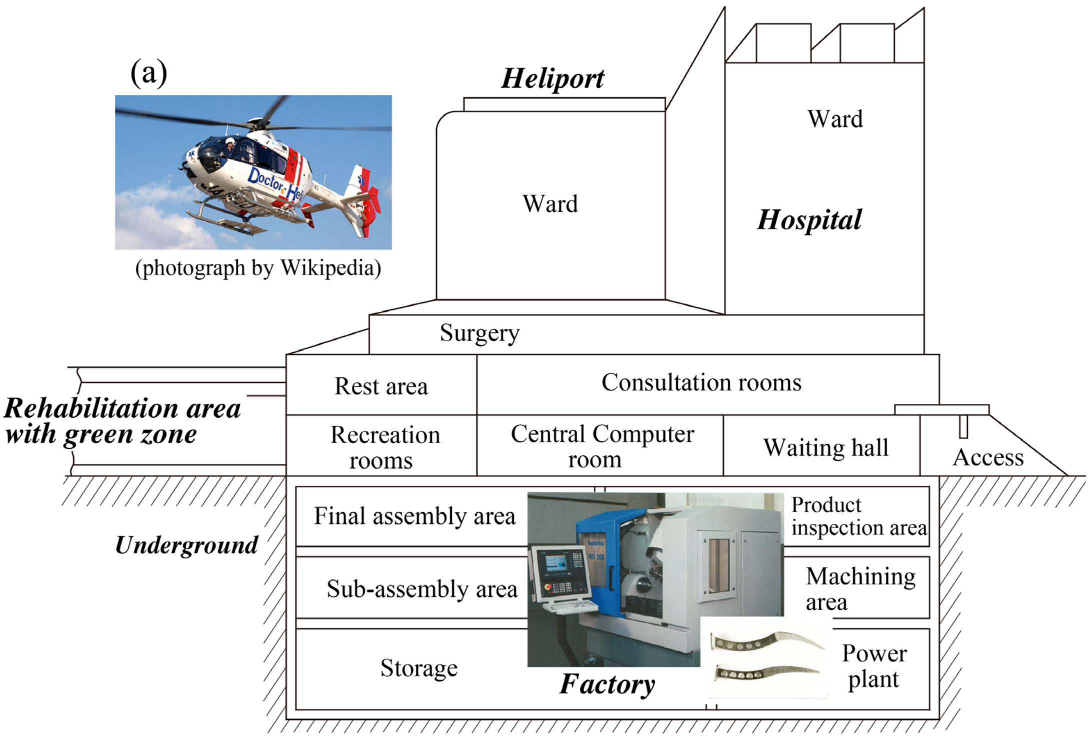
Abstract We have certain symptoms, in which FMC for one-off production is being established, and in due course, we can expect to apply such an FMC to the CPS module in the smart factory. Paraphrasing, we may verify the validity of our hypothesis to a large extent that FMC for one-off production with keen machining cost may be converted into the CPS module in the smart factory. For further verification, thus, this chapter reviews the present perspectives of the smart factory together with conducting the necessary discussion. In the review, the smart factories being on work are classified into those of (1) “Brains, Nervous System and CPS module”, (2) “Brains and Nervous system”, and (3) “ Limbs and Tools” types (see Fig. 1.9). In due course, we can find a considerable number of the interesting smart factories, and, those of Volkswagen and Bridgestone are very attractive. This is because both the factories are in fruition according to the “Original Concept of Smart Factory as a Whole” proposed by “Industrie 4.0”, and importantly, the former pays the special attention to the “Design Principle of Production Structure”, i.e. the closest linkages among the objective product, available production structure and production patterns, to a large extent. Of further special notes, primary concerns of nearly all smart factories are for the establishment of the lucrative business for the time being by not designing them in accordance with the original concept as a whole, i.e. simplified ones by placing the stress on either “Brains and Nervous System” or “Limbs and Tools” type.

5.1 First-hand View for Smart Factories in Practice

As already discussed with respect to Fig. 2.6, we need various machining systems and cells depending upon the technological, economic and social

environments across the whole world. In all the leading industrial nations, FMS and concerns are dominant including the agile machining system.
It has been believed that we can cover all the machining requirements by using FMS and concerns as already shown in Fig. 3.1. In general, FMC is for a kind of production, and also for much variation and less volume production, but not compatible with the "*One-off Production*" in general, when investigating the applicability of FMC on the basis of our long-standing experiences.
It is however worth suggesting that FMC for one-off production becomes gradually applicable to the practice by contriving mainly the cell controller and employing the function-integrated kind in the machine tool as exemplified by that of Sandvik Coromant (see Fig. 3.11 and Table 3.3). Importantly, it appears that the CPS module in the smart factory may be facilitated by FMC for one-off production. We can thus expect that the smart factory may enhance its dimensional and performance specifications by integrating a further advanced FMC for "One-off Production with Keen Machining Cost", and to get a clue for this issue, the representative case studies on the smart factory will be discussed in the following.
In this context, it is recommended to refer to a booklet published by VDMA (Verband Deutscher Maschinen und Anlagenbau). This booklet has reported about 50 case studies, although there are a very few smart factories for machining. For example, Schaeffler applies the concept of the smart machine to the mill-turn by integrating the preventive maintenance function for the main spindle (VDMA, 2016). Importantly, it is very rare cases to establish the original concept of the smart factory as a whole in practice as will be discussed later, and it is notable that nearly all case studies aim at the fruition of the lucrative business. As a result, there is a two-pronged way in the case studies now: one places the stress on "Brain and Nervous Systems" type, and the other is on "Limbs and Tools" type, and actually the former is not related to those for machining, but assembly in general (see Fig. 1.9).
For the sake of further understanding, Figs. 5.1 (a) and (b) reproduce a con-

(a)



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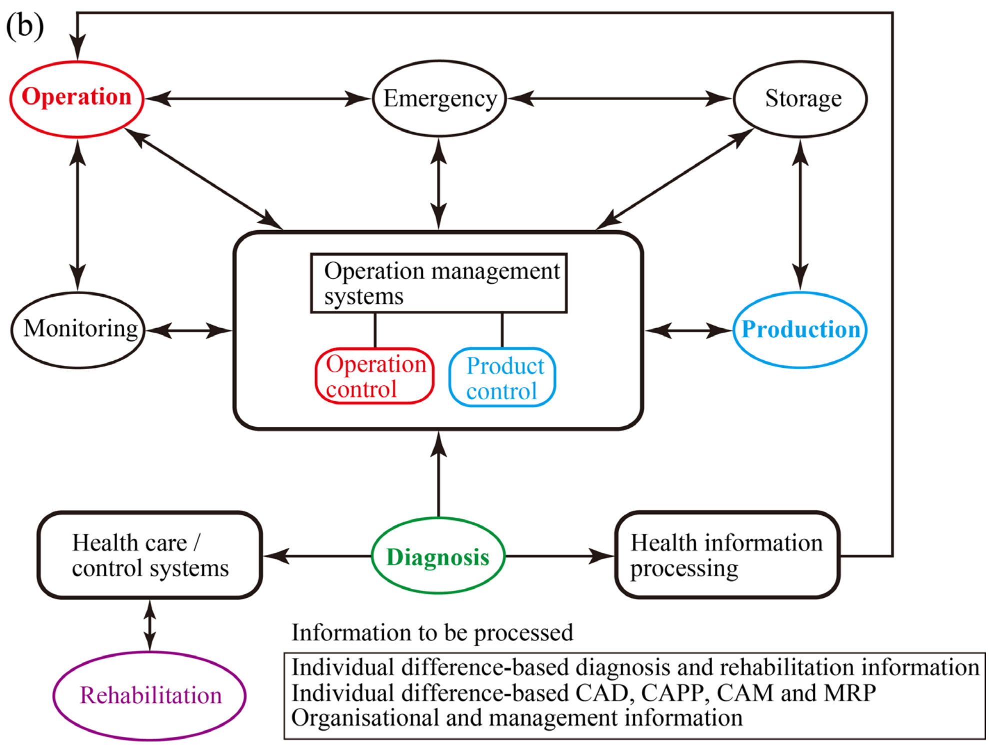


Fig. 5.1 Hospital-Factory Complex:
a Schematic view. **b** Information processing

cept of the “Hospital-Factory Complex”, one of the variants of FCIPS. Accidentally, we may envision a trial of smart factory, which applies the whole concept to the practice, from Fig. 5.1 to some extent. In fact, the “acatech” has proposed a “Smart Network for Health Control to Guarantee Smart Health”, which is a fusion of differing professional spheres, but does not include any production activities (2013). Against this context, the “Hospital-Factory Complex” is for the patient, who has a trouble in the joint, and can facilitate the prosthetic device manufacturing (Ito et al., 1990). The complex can be characterised by the following.

(1) A synergy of prosthetic device production, surgery and patient’s care, computerised information control and heliport for the patient transportation to other hospitals at the emergency.
(2) Total system flexibility as exemplified by the green area for rehabilitation.
(3) Network-connected complexes allocated within a certain area.
(4) Patient transfer function with helicopter together with patient’s medical records.

Obviously, information processing in the complex should deal with those for examination and diagnosis, healthcare, surgery-related and prosthetic device and its manufacturing. Importantly, the prosthetic device is one of the “Individual Difference-oriented Products”, and thus should be generated by the one-off production. More importantly, a crucial facing problem is a conversion from diagnosis information to that for prosthetic device manufacturing, because there are no methodologies, but experience-relied remedies.

Of special note, the core of the factory in Fig. 5.1 (a) is the CNC tool grinding machine of Schütte-brand, which is applicable to machining the prosthetic device and its surgical instrument simultaneously. In addition, it is preferable to install 3D printer hereafter to produce the model for surgical pre-simulation.

5.2 Case Studies Placing Stress on "Brain, Nervous Systems and CPS Module" Type

As already discussed in Section 5.1, we can find only a few representative case studies, e.g. those of Volkswagen and Bridgestone, in which the smart factory has been established in accordance with its original concept as a whole proposed by the "acatech".
In the case of Volkswagen, we are interested in the proposal of "MQB (*Modularer Querbaukasten*)", which pays furthermore the special attention to the design principle of the production structure, i.e. simultaneous investigation into the objective product and its production facilities.

5.2.1 Volkswagen's "MQB" as a Strategic Approach towards Mass Customised Car Manufacturing (Car Manufacturing of Quasi-One-off Production Pattern with Keen Cost)

Probably the most wide-ranging conceptual strategy pursued by Volkswagen recently is the so-called MQB, which is assumed to revolutionise car manufacturing within the global Volkswagen Group. Apparently, we have discussed MQB by placing the stress on the variation deployment of the motorcar, and in short, MQB is one of the variants in the modular design for the product.
Importantly, the production structure should be, in principle, designed in full consideration of the mutual close linkage among the (1) product, (2) configuration of production structure (in narrower scope, objective processing and system layout) and (3) production pattern. Of course, the "acatech" asserts also the same idea as shown in Fig. 5.2 (see Fig. 6.19; Anderi et al., 2012) [1].
In discussion of MQB, we must recall that FTL is the leading manufacturing facility in the motorcar industry, and as already stated in the

[1] The "acatech" asserts the importance of mutual linkage among "die Produktenentwicklung", "die Produktplanung" and "die Produktionssytementwicklung", and these German terms are translated into corresponding English terms, although there are some differing sounds.

preceding chapters, FTL is modular-designed. In addition, it is now com-

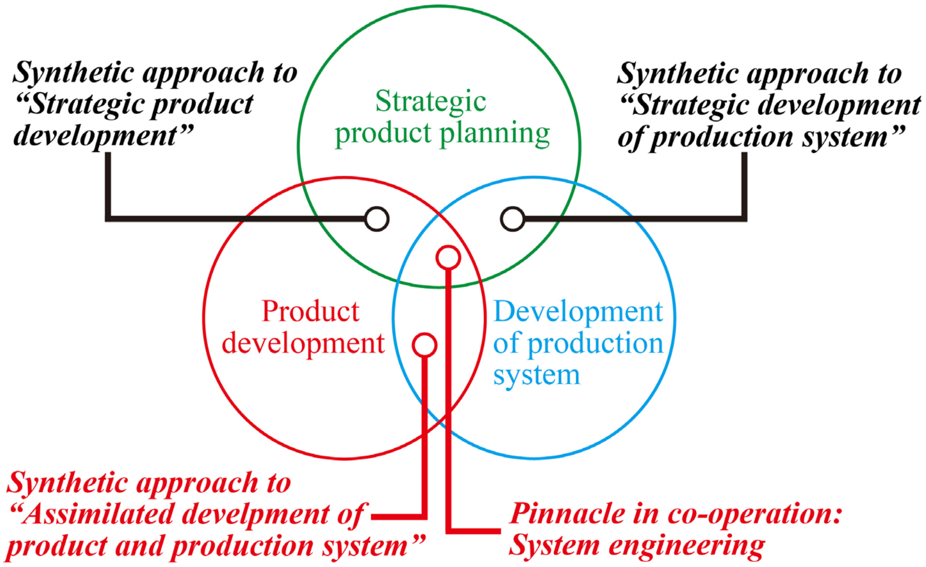


Fig. 5.2 Linkage within leading three design attributes for production structure (by Anderl et al., 2012)

mon senses that FTL is for the "*Considerable Variation and Less Volume Production*", and we may expect that one of successors of FTL, i.e. transfer centre, will be available for the "One-off Production" by reinforcing the flexibility in machining and also by contriving something necessary to its controller (see Figs. 3.25, 3.28 and 3.29) [2].

As will be clear from the above, MQB of Volkswagen is one of the typical materialisation of the original concept of the smart factory as a whole with aegis of the design principle of the production structure. Thus, we will discuss MQB in detail in the following.

When German adults talk about "Baukasten" in the first instance, they may think of toys. In the kindergarten, a "Baukasten" is a collection of standardised low number of different pieces (e.g. a box of wooden bricks). What is the reason why Volkswagen's designers and managers talk about a "Modular Building Block System" (English-language approximation to

[2] As shown in Figs. 2.11 and 2.12, FTL was developed on the basis of TL, and as widely known, TL was mainly installed in the motorcar industry, and in due course contributed considerably to the further development of the modular design during 1950s ~1960s. On that occasion, we called the modular design "BBS (Building Block System)". Of special note, we did not apply the modular principle to the car design up to 2000s, although we used to design the manufacturing facility for the motorcar industry by the modular principle.

original term) as a new concept in the production of their cars? Presumably it is not the intention to transform the production line into a kindergarten or a playground. Before clarifying the probable intentions, it helps to tentatively clarify the used term.

In the first instance, the translation of the term " Baukasten" into "Building Block System" means " Modular Design". A first tentative definition of MQB goes like this: It is a product design strategy that modularises not only parts of the car body, but rather a high number of components (modules) across different model lines. Thus, Volkswagen sees an evolution from the platform strategy over the module strategy towards MQB, the Building Block Strategy. Importantly, Gleason Pfauter Hurth, one of the leading machine tool manufacturers, initiated the concept of the platform and applied it to the gear production machine in the beginning of the 1990s, although there are certain differing features between those in the

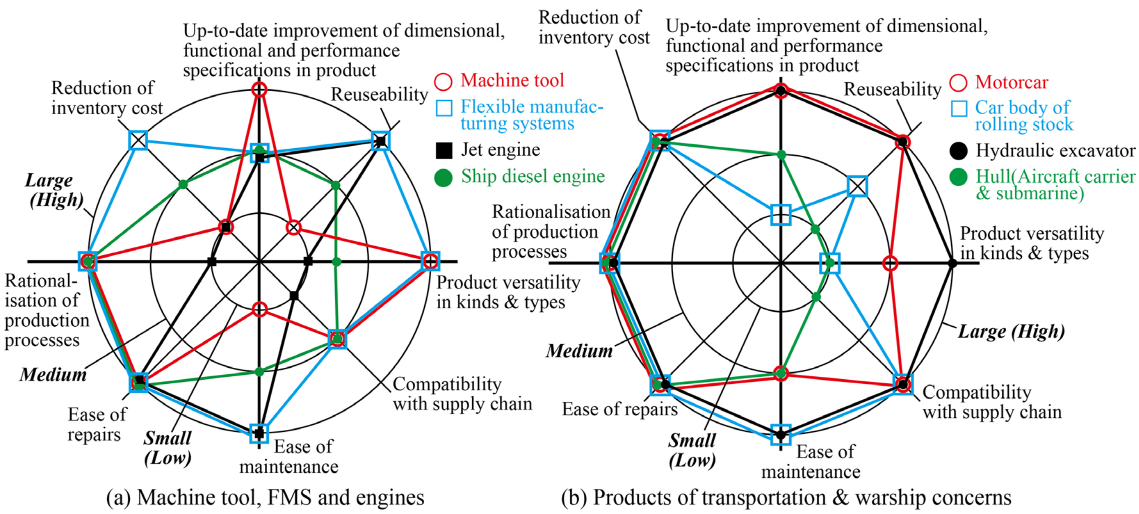
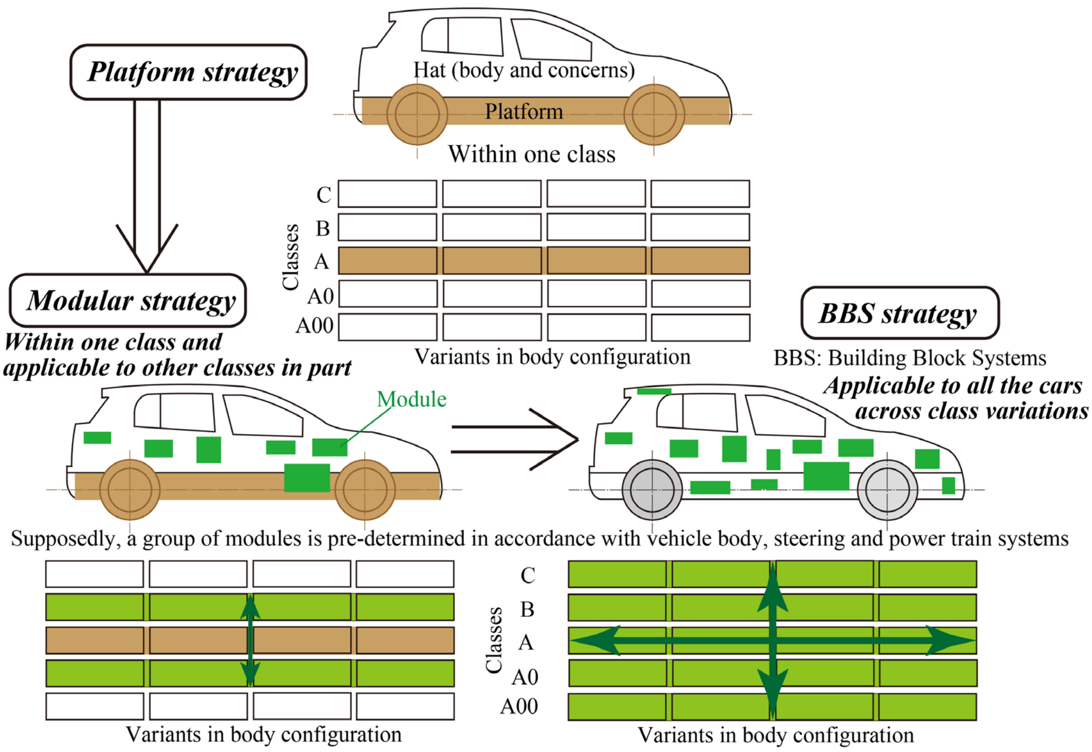


Fig. 5.3 Differing Characteristic Features in Modular Designs for Various Products

motorcar and machine tool industries (see Appendix). In retrospect, the modular design was first applied to the machine tool around 1930s, and then has extended its application spheres to the engine, rolling stock and so on as shown in Fig. 5.3. In the motorcar, we have applied the modular design to the sub-assembly like the door unit in the 2000s, but not the whole car body. Importantly, the radial axes in Fig. 5.3 indicate the leading characteristic and beneficial attributes, and thus we can understand (1) what are the weighing design attributes of each product and also (2) to what extent each product uses the beneficial feature of the modular design (Ito, 2015).

As can be readily seen from the above, MQB of Volkswagen is an outstanding trial, because the modular principle is simultaneously applied to the product and its manufacturing system, and thus now let us scrutinise it in the following (refer to HPs of Volkswagen listed in References, Waltl et al., 2014).



Note: As compared with the modular design of hierarchical system in the machine tool, MQB of VW is of reverse flow type, i.e. that from platform to versatile module-integrated types

Fig. 5.4 Total concept of MQB proposed by Volkswagen

As shown in Fig. 5.4, the expectable synergies occurring when different strategies are followed. The “simple” platform strategy allows for synergies, which are bound to one vehicle class, while the elementary module strategy (e.g. the car body) allows for synergies partially overarching one vehicle class. The MQB strategy eventually is not tied to one, but rather completely across many vehicle classes. In short, such a concept is well known as a “Modular Design of Hierarchical System” in the machine tool sphere (see Appendix).

What triggered Volkswagen‘s development of such a new production concept? After numerous acquisitions during the last decades the Volkswagen Group includes 12 brands with approximately 280 models and countless variants at more than 90 global production sites in 2013. No questions that these framework conditions created a great diversity. The sheer diversity posed a major challenge to design and production. The MQB approach standardises design and production within the Volkswagen Group. The challenge to be overcome was to promote standardisation in order to cut cost, simplify design and create synergies, but not to make all the models look the same – in other words: to maintain the diversity. The concept foresees that all the vehicles with transverse front engine use the same core components independent of car size, type or brand.

Within the Volkswagen Group more than 30 series with a huge number of engine-gearbox variants are affected by implementing the MQB concept. The advantage of the MQB lies in a reduction of several hundreds of engine-gearbox combinations down to 30-40. The advantage is even more evident when looking at the so-called ‘transmission bells’: all the MQB models use the same. The basic measure consists in establishing common physical mounting points and dimensions of certain components. For example, the engine (motor) is always tilted backwards by 12 degrees, and the distance between the pedal box and the front-wheel centre is equal to the millimetre. Together with a few other fixed dimensions in the engine bay, a considerable number of the expensive parts can be standardised on the one hand, on the other hand still other dimensions are freely selectable (see Fig. 5.5). When it comes to wheel sizes, track width, wheelbase, seating position, roof height, and so on, a realm of freedom opens up. In conclusion, the fully implemented MQB system allows shorter development times, a cost- and time-efficient manufacturing of variants and niche models in low quantities – and this is all hidden to the customers, because the unified parts are non-visible.

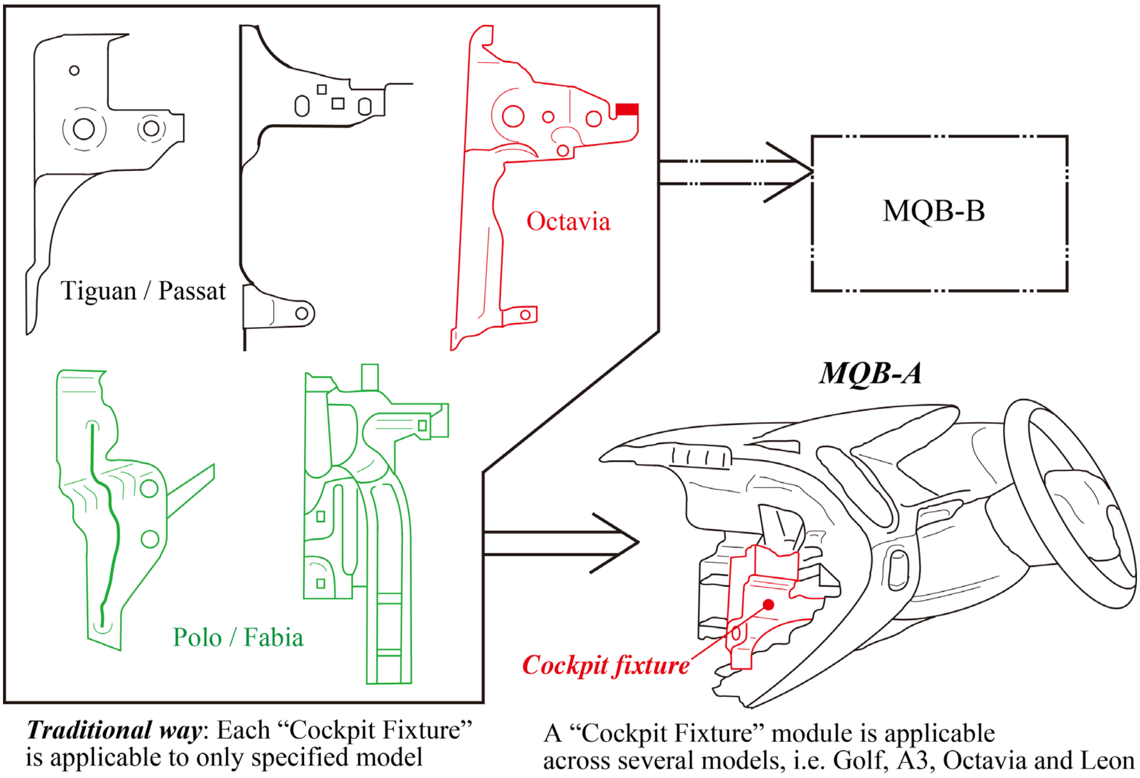


Fig. 5.5 Beneficial feature of MQB by exemplifying "Cockpit Fixture" (based on publicised material by Volkswagen)

Needless to say that the MQB strategy requires standardised module families. At this point, it must be stated that besides MQB within the Volkswagen group further "Baukästen" have been developed, such as MLB (Modular Longitudinal Matrix) which stands for the modular building block system with longitudinal front engine, and the MSB (der Modulare Standardantriebsbaukasten) as the third big modular building block system for standard drives. All these systems build upon the definition of module families. All the modular building block systems include module families for drive units, electrical equipment/electronics, the chassis and the vehicle body. Within each module family different standardised components can be used to produce individualised variants, e.g. in the drive unit module family, and there is a choice between Diesel engines, Hybrid engines, Eco Fuel engines etc.

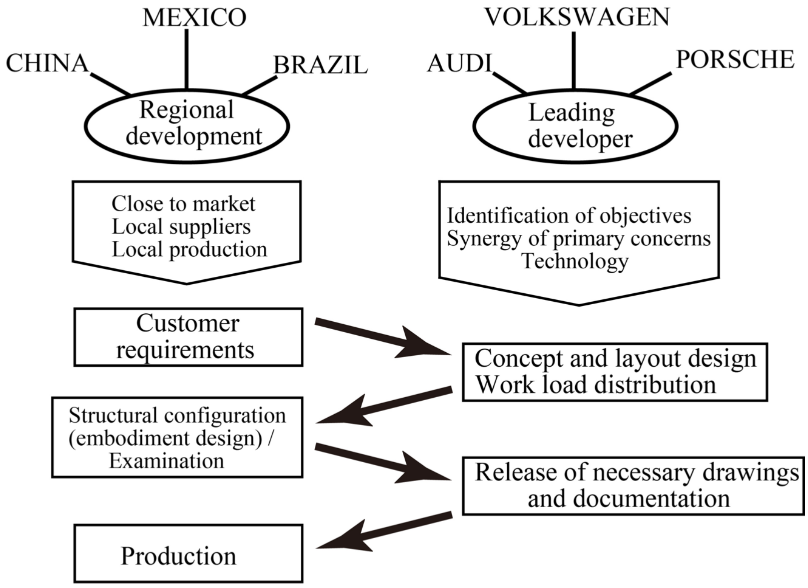


Fig. 5.6 Central control for development activities in globalisation era (by Volkswagen, 2013)

Concerning the cost savings potential and the flexibility in manufacturing inherent to Volkswagen's "Modular Building Block System", it is difficult to estimate the savings from an outsider's perspective, but more important is the rising flexibility in car manufacturing, which is a kind of paradox: the modularisation of products goes hand in hand with standardisation of assembly processes, which are accompanied by modularised production facilities (equipment). This leads to standardised factories and eventually a global manufacturing turntable that allows a location-flexible production of different models of the same modular building block system at different production sites as shown in Fig. 5.6 and Table 5.1. Not to be neglected for a globalised car manufacturer is the advantage of faster follow-up operations, i.e. experience gained during initial assembly start-up in one country can be used for subsequent start-ups in other countries. In addition, on one production line, different models of the same "Modular Building Block System" can be produced with almost no modifications of the production line.

India	Malaysia	Russia
Frequent occurance of flooding	Warm climate with high humidity	Extremely cold climate
Poor road conditions with rough coating, muddy states, rubble stone and so on	Megacity / Traffic jam	Poor road conditions with rough coating, muddy states, rubble stone and so on
Fuel quality / Awareness for fuel cost		Slippy and dirty road conditions

Table 5.1 Region-specified design attributes in motorcar (by Volkswagen, 2013)

As can be readily seen, this aspect of MQB is very similar to the design specifications of flexible manufacturing shown in Table 1.2, and thus implies the growing importance of the manufacturing culture.

The probably biggest challenges are faulty core components, which are built in a variety of models and thus can cause much bigger problems. This risk can only be countered by strict quality control.

In conclusion, what is the deeper meaning of what Volkswagen is doing since a couple of years? It is transforming the world of car manufacturing towards mass customisation, which must be seen as an essential objective of the "Industry 4.0". Through strict modularisation and standardisation in the form of a building block system, it is possible to maintain or even increase the variant diversity, which is a major requirement in the production of consumer goods. Therefore, the concept of mass customisation might be a viable approach to be followed by manufacturing sectors with a similar structure. But also for other industrial sectors the concept underlying MQB might be feasible option.

As mentioned above, a concept similar to Volkswagen's MQB system is known in the machine tool sector as "*Modular Design of Hierarchical System*", therefore the experiences gained at Volkswagen could also be relevant for machine tool building – even if the products are not in a strict sense of a mass production type. And additionally, Volkswagen's MQB system requires appropriate "smart" equipment, which must be developed and provided by the machine tool sector. This will, of course, have an impact on machine tool building as like as those of TL in the past, i.e. those on the type of machines, systems and control units.

Of special notes, MQB may be highly appreciated by the following two characteristic features.

(1) Enhancement of the fundamental concept of the modular design with hierarchical structure to be applicable simultaneously to both the product and its manufacturing facility.
(2) A trial in the modular design of wider scope to be available for the localised globalisation era (Ito, 2011)

5.2.2 Advanced Tyre Moulding Systems with AI (Artificial Intelligence) Function

Hikone Plant of Bridgestone has installed a smart factory to produce the tyre for the passenger car and pickup truck. It is worth suggesting that this smart factory consists of a tyre moulding machine with AI function, i.e. a CPS module, information communication network and cloud computing in accordance with the original concept as a whole proposed by the "acatech" (HP of Bridgestone, 2017). Importantly, it is extremely notable that the "*Division of Work in Information Processing*" is obviously identified as shown in Fig. 5.7, where cloud computing is for moulding data analysis and identification of factory floor states, and AI controller plays the role of fog computing.

More specifically, we can observe furthermore the following characteristic features.

(1) The tyre moulding machine has been newly developed and of multiple-drum type. As a result, the productivity increases around double as compared with that by the old machine, which is of single-drum type.
(2) The tyre moulding machine can detect 480 attributes related to the quality data by a group of sensors, and control the tyre assembly procedures with AI of real-time mode.

(3) The AI controller incorporates the skill of the mature technician resulting in less fluctuation in the product quality caused by the human intermediation.

(4) The technician has a handy device to recognise the current states of the factory floor, to mange the trouble, to change the raw material and so on without any time delays.

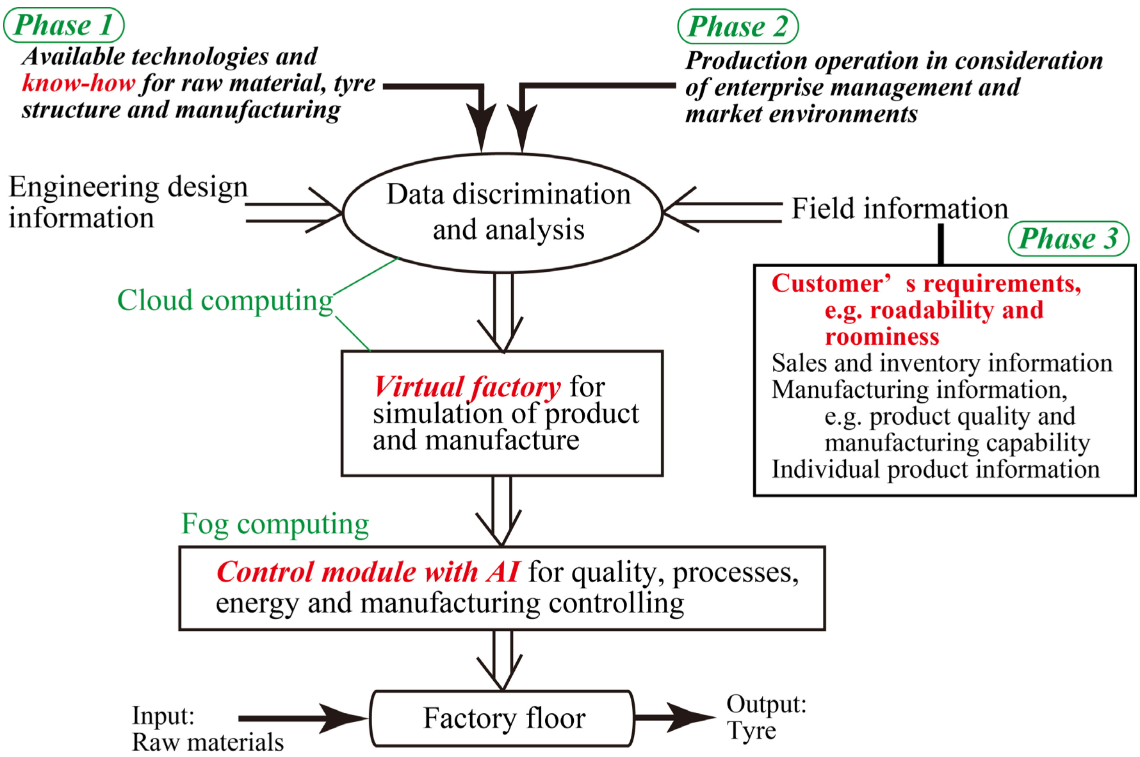


Fig. 5.7 Concept of smart factory for producing tyre (by Bridgestone)

Of special note, this smart factory is very interesting and a typical example for understanding the property conversion of information while processing. In general, we believe that the information has mono-property; however, the virtual factory shown within Fig. 5.7 should process information with various properties input from phases 1, 2 and 3 as follows.

(1) Phase 1: We must process mainly the information related to the engineering design; however, even in such information processing, there are a considerable number of the procedures, where the

information changes its property (see Fig. 6.3). In this case, a root cause of difficulties lies in information processing for uncertain attributes, e.g. flair and inspiration of the mature technician, which is too difficult to the quantification.

(2) Phase 2: There are market-related, enterprise management and production control information, and thus no conversions of information properties.

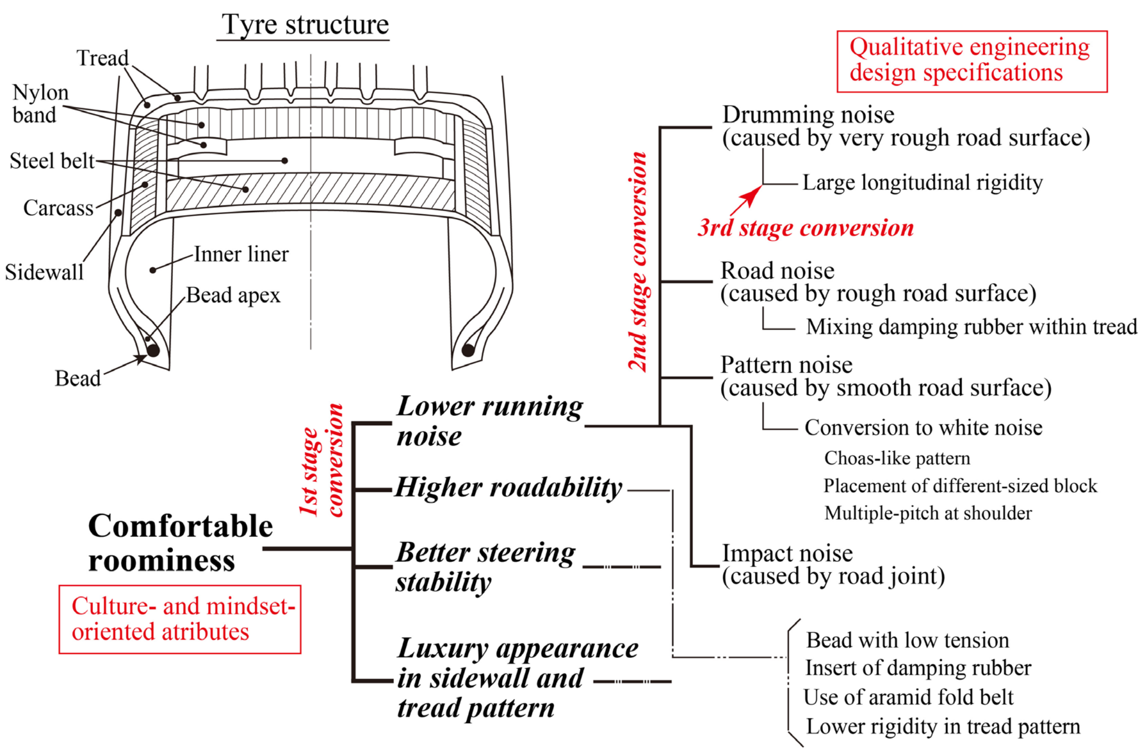


Fig. 5.8 Hierarchical tree structure representing conversion procedure of uncertain attribute-related information to engineering design requirements in case of tyre

(3) Phase 3: We must process information with various properties ranging from those related to the market, through enterprise management and production control, to manufacturing. Importantly, primary concern is the conversion of customer's requirements with uncertain attributes to the quantified engineering design specifications of the product (see Figs. 6.4 and 6.5).

Figure 5.8 reproduces the conversion procedure of the "Roominess" to the qualitative specifications for engineering design of the tyre. As can be readily seen, we can observe clearly the change of information property, and at issue is to establish the conversion methodology (see Fig. 6.7)

Such a problem mentioned above has not been suggested anywhere so far, and in practice, we can manage it by case-by-case manner, whereas we must conduct the corresponding academic research to clarify the essential features in information processing (see Section 6.3).

5.3 Case Studies Placing Stress on "Brain and Nervous Systems" Type

Apparently, we have now a considerable number of the smart factories in practice; however, in nearly all cases, we can see that the concept of the smart factory is not applied to the practice in its whole state as yet, but in part. This is because the enterprise intends, in general, to grow the lucrative business by utlising the present manufacturing facility with a less investment. Of note, we can thus observe such applications as follows.

(1) Cloud computing places its main stress on something related to MES (Manufacturing Execution System) and ERP (Enterprise Resources Planning), but does not deal with information processing for "Engineering Design of Product". As already suggested, we must deal with the human-intelligence-based knowledge and also property changes in the product-related information processing; however, such a methodology is far from completion.

(2) The hardware of the CPS module (Limbs and Tools) is given beforehand, and has been suggested for the assembly together with the transducer for collecting big data, but not for machining. In short, the machining space is of ill-defined environment for the transducer for in-process measurement.

5.3.1 BMW Regensburg Plant (Brambley, 2017)

This smart factory is for assembly line as shown in Table 5.2, and under the aegis of the software for production control of Ubisense-brand, which has been merchandised aiming at the smart factory. In addition, each assembly station can be regarded as a CPS module, where the hardware and software consist of the "Data Tag and Sensor", and also the lower hierarchy in RTLS (Real Time Location System), respectively.

Number of assembly line: One	Number of assembly stations within a line: 150
Total number of sensors: 470	Total length of assembly line: 1.9 km
Production capacity per day: 1,100 cars	
Types possible to assemble: BMW 1 Series, BMW 3, BMW M3, BMW Z4, and Four-wheel drive (Within these types, capable of responding requirements of each customer)	

Table 5.2 Specifications of assembly line

More specifically, RTLS can visualise the current states and actions of all the manufacturing resources, e.g. product, worker and assembly tools, within the virtual space system, so that the manager can control and adjust the line flow.

As a result, BMW can benefit considerably by the rationalisation of the assembly line such as follows.

(a) Real time recognition of the assembly line.

(b) Agile and flexible work indication and quick decision making on the basis of collected data.

(c) Reduction of re-work cost and minimisation of workflow loss.

(d) In customisation of the product, ease of optimisation and prevention of miss-operation in hand work.

Although BMW asserts that the assembly line is one of the smart factories, we can suggest some controversial points as follows.

(a) In accordance with the proposal of the "acatech", the smart factory consists of both the horizontal and vertical networks; however, BMW system uses only the vertical network within a factory.

(b) Admitting that the objective process is only for assembly, the system is not cell (CPS module) type as proposed by the "acatech" in the flagship project entitled “Custom Manufacturing”, but line type.

Thus, Fig. 5.9 visualises such differences between the practical application and the original concept by the radar chart to ease of understanding to what extent we can benefit, and by how to employ the concept of the smart factory.

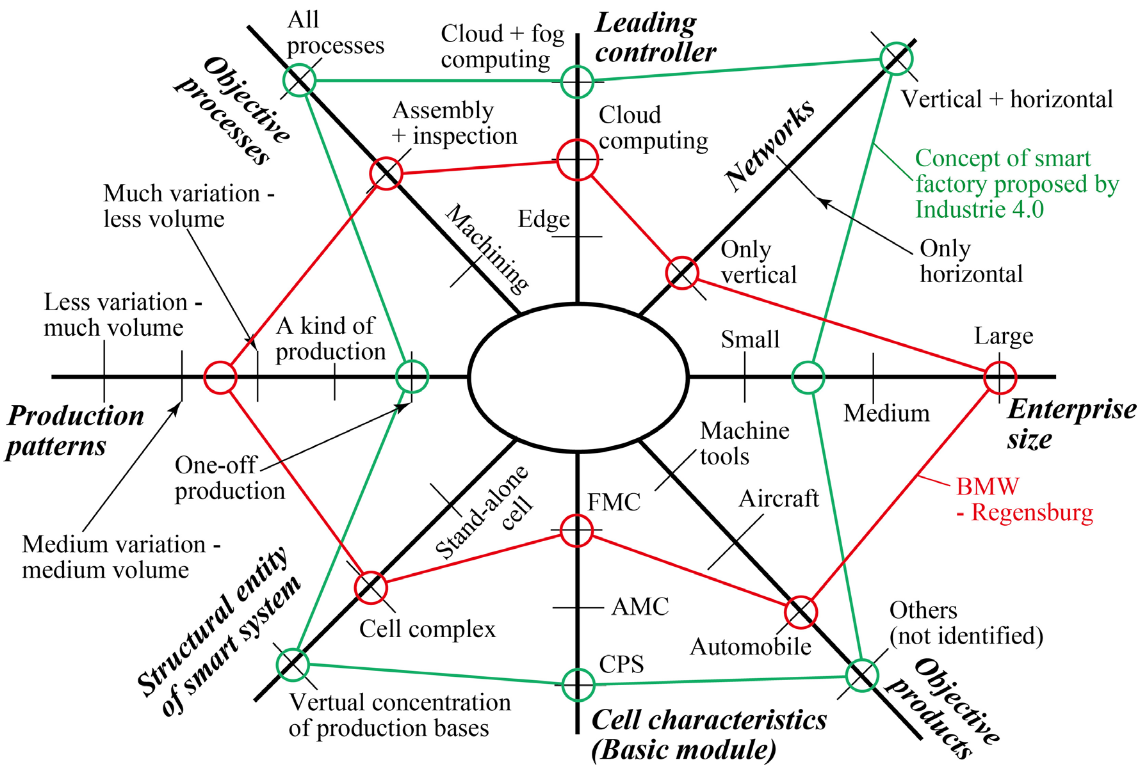


Fig. 5.9 Comparison of practical application by BMW with original concept proposed by “acatech”

5.3.2 Bosch Rexroth Homburg Plant (Rexroth-Bosch, 2017)

This smart factory is for the assembly of the hydraulic valve for the truck and forklift, and aims at (1) the improvement of the product quality, (2) saving the cost, and (3) shortening of the delivery time. More specifically, the factory consists of nine assembly stations with cell configuration, and can assemble six product families (number of variants: 250, total number of components: 2,000).

Importantly, the smart factory can be extremely characterised by its human-centred CPS module with AI (Artificial Intelligence) function, i.e. autonomous intelligent workstation, as summarised in Table 5.3, assembly of small batch size, and requirement of the mature worker for each family. Bosch Rexroth has publicised the following valuable effects by trying its one-year long (2014-2015) operation.

(1) Total cost reduction per year: 500,000 €.

(2) Reduction of work preparation time: From 450 to nill sec.

(3) Work-in-progress days: From 3 to 1.5 days.

(4) Reduction of cycle time: From 474 to 438 sec.

Quickly switch between products as required
Better connectivity to MES and ERP by controller of CPS module called "ActiveCockpit"
Digital connection among worker, product, workstation and process together with collecting, filtering and visualising data on whiteboard by "ActiveCockpit"
Control of product flow by RFID (Radio Frequency Identifier) chip
Sensors collecting and collating data for decision-making process
Adjustment for work area automatically to individual requirements including language, front size and individual skills and experiences of each worker by automatic recognition function of workstation
Display of work steps for each different product type to worker at every workstation and collection of achievements
Supply system of only essential parts to worker by KANBAN and part supermarkets

Note: RFID is "RF Tag" with integrating ID information

Table 5.3 Functional and performance specifications of autonomous intelligent workstation

5.3.3 Application of Statistical Analysis Software to Cost Reduction

IBM has merchandised a wider production control system compatible with the smart factory, and one of the cores is the statistical analysis software (commercial name: SPSS). Fig. 5.10 shows an application of SPSS to the X-ray inspection for the castings in the motorcar industry, which aims at both the minimisation of the inspection objectives and the reduction of the necessary number of the inspection devices.

More specifically, the data are collected at the melting process for the molten iron and also the inspection process of the castings. In due course, the former data are processed by the predictive analysis method, i.e. SPSS, and in certain cases, the X-ray inspection of the castings renders useless, provided that the predictive analysis results in the satisfactory evaluation value. In contrast, the latter should detect the casting flaws, e.g. pinhole, shrinkage crack, and inclusion of micro-bubble.

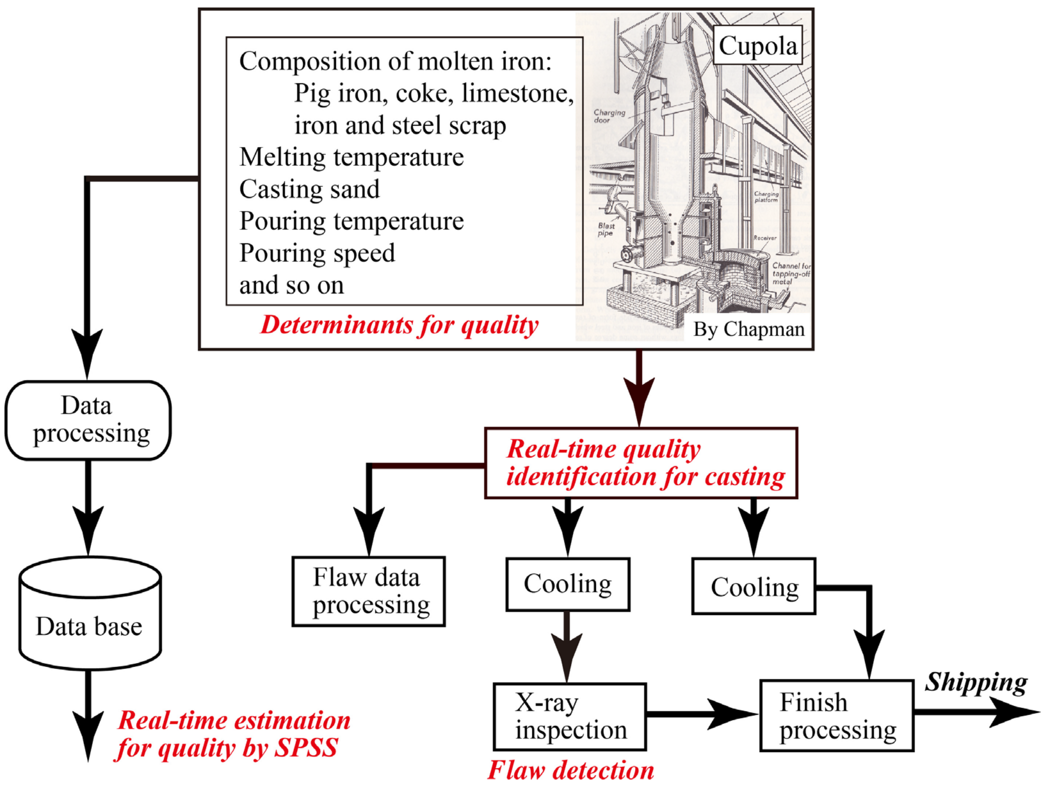


Fig. 5.10 Product quality control system with statistical analysis software (by IBM)

As can be readily seen, the kernel of this smart factory is the comparative procedure between the predictive analysis and the X-ray inspection, i.e. real-time quality identification, and thus IBM suggested the importance of the knowledge know-how in the comparison, although not stating the details because of company's confidentiality.

In general, we must be aware the very difficulty in the estimation of the casting flaw including the residual stress from the melting condition of the molten iron. Apart from such uncertainties, IBM reported the cost reduction is 450 Mill. Yen/year (equals to 4.142 Mill. US $). Paraphrasing, we may benefit considerably by improving the procedure for the product quality control rather than the concept of the smart factory.

5.4 Case Studies Placing Stress on "Limbs and Tools" Type

It is said that the smart factory is SME (Small- and Medium-sized Enterprise)-oriented, and importantly, FMC has been expected to be suitable for installing at SME since its development of first stage in the 1980s. More importantly, we can verify the much more applicability of FMC to the manufacturing facility for SME by its amazingly increasing number of the installations within SME so far than our expectation.

As already discussed, thus, authors assert the applicability of the cell controller of FMC for one-off production to the controller of the CPS module in the smart factory, i.e. fog computing (edge), provided that the cell controller has an autonomous function to some extent. Fortunately, German Government has announced a success story of 3D-Schilling on the web entitled "Effective Metallteilbearbeitung für Losgröße 1" (BWE und BBF, 2017). In this case, the driving force is extremely the contrivance of the software in machining the prototype with 3-dimensional complex form as follows, although not having the autonomous function.

(1) Identification of the work and tools by RFID (Radio Frequency Identifier).
(2) Quality measurement of all the finished parts, digitization and documentation of measured results, and their effective use.

In addition, the Czech Technical University in Prague has developed a CPS module for one-off machining of the large-sized work under the project, "Intelligent Machining Systems with Digital Twin". In this project, the digital twin means a couple for actual and virtual machines, where the actual core machine is of TOS-brand (Kolar et al., 2016). As can be literally shown, this machining system can be characterised by the following.

(1) Intelligent fixture: the technician receives the indication for the "Positioning and Adjustment of Work" by the handy display, and also

can ask questions through it, resulting in the reduction of the idle time up to 75%.

(2) Production of NC information from CAD/CAM data: We can reinforce such a function by the "Virtual Machining Simulation Based on FEM (Finite Element Method) Model", which can optimise the machining sequence.

(3) Identification of machining errors by "Digital-Twin".

Admitting that the authors' assertion is acceptable with respect to the applicability of FMC to the CPS module in the smart factory as mentioned above, one of the determinants is the better connectivity of the CPS module with the information communication network, whereas FMC is, in general, for stand-alone operation or of the basic module for FMC-integrated FMS and FTL. This implies that FMC has not so strong tie with CIM through the information communication network, although each FMC must receive and send some information from and to CIM with descending and ascending flows.

In R & D (Research and Engineering Development) for "Limbs and Tools", thus, nearly all activities concentrate to develop the controller for the CPS module. In fact, we conduct such activities without considering the applicability of the current cell controller.

Reportedly, some German machine tool manufacturers have steadily merchandised the advanced NC controller applicable to the CPS module. For example, NC controller of Index-brand is capable of connecting the management organisation of the enterprise through the network, changing its display to be the "Paperless Machining" in reality, and also of accumulating machining knowledge and history of each user. In addition, Siemens announces the marked features in its product (brand name: SINUMERIK) as follows, although being not obtainable the detail.

(1) Integration of CAD/CAM with CNC by virtual machine for optimisation.

(2) Display of user's order specifications.

(3) Paperless production.

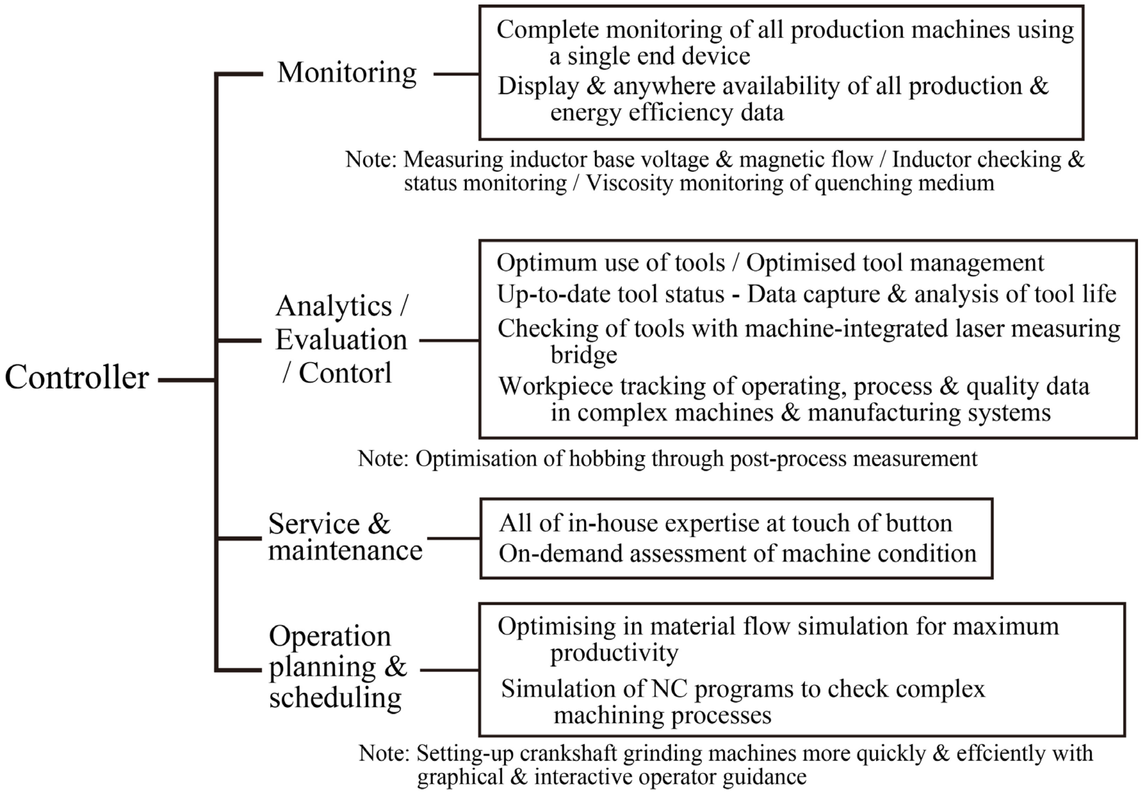


Fig. 5.11 Controller compatible with Industrie 4.0 - EMAG-brand, 2016

In contrast, the “Autonomous Function” is not established in both the advanced NC controllers as yet, nevertheless it is mandatory for the CPS module for the smart factory.

To deepen the understanding, Fig. 5.11 shows the function of the advanced NC controller of EMAG-brand; however, we may face certain confusion regarding what are differing characteristic features between the controllers for the CPS module and FMC. Importantly, such confusion may be enlarged by the reinforcement of the marketability of the cell controller. In general, primary concerns in the cell controller of FMC are (1) production of NC information together with machining sequences, (2) tool control and tooling layout, (3) surveillance for operating conditions of cell itself and cell components, (4) quality control of finished part and report of machining achievements and so on (see Fig. 3.13).

We must however advance the differentiation of the function and performance of the cell controller, and thus the facing crucial issue is the “Division of Work” in information processing between CIM and the cell controller, resulting in the growing confusion as mentioned above.

Enterprises and other	Monitoring - Surveillance machine states / Display of production control data	Service & maintenance - Evaluation for healthy condition of machines / Long-distant services	Recognition for tool status and its up-to-date Optimisation of tool utilisation & control	Control for machining history of work & quality data histroy	Work planning & scheduling	NC information production & process simulation based on part drawing	Remarks
EMAG	○	○	○	○	○	○	
Index Xpanel	○	○	○	△ Processing machining history data is not clarified	○	———	NC controller integrated with personal computer facilitating “Paperless production” (Direct connectivity with business organisation)
FMC Cell controller	○	○	△ None up-to-date function for tool status	○	△ Supply of due data from computer of upper layer		

Table 5.4 Comparison of controller for CPS module with cell controller

Table 5.4 shows a functionality comparison between the advanced NC controller and the cell controller in general so as to solve easily from such confusion. As can be readily seen, we can understand the differing features at glance, and in short, nearly all functions in both the controllers are similar; however, we can see a typical differing feature in the division of work mentioned above. In the simplest case in the advanced NC controller, the router only is attached to NC controller to communicate with the enterprise organisation especially reporting the machining achievement.
More specifically, the controller for the CPS module can process a part of the information belonging to the production control and enterprise management such as work scheduling, tool layout planning and process simulation, which are under the control of CIM in the traditional controller of FMC. As exemplified by the controller of Index-brand, the controller

can switch from NC controller to the personal computer to connect directly with ERP and MES, which are equivalent to CIM in the past.

To this end, it is extremely worth suggesting that we cannot find any functions closely related to the autonomous choice of the corresponding CPS module, when carrying out machining with the smart factory. In many respects, this is one of the facing controversial points even when the CPS module is of "One-Machine Shop-like" by using the density function-integrated machine tool.

5.4.1 Real Time Visualisation of AGV States by Long-distant Surveillance and Control

This system is closely related to "Fog Computing", and can be characterised by its stable and reliable wireless communication system with 920 MHz in frequency band. In short, the system was successfully installed in Tochigi Plant of Nissan Motor, which can finish the passenger car about 250, 000 units per year (HP of OKI, 2016).

More specifically, the system can control AGVs about 300 units without any trouble, which are caused by various hindrances for telecommunication within the factory floor. Fig. 5.12 illustrates the publicised concept in the prototype of AGV control system, and can be characterised by the following.

(1) The monitor is for on-line surveillance of the states in each AGV, e.g. position, travelling speed, battery capacity, and trouble detection by sensor.
(2) The monitor can control AGVs, if necessary.
(3) It is expected to achieve the effective operation of AGV by analysing the accumulated data in the monitor, although AGV is not of special type, but widely available at the market.

In contrast, it is worth suggesting that each AGV has not the autonomous function, which is the utmost characteristic feature of the smart factory. In addition, there are about 30 transportation routes of loop type for AGVs; however, it is not clear regarding whether a group of AGVs is under the block control system or not.

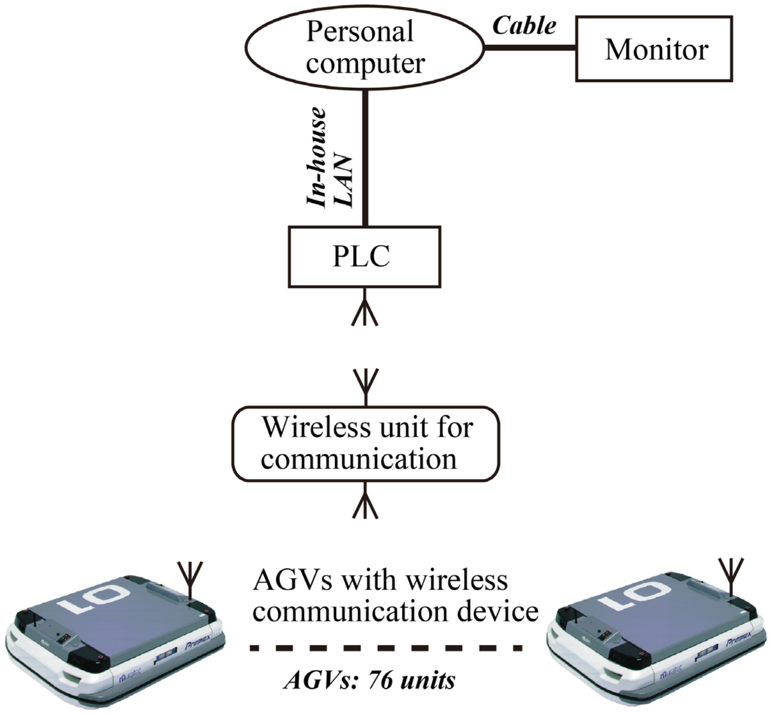


Fig. 5.12 Concept of AGV control (by Nissan Motor)

5.4.2 CPS Module for Tapered Roller Bearing Production

It is said that Kagawa Plant of JTEKT has successfully run the smart factory to produce the tapered roller bearing for the motorcar in 2016. Actually, JTEKT aims at the improvement of the assembly and inspection processes to increase the operational efficiency in consideration that the production volume is 5.5 million bearings per month. More specifically, this factory applies IoT (Information of Things) to gather the information related to the product quality, i.e. grinding burn in the inner race, and also the state of manufacturing line, from CNC machine tools and PLC (Programmable Logic Controller).

Importantly, the raw material for the outer and inner rings is warm-forged to render turning for rings useless, whereas we need the die with the higher accuracy and press machine with higher performance.

As will be clear from the above, we can interpret that the visualisation of the manufacturing line by the monitor is similar to that of Werk Regensburg of BMW, and that the detection of the grinding burn is one of the variants of the in-process measurement for grinding so far performed. Although saying so, we can observe a considerable number of the so-called smart factories, in which the core is facilitated by the in-process measurement. This may be attributed to some key terms related to the CPS module in the smart factory. In fact, the "acatech" suggests that the sensor is the core of the hardware in the CPS module to collect the big data.

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Chapter 6 Leading Subjects for Research and Engineering Development

Abstract As shown in some practical applications of the smart factory within Chapter 5, we must be aware that the production activity should create the wealth for the human society by conducting, in preferable cases, the lucrative business. In fact, it is rare that the original concept as a whole of the smart factory is in fruition, but the smart factory being on work has been established by employing a part of the original concept especially activating its beneficial features, which depends considerably upon the customer's requirements.

In the full application of the original concept, a root cause of difficulties lies in the preferable harmony and chemistry among various reciprocal attributes, which can determine the system characteristics. Obviously, we must establish a smart factory in accordance with the customer's requirements, and thus a further hindrance is certain uncertainties in such requirements. In addition, such leading attributes ranges from engineering, through economics, to social attributes (see Fig. 1.9).

As a result, nearly all production engineers and researchers do not delve into the essential features within a facing problem, but do solve such a problem by the case-by-case way in both FCIPS and the smart factory to certain extent. Obviously, the solution obtained by the case-by-case method is very valuable together with high applicability.

In contrast, it is desirable that people in the academia should scrutinise in detail the essential features of each R & D (Research and Engineering Development) subjects and could transfer the valuable achievement into the practice after conducting an innovative research. Paraphrasing, we may appraise often the well-intellectual backup method rather than the experience-based remedies to solve the engineering problem.

In many respects, we must investigate leading R & D subjects in FCIPS and the smart factory in consideration of their essential features, and this chapter will place the stress on the technological subjects. On the basis of our long-standing experiences for FCIPS and investigation into the crucial problems in the smart factory, we first analyse and suggest some leading R & D subjects in both FCIPS and the smart factory, and then some representatives in such subjects will be detailed and discussed herein. Of note, Chapter 7 will discuss the R & D subjects within manufacturing culture and industrial sociology aspects.

6.1 First-hand View for Leading R & D Subjects

Tables 6.1 (a), (b) and (c) summarise some leading R & D subjects in the 2010s after delving into three branches, i.e. (1) system layout issues in general concerns, (2) CIM and cell controller, and (3) cloud and fog computing.

(a)

Desirable virtual concentration of a group of FMCs
System and cell descriptions by directed graph, Petri Net, and so on - Establishment of design methodology for autonomous cell
Modular design of FMC and FMC-integrated system for "One-off Production" available for localised globalisation era - With open auction function
Future perspective of system components
Development of "Function-integrated Machine Tools" in consideration of "Linkage Diagramme within Machining Space"
One-machine shop compatible with FCIPS - Enhancement of "Platform Method"
Evaluations for "Flexiblity" and "System Similarity"
Contribution of "Manufacturing Culture" to production systems - For example, design specifications for Asian region-oriented FMS and FMC
Clarification of differing features of "Agile Manufacturing System" from "Flexible manufacturing System"
Estimation of machining cost in consideration of system layout and production pattern when inputting objective products

(b)

Incorporation of human-intelligence into CIM - System design to integrate deep knowledge of mature engineer and technician - Quantification of “Flair and Inspiration” of mature engineer and technician
Information conversion methodologies between uncertain and functional attributes, between functional and structural attributes, and also between structural and manufacturing-related attributes
“Division of Work” between CIM and cell controller including effective use of data tag, e.g. RFID
Funcition and performance of advanced cell controller (NC controller + Personal computer)
Convertibility of FMC and AMC into CPS module - Cell controller for FMC of “One-off Production” and its applicability to controller for CPS module
Sensor fusion for flexible machining system - Detection of reliable and valuable information from very noisy output signal

(c)

Desirable basic layout configuration of CPS module and its connectivity with information communication network
Definition of “CPS module” as compared with that of FMC for “One-off Production”
“Division of Work” between cloud computing and fog computing (edge) with preferable connectivity
NC controller applicable to smart factory and convertibility of cell controller to fog computing
Determination of dimensional and performance specifications of smart products like “Culture- and Mindset-Harmonised” , “Individual Difference-oriented” , “Sensitivity Compatible” and “Aesthetic-based” types

Table 6.1 R & D subjects for system design in general, FCIPS and Smart factory: **a** System layout issues in general concerns.
b CIM, information network and FMC.
c Cloud computing, information network and CPS module

Within R & D context, it is very interesting that we have three categories, i.e. (1) subjects already suggested, but not investigated as yet, (2) subjects once investigated, but not so active since then, and (3) subjects newly arisen. Of course, the newcomer is related to CPS module and the division of work in information processing among cloud computing, fog computing and CPS module.

For example, we recognise the importance of CIM with human-intelligence incorporation, and thus there have been a considerable number of the developments for CAPP (Computer-Aided Process Planning) with expert system; however, its advanced type, i.e. *CAPP of Flair Type*, was once investigated, but far from the practical use (Ihara and Ito, 1991). In the evaluation of the "*Flexibility*" of FMS, surely we have had a considerable number of the studies; however, such studies are not considered the differing characteristic features among FMC, FMS and FTL. In fact, we have not had any proposals to evaluate quantitatively the flexibility of FMS in consideration of the system configuration to a large extent, apart from that of Ito et al., (1985).

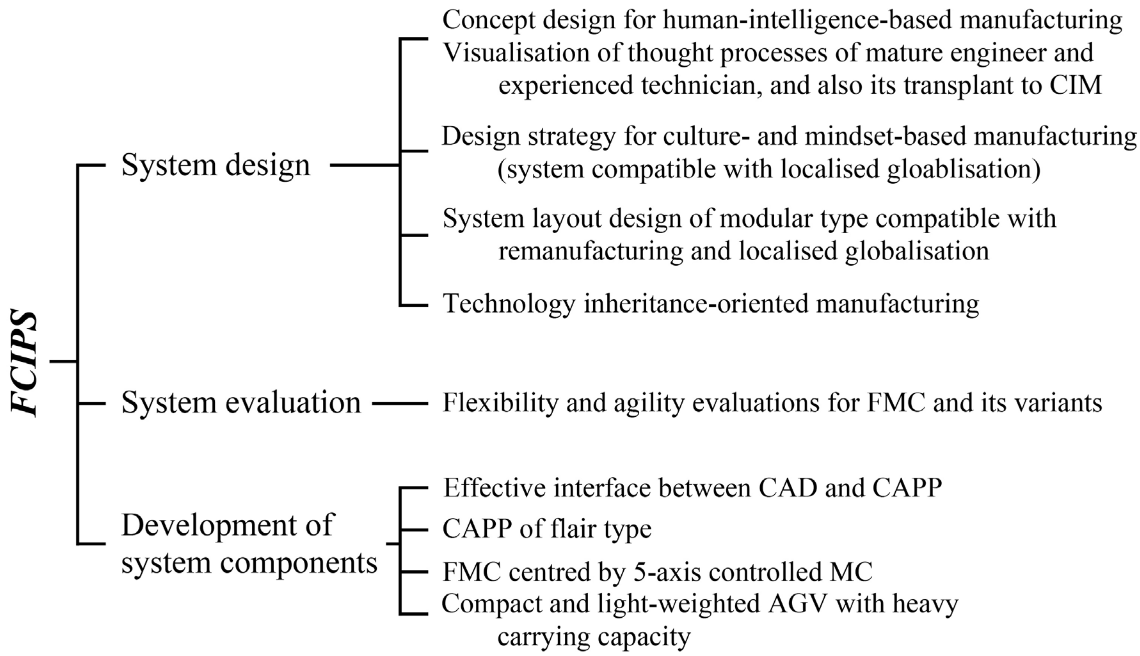


Fig. 6.1 Major research subjects for FCIPS around 2005

In principle, it is desirable to carry out the academic research into FCIPS and the smart factory; however, the research subject itself is ill-defined by nature, when we consider all the conditions surrounding the research subject. In general, we may suggest the difficulty of modelling properly the objective subject, and manage the facing problem with the case-by-case method in practice. It is furthermore worth suggesting that the R & D subjects for FCIPS may be much more detailed by the advent of the smart factory than ever before, because we must discuss the convertibility of FMC for one-off production into the CPS module in the smart factory. Thus, Fig. 6.1 reproduces the R & D subjects for FCIPS around 2005 to deepen the related knowledge.

In the following, we will discuss some leading R & D subjects to clarify their present perspectives and also to suggest the facing problems to be solved.

6.2 Investigation into Smart Products and Their Production Systems in Detail

As already shown in Table 1.4, the smart factory can facilitate the generation of the "*Smart Product*"; however, the smart product itself is not obviously defined as yet, but is only said to be compatible with the individual requirements.

Types	Prototype and merchandised products
Region-specified	NC lathe with total enclosure made of bulletproof glass
Individual difference-oriented	Painless injection needle Steering system with high operability in passenger car
Sensitivity-oriented	Bioprosthetic devices Home robots for mental cure
Aesthetic-like	Wall clock decorated with gold and silver foils Exhaust gas filter made of ceramics and produced by earthenware manufacturing technology Water lubricated step-land bearing by using wooden parquetry I phone case made of Maekawa Inden since Edo era Leather fabric made of leather and crystal string and by applying Nishijin-brocade technique
Individual difference- and sensitivity-oriented	Clothes, shoes, and underweare Cosmetics - Lasting with slippy feeling

Note: Inden is one of traditional artefact, and a variant of "Buff" made of deer leather and japan

Table 6.2 Products placing stress on culture- and mindset-harmonised attributes around 2010

To discuss R & D subjects, we need thus to envision some concrete images of the smart product, and in due course a clue is to delve into the

"Manufacturing Culture-related Products". In fact, the manufacturing culture has proposed the "*Culture- and Mindset-harmonised Product*", "*Individual Difference-oriented Product*", "*Sensitivity Compatible Product*" and "*Aesthetic-like Product*", which appear as to be within a family of the smart products (Ito and Ruth, 2006).

Table 6.2 shows some manufacturing culture-related products around 2010, which was already merchandised or being in prototype. As can be seen, it appears that we have already much more smart products than our imagination. Importantly, these products should be designed by converting the uncertain attributes into the engineering design specifications.

To deepen what are the facing problems in this R & D sphere, Fig. 6.2 shows a "Sari" for Indian ladies, which is one of the individual difference- and sensitivity-oriented products as exemplified already in Table 6.2. In this context, Rajagobalan (2016) has established a "Digital Fashion" system by using the digital mirror and a design-factory system located in both Singapore and India.

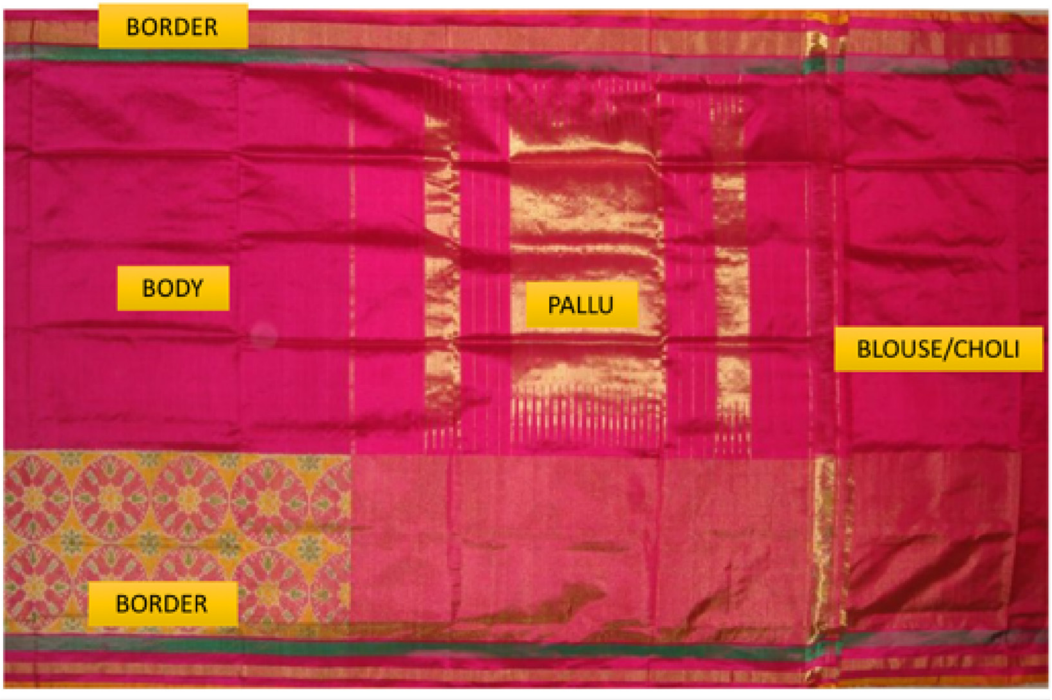


Fig. 6.2 A pattern design of "Sari" for digital fashion

The "Sari" is made of monolithic cloth with various colours and patterns, which results in the attractive appearance after dressing duly. Thus, the dressmaker in Singapore measures the posture of a lady by the digital mirror together with quantifying the uncertain attributes like the preference and sense of beauty through conversation while measuring. Then, the final digital information is transferred to India to produce the corresponding "Sari".

Reportedly, Adidas has publicised a concept of "Speed Factory" to produce the order-made shoes in October, 2017, which can be also regarded as one of the individual difference- and sensitivity-oriented products together with placing the stress on the local needs. In fact, the first product was tailored for London and the next comer is that for Paris within the product series AM4, which can be, of course, characterised by the compatibility with each customer's requirements.

More specifically, the "Speed Factory" is an integrated manufacturing and design concept developed by Adidas since 2015. The aim is to establish a global automated manufacturing network that will allow the transfer of the production to where the brand's consumers are located [1]. Ultimately, the "Speed factory" concept pursues the design of highly functional and customised products, first and foremost sports shoes, in a unique design and within extremely shortened time span (of just a few hours) between design and the delivery of the product in the store. This is being implemented through a high level of automation based on robots, 3D printers, laser and computerised knitting machines.

Most importantly, the concept of "Speed Factory" relocates manufacturing to where the design originates and where the customers are. This enables highly customised, individualised - and thus on-demand production, which includes modular and hyper-flexible factories (mass personalisation).

Since recently a prototype of "Speed factory" operates in Ansbach, Germa-

[1] Evidently, the "Speed factory" with its global automated manufacturing network bringing the production to the customer bears the potential to reduce the transportation-related emission and cost. Furthermore, Adidas has claimed clearly to reduce the use of adhesives through the use of advanced technology.

ny, another one is being launched in Atlanta, USA. If this development continues, the global production structure will change [2]. Still, mass production will be concentrated on selected Asian countries, but customised share of production will increase and become dispersed across the globe.

6.3 Property Conversion in Design Information Processing

Figure 6.3 shows a simplified design flow of the product in general, and as can be readily seen, there are several procedures, where the information change their properties, e.g. those from "*Uncertain Attributes*" to "*Functional Attributes*" in concept design, and from "*Functional Attributes to Structural Attributes*" in basic layout design.

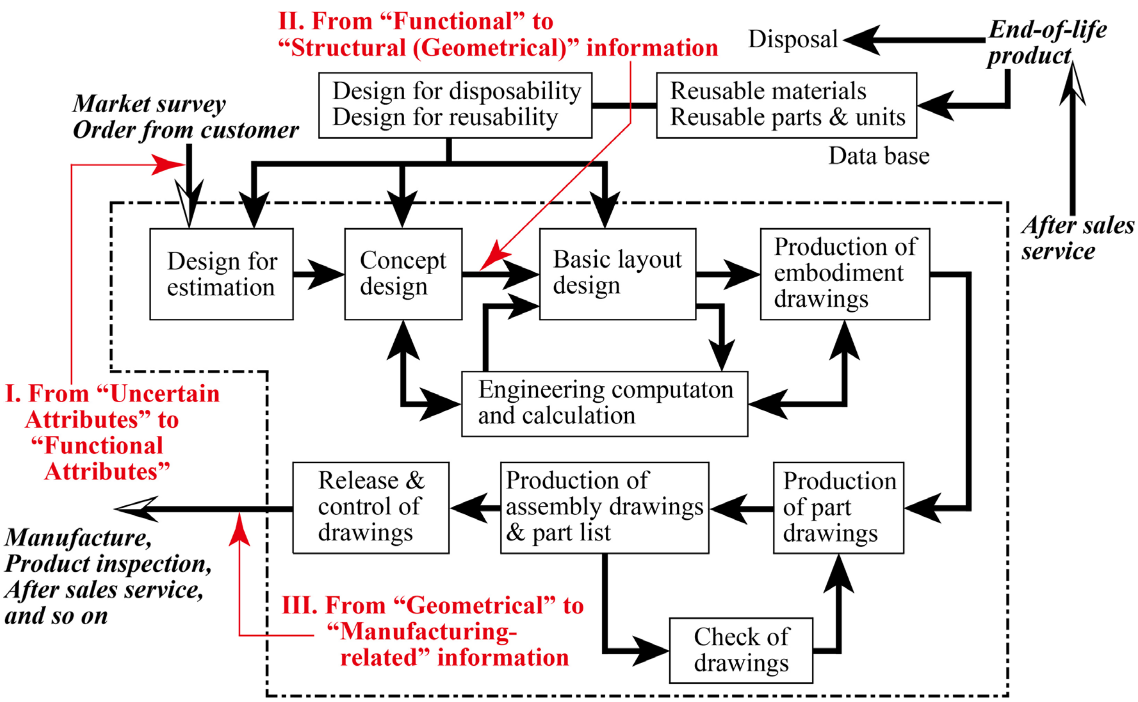
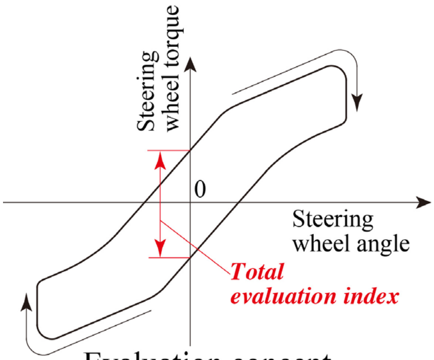


Fig. 6.3 Simplified flow in engineering design for product and several processes with property change in information

Such an information change may be called "Property Conversion in Information processing", and as will be clear from Section 6.1, it is very

[2] For each consumer, a personalised product can be manufactured.

important in the design of the smart product. This is because the smart product is individual requirement-oriented, and thus includes, more or less, the uncertain attributes within its engineering design specifications of first stage.



Evaluation concept

Expressions for steering feeling

Phenomena, Function	Sensory evaluation term
Self-aligning torque transformation to steering wheel	On-center feel Build-up feel Direct feel etc.
No sticky or dragged feeling	Smooth without stick Low-friction etc.
Moderate effort during quick steering	Low-inertia feel High rigidity feel Wall effect etc.
Stable on-center or at keeping angle	Stability Steadiness Solid feel etc.
Self-aligning torque transformation without variation or vibration	Smootheness Continuous Silky etc.
Assist torque characteristics	Easy driving Preferred/not preferred etc.

Fig. 6.4 Total evaluation index for steering feeling of motorcar and its composition (By Nakano et al)

Figure 6.4 shows a concept for totally evaluating the steering feeling of the motorcar by the steering torque. In short, the evaluation value becomes high, when the steering torque is within a certain magnitude at nil in the steering wheel angle as shown also in Fig. 6.4 (Nakano et al, 2009). Importantly, the steering torque may however be determined by a handful of factors as shown together in Fig. 6.4, and in this case, a root cause of difficulties lies in the determination of the evaluation expression in consideration of the cross- and synergistic effects among the evaluation indexes.

More specifically, Fig. 6.5 reproduces a conversion procedure for the shotgun, which necessitates the concert with the penchant of the user. The uncertain attribute, i.e. “Penchant for Shotgun” can be converted into the “Qualitative Engineering Design Specifications” by using the tree structure of hierarchical type. In fact, there are three steps in the conversion, and such a conversion is carried out by the long-standing experience of the mature engineering designer in practice. In short, the "*Fitness in Folding Action*" is finally converted into the "*Damping Capacity at Tight Fit between Barrel and Frame*".

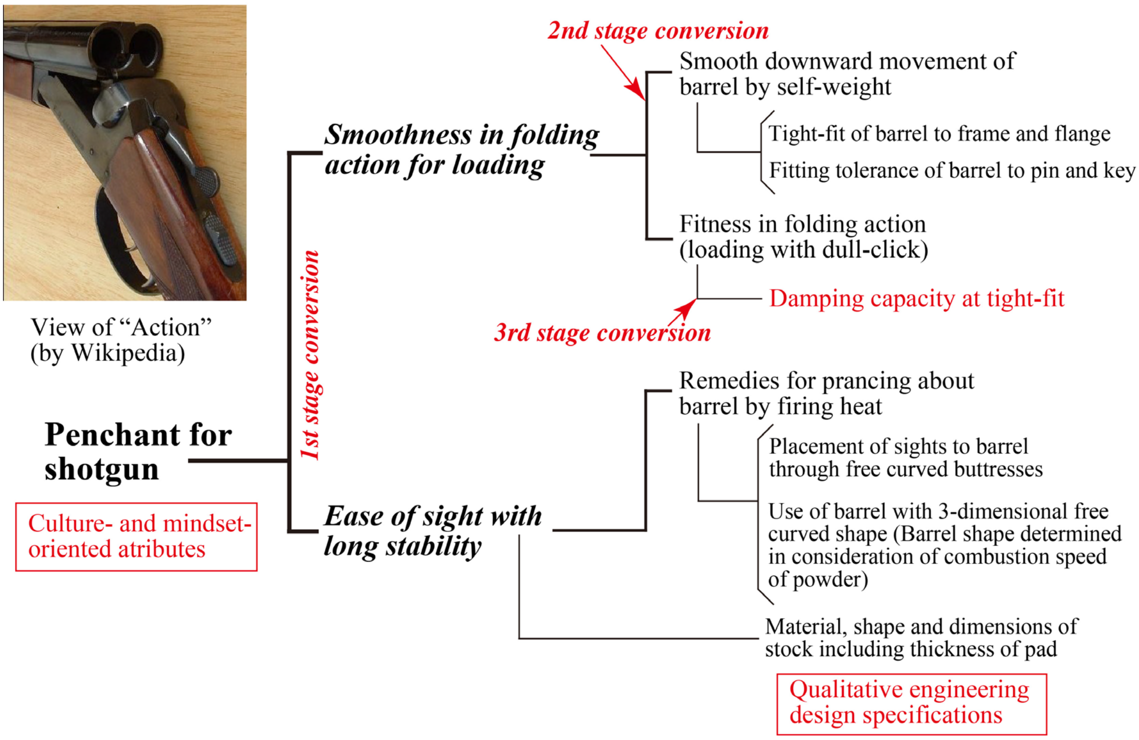


Fig. 6.5 Hierarchical tree structure representing conversion procedure of culture- and mindset-oriented attributes to engineering design requirements - in case of shotgun

Importantly, in this case, the barrel with long-term stability in sight alignment can be guaranteed in full consideration of the powder burning velocity. In fact, it is preferable to use the barrel of free-curve configuration rather than cylinder barrel, and even in such a qualitative information conversion, we must conduct it with the experienced engineering knowledge about the product (Barthold, 1986).

In fact, an uncertain attribute consists of a considerable number of the determinants as shown already in Fig. 6.4, which should be considered in the conversion as a decision index. Admitting the very difficulty in the conversion of the uncertain attribute into the quantified specifications, we need a conversion criterion, e.g. representative total index, in consideration of all the indexes; however, each index is, in general, not independent, but in mutual relation with others having different affecting magnitudes. Paraphrasing, a representative total index is given by an evaluation function, which consists of individual indexes with weighing coefficient together with considering the cross-effects among indexes, and synergistic effects among indexes.

To deepen our knowledge, we discuss now the conversion in the descending flow of the product design, i.e. that from the part drawing (*Geometric Information*) to process planning (*Manufacturing-related Information*). When placing the stress on cylindrical component turning,

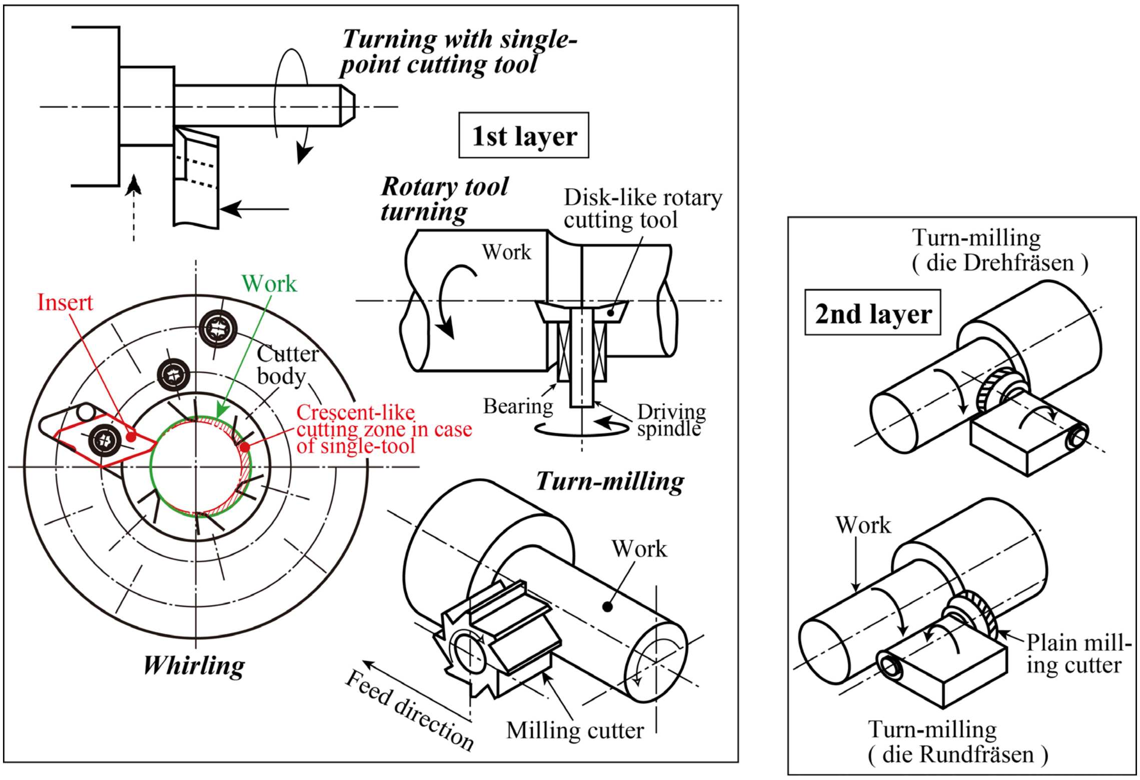


Fig. 6.6 Various turning methods to generate cylindrical component

process planning should be produced from the given part drawing as already shown in Fig. 6.3. As can be readily seen, a component can be turned by various methods as shown in Fig. 6.6, and thus the single geometrical information may be converted into a considerable number of the manufacturing-related information. In short, we cannot guarantee "*One-to-One Relationship*" between both the information, even when we determine the constraints from machining accuracy, cost, delivery date and so on.

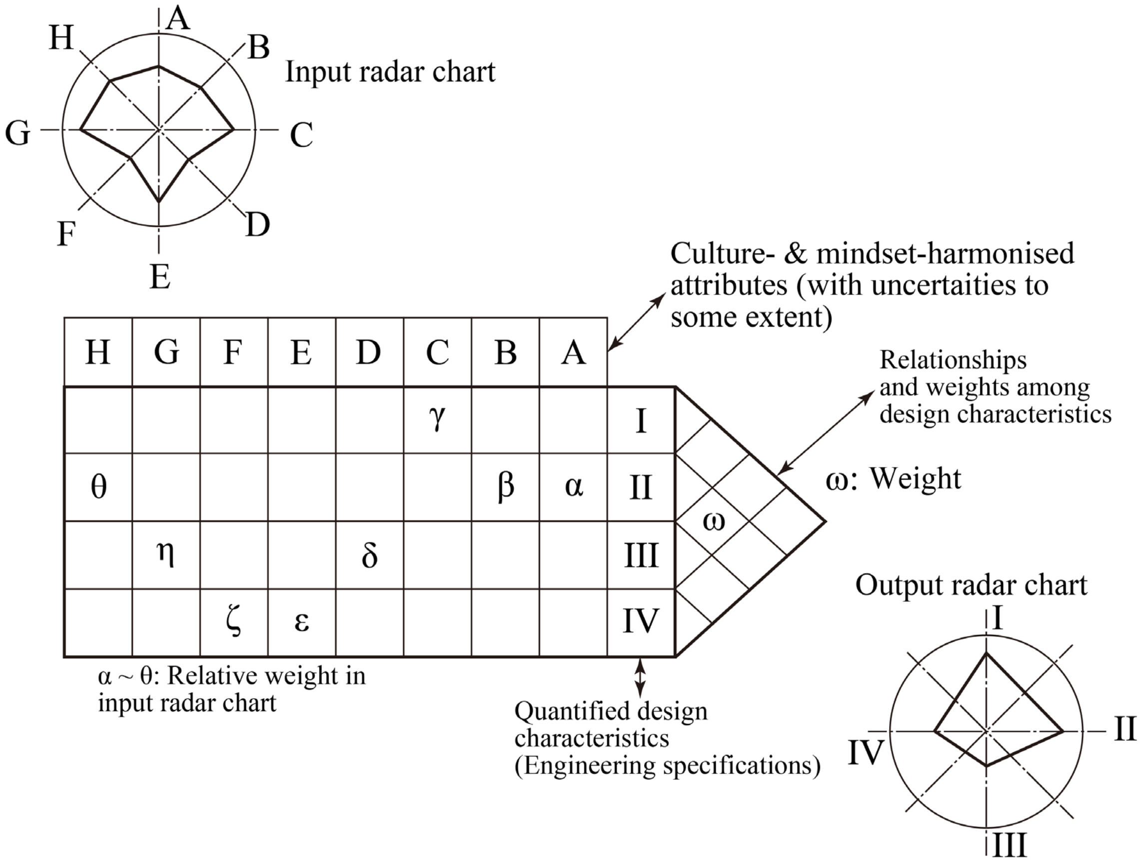


Fig. 6.7 Conversion method from culture- and mindset-harmonised attributes to engineering specifications by QFD of hierarchical type and radar chart (by Höft)

Obviously, such a conversion work is very time and cost expensive, and thus we must develop a methodology. In this context, Höft (1999) proposed a conversion method by using QFD (Quality Function Deployment) of hierarchical type as shown in Fig. 6.7, although it is far from the practical application. As can be readily seen, the uncertain attributes within a product are first represented by a radar chart in consideration of the superiority order, e.g. relative weighing rate among attributes, and then converted into the quantified design characteristics by compensating the cross-receptance (mutual affecting rate) among the characteristics. Of course, the conversion is carried out by the step-wise way. It is furthermore regrettable that there are no succeeding research activities following that of Höft.

6.4 Quantitative Evaluation of System Flexibility

Because of the very practical-oriented technology, once the manufacturing system raises certain benefits after its installation, even professional people are gratified with such benefits and forget the dire necessity of carrying out its rational evaluation. As a result, there have been no noteworthy researches into and engineering developments for the system evaluation, apart from that for the simulation tools of production and operational controls. In addition, such a trend is accelerated by the difficulty in determining the definition for and evaluating of the system flexibility even in the 2000s.

In contrast, we must be aware of the utmost characteristic feature in the correlation of the “Design and Evaluation”, which can be represented with “Two Sides of the Same Coin”.

Having in mind the amazing effects of FMS, from the past we have tried various evaluation methods, and Fig. 6.8 is a first-hand view of such trials in the 1980s; however, these trials have not been established up to certain technologies satisfactorily applicable to practical use even now. For example, we have a considerable number of the software tools for the “System Simulation”; however, the most of the software has some shortcoming in its mathematical model.

Importantly, we must investigate now each subject shown in Fig. 6.8 in consideration of the advances of the corresponding technologies after then. For example, the cell description was one of the auxiliary design methodologies of FMC to determine the (defacto) standardised type in the past, whereas its primary concern is, at present, to facilitate the "Autonomous Function", so that FMC will enable to convert to the CPS module.

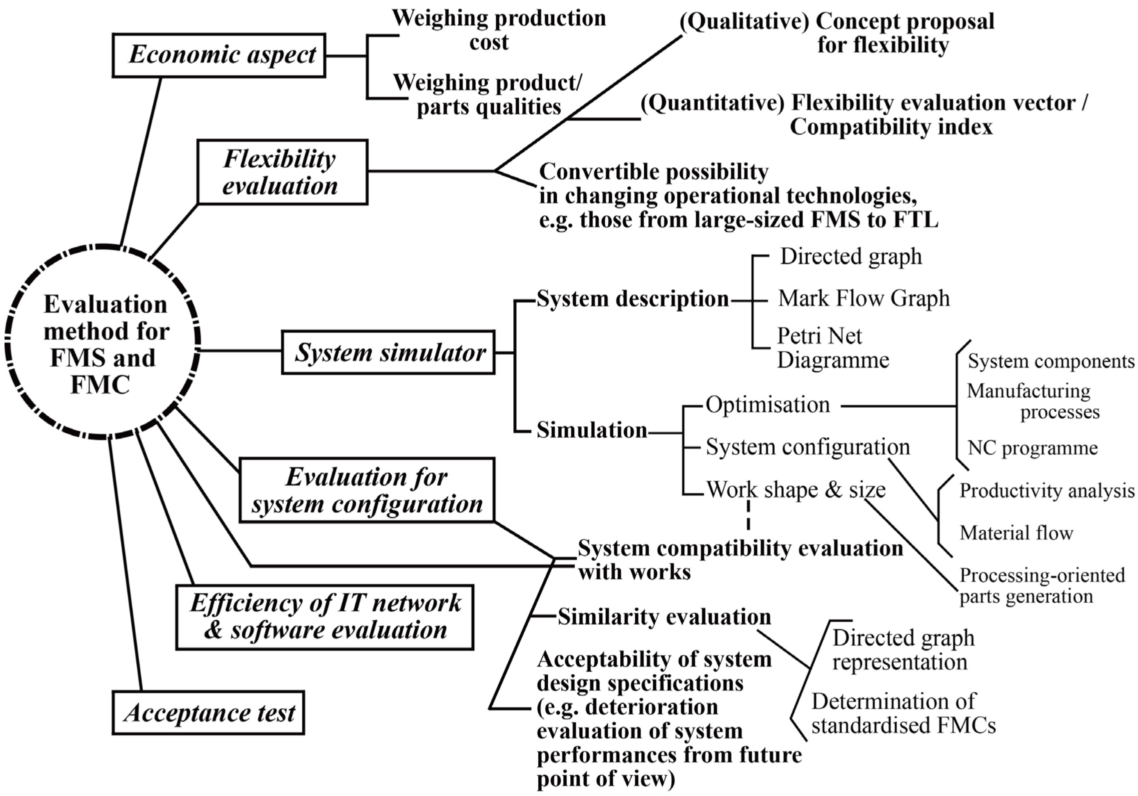
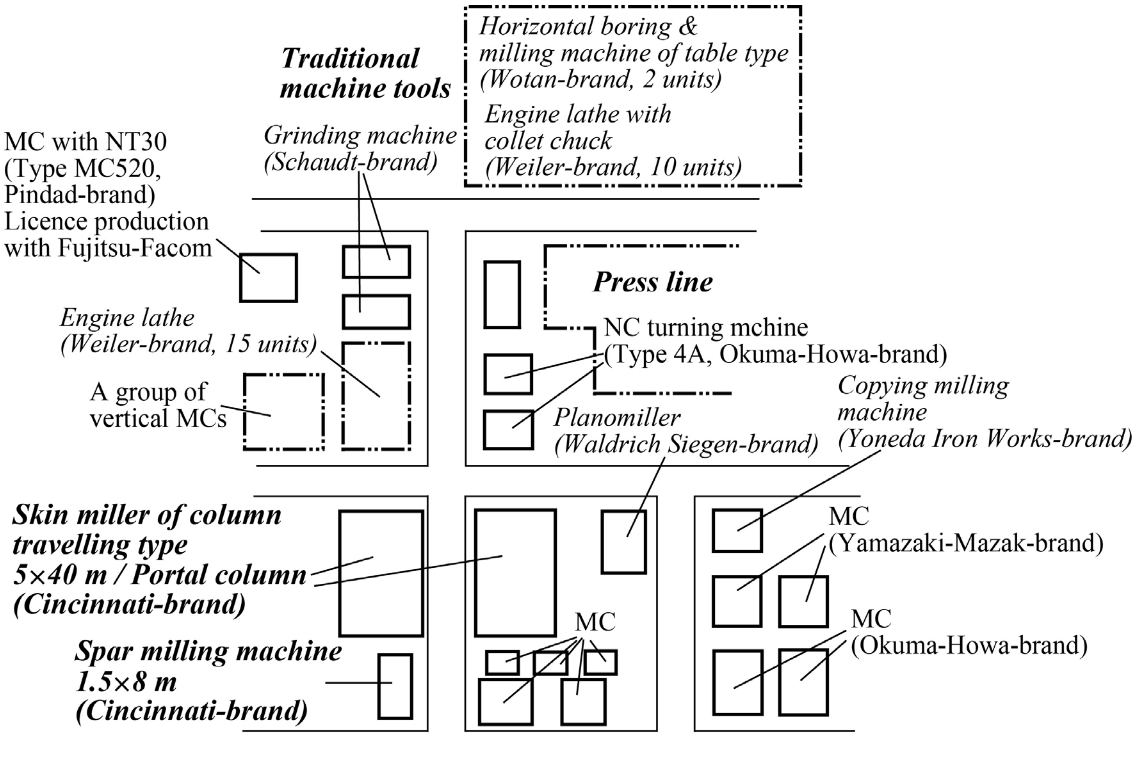


Fig. 6.8 A first-hand view for evaluation of FMS and concerns in 1980s

In fact, it appears that the enterprise uses its own evaluation method on the basis of enterprise's own experiences especially from the economic aspect. As can be readily seen, the utmost simplified method is to evaluate the system flexibility by measuring the change-over-cost, which is necessary for the re-configuration of the system when the objective product is changed. Obviously, a less change-over-cost of the system, the more flexible is the system configuration.

Now let us discuss the evaluation of "*System Flexibility*". In fact, the flexibility is the utmost characteristic feature in FMS, and we have endeavoured to establish the quantitative evaluation of the flexibility since the 1980s. Of special notes, we must furthermore be aware of another problem regarding what is the acceptable definition for the system flexibility in the case of the manufacturing system for the aeroplane shown, for example, in Fig. 6.9. In the aeroplane industry, such a system configuration, which involves the three sub-systems consisting of the traditional machine tools, special-purpose machine tools and NC machine tools, is very common. In short, there have been no acceptable evaluation methods for the flexibility.



Note 1: Machining capacity - 1 passenger plane (around 40 passengers) /month
Note 2: Combination of traditional machine tools, special-purpose machine tools and NC machine tools

Fig. 6.9 Machining systems in Nusantara
(Aeroplane manufacturer in Indonesia, 1993)

6.4.1 Evaluation of Specified Flexibility

In consideration of the complexity and to ease of evaluation, the system flexibility has often been evaluated after specifying the characteristic factor, i.e. "*Specified Flexibility*". In retrospect, there were various proposals for evaluating the specified flexibility in the 1980s as shown in Table 6.3. These were of limited help to advance the due technology, but also remained in the merely qualitative evaluation without having any relation to the system configuration. In addition, these are furthermore under the hypothesis that all the factors are independent one another [3].

Proposers (Year)	Kinds of specified flexibilities
Warnecke & Steinhilper (1982)	Long and short terms
Buzacott (1982)	Job, Machine, Action and State
Rathmill & Browne (1983)	Customizing
Gerwin (1983)	Mix, Parts, Routing, Design change and Volume
Suga of Hitachi Seiki (1986)	Mix, Routing, Design change, Volume and Unexpected order placement

Table 6.3 Various proposals for specified flexibility in 1980s

Against this context, Yamashina suggested the importance of the mutual correlation among the factors in practice. He proposed an idea to show certain correlation with the system design specifications as shown in Fig. 6.10; however, there remained something to be seen. For example, the transfer flexibility means the possibility for getting a new work ahead of the forerunning work in the transfer line within the system. Thus, this flexibility for FMS of line type differs considerably from FMC-integrated FMS; however, it is critical that we may have apparently the same qualitative value, which does not reflect actually the correct specified flexibility in practice. In general, the linear type with sub-transfer line is very suitable for the realisation of the transfer flexibility, although the

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[3] For ease of reference, Table 6.3 was produced on the strength of the review paper of Nisanci and also by adding other proposals so far publicised on the occasion of the lecture course of JSME by Ito.
Ito Y (1989) Present Perspectives of Evaluation Methods of FMS. In: Handouts for Evaluation Methods for FMS and Its Case Studies, No. 890-8, p. 1 ~10, JSME.
Nisanci I (March 1985) Survey of FMS – Applications, Problems and Research Areas. SME Technical Paper MS85-146.

system redundancy increases.

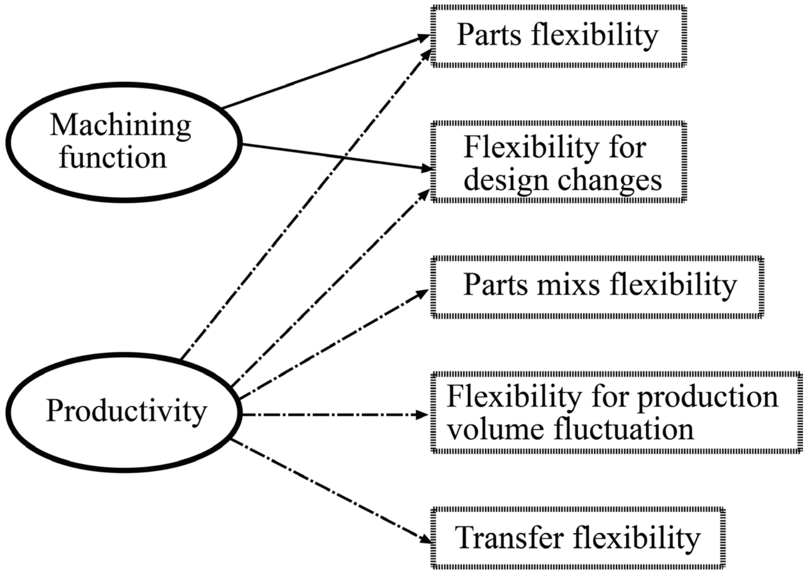

Fig. 6.10 Definition of various specified flexibilities with relation to design specifications (by Yamashina of Kyoto University, 1987)

Product flexibility:
Ability of a manufacturing system to make a variety of parts type with the same equipment

Market flexibility　Volume and mix flexibility

Sequence flexibility:
Ability of a manufacturing system to master a variety of sequences to cope with product variety

Process flexibility　Operational flexibility　Program flexiblity

Routing flexibility: Ability of a manufacturing system to use multiple alternative routes to produce a set of parts

Production flexibility　Capacity flexibility　Machine flexibility

Expanshon flexibility

Table 6.4 Various proposals for specified flexibility in 2010s

At present, such an evaluation method is still in leading position together with trying the quantification as shown in Table 6.4, which summarises the specified flexibility by the literature survey around 2010. Importantly, each researcher defines the specified flexibility differently under the same term, resulting in uncertain selfish evaluation, which may not be accepted commonly.

For example, Rogalski and Ovtcharova (2009) have publicised a research paper into the flexibility evaluation, in which the technique called "ecoFLEX" can facilitate for estimating the "Flexibilities of Volume, Mix and Expansion". They have referred to the forerunning researches especially within the information and management technologies, and not in the system design aspect in the 1980s. In addition, Metternich et al (2013) introduce the volume flexibility proposed by Parker and Wirth as follows.

$$VF = 1 - \frac{F}{C_{max}} \left(\prod_{i=1}^{n} \frac{a_i}{b_i} \right)^{1/n} \text{-------(6.1)}$$

where, VF: Volume flexibility, F: Fixed costs, C_{max}: Production system capacity, a: Required amount of capacity units to produce one product unit, b: Contribution margin of one product unit.

In this context, we must be aware that the specified flexibility cannot evaluate the essential feature of FMS in practice, but actually its validity is verified by using the hypothetical operating data of the system. More specifically, in the research into the evaluation of the flexibility mentioned above, the utmost fatal shortcomings lie in the problem setting, where the mathematical model is too simplified and departs from the states of FMS and concerns in practice as follows.

(1) As already shown in Fig. 3.1, we have various kinds and types of FMS and each variant has its own characteristic features; however, the researchers don't pay any attentions to such important factors.
(2) In the system design of FMS, the flexibility is, as mentioned above, one of the leading design attributes together with expandability and redundancy, which can be facilitated by the "*Modular Design*". It is thus rational and preferable that we must evaluate to what extent the

flexibility estimated in the design is being used while machining a part family.

Paraphrasing, some specified flexibilities should be re-investigated their validities from the viewpoint of either including in the system design specifications or in close tie with the system configuration. For example, the expansion and routing flexibilities are closely related to the design specifications and system configuration, respectively. In addition the machine flexibility renders useless when considering the amazing development of the highly function-integrated kinds in the machine tool (see Chapters 3 and 4).

Having in mind that the specified flexibilities have certain restrictions particularly from the complexity caused by their mutual correlations, we must challenge its quantified evaluation, and if possible, by integrating a group of the specified flexibilities, establish an evaluation method for the total flexibility as will be discussed later.

On such an occasion, at crucial issues are what is the definition and how to quantify the specified flexibility, which are far from completion at present.

6.4.2 Evaluation of Total Flexibility

It is desirable to evaluate the system flexibility in full consideration of both the system configuration and the operation mode. As can be easily imagined, such an evaluation is very difficult, because we must consider a huge number of the system attributes together with their cross-receptances.

As a result, we have tried to evaluate such a total flexibility indirectly by considering some proper indexes such as (1) "*Change-Over-Cost*" of system to respond adequately the new manufacturing requirements, and (2) the reduction amount of the "Stock Volume" and "Work-in-Progress". Of note, MTU of Friedrichshafen defined the system flexibility by the "Ratio of Enabling Number of Processes of System to Total Required Number of Processes of an Objective Part" in 1982 [4].

Against to such the unfavourable state, Ito et al (1985) tried once to

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[4] Based on memorandum of Ito on the occasion of on-the-spot investigation to MTU.

evaluate the "*Total System Flexibility*" in consideration of the cell and sys-

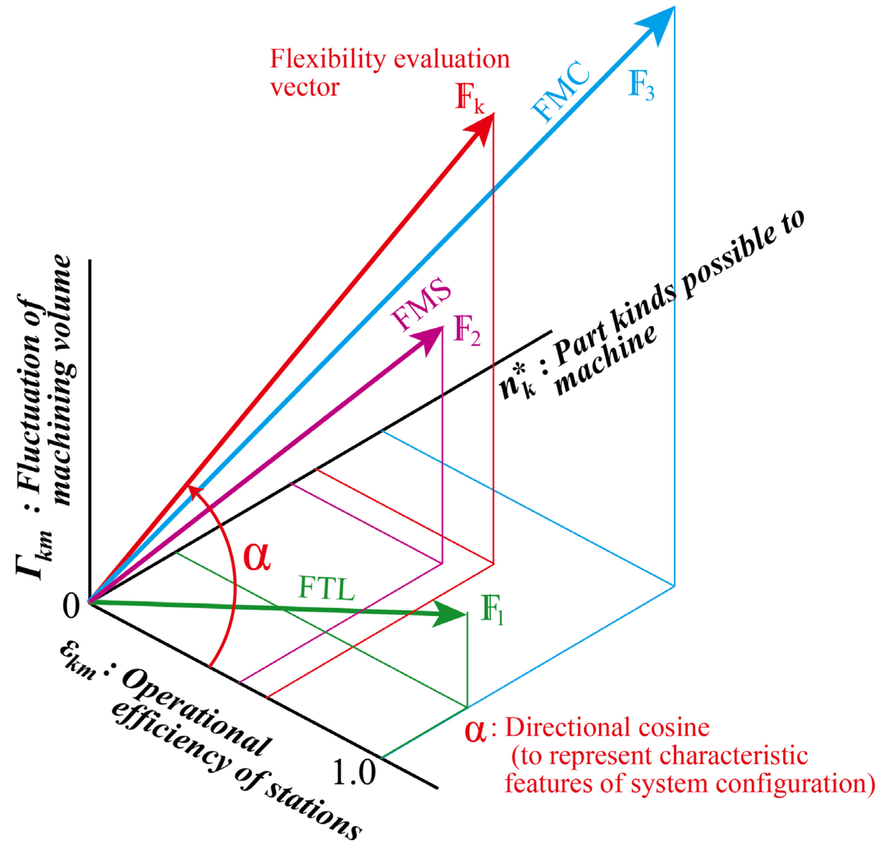


Fig. 6.11 Concept of flexibility evaluation vector

tem configuration. In this trial, the system flexibility can be represented by "*Flexibility Evaluation Vector*", which is a non-dimensional index and can evaluate, in principle, the rate of the effective use within the designed capacities of all the system components while machining a part family.

Figure 6.11 shows a concept of the flexibility evaluation vector, when placing the stress on the processing function. In this evaluation, we use an index represented by the space vector within the Cartesian Co-ordinate, in which the "Absolute Value (Magnitude of Vector)" and "Directional Cosine" can represent the "*Total System Flexibility*" and "*Characteristic Feature of System Configuration*", respectively. As can be readily seen, it is possible to add another attribute, e.g. machining cost, by extending the three-dimensional vector to the four-dimensional one.

More specifically, the flexibility evaluation vector is given by the three

attributes i.e. (1) fluctuation of machining volume for a part family (Γ_{km}), (2) part kinds possible to machine (n*) and (3) operational efficiency of stations (system components) within a system for each part within a part family (ε_{km}). These three attributes can be given as follows.
By assuming now that we have a group of part families P_k (k = 1~i), and the system J (J = 1~N) enables to process it, then, the operational efficiency ε_{ki} while machining the part i within the part family P_k is given by

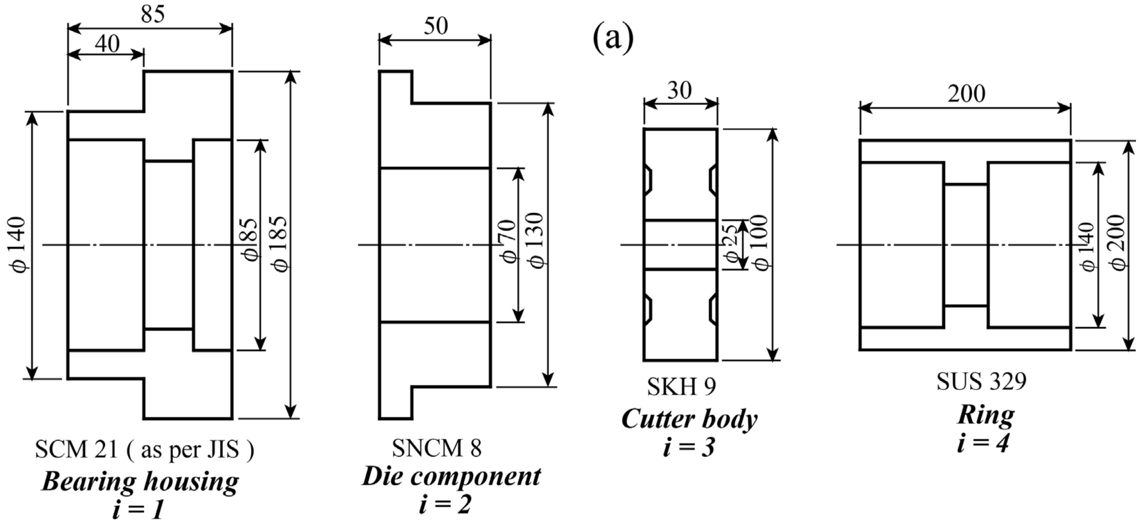
$$\varepsilon_{ki} = \frac{S_{ki}}{S_T} (\leqq 1) \text{ ------(6.2)}$$

where, S_T is the total number of stations, e.g. machine tool, inspection stand, washing station and buffer, by which the part is processed something necessary, and S_{ki} is the number of stations used for processing the part i.

By assuming furthermore, n_k is the number of part kinds consisting of the part family P_k, n_{kmax} is the maximum value within n_k, P_{kim} is the mean production volume per one month of the part i within the part family P_k during certain period (piece/month), and P_{kimin} and P_{kimax} are the minimum and maximum production volumes per one month of the part i within the part family P_k during certain period, respectively, then, we can express the flexibility of system J when machining the part family P_k by n_k, ε_{km} (mean value of ε_k) and Γ_{km} (mean value of Γ_{ki}), where, Γ_{ki} is the fluctuation range of mean production volume per one month.
After converting into the non-dimensional values, these can be duly written as

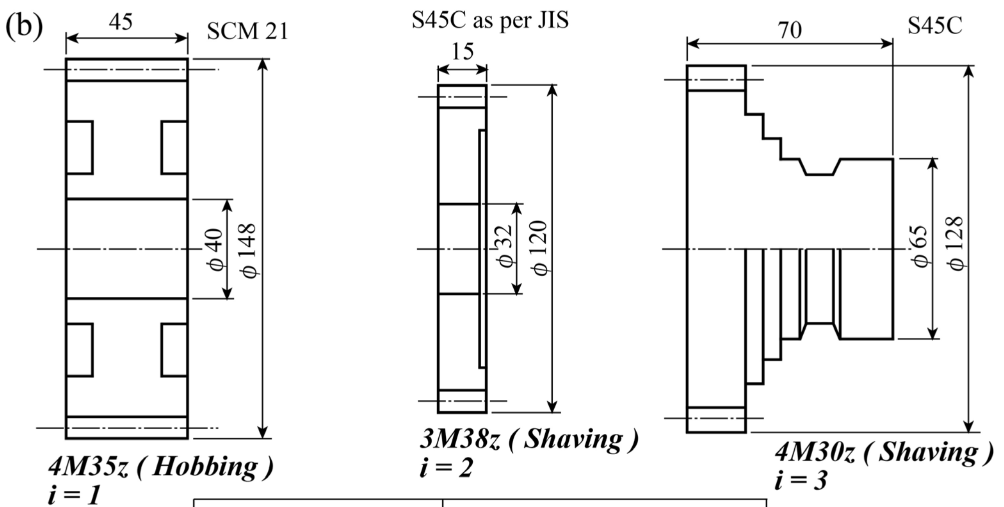
$$\left.\begin{aligned} n_k^* &= \frac{n_k}{n_{kmax}} \\ \varepsilon_{km} &= \frac{\sum_{i=1}^{n_k} \varepsilon_{ki}}{n_k} \\ \Gamma_{km} &= \frac{1}{n_k} \sum_{i=1}^{n_k} \Gamma_{ki} \end{aligned}\right\} \text{--------- (6.3)}$$

(a)



Objective parts i	1	2	3	4
Average production volume per month	1,500	2,000	500	400
Maximum / minimum prodcution volumes	5,000 500	5,000 3,000	1,000 300	800 200
Batch size per unit transportation	1			

(b)



Objective parts i	1	2	3
Average production volume per month	2,000	4,000	1,000
Maximum / minimum prodcution volumes	6,000 1,000	8,000 2,000	3,000 300
Batch size per unit transportation	1		

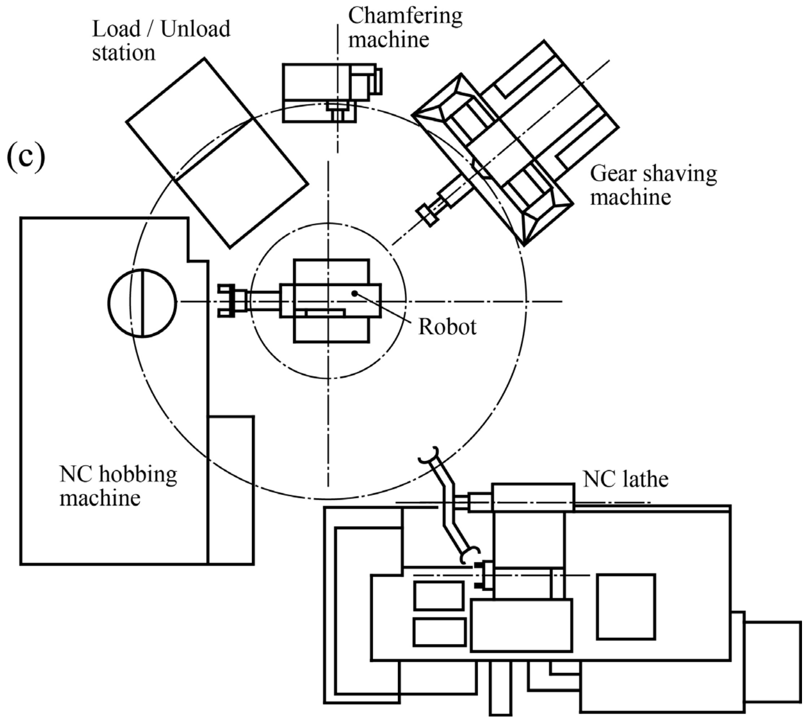


Fig. 6.12 A validity verification for flexibility evaluation vector: **a** Part family No. 1. **b** Part family No. 2. **c** FMC of centre-located robot type for gear manufacturing

where,

$$\Gamma_{ki} = \frac{P_{kimax} - P_{kimin}}{P_{kim}}$$

To verify the validity for the flexibility evaluation vector, a case study was carried out by taking an FMC as an example, and also by assuming the two part families to be finished. Figs. 6.12 (a), (b) and (c) reproduce the cell configuration and machining requirements. In this case, the part family No. 1 needs not gear manufacturing, so that we may have the obvious result.
Figure 6.13 is the evaluation result, and as can be seen, the flexibility evaluation vector can facilitate for the system evaluation to a large extent, although having further problems to be solved as follows [5].

[5] The idea of the flexibility evaluation vector was transferred to a certain number of the Japanese enterprises, and duly they applied it to their systems. Because of companies' confidentialities, there were no publicised reports, but they reported informally the better availability of the flexibility evaluation vector.

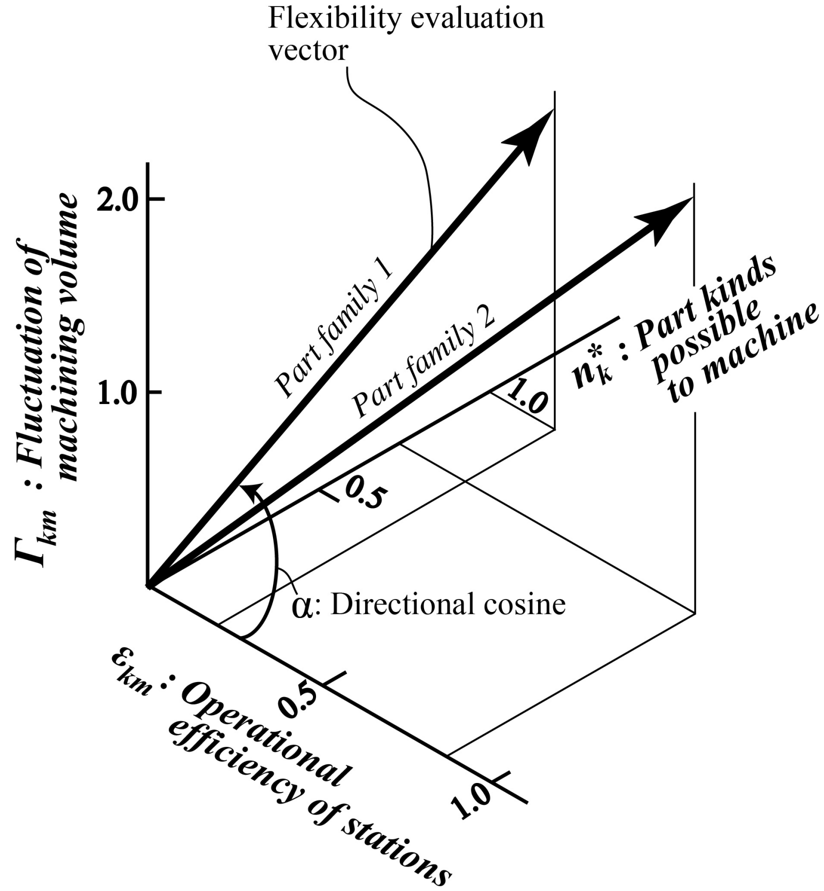


Fig. 6.13 Application of flexibility evaluation vector to conventional FMC

(1) How to evaluate the quick response capability to market change and customer requirements.
(2) How to evaluate the quick response capability for changes of product specifications and product design.

In fact, these are primarily concerned with the system flexibility in wider scope, and thus another necessity is to define the system flexibility from the hierarchical point of view.

6.5 Cell Description - Its Applications to Similarity Evaluation and Layout Design

The cell description is one of the fundamental issues for FMC in general concerns, and there are a few methods to describe the cell configuration, e.g. "*Directed Graph*", "*MFG (Mark Flow Graph)*" and "*Petri Net*

Diagramme”. Obviously, each description has its own advantages and disadvantages, and for example, the directed graph can only represent an aspect of FMC, i.e. cell configuration in still stand, whereas the Petri Net diagramme can skillfully represent the dynamic states of the system, although the representation is somewhat complex.

Figure 6.14 reproduces the Petri Net diagramme for the AGV active patterns at the work loading area. As can be seen, each working state of AGV can be visualised in accordance with the time lapse, and thus we can produce effectively the simulation software of the manufacturing systems by using the Petri Net representation. In due course, Eloundou et al (2016) applied the Petri Net diagramme to evaluate the specified flexibility, i.e. routing flexibility.

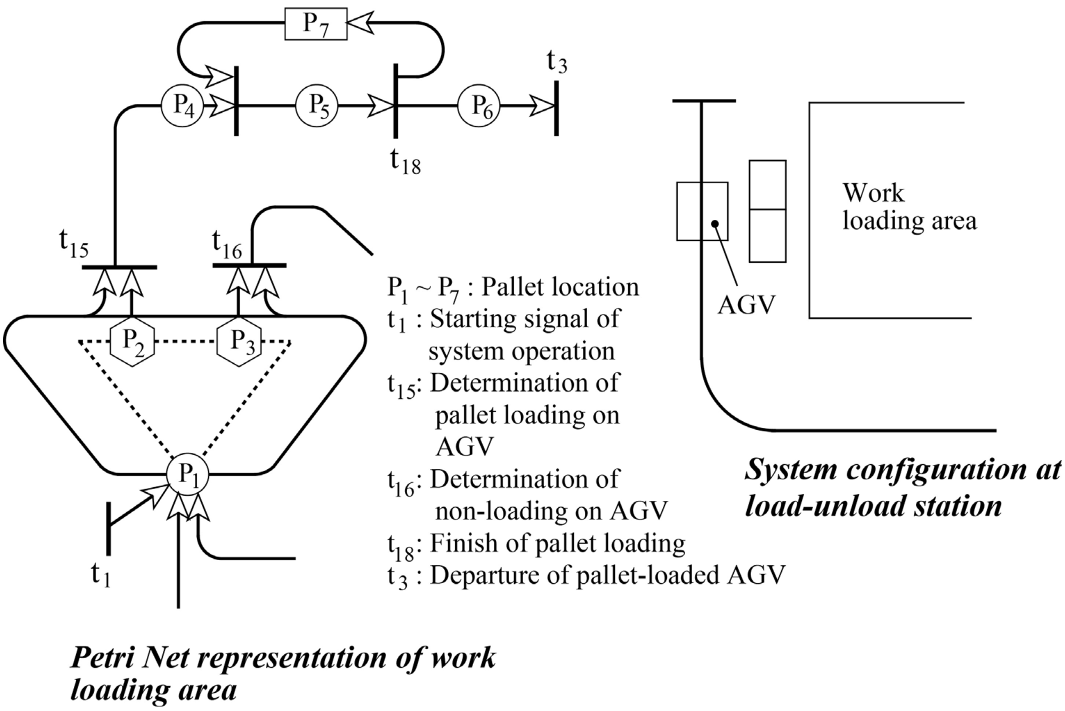


Fig. 6.14 An example of system description by Petri Net

In consideration of the complexity even in the description of FMC, we will discuss the directed graph representation and its applications in the following.

As will be clear from Fig. 3.4, FMC can be described by considering (1) the cell components, and (2) material and information flows, and we must choose a proper description depending upon the application area. For example, Hu and Ito (1987) aimed at the similarity evaluation of FMC to determine the standardised type, and thus placed the stress on the material flow.

Importantly, the material flow gets involved (1) the work, (2) end effector of robot, and (3) carousel storage magazine in the case of FMC shown together in Fig. 6.15 (see Fig. 3.6 (a)). More specifically, the robot can handle the work and end effector, and the travelling gripper located at the rear of the machine body can handle the cutting edge module in modular tooling and also the in-process gauging probe for the work. In short, the material flow has certain hierarchy depending upon to what extent the transferred objective should be considered as shown with the black, red and green colours in Fig. 6.15. Needles to say, the same story is available for the information flow.

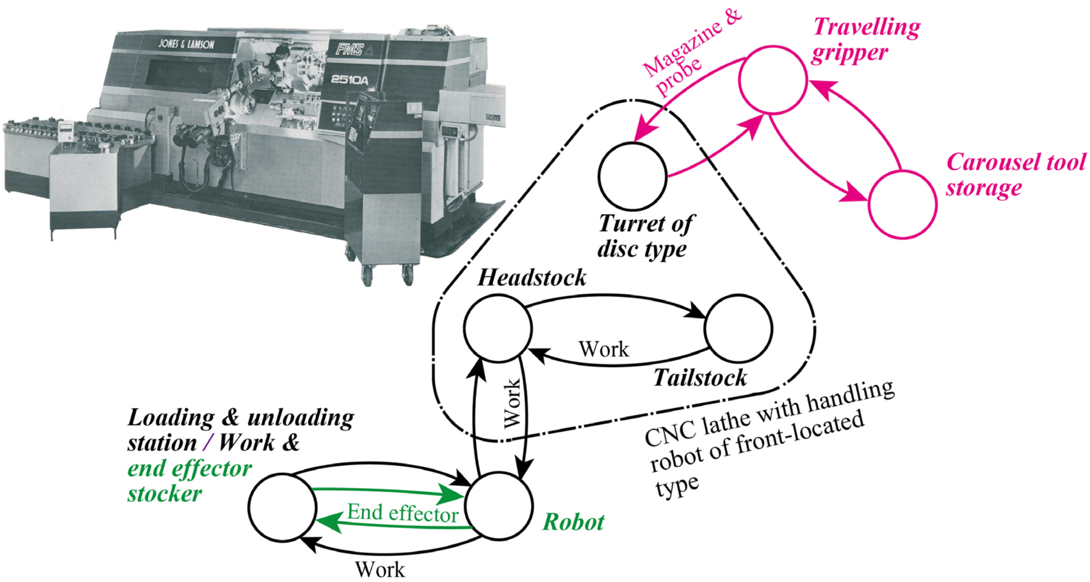


Fig. 6.15 A directed graph representation for FMC of Jones & Lamson-brand

In the directed graph, the vertex and directed edge correspond with the cell component and material flow including the transfer direction, respectively.

In addition, the vertex has its own property, e.g. kind of machine tool and type of robot, and this is a differing feature from that of directed graph in the graph theory. As a result, FMC can be evaluated from such three aspects as follows.

(1) Focusing on the vertex, i.e. similarity evaluation for cell components.

(2) Focusing on the directed edge, i.e. similarity evaluation for material flow.

(3) Cell configuration by simultaneous evaluation from both the vertex and the directed edge.

As well known, the directed graph can be converted into the adjacency matrix, and thus it is possible to calculate the rate of similarity for the material flow, when having the two cells to be compared. Actually, the rate of similarity for the material flow is given by the identity rate of (i, j) components between both the matrixes. In contrast, the rate of commonness for the system component between both the cells, i.e. similarity of system functions in the cell, can be given by the identity rate of the vertexes after describing the machine tool, transportation equipment and warehouse with the functional description. In short, the functional description for the machine tool is that for form-generating movement, and the transportation equipment and warehouse may be described as per similar methodology for that of machine tools (Ito, 2014). At burning issue is thus to what extent the graph should be detailed in the determination of the standardised FMC.

Having in mind that FMC for one-off production may be converted into the CPS module in the smart factory, the cell description will get involved in the design methodology for the smart factory by extending its application from the hardware to software, i.e. functionality design of the controller.

As a clue for such an idea, let us discuss a methodology to design the compact and cubic-like FMC (system function-integrated MC) proposed by Huang et al (1990). The proposed method is based on the spatial allocation approach of the functional and structural blocks, which are in closer relation to the six-fold system function, i.e. machining, transportation, buffer as a storage, surveillance including diagnosis and maintenance, cell controller and linkage to other FMCs. Table 6.5 reproduces the functional blocks and units, which are pre-determined as design entities for FMC in consideration of preferable configurations. In due course, the functional unit can be converted into the structural block, so that the cell configuration can be obtained as a design output, although there remains something to be seen in the "One-to-One Conversion" from the functional unit to the structural block as same as that in CAPP (see Section 6.3).

Functional blocks (FBs)		Functional units (FUs)	
A	Machining	1	Machining space
		2	Spindle branch
		3	Table branch
		4	Swarf transportation
B	Buffer	6	APC
		7	Pallet pool
C	Tooling	5	Magazine
		8	Tool transportation
D	Control	9	Controller, Linkage to other cells

Table 6.5 Representative functional blocks and units for FMC

Intuitively, the functional block should be interconnected on the basis of the material and information flows within the cell. For example, the tool and work flow between the machining and the tooling blocks, and between the machining and the buffer blocks, respectively. It is thus reasonable to consider such flows possible to connect between both the blocks, and to visualise it by the directed graph. Fig. 6.16 shows a typical directed graph, where the vertex and directed edge describe the functional unit and due flows, respectively.

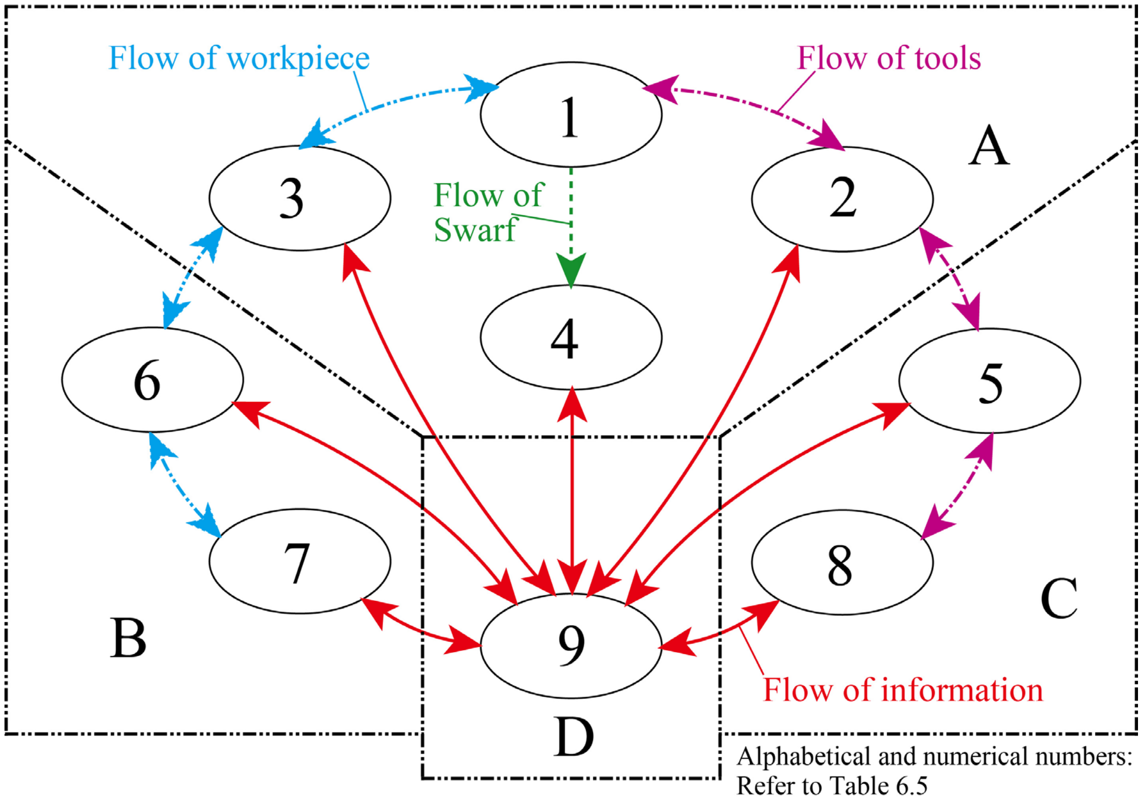


Fig. 6.16 Directed graph representation in functional unit level for FMC

Consequently, in consideration of all the flows possible within the cell, when the necessary functional units are pre-determined, i.e. "Generalised Connecting Patterns", we can produce all the cell configurations possible on the basis of a basic connecting pattern. In short, the basic connecting pattern can be chosen from the generalised connecting pattern by placing the functional unit within 3-dimensional space as the "Cube" under some necessary constraints. In fact, there are 1,100 cell configurations obtained from 7 variant patterns, which is based on the generalised connecting pattern for Table 6.5.

For example, Fig. 6.17 shows some variants obtained from a basic connecting pattern, and Fig. 6.18 reproduces an example for FMC to deepen the necessary understanding in what is the correlation between the cube representation of the functional unit and the cell configuration in practice.

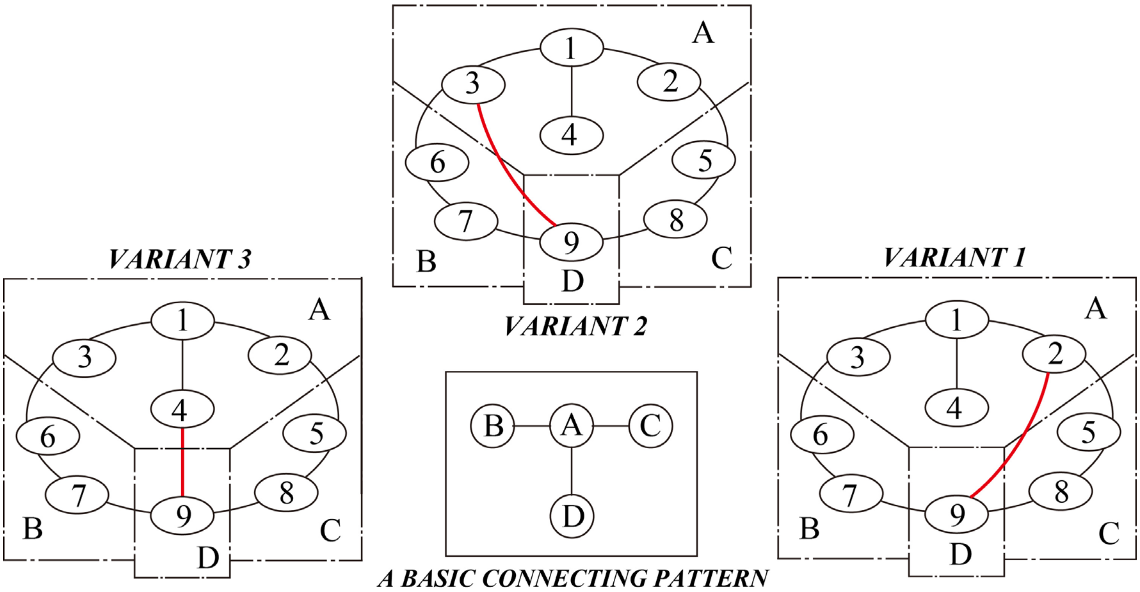


Fig. 6.17 Example of variants generated from a basic connecting pattern

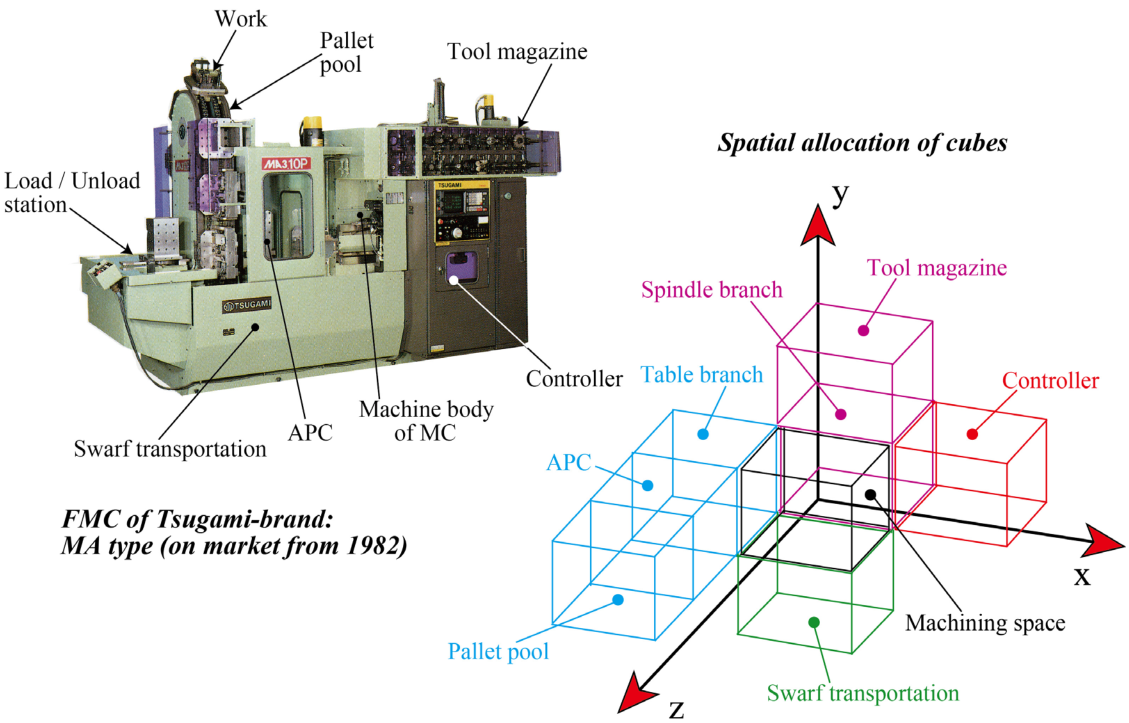


Fig. 6.18 FMC and spatial allocation of its functional units by cubes

As can be readily seen from Fig. 6.18, the design methodology mentioned above appears to be applicable to the CPS module, because such an FMC may be converted into a core of the CPS module by reinforcing the machining function much more than ever before (see Chapter 3). On that occasion, the functional block D in Table 6.5 is primary concern especially placing the main stress on the connectivity with cloud and fog computing.

6.6 Process Integration and Disintegration in FTL Design

As already shown in Fig. 3.2, generally speaking, we need the re-design of some parts while carrying out the "Analyses of Processes and Required Time of Each Process", and a group of the part families can be determined as one of the input specifications for the system design. Then, the concept and layout designs are duly carried out. More specifically, the necessary number of the machining stations, in certain cases islands and units, should be determined from the information of the process analyses and in consideration of the line balance specified by the tact time and load distribution at each station, so that we can reduce the idle time as shorten as possible.

As can be easily imagined, the determinant in this work is the allowable, acceptable and preferable allocation of the tact time between both the machining stations, provided that each station is in full loading condition while machining a part family. More specifically, such a determinant can facilitate the load allocation at each station based on the processes integration and disintegration, i.e. process adjustment.

With the advent of the function-integrated kinds in the machine tool, it appears that such a process adjustment renders useless. In contrast, we need, in certain case of FTL design, such a process adjustment, and supposedly, the very mature system designer can only manage such a work. Reportedly, we have not any methodologies for FTL design applicable to the practice even now, and thus, for the sake of further research guide, a trial research will be introduced in the following.

In principle, the design of FTL can be facilitated by the process integration and disintegration to a larger extent as proven by our long-standing experiences (Ito et al., 1993). Thus, Shinno et al (1996) conducted first the interview research into decision making of the very mature designer to clarify the characteristic features in FTL design. In short, the findings are as follows.

(1) Leading design factors are the machining process, kind of machine tool and functional configuration of the line.

(2) The factors mentioned above are in mutually tangled relation to one another.

(3) The information flow in decision making for determining each design factor results in a closed loop-like or chain reaction-like correlation, i.e. ill-defined problem.

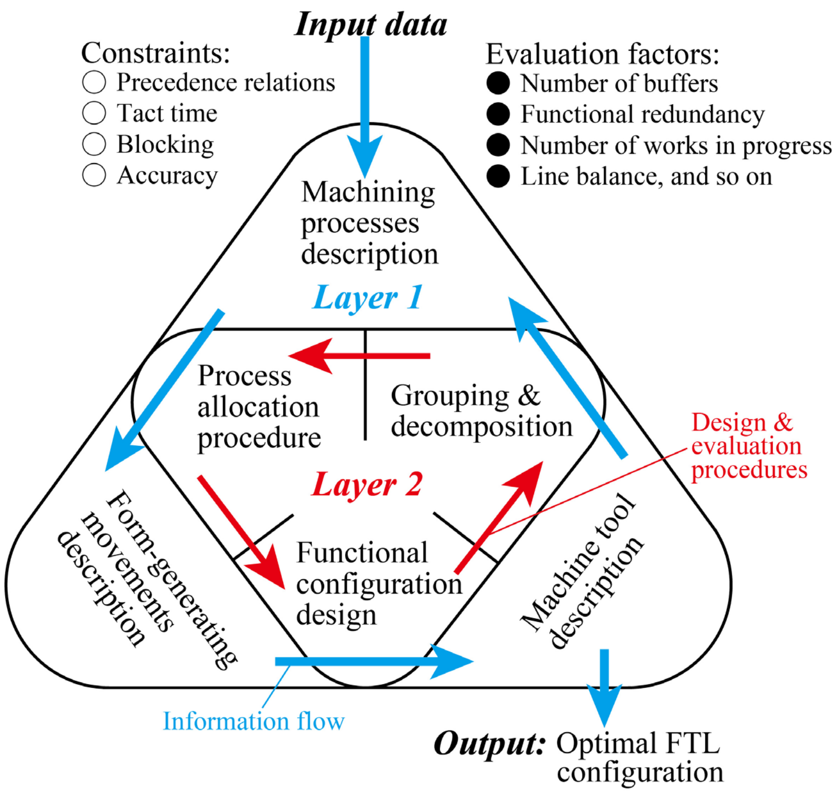


Fig. 6.19 Concept for design methodology of FTL

On the basis of such findings, a methodology was proposed as shown in Fig. 6.19, in which the manufacturing knowledge is described at the layer 1 to support information processing to design FTL at the layer 2. More specifically, the manufacturing knowledge can be represented using the logical notation, which is on the strength of the descriptions for the machining process, form-generating movement and machine tool. As can be readily seen from Fig. 6.19, the input data with constraints can be converted into the system configuration of FTL by information processing at the layer 2.

Shinno et al applied the proposed methodology to a practical design of FTL, which can machine the part families for the motorcar engine, i.e. those for carrier case, cylinder block and cylinder head of the passenger car, in corporation with Toyoda Iron Works. Through the computer simulation, FTL of asynchronous type shows higher productivity than that of synchronous type, when the monthly machining volume is up to 6,000. It is furthermore said that Mercedes-Benz applied the achievements of Shinno et al to the design of its Untertürkheim Factory later, which is called "HMS-Holonic Manufacturing System" (On that occasion, Ito, one of the colleagues of Shinno, received two-sheet of handouts from the correspondent within Mercedes-Benz).

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Chapter 7 Organisational Structure, Work Organisation and Human Resources for FCIPS and Smart Factory

Abstract So far we have been demonstrated the potentials of flexible manufacturing technology that is currently available or in the process of development for convertibility towards CPS Module in the smart factory. We have seen that an important factor of the 'Industrie 4.0' strategy is the preservation and continuous further use (and improvement, i.e. the "elevation" of technological potentials) of already existing smart production technology and to include these technologies in the emerging structures of the smart factory. Obviously this requires migration strategies towards the smart factory. But since the existing technological components are not sufficient to implement the concept of 'Industry 4.0', the pathway to this end is thus both, evolutionary and also radical innovation. And it is very likely that also the work organisation and qualification structures of the smart factory can not only be thought of as an evolutionary continuation of today's structures, but also require radical re-thinking.

This chapter will address the so far unexplained relationship between the technology of the smart factory and the organisational and qualification aspects of production under the conditions of 'Industrie 4.0'. In popular debate, this often reads as follows: Will the smart factory revolutionise the world of work? Or: Will 'Industrie 4.0' demand completely new qualifications of the work force? These and other questions will be taken up and answered tentatively. The focus will be on requirements for work organisation and qualification in the areas of design (construction) and manufacture. This means that on the one hand engineers are targeted and on the other technicians and personnel at shop-floor level. The former see themselves as developers of smart production systems, the others as implementers and maintenance personnel exposed to the newly arising challenges.

7.1 Introduction

Although not showing explicitly all the leading subjects related to the organisational structure, work organisation and human resources in Table 6.1, these subjects are very important in the discussion of both FCIPS and the smart factory, and as can be readily seen, these are in close tie with the industrial sociology and manufacturing culture. Within the manufacturing culture context, some quick notes were already suggested in Section 1.4, and from Table 1.3, we may envision roughly what are facing R & D subjects. In addition, some case studies on the smart factory exemplify the work orgnisation suitable for CPS module (see Table 5.3).

In this context, we must remember that the leading prerequisite of the manufacturing culture is that an engineering technology consists of the "*Common Technological Entities*", which are available across the whole world, the "*Region-specified Technological Entities*", and industrial culture-specific entities, of which the last-mentioned are only available at the specified local region. As will be clear from the concept, definition and prerequisite of the manufacturing culture, there are furthermore four driving factors, which can facilitate the production structure in very near future including the smart factory, as follows.

(1) Prevalence of localised globalisation with highly information-intensive and aging society.

(2) Necessity and inevitability of "*Trans-disciplinary Knowledge*" rather than "*Mono- and Multiple-disciplinary Knowledge*".

(3) Product concepts deploying from "*Customer Satisfaction*" to "*Customer Delight*" and

(4) Industrial culture-specific production concepts that consider certain peculiarities such as a prevailing qualification structure of the work force.

With the growing importance of the smart factory, we need duly to detail the aims and scope in each subject shown within Tables 1.3 and 6.1, although we may face much more difficulties caused by the complexity involving within each subject than our estimation. Such difficulties may be caused by the mutually-tangled reciprocal relationships among various attributes ranging from the production technology, through the manufacturing culture, to economics, sociology, labour science, geopolitics and so on. Obviously, we must specify the characteristic features within each subject in consideration of the concept of the smart factory, and also relative weight among a group of attributes.

As can be readily seen from the above, in fact, it is at present very difficult to sublimate each subject shown in Tables 1.3 and 6.1 into a neatly defined problem. In contrast, we can provide further supporting information to detail each subject as will be suggested in the following.

Organisation & Proposer	Year	Evidence	Remarks
Mazda Motor	1996	Evaluation of space comfortability in passenger cars	Tokioka M. Mazda Technical Report No. 14, 1996, p. 67
Comau Co.	1999	Prevalence of work organisation with multiple-nationality Enlightenment of communication ability for multiple languages	Increasing demand for obtaining Eur. Eng.
EU project: MANTYS	2001	Technology development in consideration of cultural variety	
Bangdon Institute of Technology	2003	Establishment of Department of Socio-technology	
Texas A&M Univ. / ULDA Puebla	2004	Student exchanging programe: Global Manufacturing - Technology & Culture	
Evans-Pughs C.	2004	Key to success in Mainland of China: Consideration of regional differences in customer penchant, purchasing powers and legal protection for local product by local government	“ The Great Call of China ” IEE Review, Feb. 2004
Rommel A R	2004	Suggestion for importance of shipping destination-oriented specifications in international deployment of product and services	Asahi Newspaper 18th September, 2004 “ Be on Saturday ”
Samsung Electronics	2006	In determination of design specifications of home appliances, “ Life feeling-related ” attributes are superior to functionalities	
NTTDoCoMo	2006	Analysis for social impact of mobile communication	Establishment of “ Social Science ” Laboratory

Table 7.1 Suggestions for importance of manufacturing culture between late 1990s and middle of 2000s

Table 7.1 summarises some evidences, suggestions and proposals indicating the importance of the manufacturing culture, and from it, we can understand what is under way in factory planning, work organisation and cultivation of human resources. Importantly, we must determine the work organisation by the “Case-by-Case” way, because the work organisation depends upon, in general, the objective product, system configuration, industrial cultural peculiarities and operational pattern to a large extent, resulting in the difficulty in the establishment of its generalised methodology.

For further understanding, we discuss some details of MANTYS in Table 7.1 herein. MANTYS is the acronym for "Manufacturing Technologies", which aims at the promotion of the innovation in manufacturing by focusing on the machinery technology and its interface with the manufacturing process like machine tools, assembly systems, handling systems and so on (Decubber, 2001). In the product and process innovation for the evolution of the market, we must first know the needs of customers at present and in future, and thus pay duly the influence of the cultural variety to the product specifications. In addition, we must also establish the right partnerships among enterprises worldwide by considering a new business model (Gausemeier, 2005).

To this end, we must eye the uncountable contribution of the manufacturing culture to the smart factory, and all the activities related to the manufacturing culture should be based on the comparative research into the objective problem. Obviously, it is better to visualise the research result by using the "*Cylindrical Model*", which consists of a group of the phase plane layers ordering in accordance with the time axis as shown in Fig. 7.1. More specifically, a technological system can be visualised in detail by positioning its core entities accordingly on a phase plane, i.e. radar chart (mind map) representation, so that the entity position can represent its characteristic feature correctly. Importantly, the origin of the radar chart can be regarded as a total evaluation index, and the changing phenomena of a technological system can be scrutinised by connecting the changing position of each entity as shown in Fig. 7.1. More importantly, the cylinder shape distorts in accordance with the shift of the centre of the radar chart, and from such a distortion pattern, we may understand the technological inheritance in the objective (Moritz, 1994).

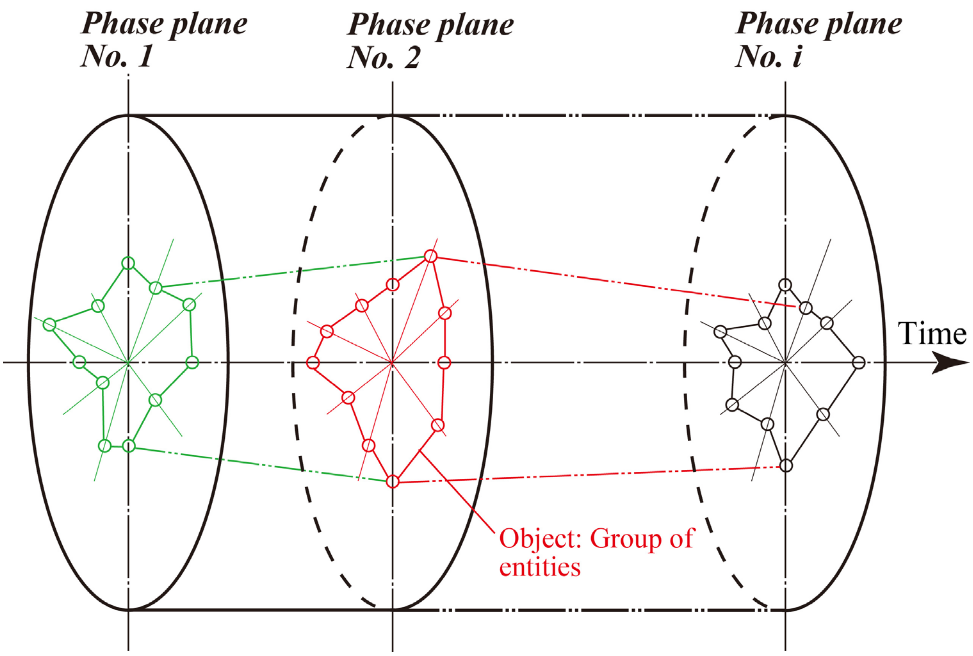


Fig. 7.1 Cylindrical model for visualising developing history (by Moritz)

7.2 Organisational Structure, Coporate Culture and Business Model

In both, FCIPS and the smart factory, we must consider that the organisational structure is in closer relation to the corporate culture (organisational culture) and business model. More specifically, one of the leading issues in the business model is the product deployment in the market worldwide. To disseminate the product, we must discuss the production method and organisation, i.e. those related to "*Production Morphology Culture*" and "*Organisational Culture* such as the *Corporation, Industrial, Regional or National Culture*".

Obviously, there have been a considerable number of the research reports so far; however, even now we need to conduct further research into, for example, the following subjects.

(1) Establishment of business models for enterprises in localised globalisation era, which is applicable to the computer simulation.

(2) Desirable model for "Division of Work" in information processing

between CIM and the cell controller, and also between the cloud and fog computing.

(3) Comparative research into the work organisation in multinational corporations.

(4) Allocation of work/tasks in the smart factory: which competences are incorporated in the CPS module, the software and the data infrastructure, and which competences remain with the engineers, technicians and shop-floor personnel?

In retrospect, we proposed already a forerunning concept of the smart factory, which is called the "Distributed Cell-integrated *FMS* Using Communication Network", in the middle of 1980s (Ito, 1987). Importantly, this concept and concerns were proposed in Norway, Japan, Germany and USA on that occasion, and suggested the following characteristic features.

(1) Use of *FMC* as a basic module of *FMS*.

(2) Distribution of a group of *FMCs* at several locations within a certain region, e.g. industrial estate and nation, and across the whole world. For example, SME-community with various industrial sectors has been established within a local industrial estate and verified its beneficial features as reported elsewhere.

(3) Integration of *FMCs* by positively using an information network, e.g. LAN, telecommunication and satellite.

Figure 7.2 reproduces one of the variants of such a concept, i.e. *FMS* of international co-operative or divisional type. In this type, it is preferable that *FMCs* for assembly and product inspection are allocated near the market of the objective product. In addition, such an international co-operative type may play the role for solving some political problems within the international technical co-operation and also trade friction.

Obviously, the concept shown in Fig. 7.2 may be converted into that of smart factory, provided that *FMC* is for one-off production with the better connectivity with the information communication network, and that the central computer can mange the human-intelligence-related function. In contrast, we must investigate (1) a remedy for realising the "Same Place –

Same Time" principle especially from the viewpoint of material flow, and (2) the cell (factory) location problem with wider scopes, i.e. from the viewpoints of technology, economics and sociology. For example, a group of FMCs for machining should be allocated at the region, where we can get a considerable number of the mature town factories, and in contrast *FMC* for final assembly should be allocated closer at the airport and harbour for shipment.

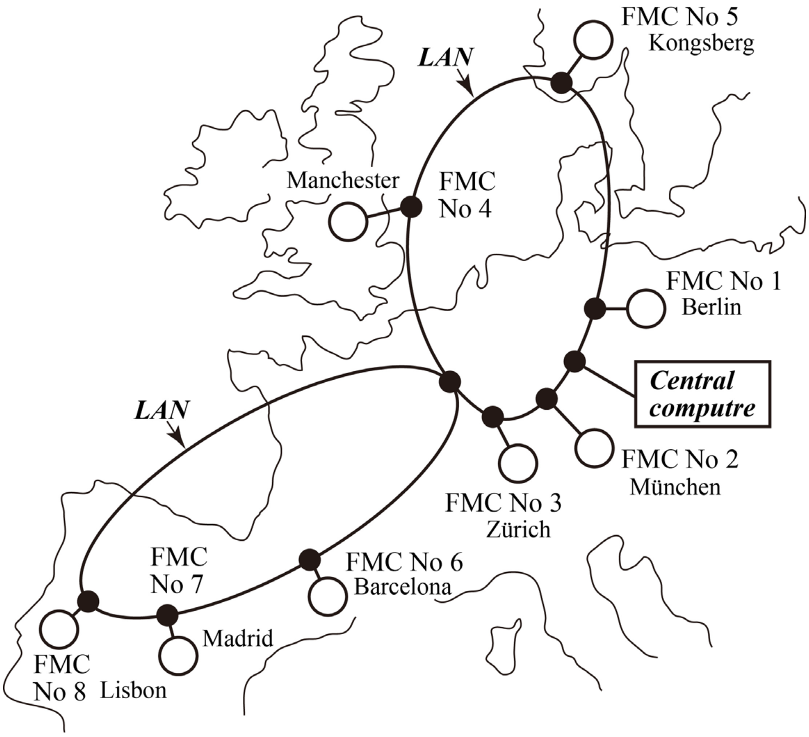


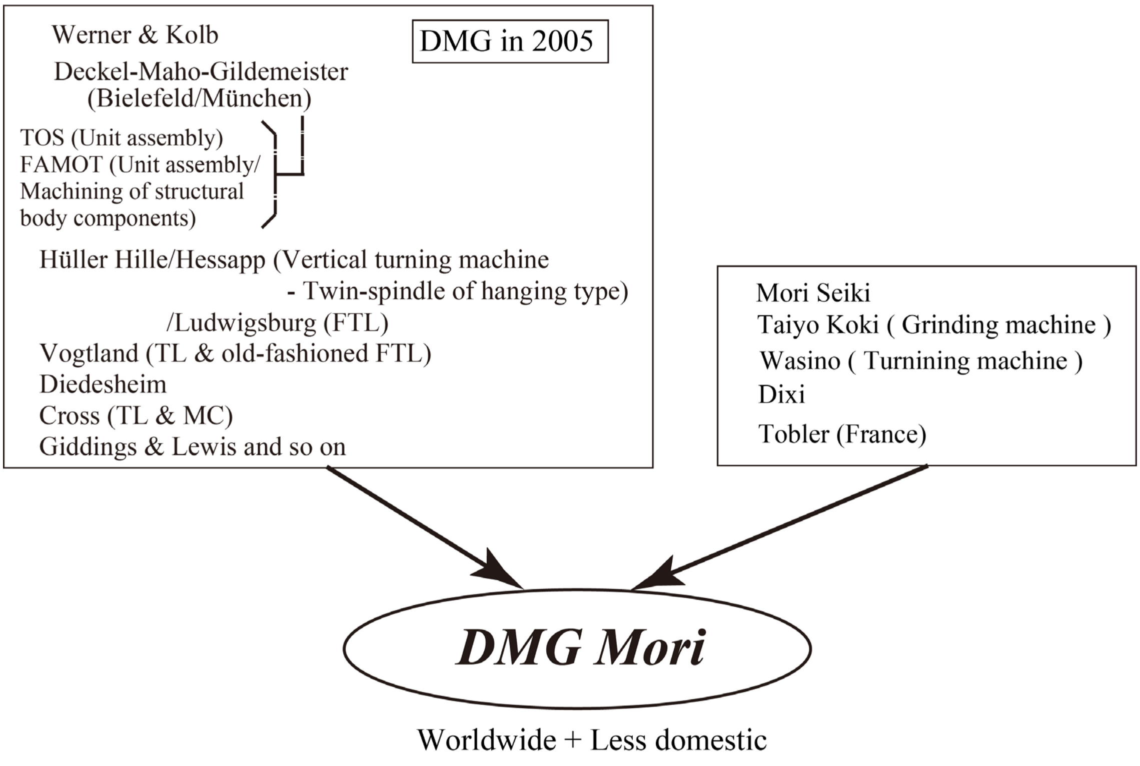
Fig. 7.2 Concept of FMS of international co-operative type in middle of 1980s

Equally, we can imagine that *FMS* of international co-operative type is very similar to the "Virtual Concentration of Production Bases" as already shown in Fig. 1.8. Together with considering the product deployment, we must eye a remarkable organisational innovation in the machine tool manufacturer. In fact, we have so far believed that SME is suitable for machine tool manufacturing, and thus we must investigate a vital problem regarding to what extent the large-sized enterprise is suitable for manufacturing the machine tool as compared with SME. Paraphrasing, we must clarify the allowable size of the enterprise in the machine tool manufacture.

Of special note, each conglomerate has its characteristic features in both the locational aspect and the segregation for product kinds by deploying the design office, factory, service bases, and so on across the whole world. This may be interpreted one of the "*Virtual Industrial Agglomeration*", which will benefit something definite, and thus is worth investigating its potential features and also the availability for the smart factory.

For the sake of further understanding, Figs. 7.3 (a) and (b) reproduce furthermore another two virtual concentrations, and a newly arisen problem is the mobility in the enterprise merger. For example, Hüller Hille Group once belonged to DMG, but now is under the umbrella of Fair Friend Group (Taiwan).

(a)



(b)

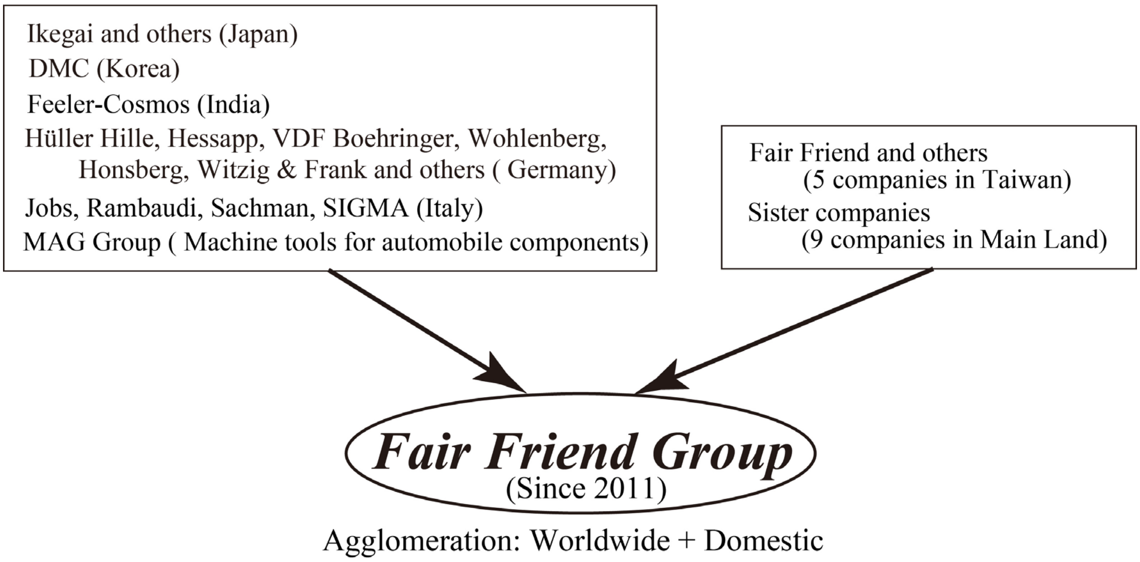


Fig. 7.3 Another two conglomerates in machine tool manufacturing: **a** DMG Mori. **b** Fair Friend Group

7.3 Cultivation of Human Resources

To establish the smart factory together with its objective product, we need to use the interdisciplinary approaches and to foster human resources with multiple-talent, e.g. product engineer with certain abilities for the information technology, psychology, ergonomics, social and occupational science and so on. More specifically, the engineering designer should create the smart product as exemplified in Table 6.1 (c), and we can observe such products on the market nowadays as already shown, for example, in Table 6.2. In short, we need now the engineering designer, who can understand the "*Product Culture*", which is compatible with the era of the smart product.

Importantly, in Table 6.2 the region-specified type should be designed as per the safety law of USA, the aesthetic-like type has been tried much more than ever before, and it is furthermore interesting that another challenging trial is a synergy of two different types, i.e. amalgamation of individual difference- and sensitivity-oriented types. For example, the underwear must have large sweat absorbing and quick-drying capabilities as well as the comfortable wearing with cool touch.

Although not calling the smart product, from Table 6.2 we can intuitively understand the necessity of fostering the engineering designer with multiple-talent, which is based on the knowledge of trans-disciplinary. Of note, Fig. 7.4 visualises the qualification requirement of the engineering designer for the product, which involves to some extent the culture- and mindset-related attributes. Such attributes are uncertain and difficult to quantify as exemplified by the industrial design for the total enclosure in the machine tool, where at issue is "*Penchant and Preference of User*". Apparently, the engineering designer should pay the special attention to the "*Folklore*".

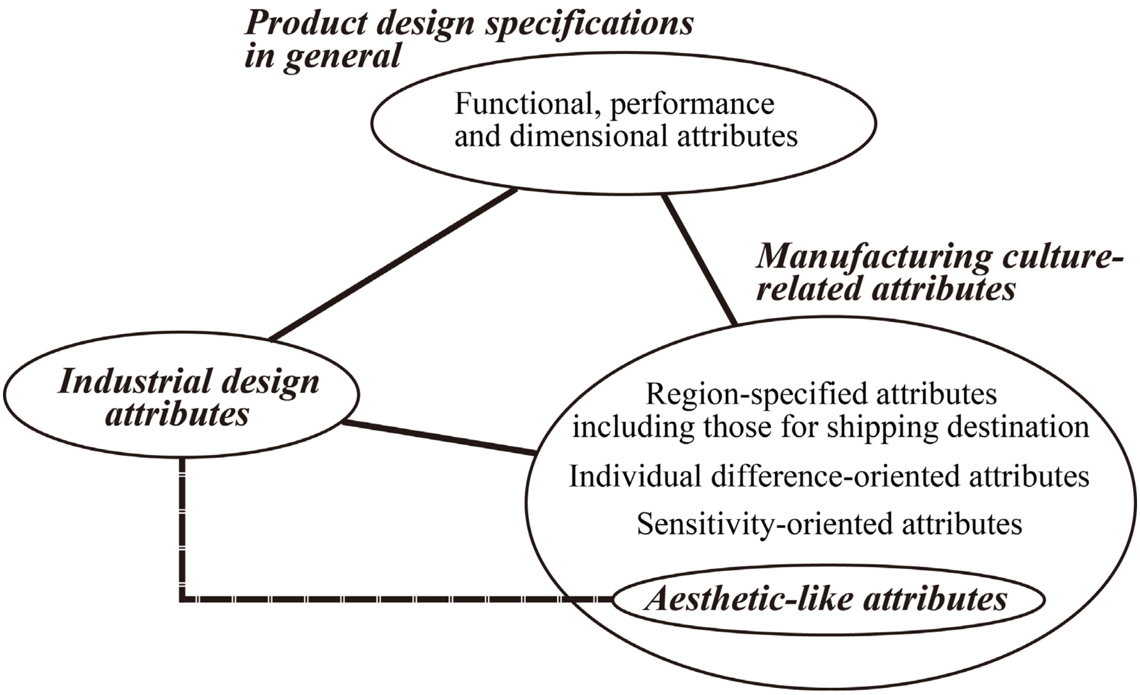


Fig. 7.4 Three leading attribute groups in culture- and mindset-harmonised product

In due course, a facing engineering problem is to conduct the preferable synergy of all the attributes within these three groups concerned. In addition, Table 7.2 summarises the leading beneficial features of the region-harmonised machine tool, and from it we may guess also the necessity of fostering the machine tool designer with multiple-talent.

Having in mind the importance for fostering human resources with multiple-talent, we must also be aware that the design procedure applicable to the practice is far from completion, because we cannot solve the fatal problems as follows.

Ease of operation based on harmony with amenity and mentality
Employment of lean design specifications compatible with regional environments
Product design with high disposability by using indigenous raw materials

Table 7.2 Some beneficial features of region-harmonised machine tools

(1) The three leading attribute groups are mutually in reciprocate relation to one another, and even within a group, we can observe such the reciprocate relationship among a considerable number of the attributes.

(2) Apart from the product design specifications, other attributes include uncertainties to various and larger extents. Obviously, such attributes are not quantified and induce certain difficulties in the product design.

(3) Even within a leading attribute group, e.g. product design specifications in general, there are various attributes with different information properties. For example, the part drawing gives us the geometrical information, and duly it should be converted into the manufacturing-related information to be the part in reality (see Section 6.2).

These fatal problems imply simultaneously further hindrance in the cultivation of human resources.

Within the cultivation of human resources, another leading-edge topic is to foster the region-specified engineer. As can be readily seen from the leading prerequisite of the manufacturing culture shown in Fig. 7.5, we need now the human resources, who have satisfactory qualification applicable to the specified professional sphere across the whole world and simultaneously the deep region-specified technological, economic and social knowledge.

Prerequisite of manufacturing culture

Technological system	**=**	***Common tchnological entities***	**+**	***Region-specified tchnological entities***

In case of cultivation of production engineers

Qualification of manufacturing engineer	=	Academic, experienced and grass root-like knowledge available across whole world	+	Region-specified knowledge

In case of technology transfer

Technology creation	=	Technology transfer for common technological entites by transferor	+	Self-development of localised technology by transferee

Fig. 7.5 Educational system of production engineer and technology transfer in consideration of manufacturing culture

Obviously, the same story is applicable to the technology transfer and we can interpret that the product deployment means one variation in the technology transfer of wider scope. More specifically, such a technology transfer ranges from the same product with the same production method, through the same product with differing production method, to the differing production organisation for the same product with the same production method in accordance with various environments of each region.

In short, the technology transfer should be limited within the common technological entities as shown already in Fig. 7.5, and in turn the technology transferee (receiver) must conduct the self-development for the region-specified technological entities and integrating it with the common technological entities to accomplish a technology creation. As can be easily imagined, it emphasises that the methodology for the technology creation is far from establishment, although suggesting its very importance more than 20 years ago.

Within the context of the cultivation of human resources, an interesting trial is CDIO, i.e. an Initialism for Conceive-Design-Implement-Operation, founded by MIT (Massachusetts Institute of Technology) of USA in the late

1990s to foster the engineer of next generation. CDIO has conducted an international engineering education in the aerospace, mechanical, electrical and applied physics spheres by the collaboration of 50 institutions in over 25 countries worldwide. The education ranges, for example, from the complex value-added engineering systems (level 1) to the hands-on experience and a cycle of conceive-design-implement-operate (level 4) (CDIO, 2007).

Importantly, CDIO has incorporated two subjects in the educational programme, i.e. external and societal context, and also enterprise and business context. The former consist of "*The Impact of Engineering on Society*" and "*The Historical and Cultural Context*". The latter is concerned with the appreciating different enterprise cultures. In tis context, Saini (2012) suggested also the importance of the synergy of the social science and technology when discussing the ethics of the engineer.

Reportedly, CDIO is surely a very interesting trial; however, we must also delve into the educational organisation, and for such a discussion, a good case study is that of the University of Cambridge, when considering the preferable pattern in the technology transfer.

Although not discussing the aspect of the manufacturing culture, the University of Cambridge has established a new educational system by incorporating the "*Departmental System*" in the traditional college system. In accordance with the private information from Professor Keith Foster of EPSRC in February 2004, the departmental system aims at the education like the experiment and practice for the relatively large group of the student. As well known, the college system can be characterised by the "*Mentor System*", which is for the education of the small group of the students.

It may thus be suggested that the region-specified engineer will be educated effectively by providing the student the region-specified engineering knowledge from the mentor. In contrast, the departmental system may facilitate the education of the common engineering knowledge.

7.4 Cultivation of Shop Floor Skills for Smart Factory

This section focuses on the design of the smart factory as a socio-technical system and the interaction between humans and their surrounding environment, including the machines and systems. Therefore, we must have a look at other, non-technical disciplines and their concepts of 'Industrie 4.0'. The main focus of relevant scientific disciplines (and sub-disciplines) such as industrial sociology, work sciences etc. undoubtedly is on work organisation, qualification, lifelong learning and career models, knowledge management, team building and health management.

Even if a socio-technical design approach is conceptually linked to 'Industry 4.0', or smart factory programme, which is intended to integrate technical with work organisation and qualification aspects, there are fears that the design of work systems will only be tackled once the technical artifacts, networks or systems have already been developed and implemented. There is little doubt that such a procedure restricts the creative freedom of work organisation and qualification on shop floor level.

From a sociological perspective, the qualification of the work force in particular is placed at the centre of the assessment of changes in the world of work induced by 'Industry 4.0'. Together with vocational training research, industrial sociology tries to assess the qualification requirements of the smart factory. Acatech's high-flying vision of realising extended decision-making and participation scope as well as possibilities for the working load regulation on the shop floors of the smart factory is doubted. At least sociological researchers do not see a direct predetermined pathway towards more self-responsible autonomy and greater decision-making scope for workshop personnel. From their point of view, certain precautions must be taken to make shop-floor workers fit for work in the smart factory and to ensure the highest possible level of the "decent work". The most suitable means of implementing and securing this are in-company qualification or further training measures. One way to go is selecting those occupations in the metal and electrical industry that will have to work in the smart factory and to compare their competences with the competence requirements of the smart factory. By determining the differences, it can be estimated whether and to what extent a need for requalification exists; however, the concrete contents are only roughly outlined and cannot (yet) be specified down to the smallest detail. For the case of Germany, Spöttl and Windelband (2016) have made an attempt to assess the compatibility of occupations like industrial mechanic, mechatronics and electronics technicians for automation technology, and the cover ratio of their competence portfolios with the assumed requirements of production under the regime of 'Industrie 4.0'. In short, they found that there is a considerable match of the mentioned qualifications with the assumed and expectable new requirements. The anticipated competences for the work area 'system integration' of electronics technicians for automation technology might be the following.

(1) Analysing functional relationships and 'Industrie 4.0' process flows.
(2) Install, configure and parameterise the 'Industrie 4.0' components, systems and networks as part of the Reference Architecture Model Industrie 4.0 Layer.
(3) Connecting components to complex automation devices and integrate them into the functional Industrie 4.0 layers;
(4) Monitoring, testing, maintaining and repairing Industrie 4.0 systems. (IG Metall et al. 2017, p. 28 – translation by the authors).

It is easy to see that there is a high degree of overlap between these competences (likely to be required by Industrie 4.0) and those already available. The only difference is that new technical objects must be added and new standards (such as RAMI4.0) must be taken into account. Therefore there is no need to define completely new occupational profiles, but rather to augment the existing outline of competences. This is where in-company qualification becomes a crucial success factor for dealing with the challenges posed by the smart factory. But they also say, that there are other occupations and jobs in the metal and electrical industry, which need more efforts to develop their skills and competence profiles towards the emerging requirements of the smart factory, in some cases it could require a re-design of job profiles (Spöttl, Windelband 2016). They expand their argument by stating that the alignment of competences towards the requirements of ‘Industrie 4.0’ demands concise analyses of the work processes and activity fields, which are the cooperative effort among engineers, sociologists, work science with the work scientists, industrial psychologists and the like.

If the production concepts described in chapter 5, such as Adidas' speed factory becomes reality, it is also increasingly important that this kind of production can be operated under different qualification conditions worldwide. Thus, the technology must be highly resilient or the workforces’ qualifications must be more ‘mouldable’. In both cases, design approaches that are committed to the concepts of manufacturing culture or industrial culture, are inevitable.

It is also very important to consider the influences of the global networking structures linked to ‘Industry 4.0’ on skill formation. Globalised networks can thus become a limiting factor for autonomous, self-directed action of the workforce. Let's construct an example that goes beyond the existing supplier structures: By using “Cloud Computing”, it becomes possible to send the sensor/actuator data relevant for preventive maintenance of a company to external service providers almost in real time and have them evaluated. This links work organisation and process control between two or more companies on a global scale. There is a danger that autonomy of action is limited and self-control is replaced by external control. By integrating further operational functional areas into these Cloud Computing-base networked structures, highly complex couplings are created whose effects on internal company organisation structures and work processes – and thus also on skill formation – are not yet foreseeable.

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Appendix
Modular Design for System Layout and Platform Concept in Machine Tool Design

As reported and suggested elsewhere, primary concerns in flexible machining are FMC of stand-alone type, large-sized FMC, FMS and FTL. Importantly, nearly all flexible machining systems are, at present, modular-designed, where the basic modules are FMC and a machine as a whole, e.g. mill-turn and MC of line type. In fact, FMC-integrated FMS and FTL have recently prevailed. In contrast, we need also the conventional FMS and FTL, where the system components are such as a machine tool, transportation devices, warehouse and so on as a whole.

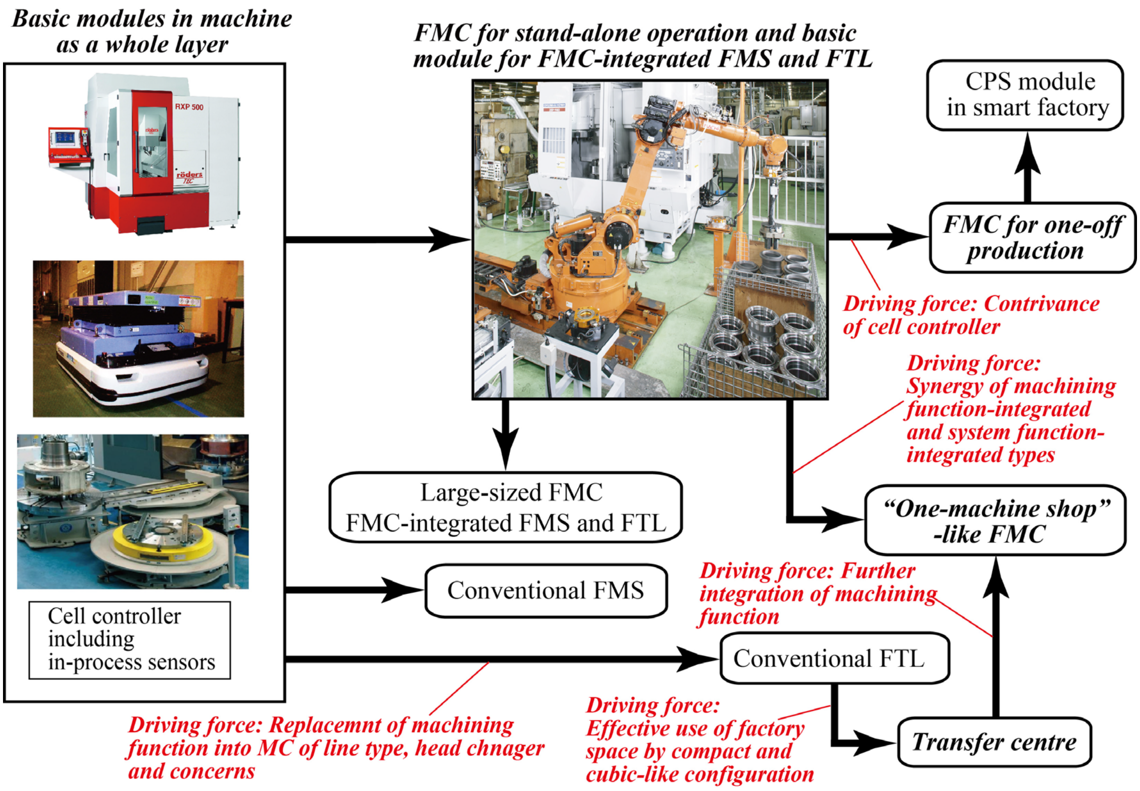

Fig. A. 1 First-hand view of modular design in flexible machining and convertibility into CPS module

In the machine tool sphere, the modular design of hierarchical type was already established, and its upper layer is, in principle, applicable to FMS and concerns, so that the system can be facilitated the "*Flexibility*", "*Expandability*" and "*Redundancy*" (Ito, 2008). Obviously, we employ similar modular principle to other cell and system components.

Figure A.1 shows a first-hand view of the modular design in FMS and concerns at present, and importantly, FMC for one-off production with keen cost and "One-machine Shop"-like FMC may convert to the CPS module in the smart factory by contriving properly the cell controller. Within such FMCs context, we must, furthermore, be aware that the core kind in machine tools for FMC is of "Function-integrated Kinds" and should be design on the basis of the "Platform Concept".

In the following, thus, some quick notes will be given to the leading issues.

FMC

At present, FMC and large-sized FMC are on leading position, and as already described, the (defacto) standardised FMCs, i.e. FMCs of pallet pool and robot types, play the role of the basic module in flexible machining to a large extent. Besides, both the FMCs and their variants become very popular and appear as to be one of the conventional machining facilities within SME (see Chapters 3 and 4).

In general, FMC is designed by the modular principle, in which each cell component related to five fundamental functions, i.e. machining, transportation, storage, maintenance, and also control and surveillance (cell controller), is of basic module, and as will be clear from the above, the "Cell Description" is very helpful as one of the design methodology (see Section 6.5).

Importantly, the standardised FMC can be, in general, characterised by the core machining function, and reportedly MC and TC can facilitate it at present to some extent; however, with growing importance in the flexibility reinforcement, the machining function can be facilitated, for example, by quinaxial-controlled MC, MC convertible into the simplified or special-purpose type and mill-turn. In certain cases, the mill-turn becomes much more dexterous by integrating the quinaxial-controlled MC and TC of twin-spindle type than ever before, resulting in the core of an advanced FMC. In fact, we can expect highly such an advanced FMC; however, we must furthermore consider that the more flexible the FMC, the more difficult is its availability because of its higher purchasing and running cost.

Following such an interesting trend, as can be seen from Fig. A.1, FMC has been deployed into the "*One-machine Shop*", i.e. FMC facilitating by "*Function-integrated Kinds*" in machining function. In fact, the function-integrated kind is two-pronged: one is of "*Machining Function-integrated Kind*" and the other is of "*System Function-integrated Kind*" like the transfer centre as already shown in Fig. 3. 25. For the function-integrated kind, the modular design of hierarchical method is available (Ito, 2008).

In this context, at facing issue is the flexibility evaluation of such advanced kind like mill-turn itself; however, there are no ways, and thus the authors assert to define the flexibility of the function-integrated kind in full consideration of the following factors.

(1) Compact integration of various core system functions.
(2) Integration of multifarious processing methods.
(3) Tooling versatility for machining.
(4) Accessibility to machining space.
(5) Function promptly facilitating special-purpose machining.
(6) Connectivity with fog computing and also better division of work in information processing.

Large-sized FMC and FMC-integrated FMS

Although FMC and large-sized FMC are dominant, if necessary we must install FMS. In general, FMS is of FMC-integrated, which can be established by integrating, at least, the standardised FMC and special-purpose FMC. In certain cases, FMS is modular-designed by determining the basic modules consisting of the machine tool, transportation facility, warehouse and so on as a whole.

FTL and FMC-integrated FTL

An FMC-integrated FTL is already shown in Fig. 4.7; however, it is not common at present to employ FMC-integrated FTL, whereas the conventional FTL is dominant as shown already in Figs. 3.14, 3.15, 4.14 and 4.16. As widely known, the conventional FTL consists mainly of MC of line type (see Fig. 4.2), and is modular-designed by also determining the basic modules consisting of the machine tool, transportation facility, warehouse and so on as a whole (see Fig. 3.14).

Platform Concept in Machine Tool Design

It is worth suggesting that the "Function-integrated Kinds" in the machine tool should be designed in accordance with the "Platform Concept", which is one of the variants of the modular design of hierarchical type. In short, the "Platform" is of large-sized structural module of monolithic type, which consists of a group of the structural body components, i.e. structural units, allocated far from the machining space. Importantly, in the "Platform Concept", we can provide the machine tool with much more various machining methods than other modular design methods by changing only the structural units surrounding the machining space like the turret head, main spindle nose, and barrel of the tailstock. We call it "Variant Type in Modular Design", and obviously we can benefit considerably.

Figure A.2 clarifies a typical differing feature between the conventional modular design and the platform concept. Of special interest, the platform system is machining space-oriented and user-oriented, and also may reinforce its capability of primary form-generating movement when some structural units is able to interchange "In-suit" at the user's factory (Ito, 2017). It is extremely worth suggesting that with the advance of both the modular attachment and modular tooling, the platform system becomes much more effective than ever before. This is because such the attachment

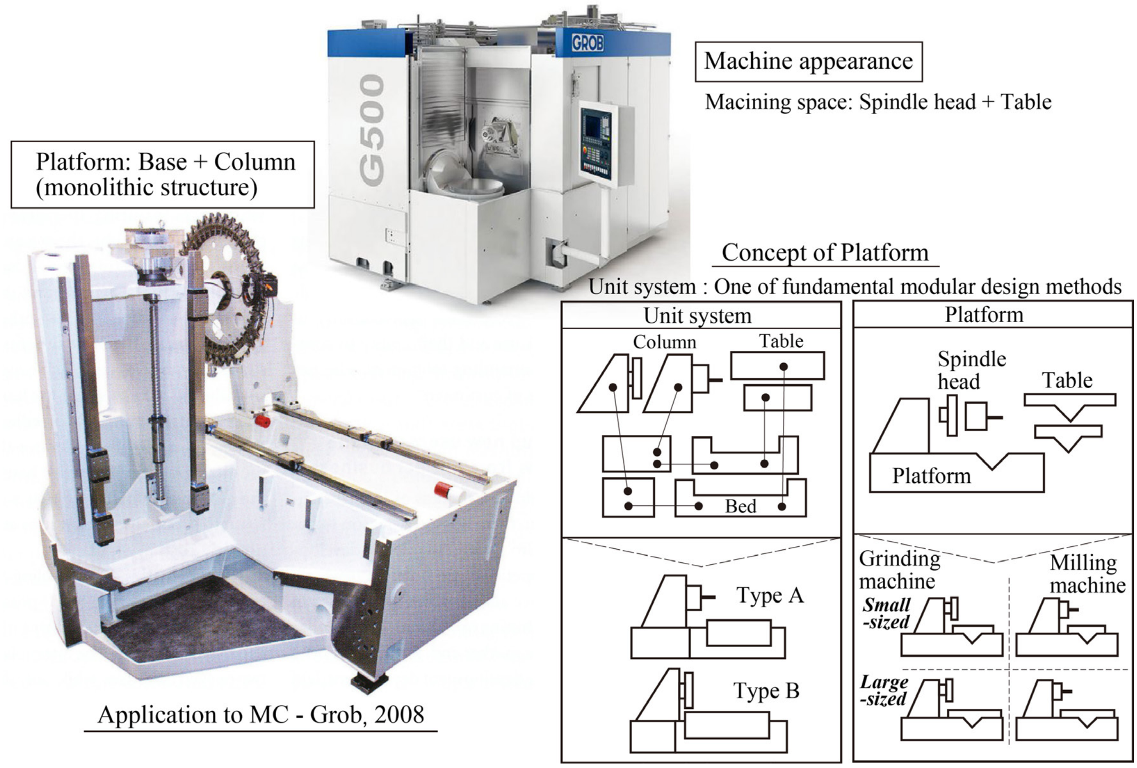

Fig. A.2 “Platform Concept” and its application to MC

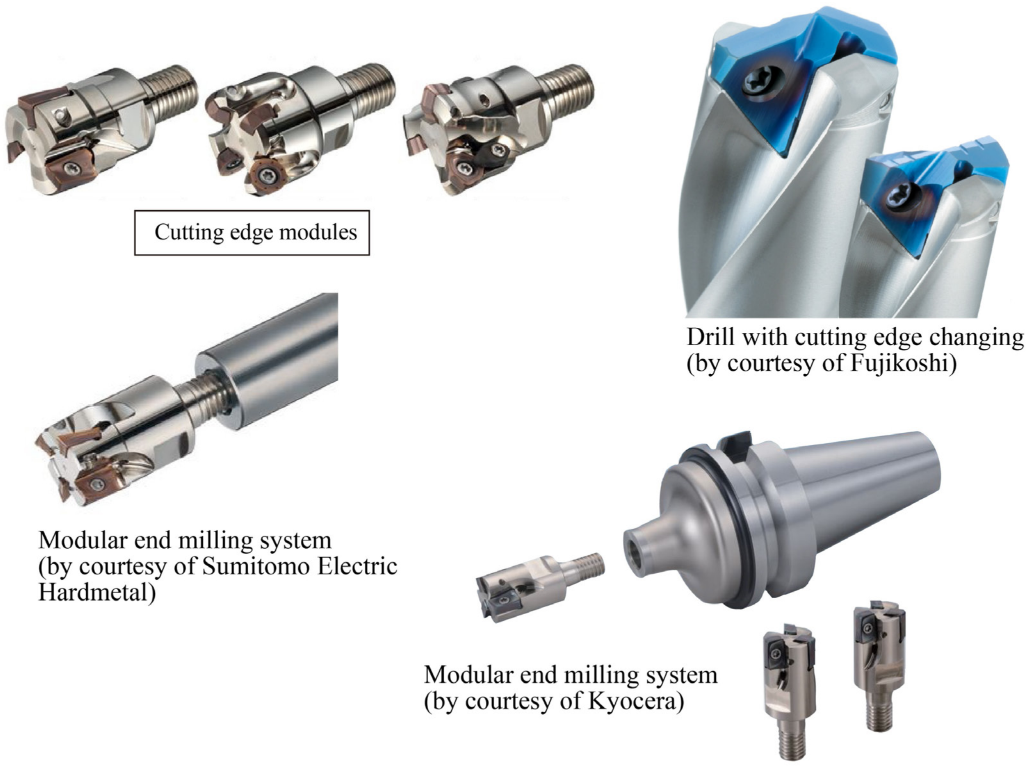

Fig. A.3 Modular tooling and quick-changing cutting edge around 2015 and cutting tool can enhance the capability of secondary form-generating movement. Figure A.3 shows the cutting tools of modular type and also of quick-changing type, i.e. one of the variants of modular tooling. In both the types, the cutting edge is quickly changeable to respond with the machining requirement without any time delay, and it is notable that the buttress thread can joint the cutting edge with either tool shank or adapter to prevent unfavourable loosing.

As will be clear from the above, another facing issue is to establish a design methodology for FMC when inputting a group of the part drawings to be machined. Importantly, we must be aware that the core of machining function can be, at present, facilitated by the mill-turn and its variants in responding nearly all machining requirements. Paraphrasing, we must discuss the design flow of FMC, provided that the primary form-generating movement is the same for nearly all machining requirements. Thus, at burning issue is the secondary form-generating movement, which can be facilitated by the attachment and tool mounted on machine bodies closely allocated to the machining space.

Figure A.4 shows a proposal for the design flow of FMC and process planning in consideration of FMCs applicable. Obviously, a key is simultaneous processing of the compatibility evaluation of FMC with the machining requirements and generation of process plan when employing FMC already evaluated.

From the practical point of view, such a design flow appears not to be effective, because the experience-based know-how is crucial in the design of FMC. In contrast, such a design flow is very effective to explore and unveil the research subjects in the academia. In fact, we can suggest some interesting research subjects along with the design flow as follows.

(1) Determination of a group of the basic functional modules, provided that the primary machining function remains the same in the most cases, and that the secondary machining function may be determinants for another four cell functions.

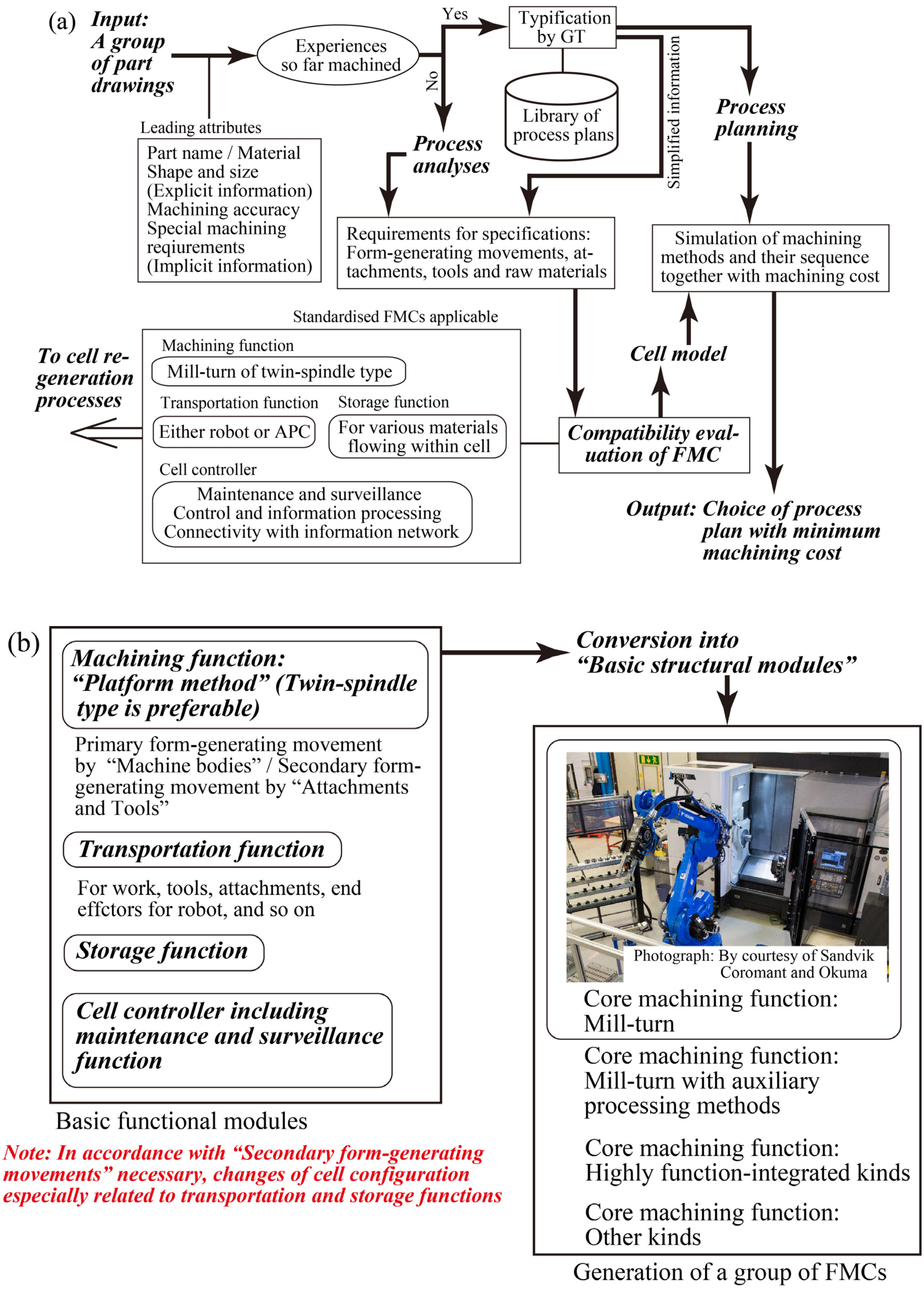

Fig. A.4 A proposal for design flow of FMC: **a** Compatibility evaluation and choice of process plan. **b** Re-generation procedure of FMC

(2) "One-to-One" conversion methodology of "Basic Functional Module" into " Basic Structural Module".
(3) Process analyses in consideration of secondary form generating movements carried out by attachment and tools. Paraphrasing, new horizons in process planning when employing innovative attachments and tools.
(4) Modernisation of GT (Group Technology) theory in consideration of highly function-integrated machine tools, and growing importance of secondary form-generating movements by attachments and tools.
(5) Process planning for highly machining method-integrated kind like "Mill-Turn of Twin-spindle Type" with innovative modular and combination tooling system. The "Hand-off" action between both the main spindles may contribute considerably to establish an innovative process planning, by which process planning at present could become obsolete. For example, we can first machine the cylindrical work with the stepped shape by reverse feed cutting without re-chucking, and then cut-off it after the hand-off to the second main spindle.
(6) Simulation of machining methods and their sequences by using "Digital-Twin", i.e. development of "Digital-Twin" for CAPP (Computer-Aided Process Planning) and CAOP (Computer-Aided Operational Planning).
(7) Determination of preferable "Cell Model" for compatibility evaluation with machining requirements.

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