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LAYOUT DESIGN FOR FLEXIBLE MACHINING SYSTEMS IN FCIPS AND CONVERTIBILITY TO CPS MODULE IN SMART FACTORY

Although being not in accordance with the original concept proposed in the "Industrie 4.0", the smart factory has been gradually applied to the practice. In contrast, we can observe that nearly all discourses, suggestions and discussions have been carried out without considering the convertibility of flexible manufacturing in FCIPS (Flexible Computer-Integrated Production Structure), which is the utmost leading facility within the industrial nation, to the CPS (Cyber Physical Systems) module in the smart factory. Admitting the powerful potentiality of the smart factory, at crucial issue is to discuss to what extent and how the technological and human resources so far accumulated in FCIPS are available for the smart factory. This paper proposes, first, the conceptual drawing of the smart factory on the basis of the concept of FCIPS, and then suggests the similarity of both the concepts. In fact, the smart factory consists of cloud computing, information communication network and CPS modules, whereas FCIPS consists of CIM, information communication network and a group of FMCs (Flexible Manufacturing Cells). Then, the paper describes the present and near future perspectives of the CPS module and FMC, especially placing the stress on machining, and asserts the convertibility of FMC for "One-off Production with Keen Machining Cost" to the CPS module. Finally, the paper summarizes the research and engineering development subjects in FCIPS and the smart factory necessary to be investigated hereafter together with detailing one leading subject, i.e. methodology to incorporate the human-intelligence into CIM.

1. INTRODUCTION

The concept of the "Smart Factory" is, as widely known, one of the flagship projects within the "Industrie 4.0" program proposed by the "acatech (National Academy of Science and Engineering)" of Germany around 2012 [1]. The "acatech" indicates some representative key terms and sentences to represent the smart factory; however, does not give its concept and basic layout (factory configuration) in detail to us. For example, the "acatech" has proposed that the smart factory should produce the individual-oriented product; however, the "acatech" does not identify the pattern of the material flow within the factory, i.e. either "Flow" or "Discrete" type. As widely known, the pattern of the material flow is dominant in the layout design of the production system.

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Generally speaking, the "One-off Production" is for the individual-oriented product and of discrete type, but not flow type. In short, the smart factory is a synergy of cloud computing, information communication network and the CPS (Cyber Physical Systems) module (fog computing), and in accordance with the report of VDMA (Verband Deutscher Maschinen- und Anlagenbau) in 2016, there are about 50 case studies on the application of the "Industrie 4.0" in Germany including the trial of the smart factory. Of these, in the field of the machine tool, Schaeffler has reported the predictive maintenance for the main spindle of the mill-turn based on the concept of the smart factory [2]. Importantly, we have now a considerable number of the case studies on the smart factory in Germany; however, such the smart factory is not in accordance with the original concept proposed by "acatech" especially in the aspect of the "Autonomy among System Components". In fact, each case study aims at the lucrative application to the production system being on work, and duly we benefit considerably by using the original concept of the smart factory in part.

In Japan, nearly all reviews, discourses, discussions, and reference materials have appraised highly the concept of the smart factory without any doubt, and also don't state anything about either the convertibility of FCIPS (Flexible Computer-Integrated Production Structure) being on work into the smart factory, or don't seek "Raison d'être" of FCIPS. In general, it is incredible that the enterprise abandons completely its production facilities being used together with human resources and technological know-how, which have been steadily accumulated so far, without having any remedies. Such a story is very seldom in the production activity, and sounds to be very foolish for even not professional people.

Against to this context, we must recall an outstanding proposal of FCIPS, which was already conceptualized in 1990s [3], and a considerable number of its variants have been in practical use in the industrial nation depending upon the technological, economic and social environments of each nation. In short, FCIPS consists of CIM (Computer-integrated Manufacturing), information communication network and FMS (Flexible Manufacturing System). Importantly, the concept of FCIPS appears as to be very similar to the smart factory. As will be clear from the above, we must first eye the present and near future perspectives of FCIPS and also some case studies on the smart factory, and then discuss the convertibility of FCIPS into the smart factory. It is however worth suggesting that even FMS ranges from machining, through assembly, to the product inspection and furthermore remanufacturing in the narrower scope. To ease of understanding and clarify the discussion, thus, in this paper, the smart factory for machining only will be first conceptualized and envisioned in consideration of FCIPS, and then discuss the availability of FMC for the one-off production, one of the most advanced variants within FCIPS, to the CPS module. Finally, the paper will suggest some leading research and engineering development subjects to advance furthermore the technologies related to both the smart factory and FCIPS.

2. CONCEPT COMPARISON BETWEEN SMART FACTORY AND FCIPS

The "acatech" has suggested a group of the key terms including the narration-like sentences to represent the concept of the smart factory as shown in Table 1 [1]. In general senses, it is possible to draw a schematic view or basic layout of the smart factory by combining these key terms and sentences [4]; however, the "acatech" has not produced any such concept drawings.

Table 1. Representative key terms and sentences for smart factory within Industrie 4.0

Factory concept compatible with IoT (Internet of Things) and IoS (Internet of Services) environments
Factory concept applicable to SMEs (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 organizational 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 " Remanufacturing "

Importantly, we need at least either concept drawing or system layout (system configuration) in discussing obviously and rationally the factory system, and in principle, the factory system should be designed in consideration of the linkage among "Objective Product", "Production Pattern (Embodiment)" and "System Layout".

Against to this context, we may have a clue by comparing the concept of FCIPS in detail with the key terms in Table 1. In retrospect, FCIPS was conceptualized in 1990s on the basis of the achievement obtained from the predictive research into the "Production Environments in the Year 2000 and beyond". Such the predictive research was carried out by the leading industrial nations as shown in Table 2, and up to 2010s, FCIPS in full version remains in the concept stage and is far from the practical use. This is because the computing and information communication technologies were immature on that occasion [3].

In this context, an interesting trial was an "Agent Platform" for the production monitoring and control systems around 2005. Importantly, the "Agent" implements interfaces to different communication standards, and for example, the automobile industry facilitates many isolated stand-alone information processing systems to various extent, and the agent can connect efficiently and effectively these one another [5].

Table 2. Predictive research into desirable production systems around 2020 –conducted in 1990s

Countries	Organizations	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

As will be clear from the above, the immaturity in the information communication network technology was one of the obstacles to be FCIPS in fruition. Paraphrasing, the smart factory becomes to be in reality with both the advent of cloud computing and the advance of information communication technology, and thus it emphasizes that the predictive research shown in Table 2 should be highly evaluated.

Figure 1 shows first the concept of FCIPS already envisioned and then superimposes the corresponding key terms for the smart factory on the leading functions of FCIPS with close tie. Although there are differing terms from those of the production technology, it is worth either suggesting or asserting that the smart factory is 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 as will be discussed in detail later (in the concept of the smart factory, the terms differ from those in the production technology, resulting in misunderstanding and confusion of the smart factory to some extent. For example, the "Mass Customization" is, dare to say, wrong term for people in the production technology sphere, but "One-off Production with keen manufacturing cost" is correct). In addition, to ease of understanding, FCIPS is represented by the human-mimetic model, i.e., CIM, information communication network and FMS being likely "Brain", "Nervous system" and "Limbs and Tools", respectively.

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 satisfactorily. In this context, we must be aware that the smart factory has been discoursed and discussed, dare to say, by placing main stress on cloud computing and information communication (Brains and Nervous systems), but not on the factory floor (Limbs and Tools).

Admitting that the smart factory is one of the variants of FCIPS, at the crucial issue is to describe FMC, i.e. "Cell Description", which is the prerequisite to provide FMC with the autonomous function; however, even now the cell description is far from the completion [6].

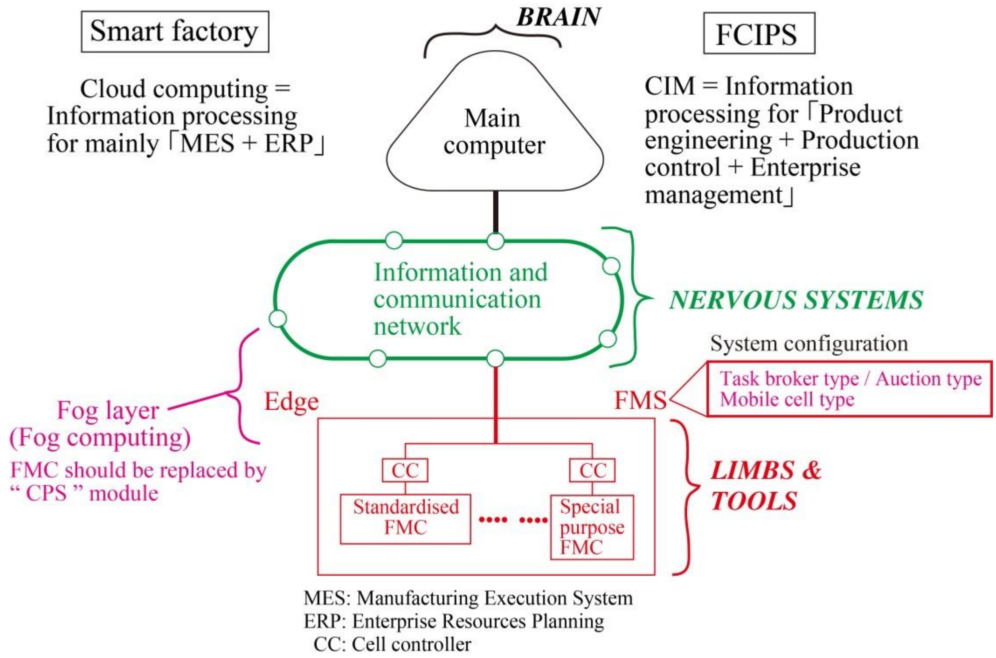

Fig. 1. Concept comparison of FCIPS with smart factory and their human-mimetic models

2.1. OVERALL VIEW OF FCIPS

Figure 2 shows especially the cell controller and information processing aspect of FCIPS in detail by placing the stress on the autonomous function. As can be seen from Figs. 1 and 2, FCIPS can be characterized by (1) CIM with human-intelligence-based function, (2) a group of FMCs (Flexible Manufacturing Cells) 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 [3].

More 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", and in nearly all cases, FMS is designed by the modular principle, in which the basic module is FMC possible to distribute within a certain region, e.g. either an industrial estate, or across the whole world [7].

It is thus capable of producing a considerable number of the variants in FCIPS depending upon the combination pattern between CIM and FMS. In addition, the characteristic feature of CIM depends upon the system configuration of FMS to some extent, and FMS can be characterized by a group of the basic modules, i.e. FMC*s*, and also by their combinations possible (actually, CIM consists mainly of CAD (Computer-Aided Design), CAPP (Computer-Aided Process Planning), CAOP (Computer-Aided Operational Planning), MRP (Material Requirement Planning or Material Resources Planning), SCM (Supply Chain Management) and so on).

In fact, FCIPS may facilitate the production activity in the era of localized globalization to larger extent. In due course, a crucial issue is to investigate the manufacturing culture, which is a synergy of the production technology and the industrial sociology. For example, the manufacturing culture has proposed the "Culture- and

Mindset-harmonized Product", "Individual Difference-oriented Product", "Sensitivity Compatible Product" and "Aesthetic-like Product", which appear as to be within a family of the smart products [8].

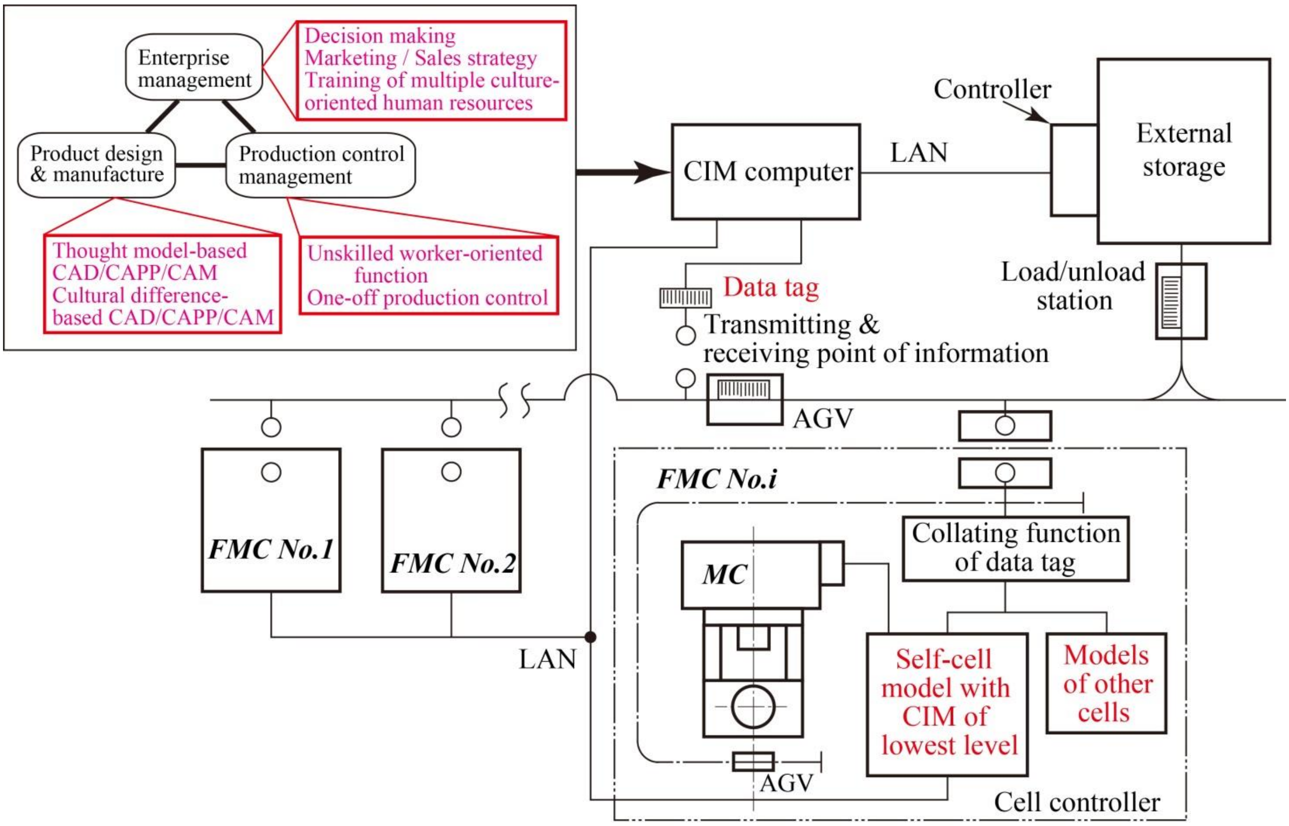

Fig. 2. Cell controller and information processing in FCIPS

To this end, we must be aware of the extreme importance of the "Limbs and Tools" in the production, and in due course pay the special attention to the hierarchical structure represented in the order of "Factory location planning - FCIPS - FMS - FMC – Machine tools - Machining space - Attachment, Cutting tools and Raw materials".

2.2. CASE STUDIES ON SMART FACTORIES

In the first stage, the CPS module can be facilitated with a considerable number of the sensors (transducers) to collect the "Big Data" and their output signal processing. Nevertheless the CPS module is not defined clearly as compared with FMS as yet, and also its configuration does not show concretely in accordance with Table 1, the smart factory in practice can give us the valuable knowledge regarding cloud computing and information communication technologies. Some case studies will thus be introduced and discussed in the following including that for assembly.

BMW Regensburg plant

This plant has been on work the smart assembly system for the automobile as shown in Table 3 and Fig. 3, which employs the software for production control of Ubisense-brand [9]. More specifically, the CPS module and cloud computing in this assembly line are a synergy of the following hardware and software.

Table 3. Specifications of assembly line

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)	

(1) The hardware consists of data tag and sensors.
(2) The software is called RTLS (Real Time Location Systems), which consists, in principle, of MES (Manufacturing Execution System) and ERP (Enterprise Resources Planning).

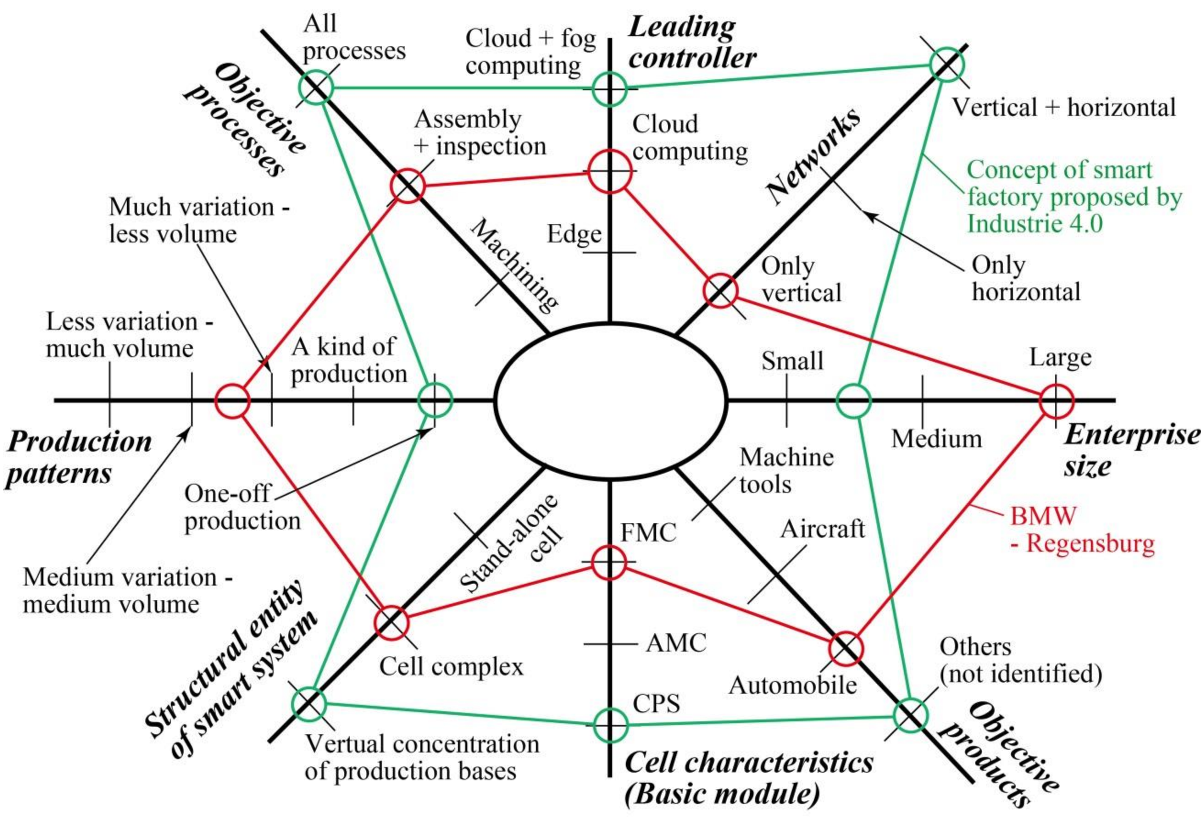

Fig. 3. Comparison of practical application by BMW with original concept proposed by "acatech"

In due course, the manager can grasp the "State and Action" of the production resources, i.e. product, people, tools and so on, in the plant by RTLS, visualize such the state and action in the virtual space, and in due course control and adjust properly the assembly flow. As a result, BMW has raised considerable achievements as follows, although they are not quantified as yet.

(1) Adjustable-free indication and decision making by manager based on real time identification of assembly states.
(2) Maximum efficiency in line flow and reduction of re-assembly.
(3) Optimization and protection of wrong work in assembly of customized product.

In contrast, the assembly system is of traditional line-flow type, but not of station (cell) of CPS module type, for which the "acatech" has recommended [1]. In addition, the assembly line consists of the "Vertical Network" only, although the smart factory should form by both the vertical and horizontal networks. Thus, Fig. 3 visualizes 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. In short, that of BMW places the stress on the "Brain and Nervous Systems".

Czech Technical University in Prague

A CPS module for one-off machining of the large-sized work has been developed under the project of "Intelligent Machining Systems with Digital Twin", where the digital twin means a couple of actual and virtual machines, and the core machine is of TOS-brand [10]. As can be literally shown, this machining system can be characterized as follows.

(1) Intelligent fixture: the technician receives the indication for the "Positioning and Adjustment of Work" by the handy display, and also can ask the question by 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 optimize the machining sequence.
(3) Identification of machining errors by "Digital-Twin".

German machine tool manufacturers

Some German machine tool manufacturers have steadily merchandized the advanced NC controller applicable to the smart factory as quickly shown in Table 4. In short, Table 4 shows a functionality comparison between the advanced NC controller and the cell controller in general.

For example, the advanced NC controller of Index-brand is capable of connecting the management organization 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. Although being not obtainable the detail, Siemens announces the marked features its product (brand name: SINUMERIK) as follows.

(1) Integration of CAD/CAM with CNC by virtual machine for optimization.
(2) Display of user's order specifications.
(3) Paperless production.

In contrast, the autonomous function is not established in both the advanced NC controller as yet, although it is mandatory for the CPS module in the smart factory.

Table 4. Comparison of controller for CPS module with cell controller

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 Optimization of tool utilization & control	Control for machining history of work & quality data histroy
EMAG	○	○	○	○
Index Xpanel	○	○	○	△ Processing machining history data is not clarified
FMC Cell controller	○	○	△ None up-to-date function for tool status	○

Enterprises and other	Work planning & scheduling	NC information production & process simulation based on part drawing	Remarks
EMAG	○	○	
Index Xpanel	○	———	NC controller integrated with personal computer facilitating " Paperless production " (Direct connectivity with business organization)
FMC Cell controller	△ Supply of due data from computer of upper layer		

To deepen the understanding, Fig. 4 shows the function of the advanced NC controller of EMG-brand, and furthermore to ease of understanding the convertibility of the cell controller, Fig. 5 shows also the function of the controller of standardized FMC in general.

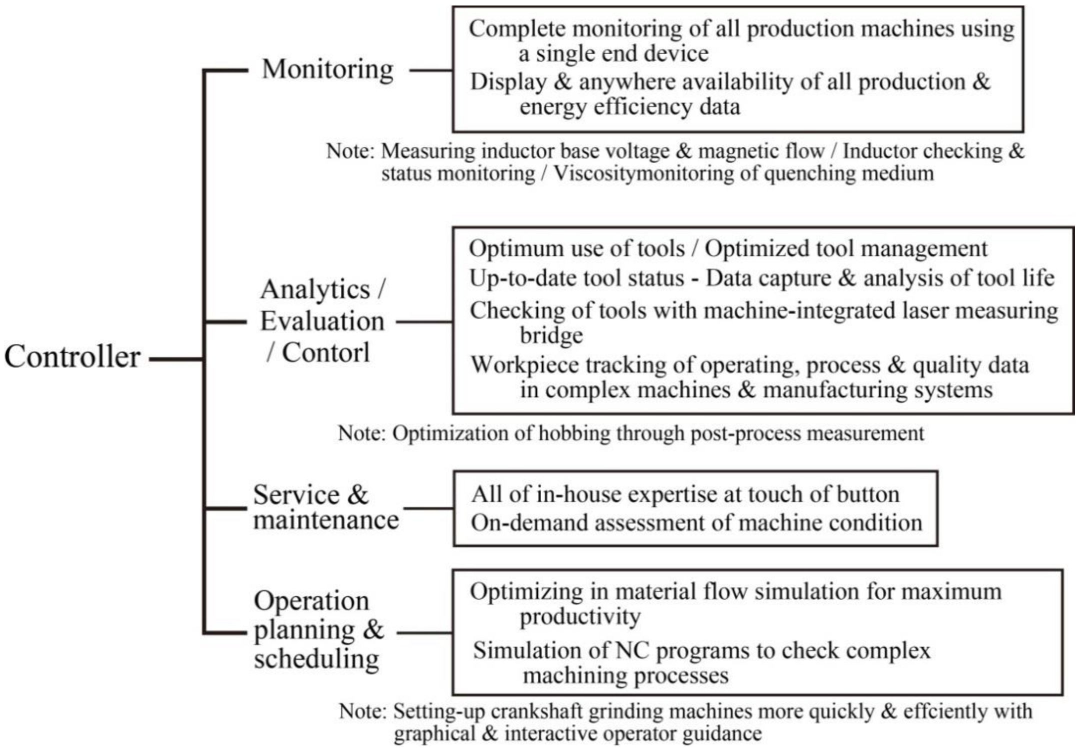

Fig. 4. Controller compatible with Industrie 4.0 – EMAG-brand, 2016

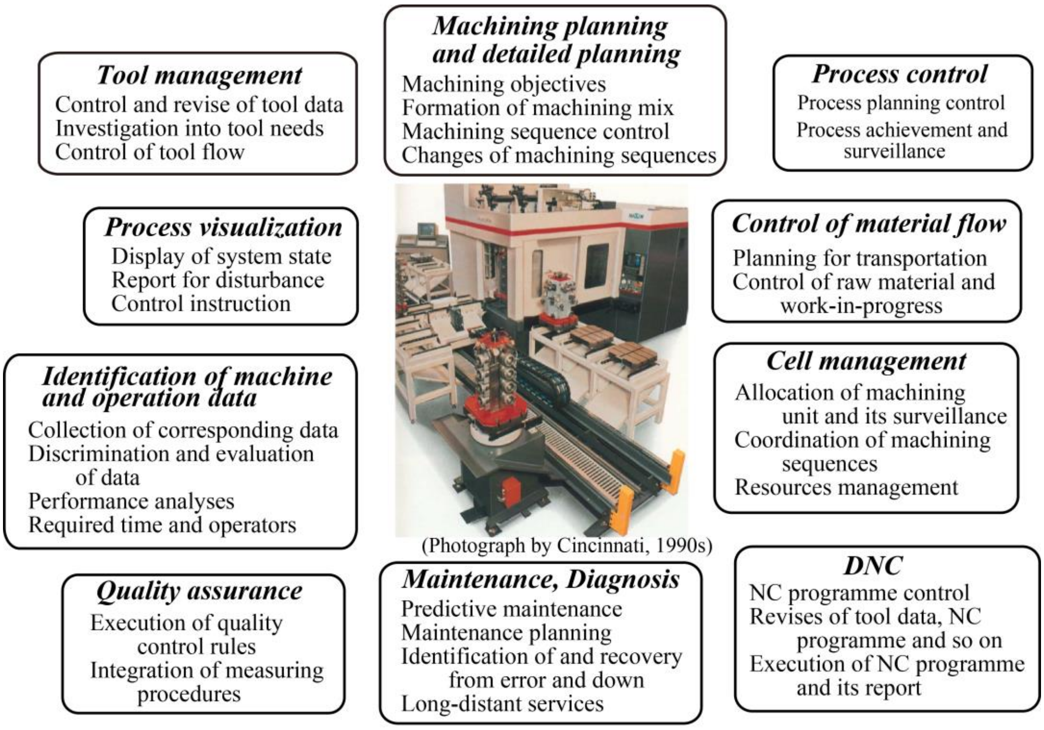

Fig. 5. Functionalities of FMS controller in general (by Uhlmann, 2008)

As can be seen from Fig. 5, primary concerns of the cell controller 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 (apart from the photograph, Fig. 5 is based on the handouts publicized on Web by Professor Uhlmann of Technische Universität Berlin under the title of Flexible Fertigungssysteme in 2008).

Because of reinforcement of the marketability, we must 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.

3. PRESENT PERSPECTIVE OF FMS AND ITS CONVERTIBILITY INTO CPS MODULE

As can be readily seen from Table 1, the configuration of the CPS module is very similar to that of FMC. Furthermore, we may understand such a similarity from the definition of FMS or FMC proposed by Weck et al as shown in Fig. 6 [11]. In fact, it is possible to interpret the horizontal material and vertical information flows as the real and virtual spaces, respectively. Importantly, the key of definition is simultaneous supply of both the material and information necessary to process the material at any stations within the system to eliminate completely the waiting time, i.e. "Same Time – Same Place

Principle". In AMS (Agile Manufacturing System), author assert that the idle time in each flow can be reduced to a large extent by keeping the same time – same place principle.

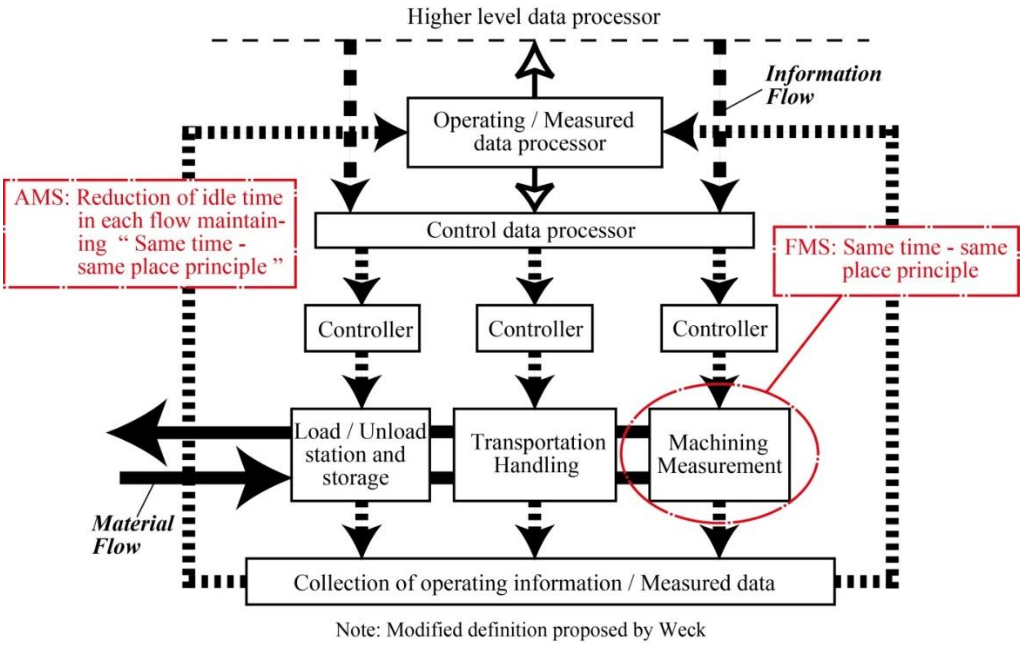

Fig. 6. Definition of FMS and AMS

In discussing the convertibility of FMS to the CPS module, thus, we need first to understand the present and near future perspectives of FMS and concerns. Fig. 7 illustrates the applicable range of FMC, FMS and FTL (Flexible Transfer Line) by indicating obviously the production patterns, 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", where FTL is mainly for the automobile industry. In this context, it is worth suggesting that FMC is, in general, available for a kind of production, but not for the one-off production. (if necessary, we can add furthermore the following production patterns, i.e. "Considerable Variation and Variable Volume Production" and "Client's Order Responding Production").

Importantly, Fig. 7 is a modification of the proposal by Klahorst around 1980 (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"). He proposed the classification for the flexible manufacturing system by using both the indexes, i.e. flexibility (manageable variation of parts) and batch size, as indicated by the green line and letters, which was based on the classification proposed by Kearney & Trecker. It is furthermore notable that his proposal is very reliable as verified by many engineers later.

Having in mind that the smart factory is for producing the smart product with the one-off production, at burning issue is, as can be seen from Fig. 7, FMC for, at least, a kind of production, and in the utmost desirable case, for one-off production with keen machining cost in discussing the convertibility of FMS and FMC to the CPS module.

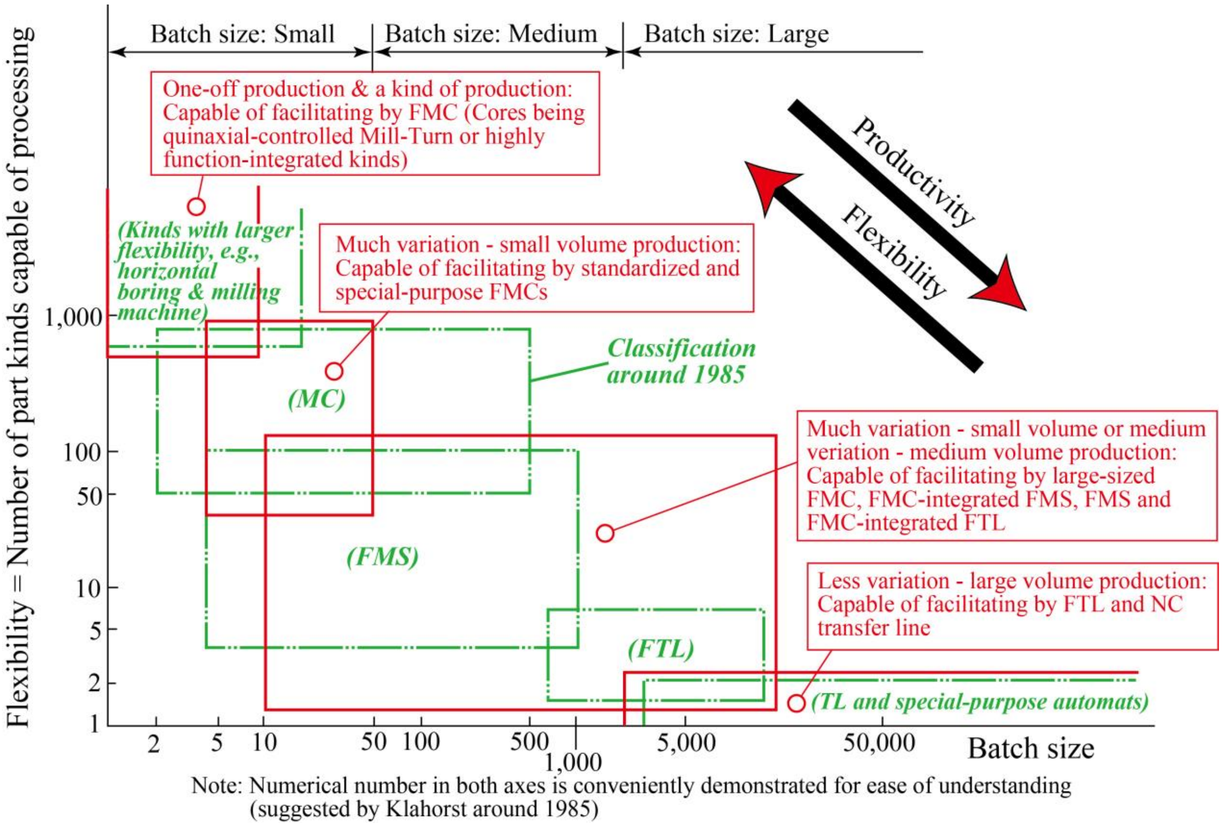

Fig. 7. Classification of flexible machining systems in 2010s

In this context, we must mind that FMC for one-off production involves considerably the technological difficulties, although FMC is, in general, very handy and easy for practical use immediately after installation without any teething troubles, resulting in the lucrative product for the machine tool manufacturer. It is however worth suggesting that FMC for one-off production is about to be in practical use by contriving an innovative cell controller, but not the machining function as already exemplified by that of Czech Technical University in Prague. Importantly, Starrag Group displays its product deployment ranging from FMS for one-off production to that for less variation and large volume production, and these FMSs are modular-designed, in which the basic module is either MC or FMC. In addition, 3D-Schilling uses FMC for one-off production to machine the prototype part.

In 2016, Okuma has supplied a standardized FMC of robot type (similar to that will be shown in Fig. 8) to Sandvik Coromant to machine the boring bar with both the “On-demand Manufacturing” and also the one-off production. The machining function is cored by the mill-turn (Type: Multus U3000), which is a synergy of TC (Turning Center) and MC (Machining Center), and furthermore reinforces 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 serves the lower turret head and external ATC for expanding the allowable capacity to the cutting tool, center and collet chuck. Importantly, Table 5 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 [12].

Table 5. Outlines of cell controller in FMC for one-off production installed at Sandvik Coromant

CNC interface to display machining state, machine conditions and so on
Exchange of NC program 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, center and collet chuck from Okuma controller
TAP system: Interface with operator Direct generation of parameters for robot and NC program from three-dimensional model of work Cognitive function for collet chuck, center 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)

More specifically, production planning can especially facilitate the generation of the NC program and robot control information from three-dimensional model of the work. In fact, we used to manage such a function by CIM.

4. PRESENT AND NEAR FUTURE PERSPECTIVES OF FMC

In consideration of the growing importance of FMC, some quick notes for it will be given in the following.

As well known, there have been two types of FMC, i.e. FMC 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. Fig. 8 shows a typical FMC of front traveling robot type.

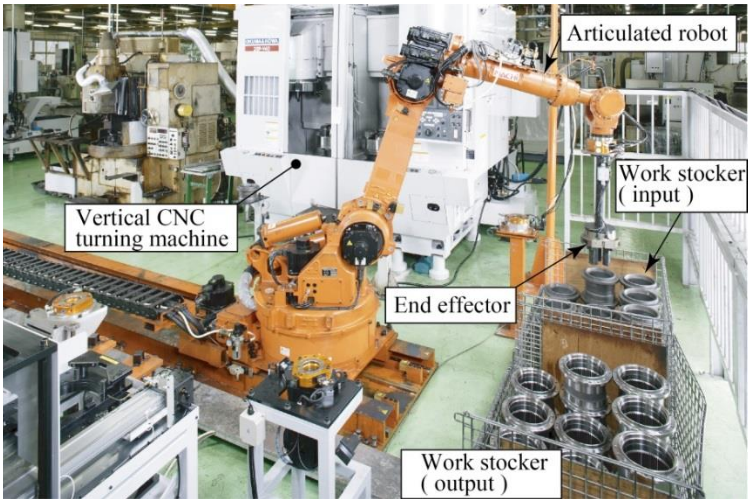

Fig. 8. Robot allocated at front of machine tool (by courtesy of Fujikoshi, 2010)

Importantly, nowadays we can regard them as the standardized FMC for stand-alone operation or the basic module for the large-sized system like FMC-integrated FTL, and more importantly there are several variants as shown in Fig. 9 depending upon the system component, by which each variant can be characterized. Of special note, it emphasizes that the standardized FMC and its variant have been mushroomed within SME (Small- and Medium-sized Enterprise). In fact, FMC was first developed to be compatible with SME, because SME cannot afford to install FMS.

As will be clear from Chapter 3, FMC for one-off production may be applicable to the CPS module without any difficulties, and we may furthermore sublimate such an FMC to the much more desirable entity than our expectation by replacing its system functions into the “Highly Function-integrated Kinds in Machine Tools”.

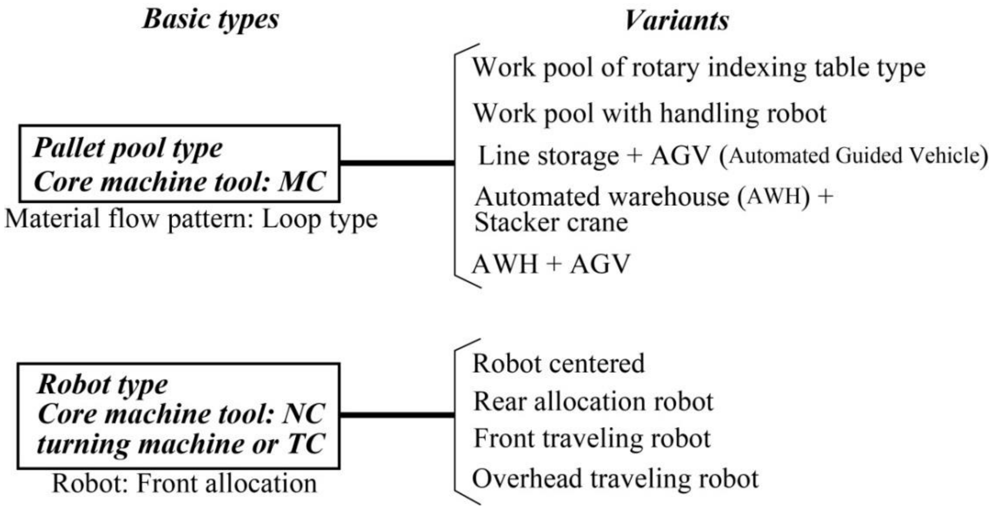

Fig. 9. Variants of FMC

Reportedly, we developed once some prototypes of such the machine tool in the past, and can merchandize successfully it at present as exemplified by MC with auxiliary form-generating movement and also the “Transfer Center” (there are three types depending upon the original types in TL (Transfer Line), i.e. those originated 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 short, there are two kinds depending upon the integration objectives, i.e. either “Machining Function” or “System Function” as shown in Fig. 10.

Figure 11 shows the utmost representative transfer center of ANGER-brand, which can be characterized by its work spindle capable of traveling within the 3-dimensional machining space, and which is of the system function-integrated type with limited specifications in 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 cutting tools with various kinds and types, i.e. those mounted on the turret head, tool cassette, single-spindle head and multiple-axis spindle head, which are placed around the work spindle.

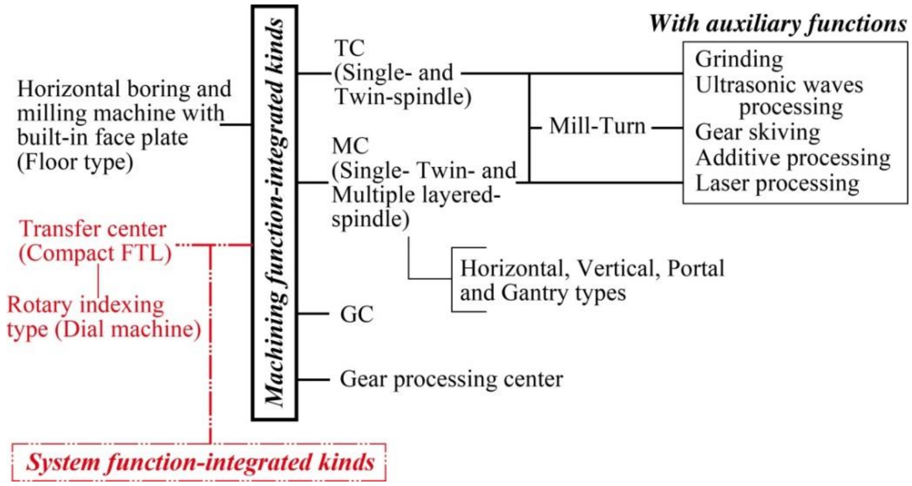

Fig. 10. A classification of "Highly Function-integrated Kinds" in 2010s

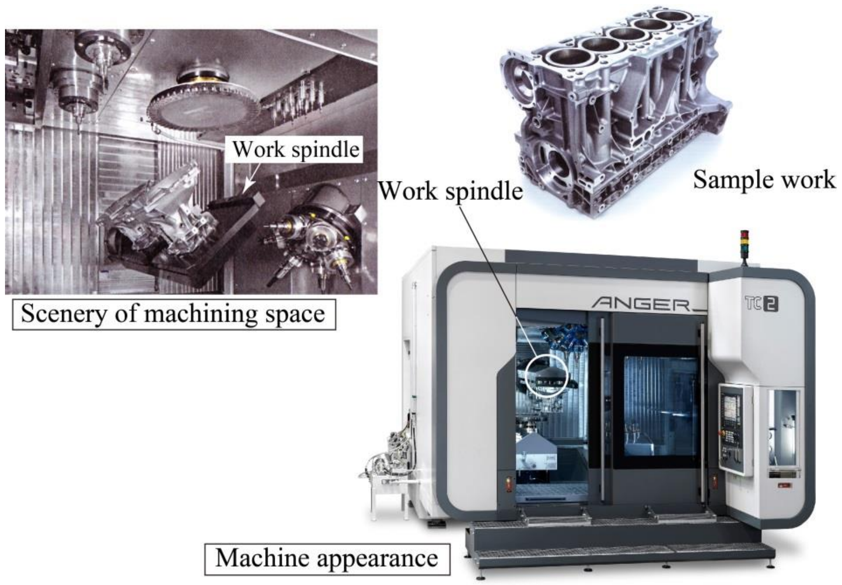

Fig. 11. Transfer center and its machining space (by courtesy of ANGER)

It is furthermore worth suggesting that the transfer center can facilitate the machining capacity equivalent to that carried out by MCs of 2 ~ 5 units. Actually, the transfer center shown in Fig. 11 may replace, for example, FTL shown in Fig. 12, which is for the considerable variation and variable volume production being very popular in the automobile industry.

Summarizing, the transfer center will be applicable to the CPS module, provided that its machining function is reinforced as like as MC with auxiliary form-generating function and also the mill-turn, whereas such an MC and mill-turn should be improved by integrating the system function.

More specifically, it is desirable that the highly function-integrated kinds are to be in reality in the form of compactly cubic and also with the ease of handling in operation, resulting in the "One-machine Shop" -like configuration and functionality. Obviously, we may expect the better connectivity with the information communication network and cloud computing, when the one-machine shop will facilitate the "Limbs and Tools" in the smart factory.

For the sake of further understanding, Fig. 13 shows TC of twin-spindle type and with grinding and gear cutting functions (Index-brand), resulting in high integration of the machining methods.

Fig. 12. FTL for cylinder block machining (by courtesy of Komatsu NTC, 2017)

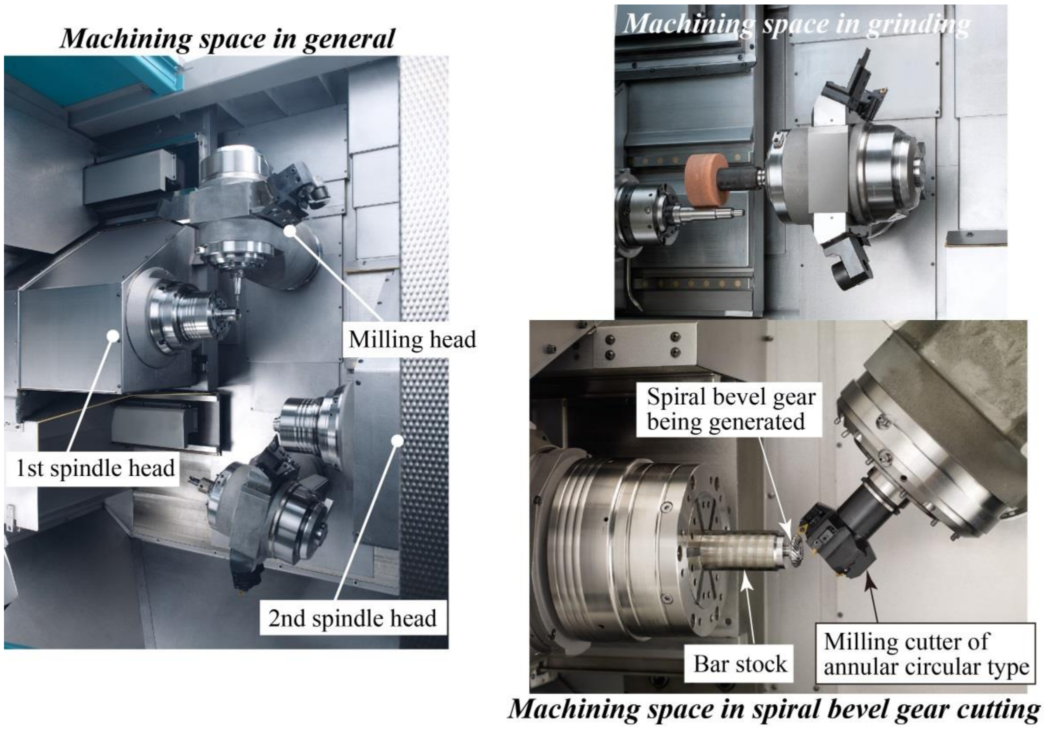

Fig. 13. Machining spaces in mill-turn – Direction quickly to "One-machine Shop" (by courtesy of Index, 2016)

In addition, Fig. 14 reproduces a trial of developing the function-integrated kind with considerable integration of the machining function, which was produced by MPM (Marwin Precision Machine) and installed within the Preston Plant of British Aerospace. As can be seen, the machine can facilitate all the five fundamental functions necessary to FMC, i.e. machining, transportation, storage, maintenance and surveillance, and also the lowest hierarchy of CIM within a whole machine-like space. Importantly, MC is kernel of the machining function.

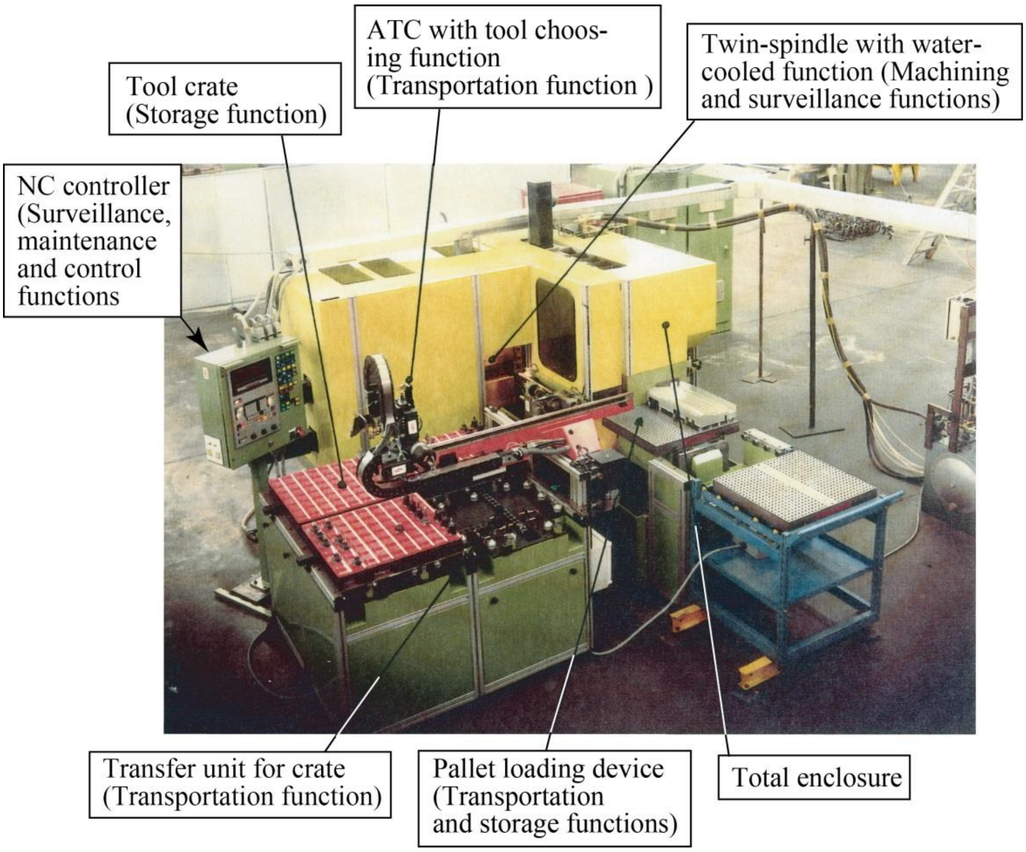

Fig. 14. System-function integrated MC of twin-spindle type (Type AUTOMAX I, by courtesy of MPM)

Of special note, FMC-integrated FMS and FTL are dominant at present, where the basic module is, as literary shown, FMC, and FMC is also modular-designed by predetermining a group of basic modules, i.e. standardized entities related to the cell components. As reported elsewhere, the modular design is mandatory to provide FMC, FMC-integrated FMS and FTL with the flexibility, expandability, and redundancy [13].

Importantly, the smart factory is also modular-designed, where the CPS module is one of the basic entities as literally shown, and author asserts that we have accidentally developed beforehand the function-integrated kinds in machine tools, which will contribute hereafter the fruition of the CPS module for machining to large extent. In retrospect, the “Industry Revolution” was launched out by James Watt’ s steam engine, which became the practical use afterward of the contrivance of Wilkinson’s cylinder boring machine.

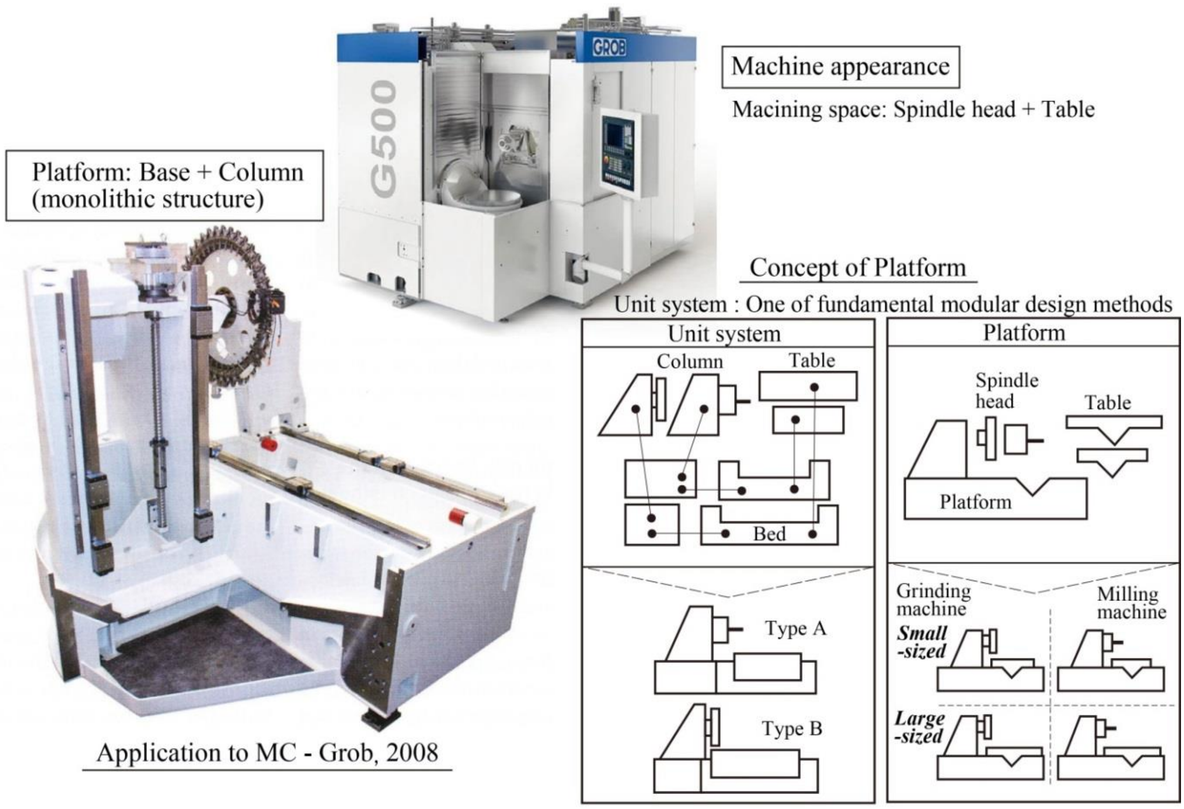

Fig. 15. Concept of "Platform" and its application to MC

To this end, it is extremely worth suggesting that in the modular design for the flexible machining system, primary concern is the "Platform Methods", which is of machining space-oriented as shown in Fig. 15 by pre-determining the large-sized monolithic module called the platform. In fact, the platform method becomes prevailed and accelerated by the advent of the modular tooling and attachment [14].

5. RESEARCH AND ENGINEERING DEVELOPMENT SUBJECTS

Tables 6 (a), (b) and (c) summarize some leading research and engineering development (R & D) subjects after delving into three branches, i.e. (1) system layout issues of general concerns, (2) CIM and cell controller, and (3) cloud and fog computing.

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 active since then, and (3) subjects newly arisen. For example, we recognize the importance of CIM with human-intelligence incorporation, and thus there have been a considerable number of developments for CAPP with expert system and also of flair type [15], although the latter is far from the practical use. In addition, we have not any proposals to evaluate quantitatively the flexibility of FMS and concerns, apart from that of Ito et al., [16]. Of course, the new comer is related to the CPS module and the division of work in information processing between cloud and fog computing.

Table 6. R & D subjects for system design in general, FCIPS and smart factory

Desirable virtual concentration of a group of FMCs

System and cell descriptions by direct 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 Diagram 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 "

(a) System layout issues of general concerns

Incorporation of human-intelligence into CIM
- System design to integrate deep knowledge of mature engineer and technician
- Quantufication 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)

Cell controller for FMC of " One-off Production " and its applicability to controller for smart factory

Sensor fusion for flexible machining system - Detection of reliable and valuable information from very noisy output signal

(b) CIM, information network and FMC

Desirable basic layout configuration of CPS

Definition of " CPS (Cyber Physical Systems) " 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 samrt factory and convertibility of cell controller to fog computing

Determination of dimensional and performance specifications of smart products like " Culture- and Mindset-Harmonized " , " Individual Difference-oriented " , " Sensitivity Compatible " and " Aesthetic-based " types

(c) Cloud computing, information network and CPS

Admitting that R & D subjects shown in Table 6 have not been investigated actively so far, now let us discuss the utmost important subject, i.e. "Change of Information Property in Processing", although we deal it with the case-by-case way in practice (we must discuss all the subjects enumerated in Table 6; however, we need much more allowance in printing. Thus, only one subject is discussed herein. For the rest, the reader may have certain knowledge from the description of the main body and related references).

Figure 16 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.

For the sake of further understanding, Fig. 17 reproduces a conversion process of the uncertain attribute-related information, i.e. "Comfortable Roominess" of the passenger car to the qualitative engineering design specifications by using the tree structure of hierarchical type. In fact, there are three steps in the conversion, and such the conversion is carried out by the long-standing experience of the mature engineering designer. For example, the better steering stability should be finally converted into (1) the use of the tread compound made of micro-carbon particle and (2) enhancement of the "Drainability" through the leverage of steering stabilities between the dry and wet road surfaces (in case of roominess, tree structures for "Better steering stability" and "Luxury appearance in sidewall and tread pattern" are not detailed to avoid complexity).

Even in such the qualitative information conversion, we must conduct it with the experienced engineering knowledge about the product, and Fig. 18 shows a conversion procedure for the shotgun, which necessitates the concert with the penchant of the user. Importantly, in this case, the barrel with long-term stability in sight alignment is to be in reality 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 [17].

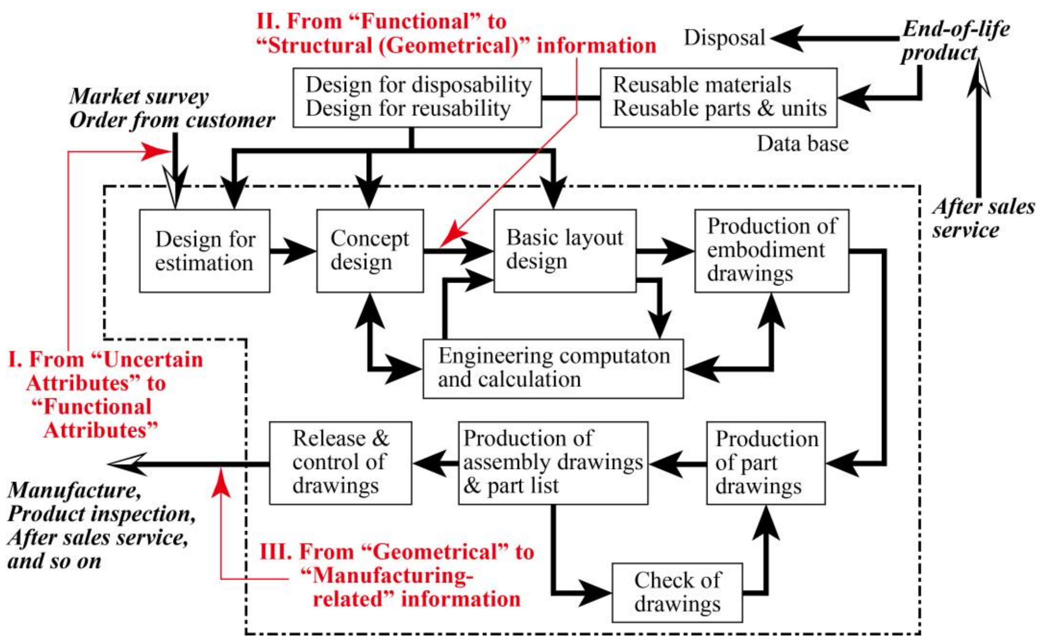

Fig. 16. Simplified flow in engineering design for product and several processes with property change in information

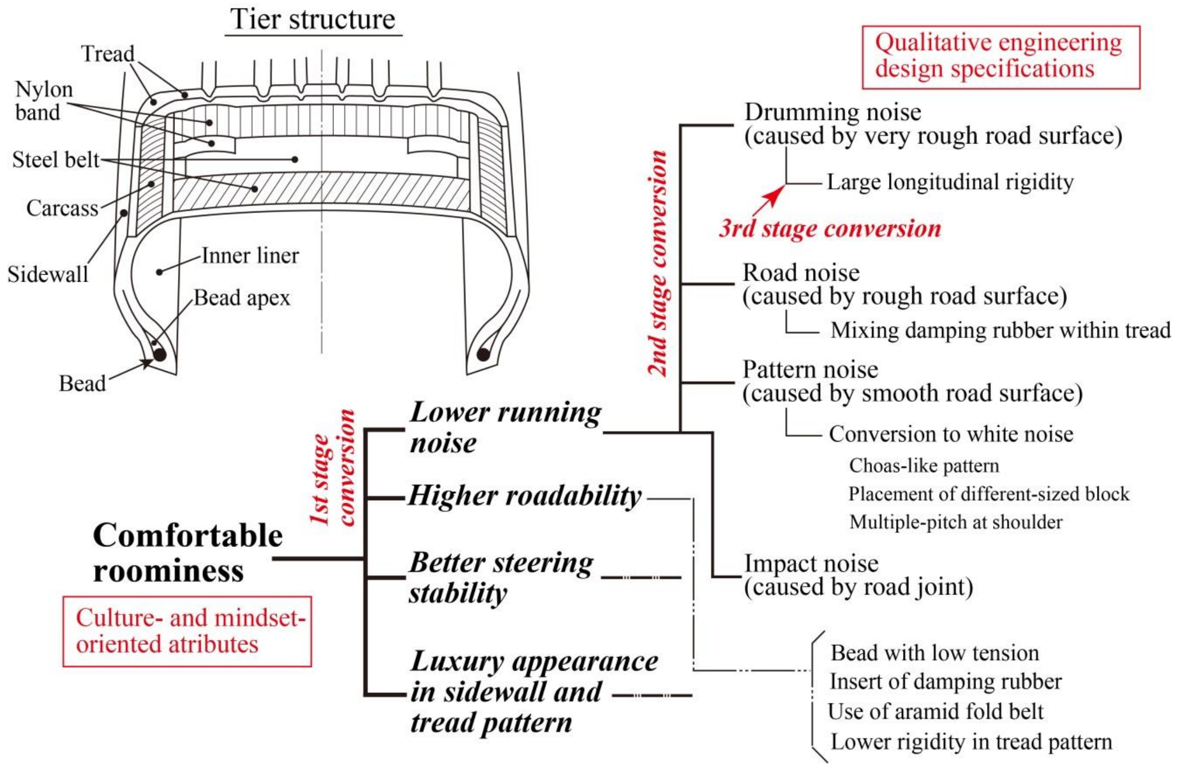

Fig. 17. Hierarchical tree structure representing conversion procedure of culture- and mindset-oriented attributes to engineering design requirements – in case of tier

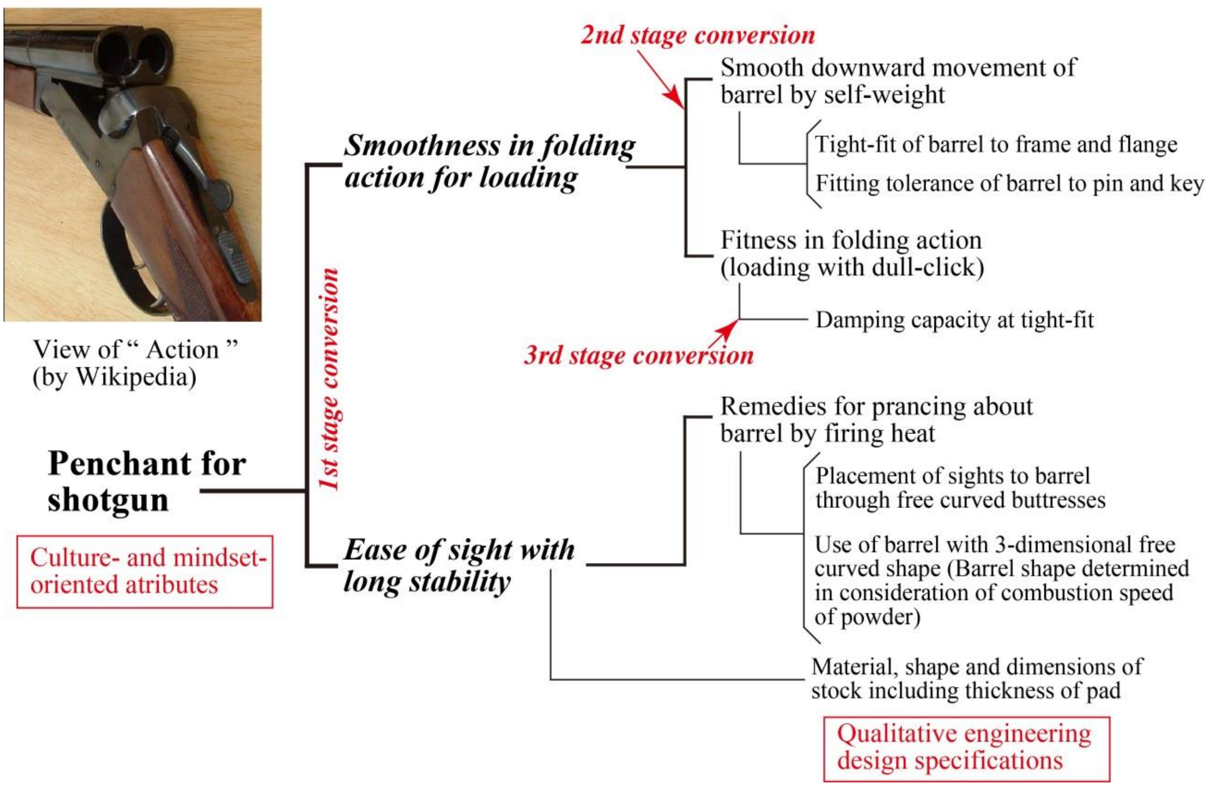

Fig. 18. Hierarchical tree structure representing conversion procedure of culture- and mindset-oriented attributes to engineering design requirements – in case of shotgun

From these two case studies, we may understand the essential difficulty in the conversion procedure from the uncertain attribute to the quantified one, and then we will discuss another case.

When placing the stress on turning of the cylindrical component, process planning (Manufacturing-related Information) should be produced from the given part drawing (Geometrical Information) as already shown in Fig. 16. As can be readily seen, a component can be turned by various methods as shown in Fig. 19, and thus the single geometrical information may be converted into a considerable number of the manufacturing-related information. In short, a root cause of difficulties lies in the establishment of “One-to-One Relationship” between both the information, even when we determine the strict constraints from machining accuracy, cost, delivery date and so on.

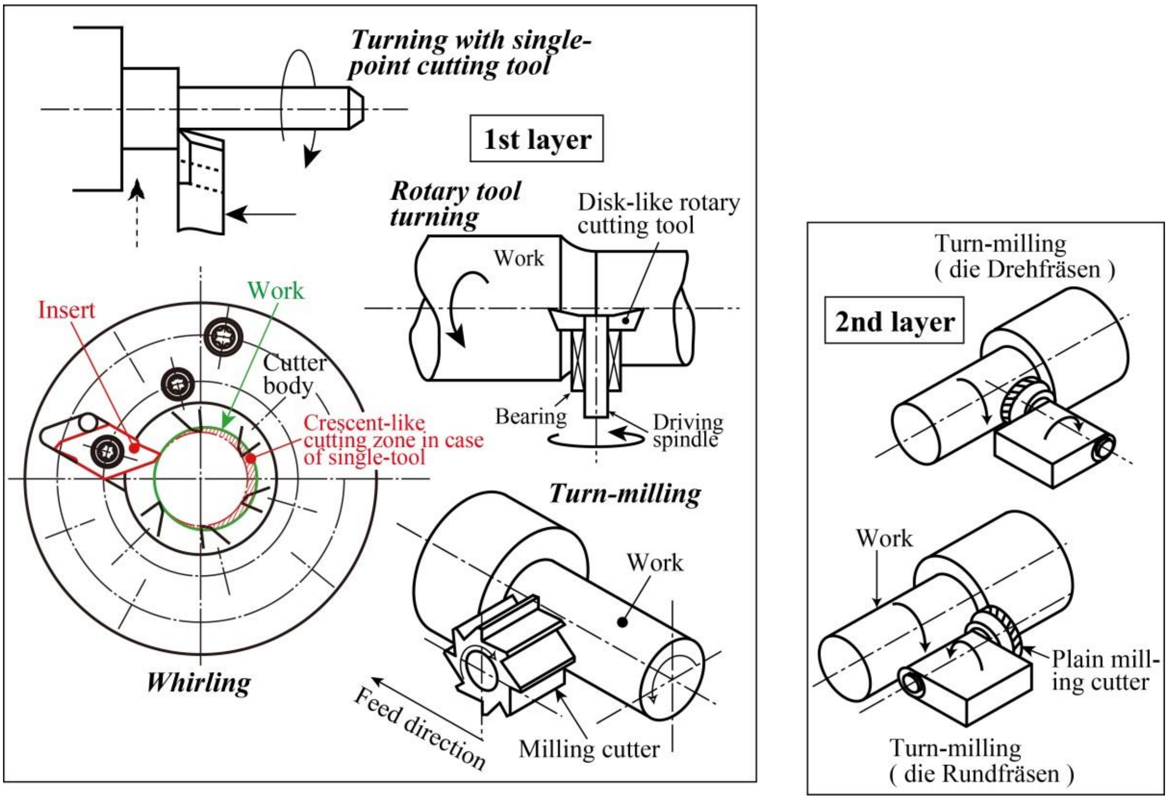

Fig. 19. Various turning methods to generate cylindrical component

Obviously, such a conversion work is very time consuming and cost expensive, and thus we must develop a methodology. In this context, Höft proposed a conversion method by using QFD (Quality Function Deployment) of hierarchical type as shown in Fig. 20, although it is far from the practical application [18]. 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 among the characteristics. Of course, the conversion is carried out by the step-wise way. It is regrettable that there are no succeeding research activities following that of Höft.

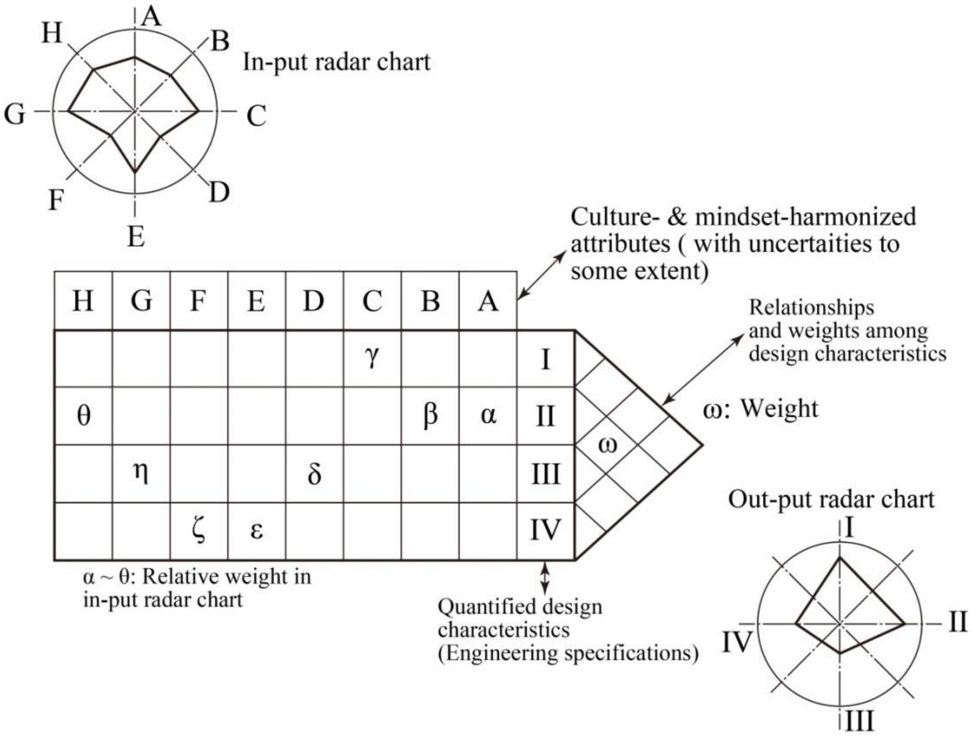

Fig. 20. Conversion method from culture- and mindset-harmonized attributes to engineering specifications by QFD of hierarchical type and radar chart (by Höft)

To this end, it is worth suggesting that nearly all case studies on the smart factory are concerned with the assembly procedures, but not for the machining procedure. This is because the machining space is, as widely recognized, very bad and ill-defined environments for the sensor. The sensor should work within the total enclosure, in which we can observe the oil mist, smokes, swarf and micro-projectile like debit caused by the scale of the raw material. In short, we must thus pay the special attention to the sensor fusion in the establishment of the smart factory for machining.

6. CONCLUDING REMARKS

There are two leading purposes in this paper: one is to suggest a clue for establishing the smart factory for machining on the basis of FCIPS for machining and being on work, and the other is to propose a first-hand view for the leading R & D subjects, which should be investigated hereafter.

As will be expected, we may benefit considerably in discussing the smart factory by actively using the technological and human resources so far accumulated in FCIPS, although the smart factory in practice is not based on its original concept. In contrast, it appears that the smart factory will be established in accordance with its original concept by conducting R & D subjects as suggested in the paper. In short, the paper may contribute the establishment of the smart factory with various deployments to large extent, although each R & D subject is not detailed.

The paper will furthermore contribute to make clear the causalities of the confusion and uncertainty in understanding the smart factory. A root cause of such confusions and uncertainty lies in the discourse, suggestion, review, discussion and so on, which are not based on the total view of the computer-controlled manufacturing systems, especially not considered the basic principle of the system design. More specifically, nearly all discourses place their stresses on MES and ERP in cloud computing, provided that the CPS module consists of the data tag and a considerable number of the sensors. In addition, the enterprise employs, in general, the smart factory for the lucrative business as exemplified by BMW and Bosch, in which the original concept of the smart factory is far from fruition. Such trials induce the confusion in understanding the smart factory.

To this end, it is worth suggesting that the "acatech" discusses another flagship project like the "Integrated Traffic Control Systems with Sustainable Energy Consumption", in which the kernels are autonomous car, communication among cars, traffic light control in consideration of jamming and so on. Obviously, such a system is to be surely in reality within a short time; however, we must be aware of the differing features in the smart factory by nature from other flagship projects as mentioned in this paper.

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