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This sentence is reconstructed in English from the technical commentary on November 2016 issue of "Kikai to Kogu"; therefore, the nuance may be different. We appreciate your understanding.

Leading Issues to Be " Smart Factory " Concept in Reality – From Viewpoints of Design for System Configuration and Production Technology -

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Abstract

The " Concept of Smart Factory " proposed within the " Industrie 4.0 ", one of the Flagship Projects, is very attractive; however, we can obtain only some key terms representing the smart factory at present. In discussion of the factory system, in general, we needs to envision the system configuration or system layout design, and in fact these key terms cannot facilitate to response such a requirement. This paper tries to detail each key term together with unveiling further issues on the basis of the forerunning achievement, which seems to be for the smart factory in general concern. In due course, we may expect to draw much more details of the smart factory, and also to suggest the research and engineering development subjects, which are necessary and inevitable to the smart factory in fruition to some extent.

1. Introduction

The " Industrie 4.0 " Project is, as widely known, under the control of the " acatech (National Academy of Science and Engineering) " in Germany. The project aims at the social revolution by positively applying the utmost advanced computing, information and communication technologies, i.e., IoT (Internet of Things) and IoS (Internet of Services), to various aspects of the human society. For example, we can expect to establish a total traffic control system with reducing the consumption of the total power sources across the whole nation. In the system, each car can be controlled autonomously, communicate with other cars, change its traffic lane after communicating other cars, reserve the car parking space near the market place, strategic allocation of stand for electric power supplies and so on (acatech 2013, 2015).

It is also very interesting that acatech suggests the " Concept of Smart Factory ", but does not detail its system configuration. Nevertheless, people believe in certain cases that the major objective of the " Industrie 4.0 " Project is for the fruition of the smart factory with CPS (Cyber-Physical Systems) module, although the concept of the smart factory is one of such social revolutions. Such a belief could be derived from the over-evaluation for the attractive key terms like the smart factory, CPS, mass customization, effective application of the information and communication technologies and so on.

In short, we may suggest a group of representative key terms for smart factory as shown in Table 1 from the publicized materials by acatech. Of special interest, the utmost serious problem being faced is " Can we draw duly a concept of system configuration or basic layout of system based on these key terms ? ", and the author dose assert that we cannot conduct such a work because of poor information related to each key term. In the production system sphere, obviously, it is common sense to delineate beforehand the system

Factory concept compatible with IoT(Inernet 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

Table 1. Representative key terms for drawing concept of smart factory within Industrie 4.0

configuration or basic layout of system and its objective product as suggested also by acatech itself (Anderl 2012). For ease of further understanding, Figs. 1 and 2 reproduce the concept of the system configuration of FMC (Flexible Manufacturing Cell)-Integrated FMS (Flexible Manufacturing Systems) and its software, respectively. The smart factory may be regarded as one of the variants of the advanced FMC-Integrated FMS by comparing the concept shown in Figs 1 and 2 with the key terms shown in Table 1.

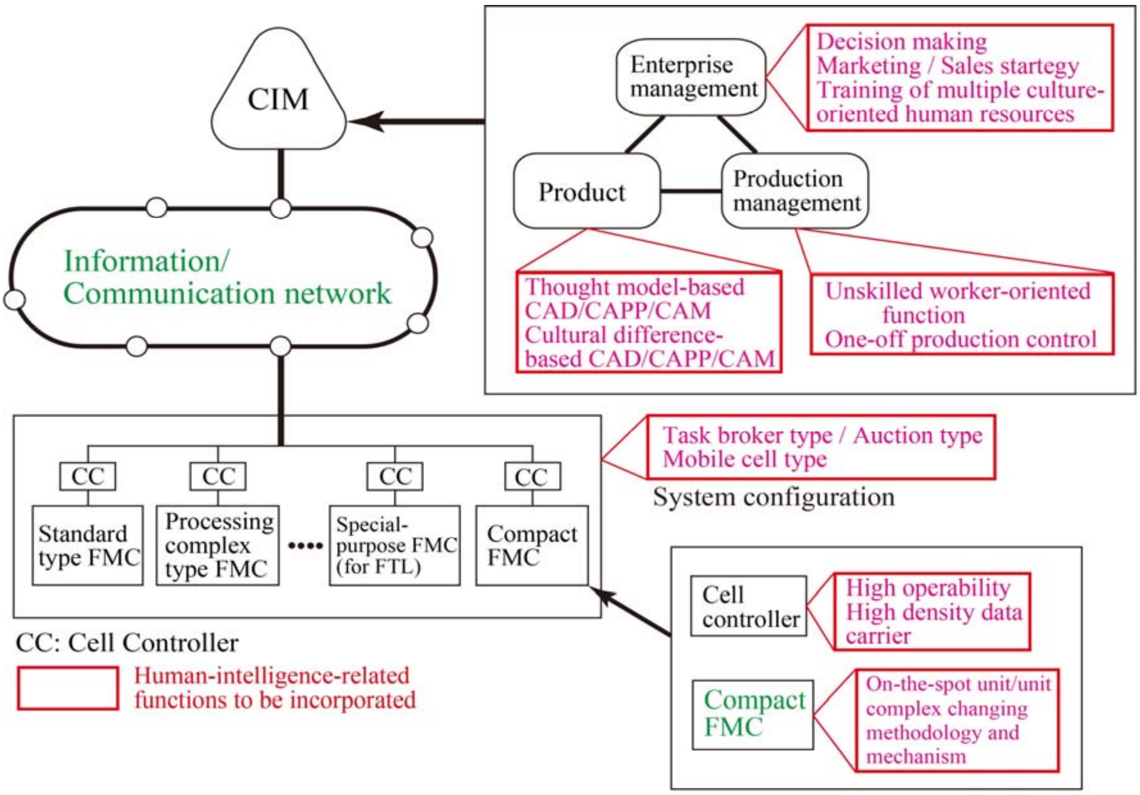

Fig. 1 System configuration in concept of FMC- integrated FMS - Auction or task broker-like type

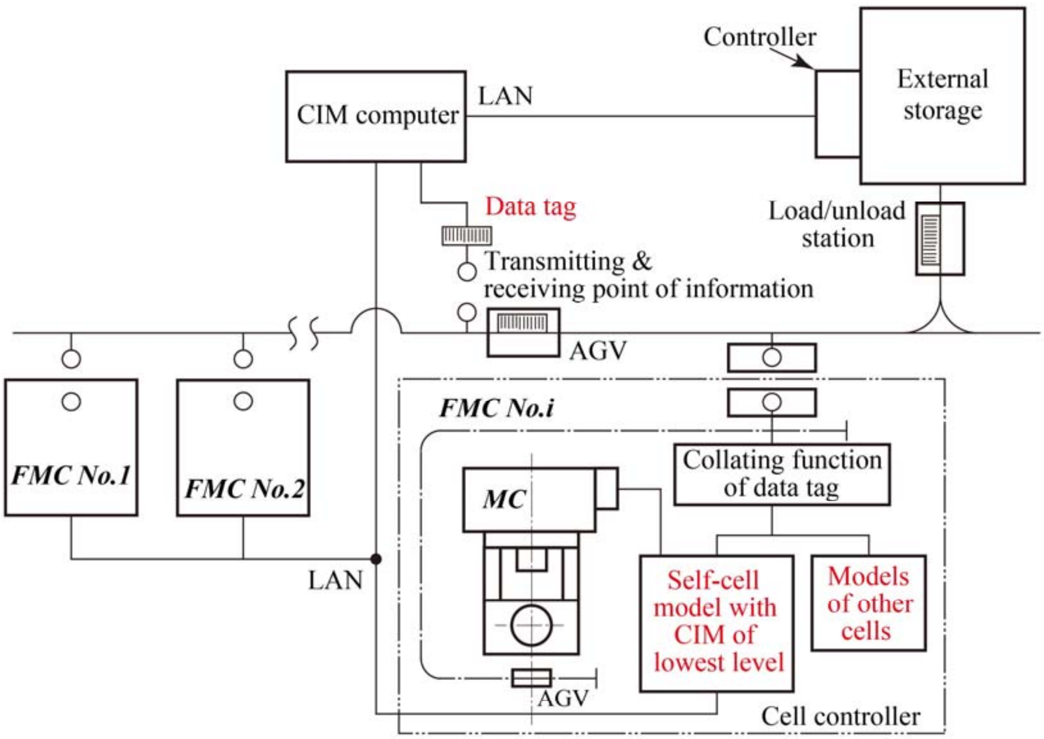

Fig. 2 Cell controller and information processing within autonomously controlled FMC-integrated FMS

More specifically, the " Cyber Space " in CPS can be facilitated with CIM (Computer-Integrated Manufacturing), information and communication networks and cell controller, whereas the " Physical Space " consists of a group of FMCs of autonomous type, i.e., those of task broker or auction type. Importantly, the cell controller and data tag (data carrier) in Fig. 2 are for autonomously distributed information processing, and simultaneous flows of material and information, respectively. In addition, it is worth suggesting that CIM is of advanced type by incorporating the human-intelligence-related functions, although such functions are far from completion even now.

Of special note, Figs. 1 and 2 were produced on the basis of the worldwide predictive research into the future factory system around 2020, which were carried out in the 1990s across the whole industrial nations as shown in Table 2 (Ito 1993).

Countries	Organizations	Projects
UK	Engineering Council	20/20 Vision
	IEE	Next Generation Manufacturing Enterprise
	Royal Society of Arts	Tomorrow' s Company Programme
	UK Government	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 2 Predictive Research into Desirable Production Systems Around 2020 (Conducted in 1990s)

As will be clear from the above, the concept of smart factory has not been detailed yet together with remaining a considerable number of controversial points. In this context, we must be aware of the characteristic features in the production system, for which acatech does not pay any attention so far. For example, we must discuss the validity of the term " Mass-Customization " proposed by acatech. In fact, the system configuration for mass-production differs completely from that for producing the customized product, e.g., one-off production or a kind of production. In general, these two system concepts cannot be integrated with each other, and thus we must discuss concretely what is the mass-customization, which product is compatible with the mass-customization, what is a suitable system configuration for the mass-customization, and so on.

In addition, we must discuss the availability for the further forerunning trials and achievements in the sphere of the production system. Acatech indicated some application examples of the smart factory in its report like " Example 3 Custom Manufacturing " in the car assembly. In this case, the assembly shop consists of a group of CPS workstations, and the car travels autonomously among the necessary workstations up to its completion. It seems to be very attractive; however, in retrospect, Denso of Japan established already a forerunning system, i.e., assembly system of traveling robot type for the stator, in the late 1990s. In this system, the robot can corporate and communicate each other, and facilitate autonomously the re-configuration of the system in accordance with the change of the product Summarizing, although the concept of smart factory is, without any doubt, very important and attractive, there remains something to be seen in the establishment of its system layout in practice. Thus, this paper describes first the facing problems, but not mentioned in the reports of acatech in consideration of the achievements so far obtained in the production system sphere, e.g., system configuration design and production technologies. Then, the paper discusses and suggests further technological problems, which have not been identified yet by acatech, even though these problems are closely related to the essential features of the production system. Within this context, furthermore, we must consider the growing importance of the " Localized Globalization " and " Virtual Concentration of Manufacturing Bases " across the whole world.

2. Quick Notes for Questioned Points in Smart Factory Concept Proposed by acatech

The smart factory can be characterized by the following.

(1) The smart factory is of CPS and consists of the processing machines, storages and industrial facilities of smart and autonomous type.

(2) Each factory can work independently under the closer co-operation with other factories by exchanging autonomously the necessary information among one another.

(3) The smart factory can create the product by adequately responding the requirement of the individual user.

(4) The smart factory is " SME (Small- and Medium-sized Enterprise) -oriented ".

As can be readily seen, it is far from completion to draw the system layout to certain extent on the basis of these characteristic features. Importantly, the production system is a synergy of the hardware, software and also of the information and communication network, and acatech has only suggested the importance of the sensor and actuator, but not detailed anything about other hardware aspects of the smart factory. At least, we need to know the objective product, production mode and material flow pattern within the system in the design of the system layout.

In this context, thus, we must discuss the further issues within some leading subjects proposed by acatech in consideration of the earlier work. In fact, acatech has proposed a " Smart Network for Health Control to Guarantee Smart Health ", which can be characterized by the fusion of differing professional spheres, but does not include any production activities. Against this context, Figs. 3 and 4 reproduce a " Hospital-Factory Complex " for the patient having some troubles in the joint (Ito et al., 1990). As can be seen from Figs. 3 and 4, the " Hospital-Factory Complex " is a variant of the smart health control network, i.e., that with

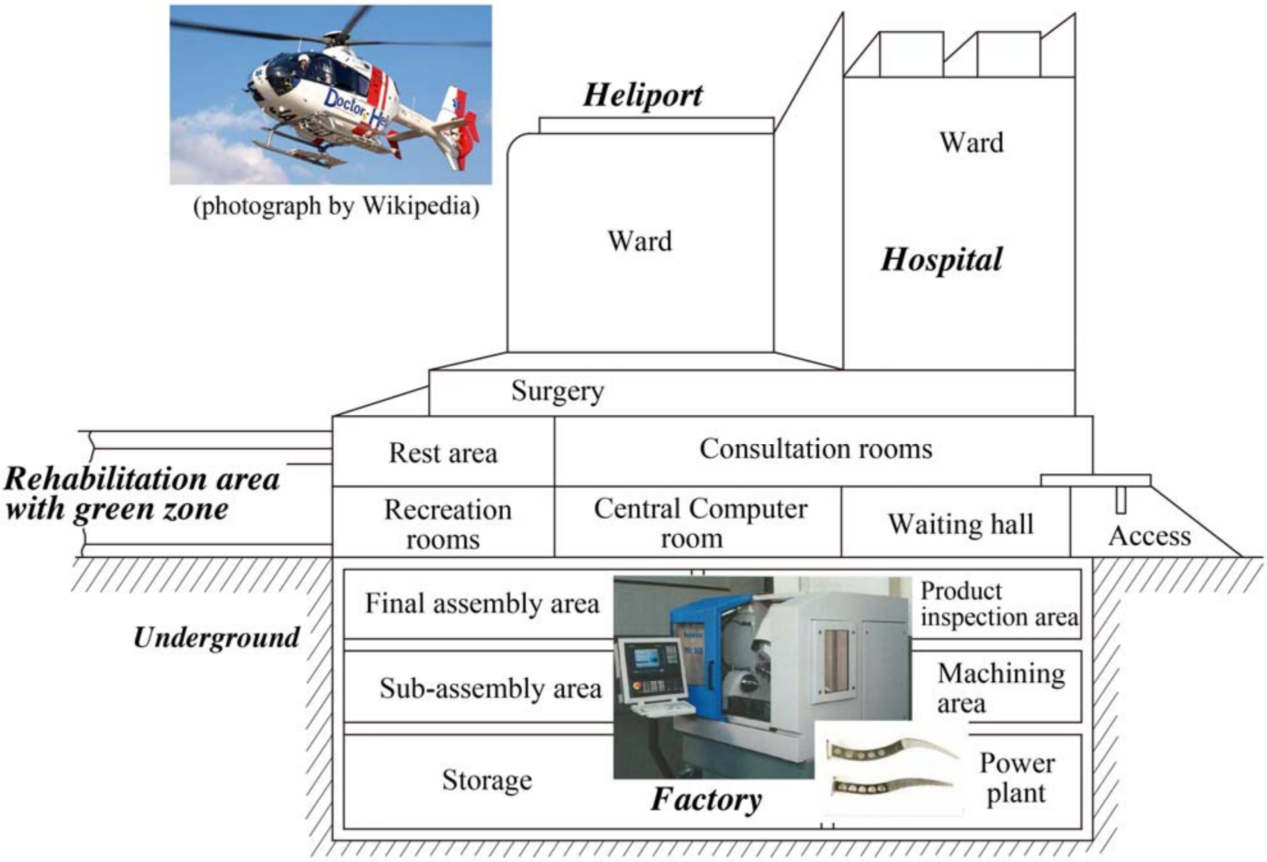

Fig. 3 Schematic view of Hospital-Factory Complex - For matters of prosthetic devices concerns (by IROFA)

prosthetic device manufacturing. The complex can be characterized by the following.

(1) A synergy of prosthetic device production, surgery and patient's care, computerized information control and heliport.
(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, now let us revise the core of the factory in Fig. 3 in consideration of something available at present. Instead of conventional MC (Machining Center) in the past, the CNC (Computerized Numerical Control) tool grinding machine of Schütte-brand is applicable to produce the prosthetic device and its surgical instrument simultaneously. In addition, it is preferable to install 3D printer to produce the model for

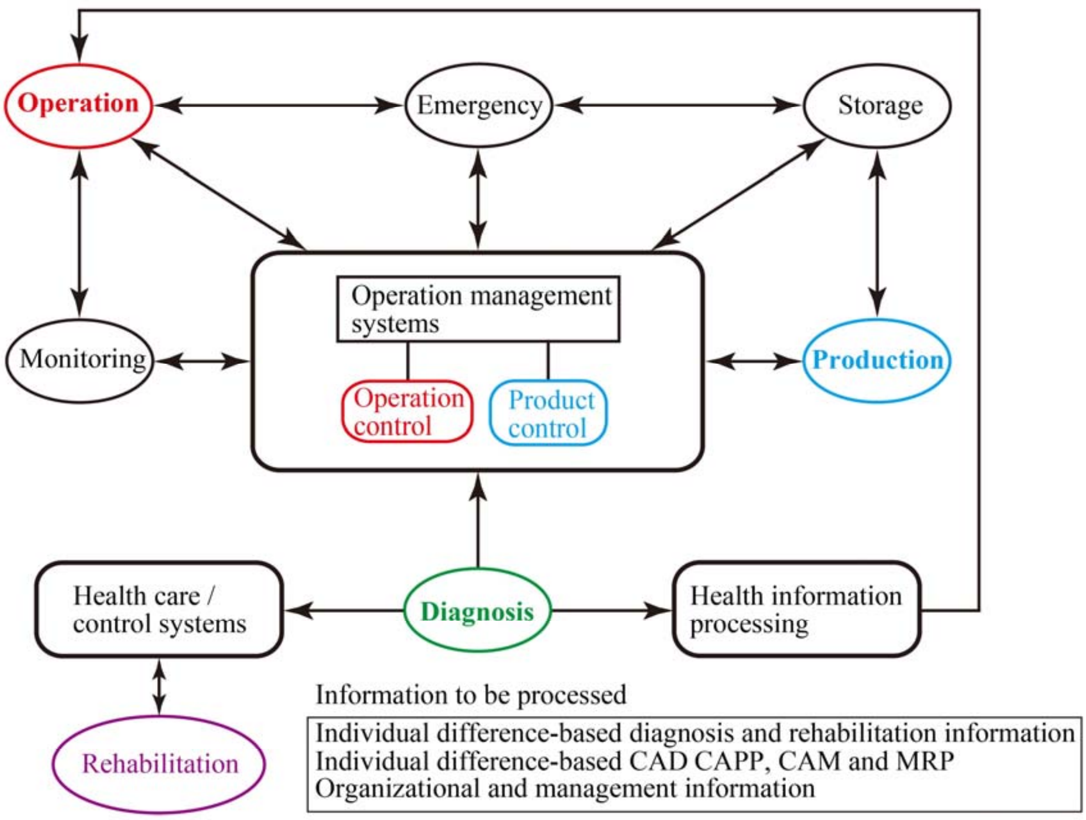

Fig. 4 Information processing within cell-like Hospital-Factory Complex (by IROFA)

surgical pre-simulation.

To this end, it emphasizes that we can benefit considerably from the system layout in investigating the research and engineering development subject as exemplified by the " Hospital-Factory Complex ". In addition, we may suggest that acatech must conduct the further research into the earlier work related to the flagship project as follows.

CPS Module – Its Configuration and Core Components in Production System Design

In consideration of the importance of CPS module, we need to detail its desirable configuration and necessary components, especially clarifying what are differing features from those in FMC or its advanced type, i.e., " Agile Manufacturing Cell ".

When discussing this issue, it is very helpful to refer to the definition of FMS proposed by Weck (1974) as shown in Fig. 5. Weck eyed the utmost characteristic feature of FMS in the material and information flows, i.e., simultaneous availability of both the material and information at a processing station, to eliminate completely the waiting time.

As can be readily seen, such a characteristic feature is to be in reality by using the computerized control, and in the agile manufacturing, the idle time in each flow can be reduced to a large extent by maintaining simultaneous availability.

Importantly, we may identify the material and information flows as to be the horizontal integration through value networks (physical space) and the vertical integration and networked manufacturing systems (cyber space) in the smart factory concept, respectively. In short, FMC can be regarded as CPS module of lowest level.

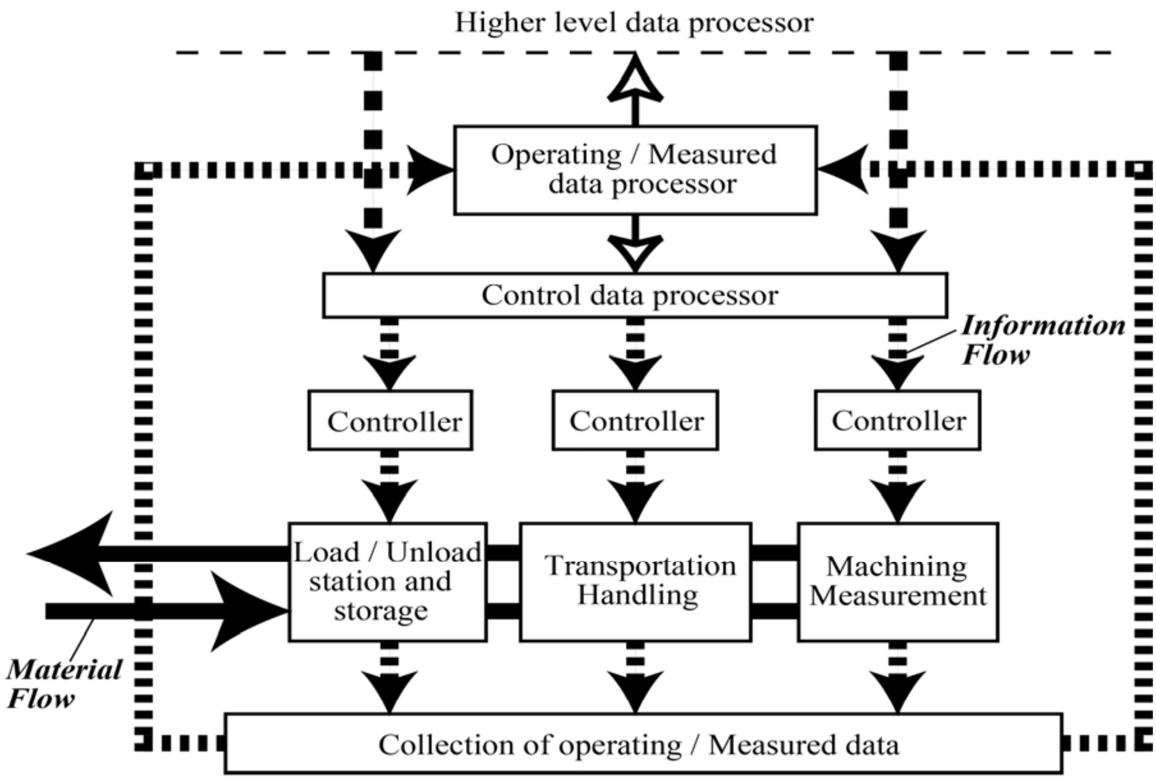

Fig. 5 Definition of FMS (by Weck)

Smart Product – What Are the Characteristic Attributes ?

In Industrie 4.0, the smart product is for the individual customer requirements and has knowledge about its own history, current status and alternative routes to achieving its target state. This definition for the smart product is not sufficient to determine the engineering design specifications. Obviously, it is also very difficult to carry out the layout design of the smart factory for such a product.

In this context, we must discuss what is the difference of the smart product from the culture- and mindset-oriented product, which was already characterized in the beginning of 2000s within the " Manufacturing Culture " sphere.

Reportedly, the culture- and mindset-oriented product can be classified into the " Region-specified ", " Individual difference-oriented ", " Sensitivity-oriented " and " Aesthetic-like " types (Ito and Ruth, 2006). As can be imagined, the individual difference-oriented and sensitivity-oriented types seem extremely as to be the smart product, and thus we enable to duly exemplify the smart product for further assistance to carry out the work hereafter.

Equally, we must be aware of the applicability of the manufacturing culture to the " Industrie 4.0 " Project. In fact, it is emphasized that the interdisciplinary approach is must in the " Industrie 4.0 " Project. Paraphrasing, the " Industrie 4.0 " should be carried out by the close co-operation among the engineer, IT expert, psychologist, ergonomist, social and occupational scientist and so on. Of note, the manufacturing culture is a synergy of manufacturing and industrial sociology.

End-to-End Engineering without Remanufacturing

One of the leading topics in Industrie 4.0 is " Resource Efficiency " including the smart product. Although aiming at the resource efficiency, it is incredible that the " End-to-End Engineering " does range from the product design, through production to the services, i.e., production morphology of old fashion, but not

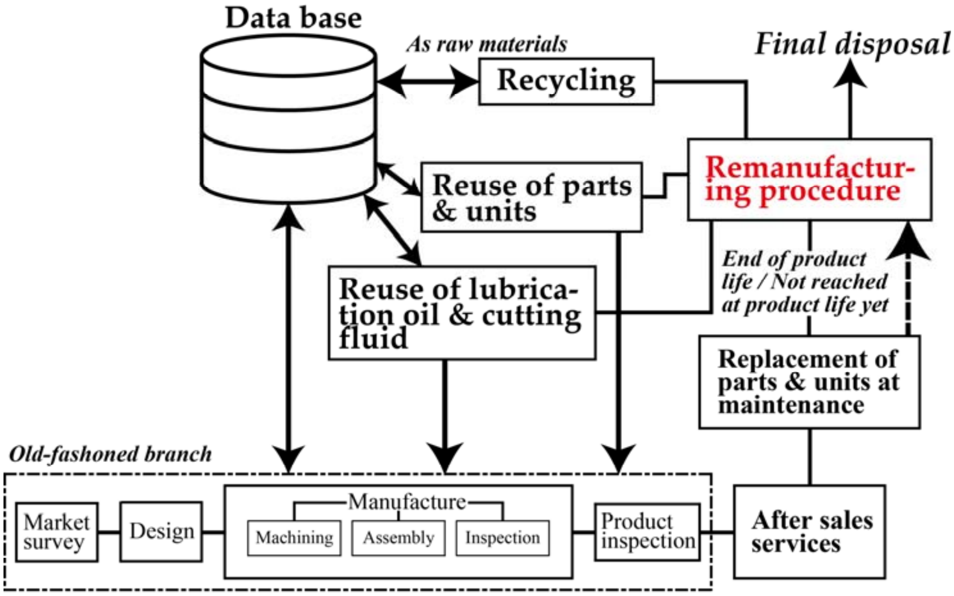

Fig. 6 Concept of production morphology

include the remanufacturing procedure as shown in Fig. 6. In addition, there remains something to be seen for DFM (Design for Environments). It is thus necessary to include the corresponding issues in remanufacturing. Importantly, German automobile industry has been very keen to develop the necessary technology for the disintegration and collecting system of used car for remanufacturing.

Sensor-fusion in sensing technology

In accordance with our long-standing experience, the manufacturing environment is not suitable for the sensor, but very bad environments. Paraphrasing, the sensor should work within the dusty and oil-misty, higher humidity, severe vibration and higher temperature, resulting in the ease of sensor down.

In short, the more various sensors and sensor settings within a machine tool, the more dangerous are their downs. It is thus necessary to use the sensor fusion in the smart factory, although acatech has not suggested anything about it.

Reportedly, the sensor fusion can be classified into the three types as shown in Fig. 7, and of these, the utmost prevailed sensor at present is the dynamometer of piezoelectric type (Kistler-brand). This sensor is based on the same measuring principle and capable of detecting a considerable number of the different output signals by processing the output signal with various methods as shown, for example, in Fig. 8. Importantly, Fig. 8 is produced by gathering the research results reported by Langhammer (1973), Lay et al (1984) and Chung et al (1989), and their validities are not verified satisfactorily as yet.

To enhance the sensor fusion, in principle, it is desirable to use the sensor with different measuring principles as exemplified by the ultrasonic waves method. In this sensor, the work diameter and tool wear can be detected by using the reflection time (horizontal axis in CRT) and change of echo height (vertical axis in CRT), respectively, as shown in Fig. 9. In retrospect, Spur and Leonards (1973), and also Itoh et al (1991) measured only the work diameter and flank wear of the cutting tool while turning, respectively.

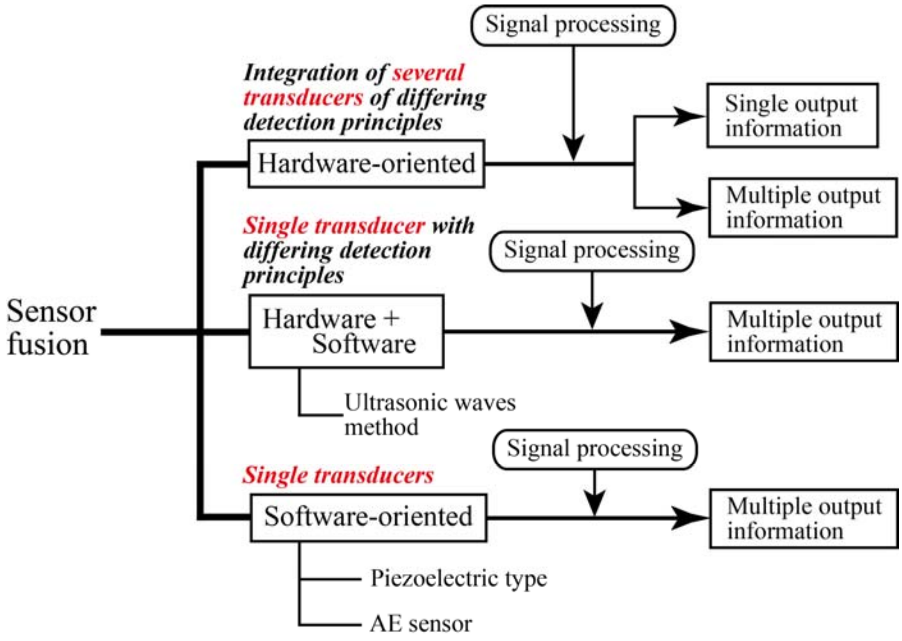

Fig. 7 Three representative types in sensor fusion

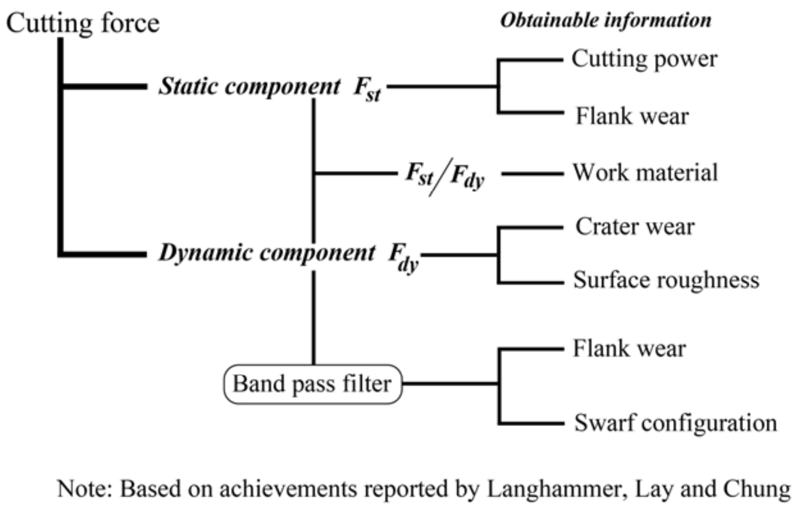

Fig. 8 Sensor fusion using piezoelectric transducer of Kistler-brand

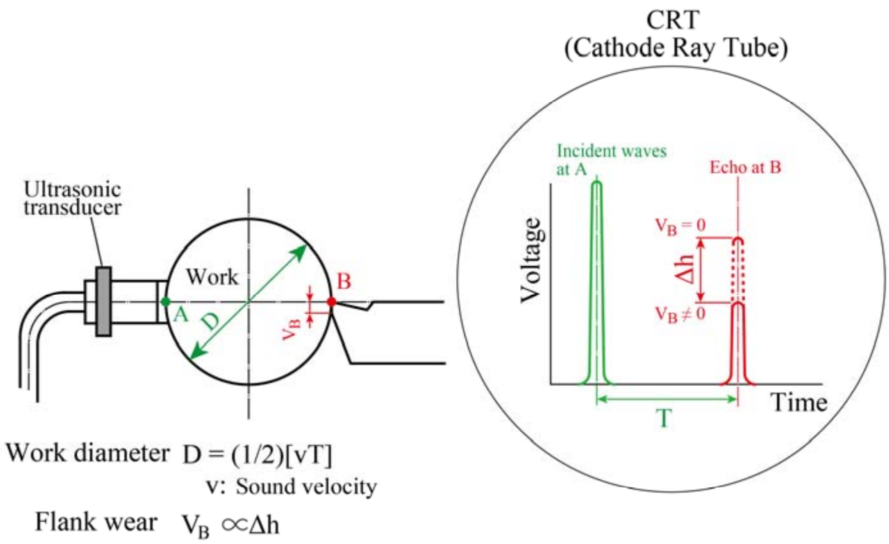

Fig. 9 Concept of sensor fusion by single transducer with differing detection principles

3. Further Issues Being Not Suggested by acatech – Conversion of Information Properties in Design Attributes and System Component with Platform Concept in Production System

As already mentioned, the production system should be, in principle, designed in full consideration of its characteristic features by nature, which are derived from the objective product and its production mode. Typically, such the essential features have been well known and are such as follows, although acatech does not suggest them.

(1) Conversion of information properties in " End-to-end Engineering " across entire value chain.

(2) The system configuration or layout design can be facilitated with the available system component to a large extent. In the case of machining, we must eye the amazing development in the machine tool with " Platform Concept ", which will be very helpful to be a " One-machine Shop " in reality.

Conversion of information properties

Figure 10 shows a simplified design flow of the product, 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

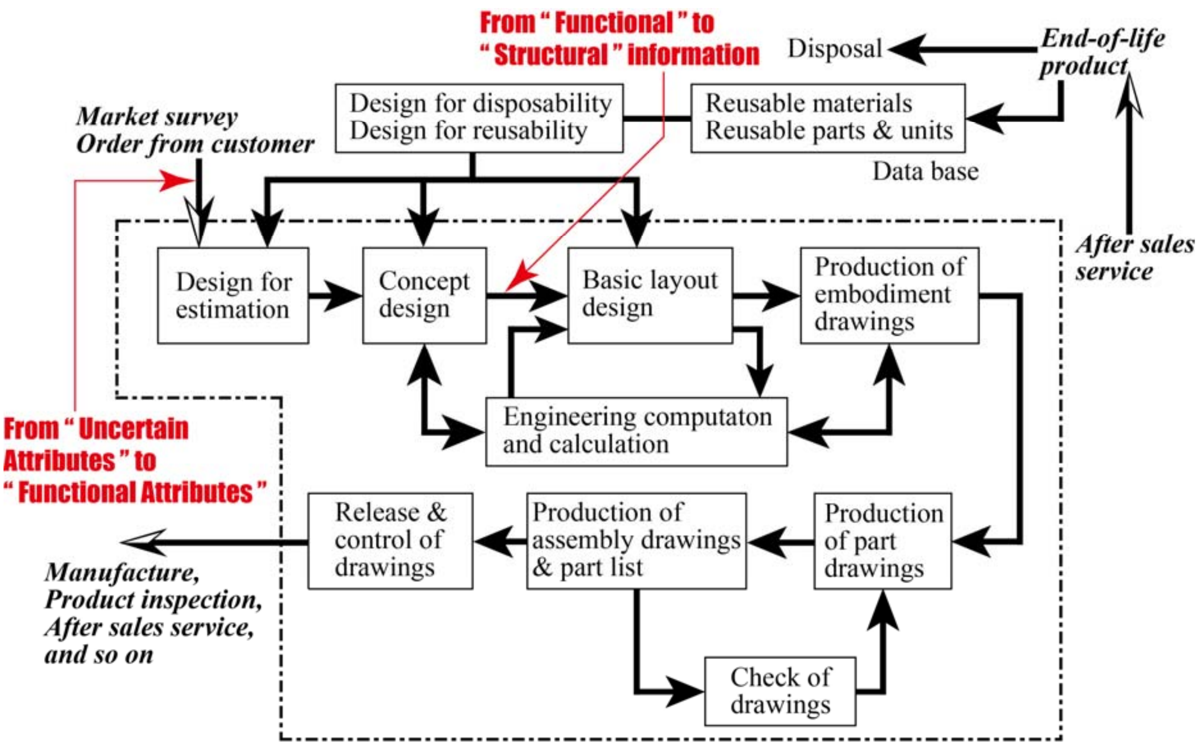

Fig. 10 Simplified design flow - A model of design work

basic layout design. For the sake of further understanding, Fig. 11 reproduces a conversion process of the uncertain attribute-related information, i.e., " Comfortable Roominess " of the passenger car to " 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 matured engineering designer.

Obviously, such a work is very time and cost expensive, and thus we must develop a conversion methodology. In this context, Höft proposed a conversion method by using QFD (Quality Function Deployment) of hierarchical type as shown in Fig. 12, although it is far from the practical application (1999).

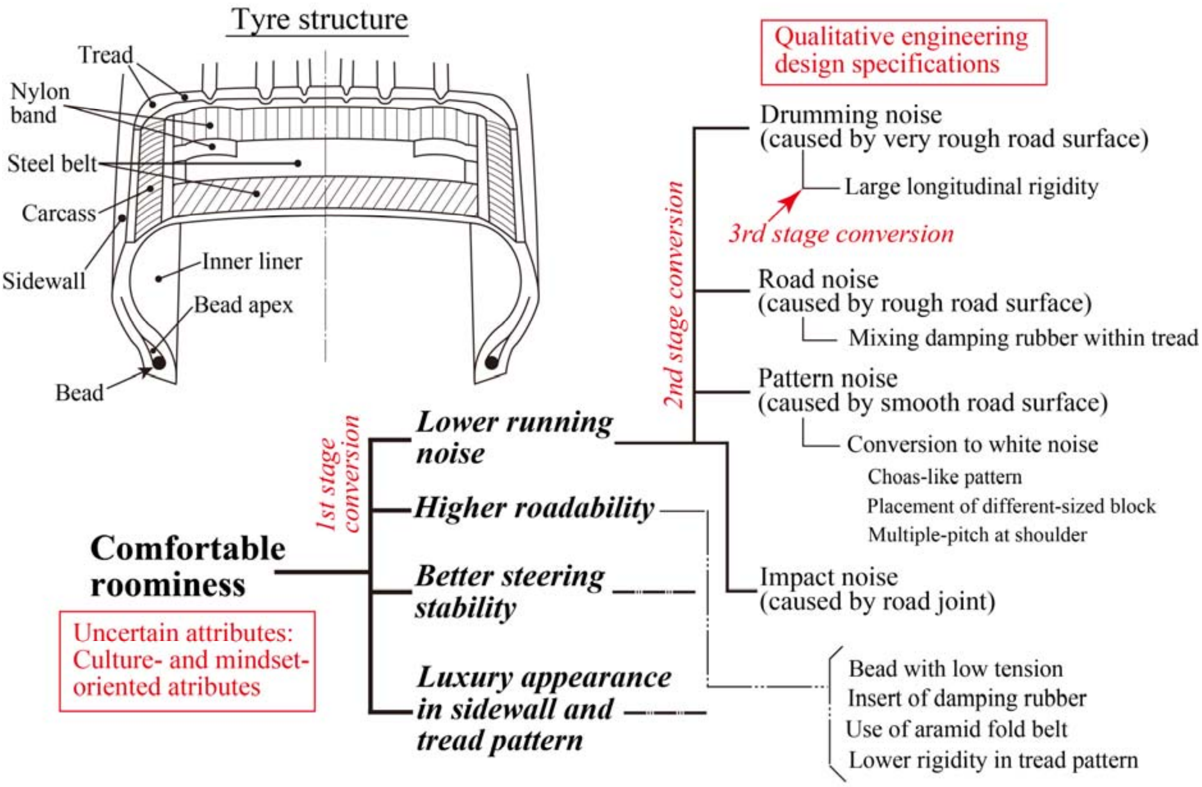

Fig. 11 Hierarchical tree structure representing conversion procedure of uncertain attributes to engineering design requirements - In case of tyre

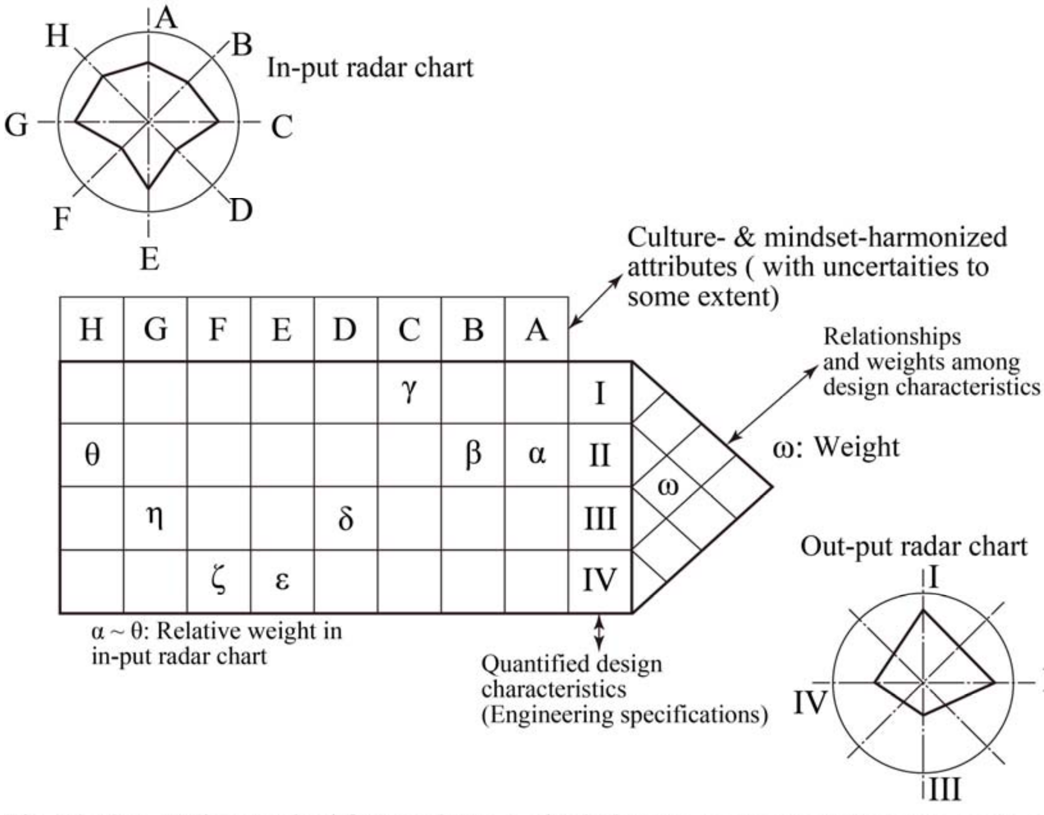

Fig. 12 Conversion method from culture- and mindset harmonized attributes to engineering specifications by QFD of hierarchical type and radar chart (by Höft)

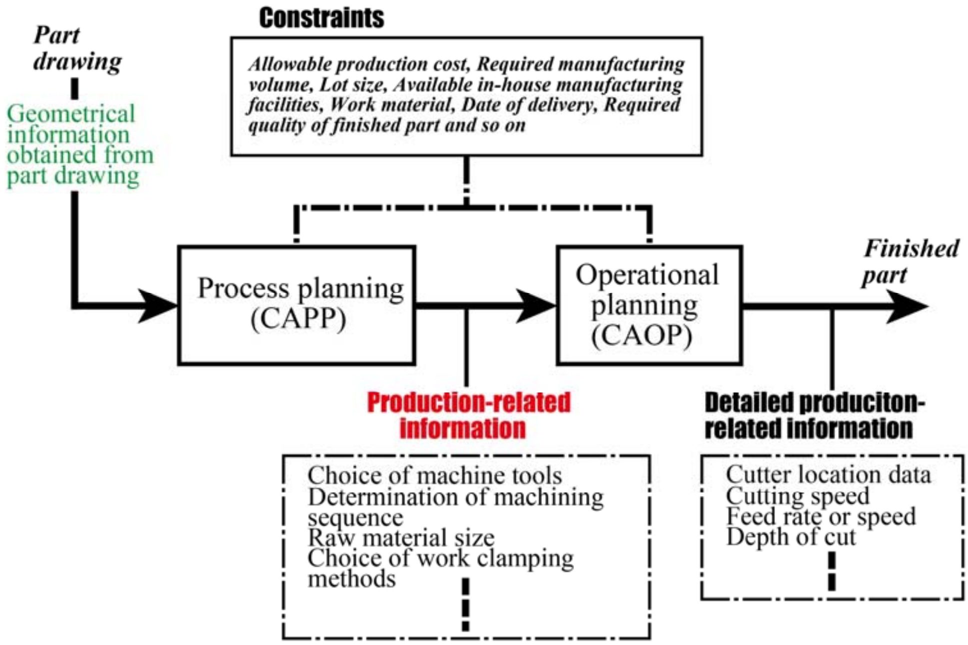

Fig. 13 Conversion of information in descending flow following release of part drawing

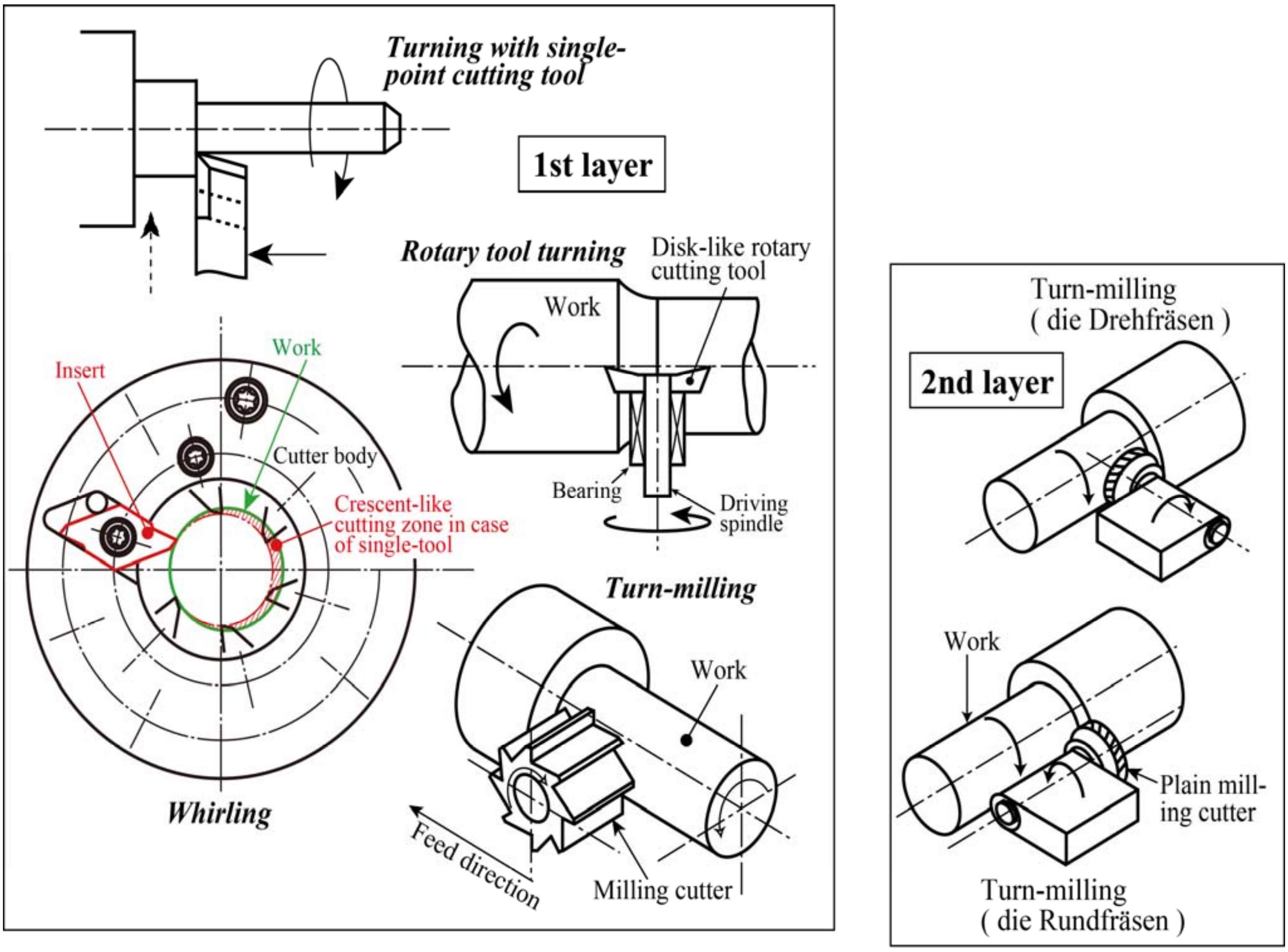

Fig. 14 Various turning methods to generate cylindrical component

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.
Now let us consider the same problem in CAPP (Computer-Aided Process Planning). In CAPP, the geometrical information described on the part drawing should be converted into the production-related information as shown in Fig. 13. Even in the simplest case, e.g., turning of cylindrical workpiece, there are various turning methods as shown in Fig. 14. 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 constraints from machining accuracy, cost, delivery date and so on as already shown in Fig. 13.

Potentiality of “ One-machine shop “

It can be said that the “ Industrial Revolution “ could be several years overdue if the “ Wilkinson’s boring machine “ was not contrived on that occasion to machine the cylinder of Watt’s steam engine with allowable accuracy.
Accidentally and fortunately, we can use the machine tool with highly machining function-integrated kind at present, and they can be classified into those shown in Fig. 15 depending upon the integration density of various machining methods for general use. Importantly, having in mind the key terms representing the smart factory, these kinds will be applicable to CPS module. In preferable case, CPS module will be facilitated by the utmost advance kind, i.e., “ One-machine Shop-like Machine Tool “.

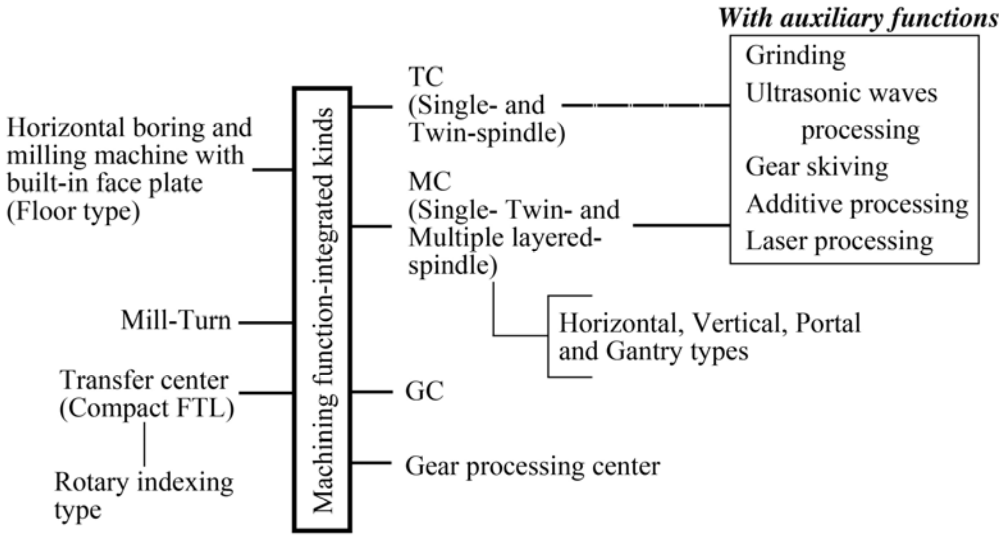

Fig. 15 A classification of machining function-integrated kinds in 2010s

For example, Fig. 16 shows a mill-turn with grinding and gear cutting functions of Index-brand, which may carry out nearly all machining methods for general purpose, i.e., quasi-one-machine shop. Of special note, Fig. 17 shows the “ Transfer Center “ for machining the automobile components, which is of compact type of the flexible transfer line. As can be readily seen, the work spindle can transport and automatic tool changer can accommodate various materials within a machine. Paraphrasing, the transfer center seems to be applicable to the smart factory by directly connecting with the information and communication network. In short, the transfer center has the machining capability equivalent to those of MCs of two to five units, and for example, can replace a Flexible Machining Line, a variant of Flexible Transfer Line, shown in Fig. 18, which can machine the cylinder head of either four- or six-cylinder engine with production volume of 50,000 units per year (4 min. in cycle time).

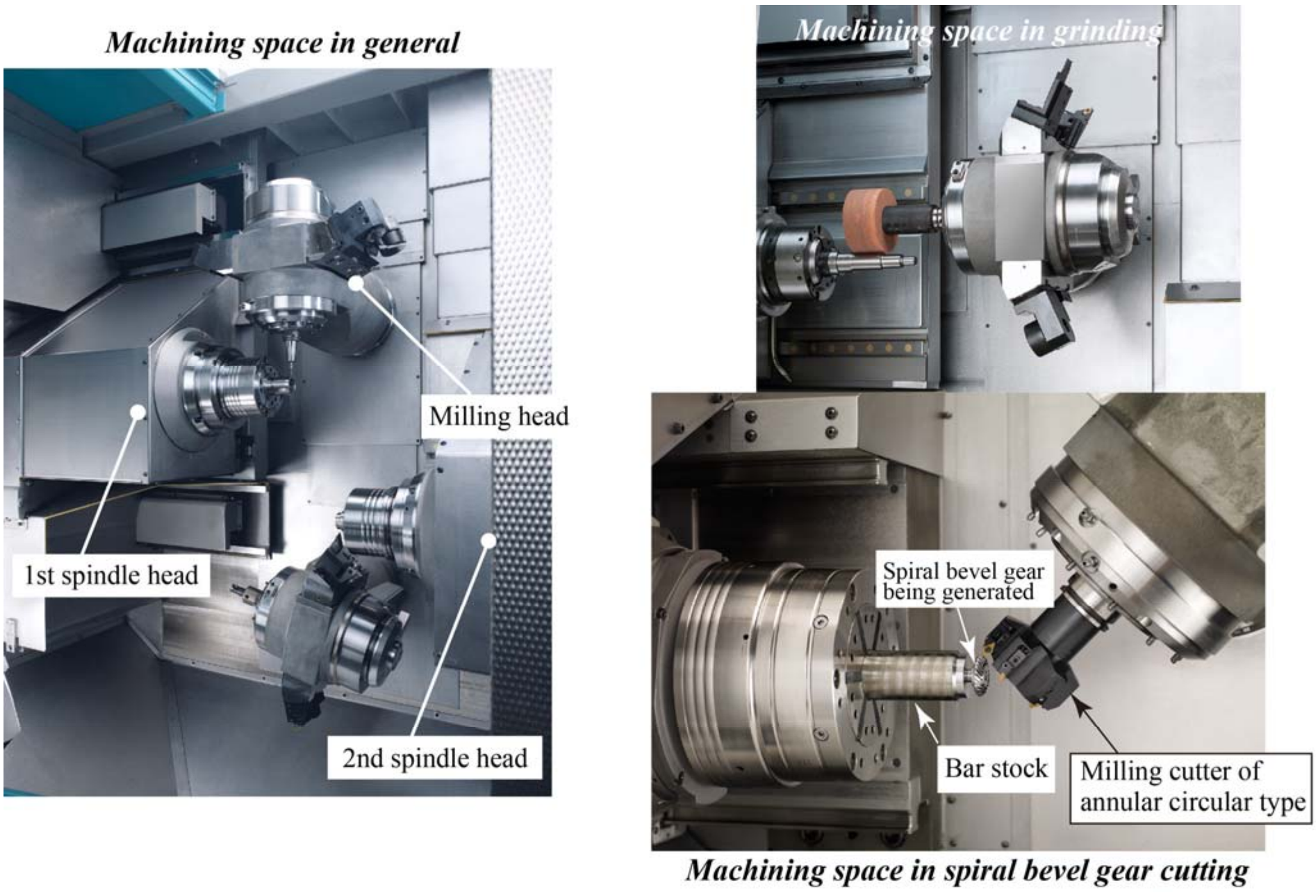

Fig. 16 Machining spaces in " Mill-Turn " - Directing quickly to " One-machine Shop "
(R Series, by courtesy of Index, 2016)

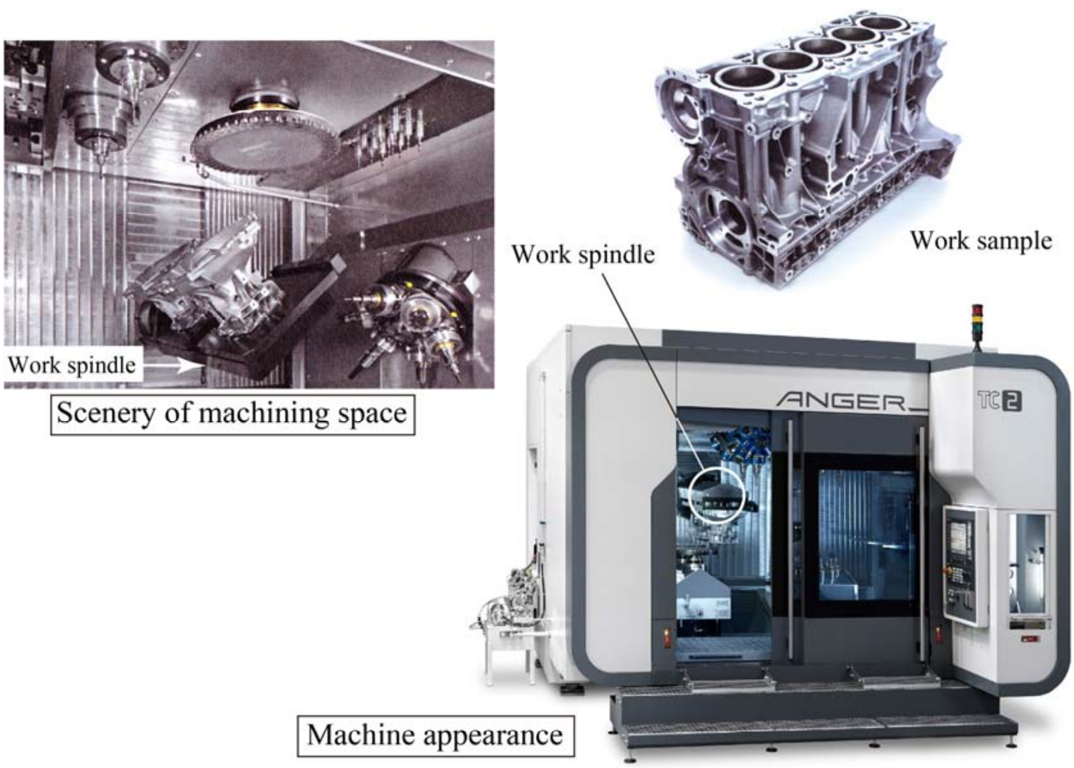

Fig. 17 Transfer center and its machining space (by courtesy of ANGER)

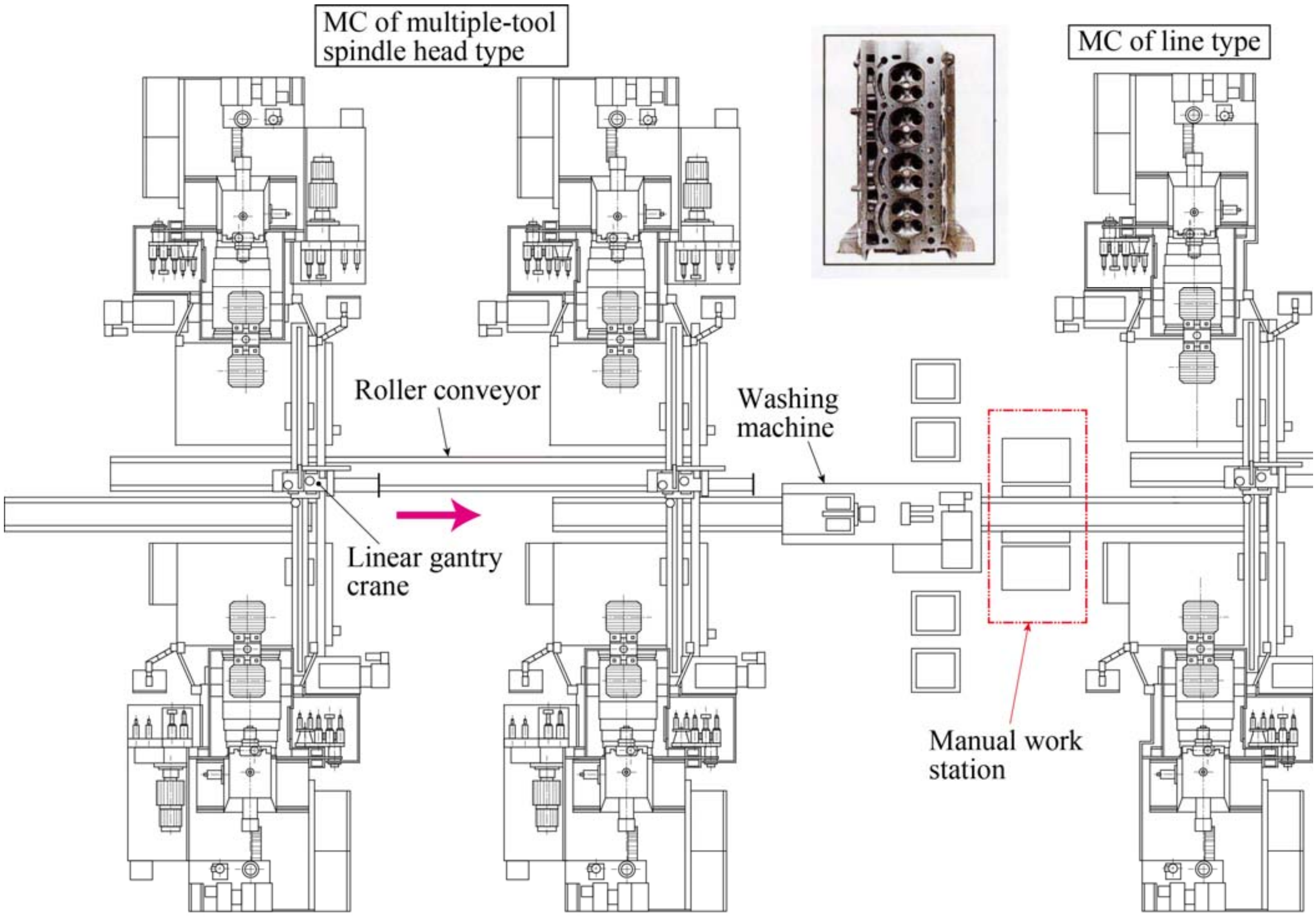

Fig.18 Flexible machining line for cylinder head - Fritz Wener, in 1993

To this end, we must be aware of the three leading design attributes in the production system, i.e., " Flexibility ", " Redundancy " and " Expandability ". In principle, these three attributes are in the reciprocal relationship among one another, and thus one of the remedies is to employ the modular design to the production system so as to leverage properly these attributes. In this context, we must develop a modular design applicable to the production system for the localized globalization environment (Ito 2011).

4. Concluding Remarks

Having in mind that the smart factory is of human-centric and socio-technical type as defined by acatech, the utmost key determinant is the cultivation of human resources with highly matured skill in specified field and also with multiple-disciplinary knowledge. Extremely in the cultivation of skilled and multiple-talent worker with multiple-nationality, it is necessary to overcome the language barrier including the factory jargon. Importantly, we need furthermore to develop a methodology to transfer the outstanding flairs and flashes into the computer system.

In retrospect, we encountered the language barrier in the merger of Mercedes-Benz and Chrysler, and even in the manufacturing culture sphere, we have still the language barrier between the production engineer and the industrial sociologist.

Obviously, we must endeavor to enhance our knowledge about the smart factory including the forerunning achievements and trials in concern. As a result, we can scrutinize the leading subject in the research and engineering development especially in the design of system configuration and components. In due course, we can conduct correctly the due work on the basis of such a work. In short, acatech seems to propose the smart factory concept and identify the necessary R & D subjects based on unsatisfactory investigation and information.

In this context, we must be aware of the growing importance of the manufacturing culture, which is a synergy of manufacturing technology and industrial sociology. Of note, the industrial sociology was initiated in Germany; however, acatech did not pay any attention to it.

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