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Design of Productive Socio-Technical Systems by Human-System Co-Creation for Super-Smart Society

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Abstract: The realization of the 'super-smart society' of "Society 5.0" is being promulgated as the 5th Science and Technology Basic Plan by the Japanese Government. This article summarizes what is needed to promote new science and technology for achieving a super-smart society. Especially, to accelerate the development of "control for societal issues," three aspects of "Feedback," "Ring" and "Harmony," each of which corresponds to the means, the object and the goal of the future control-related science and technology, respectively, are to be stressed. That is, the object of science and technology is to target society or community, not single persons and individuals, and we have to understand complex feedback structures made up of many interactions as essential means to attain the goal of harmonizing technology, human and environment. For this purpose, innovations will necessitate elaborating the SoS (System of Systems), mutually connected systems, including human-in-the-loop systems. It would be significant to model and understand the dynamical complexity of such an SoS and to develop a technique for guaranteeing their resilience. This article presents overviews of some of the author group's works that are related to the above three aspects.

Keywords: Society 5.0, super-smart society, SoS (System of Systems), human-in-the-loop system, resilience, learning health system, human skill modeling, cognitive task analysis, socio-technical systems.

1. INTRODUCTION

The realization of the 'super-smart society' of "Society 5.0" is being promulgated as the 5th Science and Technology Basic Plan by the Japanese Government (FY2016-FY2020) (CAO, 2015). The following three issues characterize this initiative.

1. Realizing smart manufacturing by utilizing IoT and network technologies.
2. Connecting and fusing cyber space and physical space (Cyber-Physical System).
3. Systemization of service and enterprise integrating a variety of system elements.

Wherein, the key technologies are cyber security, IoT, Big Data, and Artificial Intelligence. Furthermore, as techniques having a strength that lies new value creation, robotics, sensors, biotechnologies, materials and nanotechnologies etc. are mentioned.

In response to the above movement, the theme of the coming world congress of IFAC World Congress 2023 to be held at Yokohama, Japan, is set as "Control for Solving Societal Problems and Creating Social Values," where the main challenge is to accelerate the development of "control for societal issues" such as energy, environment, human and resilience.

In addition to the above general theme, a Japanese word of "WA" has been raised as the core concept of IFAC WC 2023 by the Invitation Team. The aim is to promote new science and technology based on the concept of three aspects of a Japanese word of "WA," having multiple meanings of "Feedback," "Ring" and "Harmony," each of which corresponds to the means, the object and the goal of the future control-related science and technology, respectively.

MEANS: "Feedback"

We have to understand complex feedback structures made up of many interactions. Wherein "data" are the lifeblood of the user experience with systems that learn, and we have to guarantee that systems can provide carefully crafted feedback loop mechanisms.

OBJECT: "Community" and "Society"

The object of science and technology is not the singles nor the individuals but is society. The players that participate there organically combine and interact, and the individuals and the whole organically combine and interact to find new values.

GOAL: "Harmony"

Finally and the most important is "Harmony" with the society that makes the best use of people and nature beyond time and space. Notably, the super-smart society is aiming to resolve various social challenges by incorporating the innovations of technologies and the sharing economy into every industry and social life. Such innovations will necessitate elaborating the SoS (System of Systems) (Selberg and Austin, 2008) approach towards the value co-creation in the whole society integrating several kinds of systems, such as nature, society, biology, and humanity. Such mutually connected systems would face a phenomenon in which some small malfunctions cause large catastrophic failure chains. Thus, they are apt to become extremely responsive to random faults. Therefore, it would be significant to model and understand the dynamical complexity of the SoS and to develop a technique for guaranteeing their resilience.

In this paper, the authors focus on the above aspects and present the ongoing works performed by the authors' research group.

II. "FEEDBACK" ENABLES "HUMAN- AND DATA-CENTRIC INNOVATIONS"

2.1 Connecting Cyber, Physical and Cognitive Worlds

The feedback has been the key to control engineering so far. It will be required in the future from feedback for control at the individual equipment level to the feedback among a connected factory/thinking factory with substantial variability and variable production to satisfy individual customer needs. It is an innovation to feedback on a larger scale that can change the production process drastically. Instead of the business model of selling consumer goods and increasing profits, manufacturers companies collect data on how their customers use the products after they reach the consumer's hands and further explore what the value of use is. As a result, a new business model that can stably generate revenue every time the customer uses the product with a marginal cost remaining almost zero. The conventional manufacturers only have had a one-time revenue opportunity of selling the product. Instead, through such a new business model, the manufacturers can keep customers charged for the value that the customer wants. Furthermore, a more global engineering chain would be possible that connects not only design and manufacturing but also subsequent logistics, sales, and maintenance that occurs after the product reaches the customer's hand. Such a global chain will generate opportunities for "learning by using." New service development, such as remote monitoring of abnormalities, understanding of operating status, failure prediction, and maintenance support, would become possible.

CPS (Cyber-Physical System) has already been attracting attention to realize the super-smart society. The cyber world and the physical world can be linked, and various means such as statistical analysis, big data analysis, artificial intelligence, and simulation techniques are expected in the cyber world to use the big collected data. The physical world of CPS is a place for activities of "people." It includes not only production activities at manufacturing sites but also daily life and social activities. In turn, data collected therein are utilized in the cyber world.

As shown in Fig. 1, the author has proposed that we should connect the cyber world with the physical world via a third world of the *cognitive world* (Sawaragi, 2016). This triad world architecture will contribute to connecting the "living experiences" ("Lebenswelt" in Germany) (Husserl, 1936) with the cyber world and the physical world. To this end, innovation in semantic information processing technology that connects data with human cognition, thinking, and judgment would be critically important. The technology of data collection is well prepared, and gathering a large amount of data, including the work log data, has already started to be done on-site. However, such obtained data are not actually utilized. The barrier to this is the difficulties in information retrieval out of the massive collection of data, that is, selection and prioritization of information, interactive provision of information in line with the activity context of individuals/organizations, all of which require techniques that can handle the "meaning value" of the data. As long as the human remains in the control loop, information must be comprehensive so that it can match the way of human recognition, which is the key to making up the third cognitive world.

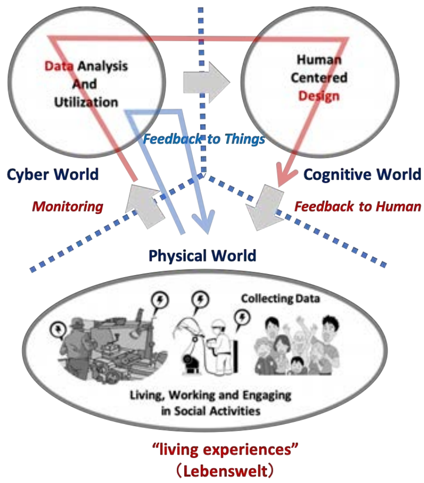

Fig.1 Multiple feedbacks connecting the triad worlds.

2.2 Cognitive Work Analysis for Connecting the Triad Worlds

As a means for connecting the above three different worlds, the cognitive work analysis (CWA) is really contributive, where a work domain analysis (WDA) and a control task analysis (ConTA) are promising means for understanding and modeling human expert's skills, and the combination of WDA and ConTA can guide us design an interface system that can contribute to connecting physical world and cognitive world via cyber world. CWA was firstly proposed by Rasmussen and his colleagues at RISO Laboratory (Rasmussen et al., 1994), and then sophisticated and formalized by Vicente (Vicente, 1999). According to Vicente's definition, the framework consists of five stages of work analysis.

- Work Domain Analysis will be used to extract functional constraints within the system being controlled.
- Control Task Analysis will be applied to see individual task structures to be performed to control the system.
- Strategies Analysis will check different strategies to achieve individual control tasks.
- Social Organizational and Cooperation Analysis will see how different roles are taken by human workers and/or technical agents.
- Worker Competencies Analysis will examine what kind of competencies are required to individual workers to perform their roles.

CWA is a formative framework for the work analysis of complex socio-technical systems, and can guide the design of well-structured information displays; how measurements and state variables to be organized into displays, and what information should be shared between different operators, etc.

The author's group has employed the finishing mill process in the hot rolling as our application domain (Horiguchi et al, 2013). A finishing mill, as shown at the top of Fig.2, consists of typically 6 or 7 mill stands in tandem. They enable the progressive thickness reduction of a steel strip passing through the mill. Loopers are pivot arms installed between two adjacent stands, engaging the bottom of a stripped thread properly through the mill behind. The process is highly automated with advanced control technologies, offering economical manufacturing of high quality products. The automated control systems, however, still require a human operators' control to cope with troubles like unexpected fluctuations in operating conditions beyond their design limits. To this manufacturing process, we have applied the Work Domain Analysis. The bottom of Fig.2 shows an example of the Abstraction Hierarchy obtained through WDA. Wherein, each node stands for a system function described from a different point of view. According to Rasmussen's way of description, functions can be viewed from five different abstraction levels: from Functional Purpose as the most abstract one to Physical Forms as the most concrete one. Connections between nodes at different levels represent constraints. They stand for means-ends relations, stating that the lower-level functions must be realized to achieve a higher-level function.

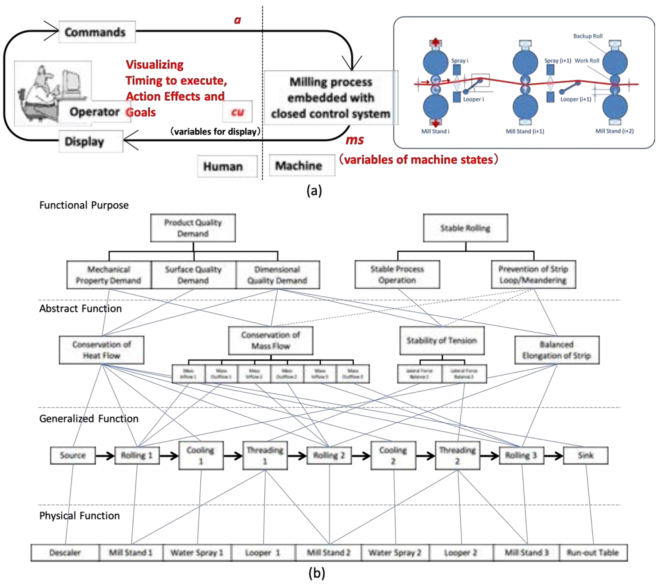

Fig.2 Human-machine system for the finishing mill process in the hot rolling. (a) Target system (b) Abstraction hierarchy

2.3 *Learning Health System for Workers: Circulating Data, Knowledge and Performance*

An attempt to construct connections among the triad worlds is ongoing in the region of health care. In recent years, the Ministry of Economy, Trade and Industry (METI) of the Japanese Government has proposed a concept of "health management" (METI, 2018). Health initiatives also affect the productivity of works, so if companies can guarantee the health of workers and employees, they can expect a return. Especially in Japan, we are facing a super-aging society, and it will be essential to form a society where older people live in happiness. The mechanism to support their health after their work retirement is particularly important. However, the data obtained at work before retirement are not contributing to health care at the time after retirement. Such discontinuity of data is a bottleneck for efficient health management in the aging society. Visualizing the lives of older people from data and using them for nursing care prevention are expected to increase in the future. In other words, it is considered to identify the group of people who are likely to be bedridden in the future and perform the individual intervention. It aims to build a model of a healthy community by integrating and utilizing health data, strengthening systems that support aging, predicting the risk of physical function deterioration, recommendations for behavioral changes, and individualizing interventions through medical care.

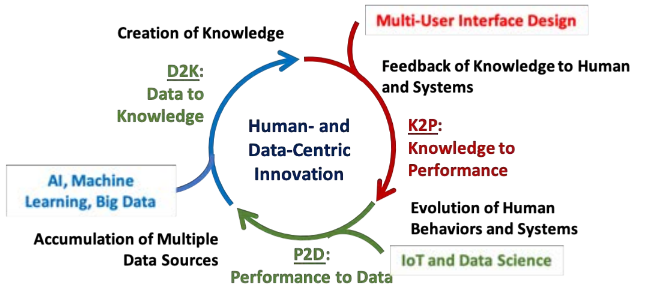

Fig.3 Learning Health System: Circulating Data, Knowledge and Performance.

Besides such preventive measures, senior citizens can work with peace of mind through monitoring sensing and data collection so that they can more actively draw out their potential working ability of the elderly and utilize their skills cultivated through experience (Sawaragi, 2019). To realize that, it is primarily needed to redesign the workplace for this purpose. Artificial intelligence and machine learning are used to integrate and utilize vast amounts of data collected from people, machines, and tasks that come to be available via IoT and various wearable sensors. By using techniques such as statistics, risk prediction of physical function deterioration comes to be possible, and non-adaptation in collaborative work between humans and machines is detectable in real-time. Thus, it could be possible to recommend the human workers in a customized way corresponding to their diverse abilities, and it might lead to the improvement of the control system on the machine side by intervening people by providing customized recommendations and care. Such a scheme is a Learning Health System (LHS) (Friedman and Flynn, 2019). Fig.3 shows the interrelations among Data, Knowledge, and Performance. That is, by collecting data on the workers' performance (Performance), the system is to analyze how the worker's performance changes (Data), then obtain knowledge (Knowledge) from the data and finally decide how to further intervene to the workers. By establishing this "circulation," the systems would be able to guarantee the "sustainability of human power" by drawing out their proactive commitment on the part of the person safely and securely. A society realized by this is not a society that is too "friendly" for people but is a "productive" society where the aging people's sustainable commitments are drawn out.

III. "RING" ENABLES "DISTRIBUTION AND SHARING OF WISDOM"

3.1 Towards Acquisition of Human Skills and Wisdom

The technology of IoT enables the management and utilization of on-site data available in the factory plants. Compared to Industrie 4.0 in Germany, in Japan, it would be more meaningful for people to be connected via machines, not only seeking the connection of machines via M2M. Notably, the introduction of IoT into the products has promoted the development of services in the manufacturing industry, including efficient remote maintenance enabling preventive maintenance, and discussions have also begun on new production collaboration services through mutual data transactions.

An important concept in considering the future utilization of data would be the "stickiness of information" (von Hippel, 1994). This is a concept related to "ease of information transfer," and the cost of transferring information necessary for solving problems in the product development process in a form that can be used by the people who need it. Magnitude, defined as stickiness of information, is a marginal expense incurred to the given recipient of that information. This represents the cost required to transfer a unit of information in a usable form to a specific purpose. When this cost is low, the information is less sticky. Conversely, when this cost is high, the information stickiness is high and expensive. Factors that determine information stickiness are summarized as follows:

- The nature of the information itself (so-called explicit knowledge or tacit knowledge)
- Difference in attribute and context of sender and receiver of information
- Amount of information to be relocated (whether or not it is an overloading burden for the recipient)

The information that can be easily transferred is, for example, manual technical information, technical information embodied in products and manufacturing equipment, and so on, which has been relatively easy to save and inherit. On the other hand, highly sticky information is implicit know-how such as technical information and process knowledge that cannot be converted to manuals (i.e., tacit knowledge). There is a huge amount of data that can be actually acquired, and even if it can be used for statistical data analysis, what can be read from the data might be dependent upon how it can be visualized and how it can be reused by humans, and these are enabled by the semantic information processing technology of the data. This includes recursively extracting and acquiring phenomena and behavior patterns, then identifying human skill models from space (time) records.

For this goal, the authors are proposing a framework of for sharing and transferring skills among spatio-temporally distant sites as shown in Fig.4 (Sawaragi, 2018). In this framework, elucidation of human characteristics by human modeling technology is needed as well as recognition on the work environment in which humans are placed and the characteristics of work objects should be analyzed in conjunction. This idea is based upon the following characteristics of "distributed cognition" commonly observable in the human expert skill performances.

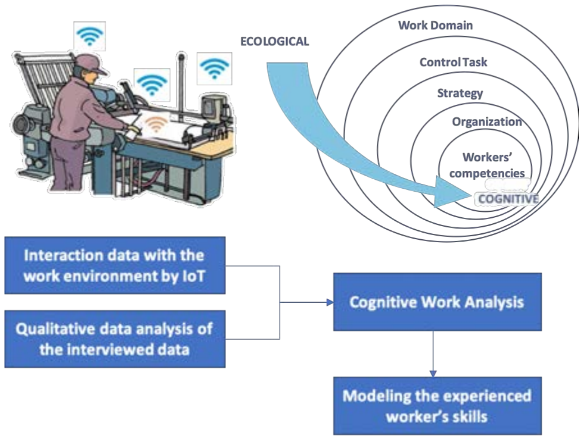

Fig.4 Data-driven modeling of experienced worker's skills

1. Knowledgeable action involves recognizing and using embedded clues.
2. Experts' data-gathering skills are exploited *in situ*.
3. Knowledgeable action lies in the ability to use local tools and resources.
4. Human interactions are embedded in the surrounding physical context. Moreover, social interactions that contribute to problem solving are also embedded in their physical contexts.

Concerning the above, the potential of IoT enabling us to measure field workers' abilities as well as their surrounding features, does contribute to performing a cognitive work analysis of workers' cognition, judgment, and operation. These can lead to developing ecological interfaces contributing to visualizing the skills of experienced workers and to training less-experienced workers.

3.2 Semiotic Analysis of Verbal and Behavioral Knowledge/Skills for Cyber-Physical Co-Coaching

Connected society will realize remote monitoring and maintenance services as well as teaching, sharing and transferring skills, as shown in Fig.5. It will contribute to establishing a novel community and to providing opportunities even to the aging people to continue working being engaged in teaching and transferring experienced skills to younger generations. Cyber-physical co-coaching is supporting two actors behaving in different spatio-temporal physical sites via cyber space.

Cyber-physical co-coaching is to be done by transferring a trainee's bodily motions to the trainer, and vice versa. The author has understood that human bodily motions and gestures are "semiotic processes" (Sawaragi, 2010). Like a verbal language, human bodily motions are organized along with the two different sorts of contexts. These are *syntagmatic* and *paradigmatic* contexts. Moreover, performing bodily motions is exactly an activity of communication between the actor and the cognizer (i.e., observer), where the two separate semiotic processes within the actor and the observer are interchanging with each other. Thus the meanings come out and become shared between them. In this sense, an activity of co-coaching is a human-machine collaboration enabled by a connected interactive semiotic processes performed by the trainer and trainee, as shown in Fig.6.

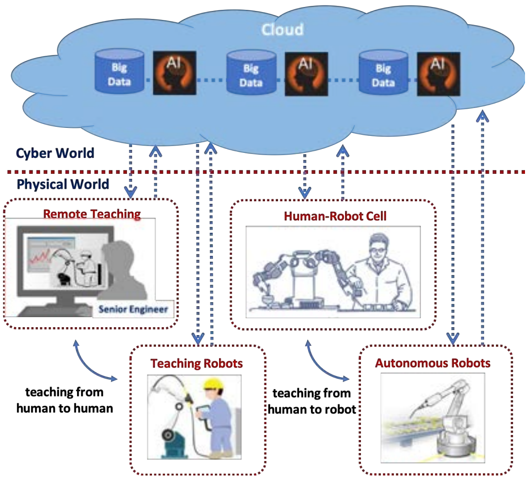

Fig.5 Scheme of connected factory

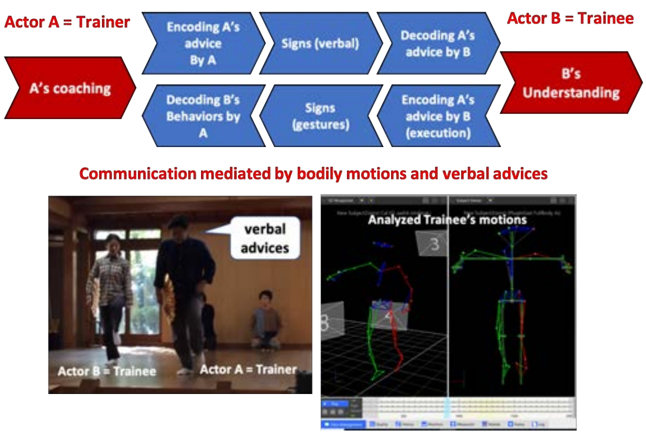

Fig.6 Interaction of Semiotic Processes in Cyber Social Co-Coaching

As for the semiosis of human bodily motions, the author's group approached the constructive semiosis from two different but interconnected perspectives, from an observer's view, and an actor's view (Mishima et al., 2010). The former deals with how a cognizer understands an actor's bodily motion emitting plenty of "signs," while the latter is how to design actions to be understood by an observer. The author's research group developed techniques for exploring the systemic structures implied in the human bodily motions. For this purpose, the authors have developed two methodologies by extending the conventional methods of singular spectrum transformation (SST) and singular value decomposition (SVD), respectively. Based on the results of the above analysis, the authors developed two testbeds of cyber-physical co-coaching systems; one is for the sport of lacrosse, and the other is for the Japanese traditional art of "Noh" play performance. In addition to the bodily motions, verbal instructions provided by the trainers to the trainees are of importance concerning; their semiotic meanings carried by their verbal signs and the timings of the instructions (i.e., progress stages of the trainee's learning). Related to this, the authors have introduced a schema theory to explain how we learn and perform discrete perceptual-motor skills. Discrete motor skills are skills that take a short time to perform and involve using our senses to understand what is happening and then using our bodies to take action. The authors developed a computational model of the schema learning that can explain how the skills are acquired and reconstructed through the iteration of assimilation, and accommodation from the trials for a simple target-tracking task (Taniguchi et al., 2008).

Such architecture of cyber-physical co-coaching systems can also contribute to assisting rehabilitation mediating between a patient and a physical therapist, skill transfer from a human to a robot, and designing robot's motions enhancing social relations with a human in the future connected society.

IV. "HARMONY" OF HUMAN-IN-THE-LOOP SYSTEMS: RESILIENCE OF HUMAN-MACHINE SYSTEMS

4.1 System of Systems (SoS)

As shown at the top of Fig.7, super-smart society will establish a collaborative production system infrastructure through the cooperation of people and machinery, thus forms an SoS (System of Systems) where a variety of human-in-the-loop system elements co-exist (Selberg and Austin, 2008). In order to get the maximum value out of such an extensive system, we should understand how each of the smaller systems works and manage it. For this purpose, we need a *systemic* approach and a holistic approach focusing on the way that a system's constituent parts interrelate and how systems work over time within the context of larger systems.

Although the SoS is expected to promote agility through their distributed and loosely coupled collaboration, the complete prediction of their holistic behaviors is a challenging issue. The SoS is the cross-, inter- and multi-disciplinary challenges. Within the control community, some axiomatic systems control theories have been provided concerning the management of complex dynamical networks and the control of multi-networks (Dimirovski, G.M. et al.,2006). Besides, adaptive control for a class of state-constrained high-order switched nonlinear systems with unstable subsystems is provided (Sun, Y. et al., 2019). The theoretical contributions for reaching control goals are provided beyond stabilization. Also, properties of the SoS are similar to the ones of complex adaptive systems, in which researchers from engineering, applied mathematics, and computer science backgrounds have provided innovative theoretical and practical insights into the state-of-the-art of complex networks and systems research. These help us to achieve not only robust stable plant system operation but also properties such as collective adaptivity, integrity and survivability at the same time retaining desired performance quality (Dimirovski, G.M. 2016).

As shown at the bottom of Fig.7, in the human-in-the-loop systems (HILS), variations in work efficiency and work quality due to differences in workers' abilities and experiences are inevitable, and fluctuations and variabilities in some work may immediately affect the other connected systems. Besides, the introduction of partial automation into work sites is ongoing, where a human is expected to collaborate well with an automated machine and infrastructure. However, when a new tool or partial automation comes to the worksite, it may alter the structures and functions of the other tasks including a human's, and even the conditions that cause people to engage in the tasks — Fig.7 shows where such sources of variabilities exist in a human-in-the-loop system with automation.

Since a society forms a mutually dependent network of the HILS, some minor malfunctions may cause a wide range of catastrophic failure chains (i.e., cascade failures), making the system exceptionally responsive to random failures. Therefore, we need some means that enable us to predict the holistic behaviors of the SoS and to find embrittlement of those.

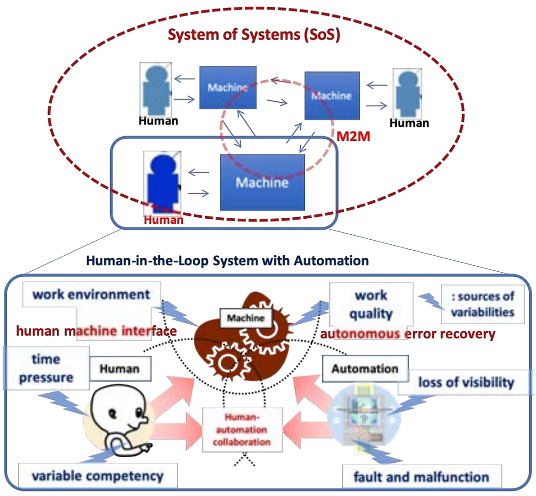

Fig.7 System of human-in-the-loop systems with automation.

4.2 *Resilience of Human-in-the-Loop Systems*

Even if the function of a particular elemental system was temporarily reduced or malfunctioned, a "resilient" system could continue functioning without falling into a catastrophic state. Resilience is an idea to avoid flaws after adhering to fluctuations guaranteeing that everything is going in the right direction (Hollnagel, 2013).

In the human-machine system, deviations and fluctuations from the expected performance are unavoidable both in human operations and machine behaviors. Human operations are affected by their physical conditions, and due to sparse labor shortages, they sometimes result in poor work quality. In response to this issue, there is a need for a mechanism that makes it possible to overcome the instability that arises from differences in ability and physical condition because utilizing diverse human resources and conducting stable production activities are to be realized. With such a background, the flexible automation technology developed so far to handle a diversity of product types should shift towards an adaptation technology for the diversity of worker abilities. We must consider the control issues on the machine side (e.g., an autonomous error recovery mechanism) so that it can continuously collaborate with people whose work quality is varied.

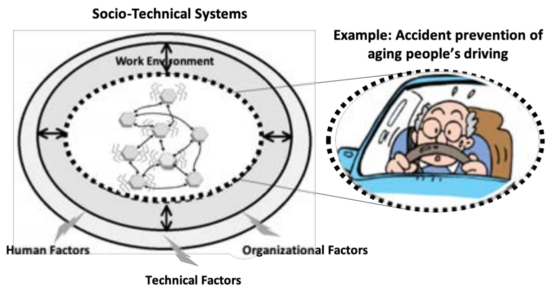

Fig.8 Unexpected human-machine interactions caused by the evolving surrounding contexts.

At worksites, facing the deterioration in work quality, the safety soundness will depend much on the work context. When we let aging people continue working, it would be indispensable to redesign their work and to conduct a thorough verification of whether or not the work procedure is safe and feasible (i.e., a stress test of the work procedure). In particular, as illustrated in Fig. 8, frequent occurrence of accidents by elderly drivers has become a major social severe problem. Their abilities to respond to the unexpectedness depend on their work context. Thus, some analytical methods to identify the potential risks that may lead to accidents in specific contexts, and the acquisition and learning of countermeasures to prevent recurrence of similar accidents are needed.

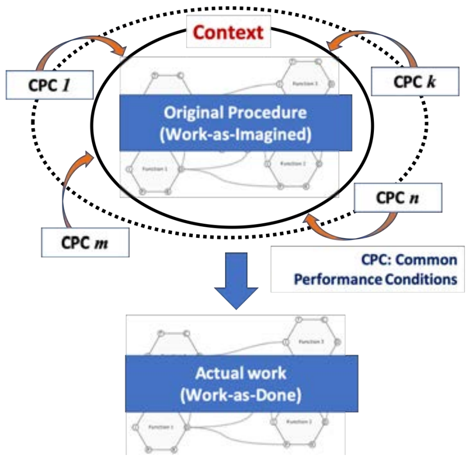

Fig.9 Stress test of a work procedure in possible contexts.

4.3 *Systemic Approaches to Safety Analysis of STS*

The biggest threat to the safety of socio-technical systems is an error in functional requirements. It is, of course, possible to verify whether each work procedure can work according to the functional requirements under the assumption of various fluctuations. However, it is still challenging to identify the emerging gaps between "Work As Imagined (WAI)" and "Work As Done (WAD)," that are gaps between the instructions and the activities carried out during the exercise. Thus, a systemic method for functional verification and validation (V&V) as a holistic system is required to predict the gaps between WAI and WAD, as shown in Fig.9.

Functional Resonance Analysis Method (FRAM) is well known as a method for modeling and analyzing the dependence and connectivity between system functions and how multiple functions interact with each other (Hollnagel, 2004;2012). It is a technique for finding out the advantages and disadvantages of the system related to safety existing both potentially and explicitly, in the interaction relations.

The author's group has proposed to expand this original FRAM in order to clarify the work transformation of workers accompanying the introduction of new machines and tools at the worksite from the viewpoint of the interaction with organizational factors (Fukuda et al., 2016;2019). We identified structures that cause deviations between prescribed work and practical work (i.e., between WAI and WAD) throughout the long life cycle. We applied our method to the work in railway safety and analyzed an actual railway accident case. Then we showed how the alteration of organizational norms and the alteration of work procedures interact with each other leading to the occurrence of accidents and unsafe events. Our proposal was useful in grasping how the work procedure alters when a new tool is delivered into practice.

Original FRAM was mostly a theoretic method, and there proposed no specific approaches or supportive tools to bridge the gap between theory and practice. Therefore, we proposed an adaptation of the cognitive reliability and error analysis method (CREAM) (Hollnagel, 1998) and developed a method for making a systemic and quantitative FRAM analysis by simulation (Hirose et al., 2016). We applied our method to the actual air crash accident near Cali Airport, Colombia in 1995, and concluded that the accident was due to the deviation from SOPs (Standard Operation Procedures) (Hirose et al., 2017). Based on the analysis, we showed that FRAM could identify the potential hazard paths that may lead to an accident. Also, we propose a new method using FRAM for pre-analysis of the safety of designed procedures. Our method contributes to visualizing the dynamics of variabilities among functions, and the potential risks of socio-technical systems.

Steel production line reveals a quite complicated process consisting of many linked work stations where a production flow might be varied frequently. Also, the processes are affected by quantities of in-process inventories, system troubles, and maintenance, all of which can be related to human operators, machines, organizations, and working environments. There does exist empirical know-how to tackle those complexities. However, these remain as tacit knowledge, and there has been no way to validate and verify their effectiveness under specific conditions.

We applied our extended FRAM model simulation to this problem. We found that a countermeasure of adequately adjusting the rate of direct delivery can improve material flows of a supply chain in actual steel production (Hirose et al., 2020). Here, the rate of direct delivery is the ratio of what is sent directly to a downstream production process to what degree sent to storage space. We simulated the performances of the process when the countermeasure is applied in the various states of the plant. We could identify when and how the countermeasure could successfully contribute to recovering the line balance of the entire process. This is shown in Fig.10, where the top figure shows the FRAM model, while the bottom figure illustrates its numerical simulation result when the countermeasure is applied at a particular time. The primary purpose of this simulation was to investigate the mechanism and determine the features of such emergent outcomes. The results of applying our extended FRAM model to this example provide several insights concerning the characteristics of experienced workers' operations to handle and manage the process's complexities, such as harnessing, phase transformation, and identifying critical points attaining resilient operations in terms of the entropy of the process status.

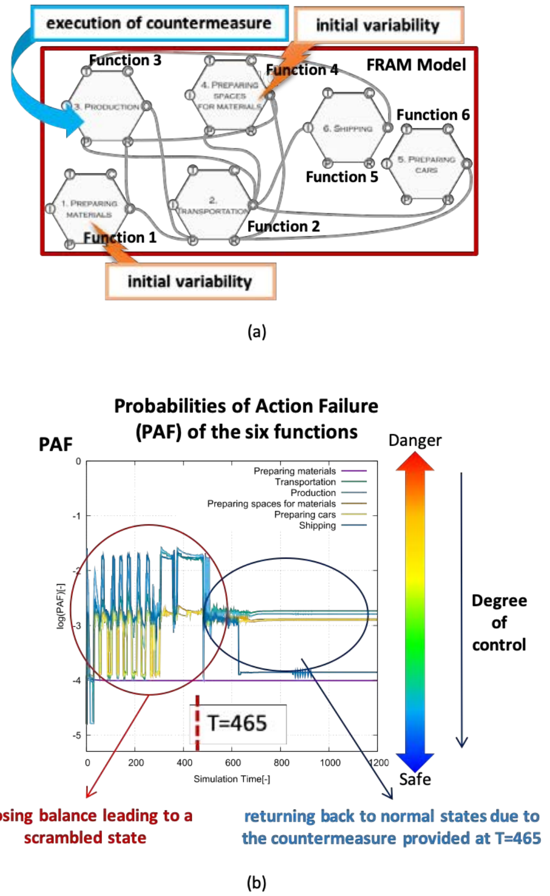

Fig.10 Validation and verification of SoS: (a) Functional Model of SoS, (b) Simulated performances of (a)

V. CONCLUSIONS

This paper summarized the issues to encounter in the coming super-smart society as well as research activities conducted by the author and colleagues. We are now facing social challenges such as global warming and super-aging society.

Historically, research on human-machine systems has evolved from the original human-machine systems, human-machine interactions, joint cognitive systems, and now socio-technical systems. Wherein AI, Big Data, and Robots were indeed expected to play a key role attaining a variety of innovations towards creating new values. However, according to such an evolution, the targets has been becoming more and more complex, and the human still remain in the loop. As for control of such complex systems, the establishment of resilience requires the co-creation between human beings and systems. Not by eliminating human beings or ultimately limiting their work, but pursuing a system design that allows some human judgment, resilience can be established through the fusion of knowledge of human beings and machines. This is surely leading to the establishment of productive society.

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