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Cyber-physical manufacturing in the light of Professor Kanji Ueda's legacy

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Abstract

Cyber-physical manufacturing, i.e., the formerly never seen integration of the physical and virtual worlds in the manufacturing domain is considered the substance of the 4th industrial revolution. Much of the changes deemed now revolutionary are originated in a long and converging progress of manufacturing science and technology, as well as of computer science, information and communication technologies. One of the pioneers and influential thinkers of production engineering who paved the way towards cyber-physical manufacturing was unquestionably Professor Kanji Ueda (1946-2015). With this paper the authors would like to pay a tribute to his achievements, by highlighting his main contributions not only to the advancement of production engineering and industrial technology but also to the sustainability of our society.

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Keywords: manufacturing, synthesis, service, cyber-physical production systems

1. Introduction

Converging and mutually interacting research of manufacturing science and technology, computer science, as well as information and communication technologies resulted in what is termed now *Cyber-Physical Production Systems* (CPPS) [1][2][29]. There is general consensus that these developments established not only the key cyber-physical enabling technologies for tomorrow's production, but have also initiated fundamental, revolutionary changes affecting science, industry, education and society alike [27].

Professor Kanji Ueda (1946–2015) took part and even shaped this evolutionary process well before the concept of CPPS was coined at all. Having focused his research from grave technical issues of production engineering up to policy and broad industrial and societal agendas involving manufacturing, he was always apt to push research frontiers, challenge well proven methodologies, open dialog with other disciplines, assume their aspects and adopt their solutions. Along his overall trajectory of research all what he investigated and proposed was challenging and thought-provoking, and had spoken of a formidable craft, disciple as well as responsibility. He left behind an oeuvre of international acclaim which is still open and inspiring for the future generations, too.

Starting his professional career in the 1970s as a *manufacturing engineer*, he dealt with *cutting* processes with special emphasis on fracture mechanisms. He invented a micro-machining equipment for use inside a scanning electron microscope [14]. He investigated both the brittle fracture of cutting tools [34], and the cutting of brittle materials [44][45]. Later on, he developed finite element methods for the analysis of micro-cutting of amorphous or single crystal metals [46][48], and analyzed the 3D burr formation process in oblique cutting [9].

While these ingenious engineering solutions established Ueda in the field of manufacturing science and technology, his real *legacy* with respect to the cyber-physical manufacturing of our days is mainly related to his following research topics:

- biological and physical analogies for controlling manufacturing systems, biomimicry, artificial life and self-organization;
- emergent synthesis and complex adaptive systems;

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- manufacturing in the context of society: artifact axiology, innovation and value co-creation;
- service science, institutional design for sustainability.

In this memorial paper we attempt to outline and summarize his main achievements in the above four–each of them by itself broad–research areas, with the aim of highlighting his contribution to those developments which led to the paradigm of cyber-physical manufacturing of today. Hence, after a brief recapitulation of CPPS we discuss the challenges he realized together with his problem statements, the key solution ideas along with their evolution and applications, as well as their impact.

2. Cyber-physical production: industry, environment and society

Looking back at the progress of computer science, information and communication technologies (ICT), as well as manufacturing science and technology in the past decades, convergent and mutually interacting developments can be observed [4][27][28]. The achievements of the former contributed undoubtedly to the advancement of manufacturing, having though not a unilateral impact: the novel opportunities came along with innovative requirements, and the highly complex nature of production created in turn time and again intriguing problems for the other disciplines.

2.1. Cyber-physical production systems

Cyber-physical systems are assembled of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, networked data-accessing and data-processing services available typically on the Internet [1][2][29]. Cyber-Physical Production Systems, may lead to the 4th industrial revolution, frequently noted as *Industrie 4.0* [18]. CPPSs consist of autonomous and cooperative elements and sub-systems that are getting into connection with each other in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks. Three main characteristics of CPPS are to be highlighted here [28]:

- *Intelligence and smartness:* the elements are able to acquire information from their surroundings and act autonomously, by doing the right or possibly even the best thing given the available information and limited computational resources. At the same time, they provide easy-to-use intuitive smart interfaces towards human users.
- *Connectedness*: the ability to set up and use connections to the other elements of the system–including humans–for collaboration and cooperation, and to harnessing the knowledge and services available in local networks or the Internet.
- *Responsiveness*: a continuously ongoing interplay and mapping between the status of physical system components and their virtual counterparts, which warrants that solutions work in reality, even under changing conditions. It is also a repeated effort of mapping projections—i.e., plans—to actual developments and actions in a real production environment [72].

Modelling the operation of a CPPS and also forecasting its emergent behavior raise a series of basic and application-oriented research issues, not to mention the control of any level of such a system. The fundamental questions are to explore the relations of *autonomy*, *cooperation*, *optimization* and *responsiveness*.

2.2. CPPS and sustainability

The potential of cyber-physical systems already permeated and changed almost every aspect of our lives. Achievements such as autonomous cars, intelligent buildings, smart electric grid, manufacturing and transportation, robotic surgery and implanted medical devices are just some of the practical examples that have already established themselves and are getting found broad application [29].

In manufacturing, the biggest changes happen where cyber-physical systems drive *disruptive innovation*. This requires strong interdisciplinary partnerships between information, communication and manufacturing companies, which will strengthen their links in existing ecosystems. Enterprises, consumers, products and services are getting massively interconnected, which opens now avenues for business, like value co-creation. There is also the potential of new players entering the market where ICT meets manufacturing competencies by offering the customer a direct benefit in form of service instead of products [69][71].

Furthermore, enterprises have to take a *socially responsible* and *sustainable* approach and be conscious of the parsimonious use of material, energy and human resources [17][72]. They have to learn to take ecological systems as fundamental life-supporting services of human civilization. A *sustainable* world is economically feasible, ecologically sound and socially just. The crux of sustainability is whether one violates the limits of what can be referred to as the *human condition*. In the context of production engineering, a poor design is unsustainable, just like a factory operating with large ecological footprint, or a supply network where parts are on a world tour before getting into a final assembly. The incentive to such a cooperative attitude between producers along the value chain—including consumers—can but come from a new ecosystem of production [37]. Solutions require multidisciplinary research over a broad range of contemporary information and communication technologies, organizational and management sciences, cooperation theory, production informatics and engineering.

3. The legacy and its impact

3.1. Biologically inspired design and control of manufacturing systems

One of the big challenges manufacturing faced in the past decades–and faces even now–is how to deal with the *growing complexity and dynamics* which arise within the production structures and in their surroundings. Nonlinear phenomena, uncertainty, combinatorial explosion of possible states make the problem hardly manageable with the traditional hierarchical approaches of production management and control. Already from the late 1980s, new concepts for the next generation of manufacturing systems were introduced, such as heterarchic manufacturing [10], fractal company [75], random manufacturing [15] and holonic manufacturing [25][67][68]. The main novelty in Ueda's *Biological Manufacturing Systems* (BMS) concept–albeit its main characteristic features, like autonomy and cooperation were somehow present in all the above approaches–was that it relied on biologically inspired ideas such as self-growth, self-organization, adaptation and evolution [47][65]. Being already an expert in evolutionary and genetic algorithms [3][19], Ueda maintained a broad and long-standing interest in engineering applications of *biomimicry* [5], i.e., in applying relevant biological analogies and emulating corresponding models, systems, and processes to solve hard problems of production engineering. In particular, under the concept of BMS he worked out a general mechanism of a biomimetic system design for complex problems of manufacturing system design and control [50]. In fact, he applied multiple *cross-domain analogies*, since

- when organizing the structure of BMS, notions of *self-organization, learning* and *evolution* were central, whereas
- in controlling the behavior of BMS, the *physical* analogy of attraction/repulsion fields was taken to assign jobs to the specific manufacturing cells.

The benefits of the BMS concept were demonstrated in

- *Real-time scheduling*, where the products decided where to go for the next process without global control [52];
- *Line-less production*, where all the production entities (e.g., machines, inspection stations, etc.,) were movable elements [54];
- *Facility layout planning*, where the facility layout emerged as a result of the material flow in the virtual domain [56] (see Fig. 1).

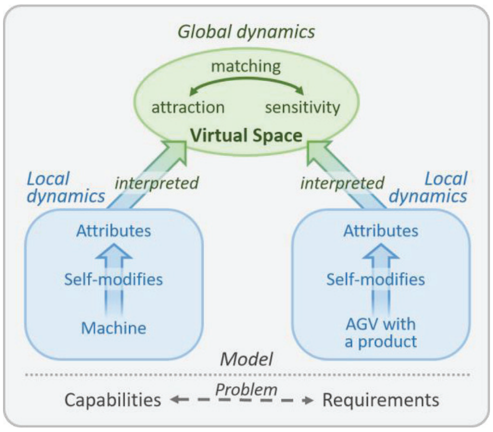

Figure 1: Self-organization on the factory floor [56].

The basic idea behind the physical analogy was to use local attraction and repulsion fields to direct transporters carrying jobs to particular machines (see Fig. 2). Decisions on which job to send to which machine, i.e., how to schedule the factory, came up from the interplay of dynamically simulated local force fields, without any predictable global solution. The emphasis was rather on adaptable and dynamic than on optimal scheduling [66].

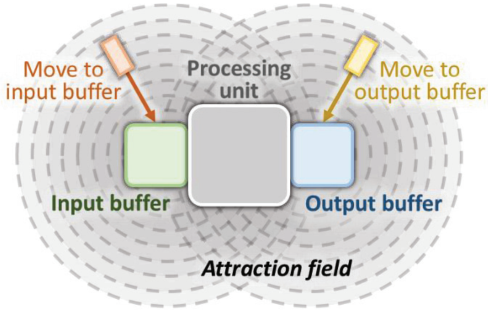

Figure 2: Interaction between machines and AGVs via attraction fields [56].

Ueda also pointed out that the evolutionary models based on spatial interactions were unable to achieve higher level global objectives, because the behaviour of each element was relied on local information only. In later realizations of BMS he used *reinforcement learning* (RL) both on local and global levels, where the global level determined the behaviour of the elements on the local level [52] (see Fig. 3). Later on he applied RL successfully also for the fault-tolerant and cooperative control of autonomous multi-robot system [76].

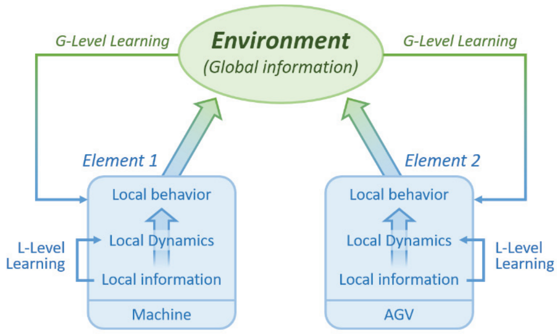

Figure 3: Cycles of global vs. local level learning [52].

Going one step forward, he investigated the use of *bounded-rational agents*, and found it advantageous in more complex settings which included human beings [59]. Including uncertainty in the perception, action and inner structure of agents, computer simulation demonstrated significant improvement in the performance of a BMS which was composed of bounded-rational agents [59]. As if limited capabilities of perception and reasoning would drive agents towards a cooperative attitude, which, in turn, pays back in improved overall system performance. It is worth mentioning that in BMS-related works of Ueda, the virtual reality models played a significant role, since the self-organization and spatial interactions proceeded in the virtual world. His work on BMS led to the development of many manufacturing systems in our current and rapidly expanding era of distributed, cooperative and responsive manufacturing enterprises [72]. In parallel there have been developed other approaches that have taken enterprises as natural, evolving systems. *Autopoiesis* in the context of manufacturing focuses on organizational knowledge as a main driver of processes and as a key capability of the system to reproduce, maintain and renew itself. It is a system theoretic model whose implications for manufacturing in general, and for the acquisition and management of enterprises' tacit knowledge in particular have been elaborated in [40].

The idea of the *dynamic co-evolution of products, processes and production systems* has later been systematically explored and extended in the SPECIES framework [41]. Departing from the requirements generated by highly changeable and unpredictable markets, this framework suggested specific tools and methods for the co-design and coordinated evolution management of products, manufacturing processes as well as systems. Recently, this framework has been extended to cover also the issues of de- and remanufacturing in the *circular economy* [42]. Finally, biologically inspired design in general became in the meantime an extensively researched topic [8][35].

3.2. Emergent synthesis of complex systems

Emergent synthesis was proposed as a theory for the generation of innovative solutions for the design and control of complex systems [53][55]. Ueda elaborated the *interactive manufacturing* idea to cope with the difficulties caused by growing complexity of manufacturing activities [7][49][51]. The research hypothesis–as an extension of the BMS concept with human aspects–was that by *interaction* among humans (designers, manufactures and consumers), resources as well as artifacts throughout the life-cycle of artifacts each participants' behavior could iteratively improve.

Within the *agent* paradigm [27], the changing environmental conditions resulting in part from the interactions of autonomous artifacts, humans and machine resources can really be captured. This, in turn, has an impact on the behavior of the agents themselves. The most remarkable phenomenon exhibited by the so-called *Complex Adaptive Systems* (CAS) [12] is the emergence of highly structured and relatively stable collective behavior over time from the interaction of more simple sub-systems, operating usually without any centralized control. Emergence has a number of alternative definitions [6][55]:

- In the *computational* model, global order arises from local computational interactions such as in evolutionary algorithms, multi-agent simulations, or self-reproducing cellular automata;
- In *thermodynamic* emergence stable global structures arise through continuous, self-organization processes in physical or chemical systems that are far away from equilibrium;
- Finally, emergence can be seen as an *unexpected deviation* of the behavior of a system from the model maintained by its observer. Hence, it involves a change in the relationship between the observer and the physical system under observation.

Any definition of emergence implies that some implicit global complexity emerges *unexpectedly* from explicit local simplicity. The key characteristics of CAS include dynamics involving interrelated spatial and temporal effects, correlations over long distance- and time-scales, strongly coupled degrees of freedom and non-interchangeable system elements, to name only the most important ones [26]. (No wonder that the core idea could be applied well to melody composition considering rhythm and pitch [13].) Both the CAS and its environment simultaneously co-evolve in order to maintain themselves in a state of quasi-equilibrium, i.e., on the edge of chaos [73].

In setting up a CAS, the central question is realising an artefactual system that achieves its *purpose* under unpredictable conditions [26]. It is difficult to address problems like this relying solely on existing, well-proven engineering methods of analysis, configuration and synthesis [36].

Synthesis in particular is a necessary component of problem solving processes along all phases of the artefacts' life-cycle which starts with design, goes through the phases of planning, production, consuming, use, and maintenance, and ends up with the disposal or recycling. Emergence was meant to play a key role in solving difficult problems of synthesis. The main concern here is whether and how the completeness of information could be warranted in the description of the environment and the specification of the purpose of the artefactual system. With respect to the *incompleteness* of information on the environment and/or the problem statement, synthesis can be categorised into three classes [53][55]:

- *Class I*: *Problem with complete description*—if all the information concerning the environment and specification are given, then the problem is completely described. The main engineering stance is finding optimal solutions within the bounds of known constraints. However, it is often difficult to find even a close-to optimal solution.
- *Class II*: *Problem with incomplete environment description*—the specification is complete, but the information on the environment is incomplete. Since the problem is not wholly described in this case, it is difficult to cope with the unknown, typically dynamic properties of the environment.
- *Class III*: *Problem with incomplete specification*—not only the environment description but also the specification is incomplete. Problem solving, therefore, has to start with an ambiguous purpose, and human involvement in mixed-initiative decision making becomes significant.

As to CPPS research, development and implementation, clearly one has to face in most of the cases Class II and Class III problems. Emergent synthesis was demonstrated in a number of fields of *production management and control*: in make-to-order production environment, for solving coupled problems of production planning and control in face of variable demand and key performance indicators [57], as well as for simultaneous manufacturing process planning and scheduling [60]. The correlation of the above problem classes was demonstrated in job shop scheduling [21]. Study of the complexity in real-life automotive production networks has lead Ueda to view *supply chain management* from the novel stance of science of complex networks [36][20]. From this aspect, the structure of a given production network can be taken as the result of emergence, through a multiplicity of repetitive decision-makings and interactions of individual companies pursuing their own profit and interest [20].

Cooperative acting of a number of autonomous partners in a CPPS can only be an emergent property of an overall system [72]. However, emergence can also be an obstacle to the practical deployment of decentralized solutions. Industry needs both guarantees for some useful properties (like high service levels) and safeguards against unwanted behavior (like uncontrollable lateness). Giving such warrants is still a problem to solve ahead us.

3.3. Value creation in manufacturing

Ueda asked time and again the provoking questions whether creating a functional artifact yields rich *value* [61][62], or any value at all? Do better functions create more value? What is the relationship between the design of artifacts and creation of value? Why to study *design* of artifacts, pursue the *science of design* at all?

He made investigations of axiology and devised classification schemes of value such as absolute or relative, affirmative or negative, objective or subjective, etc. He distinguished and studied economic, logical, ethical, and esthetic value and concluded that value is closely related to *artifact creation* acts unless we adopt the notion that value is hidden in the natural environment, like a new chemical element for example, independently from human existence and efforts [64].

In engineering, design is the decisive moment of the conception of ideas, of *creation*. Design and innovation provide frames of our life through artifacts and services. It is enough only to refer to smartphones which had an extraordinary impact on the norms of human and social behavior in the last decade. No technology (and the related services) so far might have ever changed how people behave in the society as fast as these devices (and their accompanied services) have.

Ueda was convinced that seeking the essence of design would help us to understand not only the way how artifacts are created, but also how do they shape our environment and society. Essentially, as he said, it makes no sense to treat artifacts isolated from society. Design synthesis of artifacts can only be done in the wider context of the natural environment and social institutions. Whether a designed artifact (or service) is of any value turns out only while it is being used in the social context, just like if it respects or even protects the values of natural environment. Furthermore, since society is composed of agents–individuals, groups and organizations alike–who decide and act autonomously, it is an open and emergent system *per se*.

Hence, no wonder that his answer to this designer's problem has its roots in emergent synthesis and more specifically, in decision making under informational incompleteness and self-organization of global complexity from local simplicity. His *co-creative decision making* model suggested new prospects for manufacturing and service innovation by introducing and elaborating the concept of *value co-creation*. The model makes a distinction of three classes (see Fig. 4):

- *Class I*: *Providing value*—when the producers (providers) and customers (receivers) are independently articulated in a known environment. In such closed system *optimization* is the main strategy.
- *Class II*: *Adaptive value*—when the objectives of the providers and receivers are known completely, but the environment is changing and unpredictable. In such an open system *adaptation* is the key strategy.
- *Class III*: *Co-creative value*—when in a not completely known environment providers and receivers with (partly) uncertain objectives interact with each other.

Note that in a real-world setting even Class I problems can pose quite a challenge, e.g., when coupling of multiple optimization problems that are competing in nature must simultaneously meet various conflicting objectives [16]. However, Class III is a novel concept that embraces *value co-creation* among producers and customers [61][62][64]. Its key idea is that no value is created without interaction. Accordingly, engineering has a wider scope—defined by both technical sciences and society—and it is aimed at value co-creation, instead of simply satisfying market demand.

Placing the concept of value into the core of production engineering opened new avenues for investigating patterns and mechanisms of value co-creation. As for the methodology of subsequent studies, he conducted research along three kinds of parallel paths: (1) *game theoretic analysis* typically on small-scale models, (2) *multi-agent simulation* on large-scale computational models, and (3) *experiments with human subjects* [27].

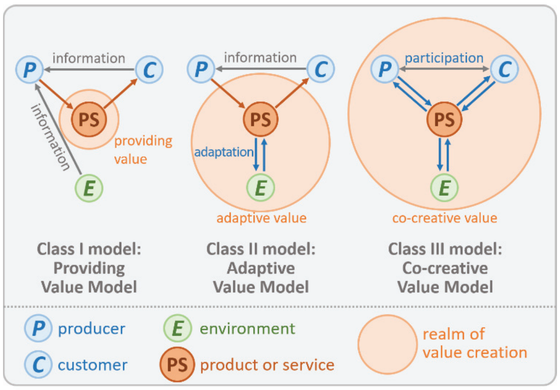

Figure 4: Classes of value creation [64].

For instance, he investigated markets with *network externalities,* where more users and use make products in a way more valuable. In such markets, like smartphone or on-line services, value is created through the dynamic interaction of consumers: use of a product indirectly benefits others who own the same product [63]. The results showed that *incomplete information* among consumers initiates new product diffusion, whereas availability of complete information resulted in a standstill of innovation. Furthermore, *community* is an added value, too.

In the value co-creation model design becomes an open-ended "democratic" process where various stakeholders along the value-chain can actively participate in the design process itself [24], ranging from mass-personalization [43] to crowd-sourced manufacturing.

In the meantime, as a recent survey summarizes, value co-creation became inherent element of the business models of enterprises who take properly incentivised innovation and knowledge sharing, building-up of an innovation ecosystem, as well as collaboration with customers and suppliers in solving major social challenges as strategic issues [11].

3.4. Service science and institutional design

Ueda realized early that *service* permeates manufacturing in many ways. Besides admitting that in production the provision of products and supporting services are inseparable, service in general offered a novel perspective for understanding and interpreting economic phenomena behind all production activities. It implies that value is created collaboratively, during a mutual exchange of intangible ideas and resources between providers and consumers [61]. Service involved the use of specific resources and competences of one entity for the benefit of another, rather than the simple production of artefacts [70]. *Service engineering* has to cope with a reality that was earlier foreign to manufacturers: namely, customers *interact* with their operations. This can be the source of a number of variabilities like arrival, request, capability, effort and subjective preference, all being essential factors of service. While manufactured goods provide rather a distribution mechanism for services, manufacturers themselves cannot deliver value, only value propositions: it is the customer, the beneficiary, who co-creates value. Service can become the dominant logic in economy [23][71], and in the broadest context, ecosystems can be modeled as service providers for a number of human activities including manufacturing [72].

Service essentially entails a *cooperative* attitude being its basic question "How can I help you?" This is just what is much needed in the era of CPPS where interrelated, but autonomous stakeholders have to align their almost necessarily disparate interests. For instance, even traditional supply chain coordination problems can be solved in terms of service. Here, there exists a wide spectrum of interaction mechanisms between enterprises, from the rigorous transactional models that work through legal terms and contracts up to the relational mechanisms that rely on moral control, informal exchanges and cooperative attitude. One may have opposing views on what a mechanism is worth applying even when setting up bilateral (typically, buyer-supplier) links [22]. According to the service model, when managing supply chains under volatile market conditions, supply can be considered a service that provides not only goods with guaranteed service level but also flexibility to another partner. Pricing this service depends not only on the goods produced and delivery performance, but also on the reliability of forecasted demand communicated. All in all, albeit partners decide autonomously, the expected total production and logistics costs can be minimized [72].

As Ueda emphasized, the offerings of the enterprise can go far beyond the provision of artefacts and involve also sophisticated services through the whole life-cycle of products. Indeed, they can form platforms, and the profitable business opportunities can be like a smiling curve [32], showing a high profitability also on the downstream phase of products. However, tail management of the life-cycle is possible only if the information control is not interrupted while the product is being used at the customer. To solve this problem for waste electrical and electronic equipment (WEEE), such as TV sets, computers, smartphones—where it is instrumental to recycle, reuse and remanufacture products—a novel service-oriented remanufacturing platform was proposed by making use of the cloud manufacturing concept [74]. Ideally, the service should cover the whole life-cycle of products, from beginning-of-life (BOL) through normal uses in middle-of-life (MOL) up to end-of-life (EOL), as shown in Fig. 5.

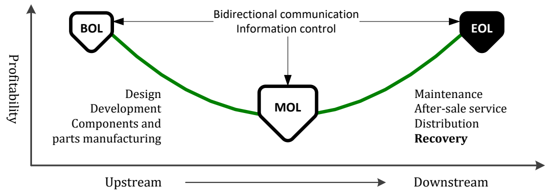

Figure 5: The smiling curve phenomenon [74], after [32] .

On the basis of platform formation studies [32], a game theoretic analysis of product-service platforms was elaborated in [33]. The service perspective greatly widened the possible scope of design as well. For instance, the role of *membership service* has been investigated in public goods problems by using economic analysis and simulation [30].

A study addressed electric vehicle product development and interdependent decision-making among stakeholders such as producers, infrastructure providers, and consumers. On this specific market, infrastructure such as plug-in stations strongly affects product value. Parallel studies with game theoretical analysis, simulation and experiments with human subjects have shown that social surplus increases in the scenario where a producer takes initiative and an infrastructure provider follows it [31].

Finally, Ueda raised the most important—and hardest—issue of cooperation: how to align requirements of *sustainable society* with those of industrial *competitiveness*? What social institutions need to be formed–in fact, designed–so as to find and maintain a resolution of the ever changing but apparently prevalent conflict?

The answer lies again in various forms of service whose nature essentially differs from that of manufacturing. Interest in human behavior (such as perception, experience, lifestyle, cognition, bounded rationality) is strongly related also to social and environmental sustainability. As for value co-creation in society, it is important to capture how decision-making agents mutually interact and behave in an inherently uncertain environment. He applied computational methods of emergent synthesis, experimental economics, experimental psychology as well as log mining to study new forms of services.

In particular, he modelled waste collection and recycling as an *institutional design* (or social engineering) problem, where the right incentives for economic agents like producers, consumers, dismantlers and used-unit dealers had to be devised [58]. Historical purchase data and results of a lifestyle survey were used to support *service engineering* so as to answer the question on how much variety is needed in products or services for people to live a rich life in a sustainable society. The answer rested on identifying appropriate *lifestyle* categories together with their purchase tendencies, as well as collaboration patterns among customers, retailers and manufacturers [38].

His last research, published posthumously, investigated the lifestyles of smart home appliances based on their acquired log data. A methodology was developed for elucidating background information on users, as well as combining it with Internet of Things (IoT) log data [39]. Future uses of the extracted information was discussed in designing personalized products and managing variety of products, as well as in providing maintenance and life-cycle supporting services. The final conclusion was that the ecosystem which can really make use of big log data should be based on value co-creation among the manufacturers, service providers and customers.

4. Conclusions

Modelling the operation and also forecasting the emergent behavior of cyber-physical production systems of large complexity raise a series of basic and application-oriented research tasks, not to mention the control of any level of these systems. The fundamental question is how to explore the relations of autonomy, cooperation, optimization and responsiveness. These are just the issues which were studied by Ueda by exploiting analogies of biology and physics, and later by elaborating his concept of emergent synthesis. Having recognized the importance of the synthesis of CAS, Ueda initiated a series of International Workshops on Emergent Synthesis (IWES) in 1999, which was organized in every 2-3 years. It is the responsibility–may be the obligation–of our society not to let this initiative wither.

By now it is clear that sustainable production and development in general is no longer a choice but a necessity that must be followed at all levels. Throughout his career, Ueda was capable to see and grasp key problems on all levels of production, staring from process level (chip formation mechanisms) up to system level (modeling, designing and controlling manufacturing systems), and, finally, by extending his vision on the relations of manufacturing, economy, nature and society. Having an impact on policy making he contributed to the sustainable society through the advancement of production engineering and industrial technology.

When investigating innovation he was seeking in fact the essence of creation and understanding. He challenged the idea that understanding foregoes creativity and was in favor of a mutual interplay of analysis and synthesis, understanding and creativity. His lesson is that we might be able to understand something only through the process in which we are creating it. In his view innovation is inevitably linked to uncertainty and incompleteness; it is like a risky journey of exploration into a strange land. Though, it will not be a lonesome and aimless journey for those who choose Ueda as a companion.

Acknowledgements

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