Co-creative Value Manufacturing: a methodology for treating interaction and value amongst artefacts and humans in society

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This paper presents a new concept of co-creative value manufacturing, considering interaction among artefacts and humans in society. In response to recent social changes such as globalization of business, diversification of culture, individualization of lifestyle, environmental problems and short product lifecycles, manufacturers are confronted with difficulties in terms of creating product value. It has been observed that products with high functionality do not necessarily create value. The reason can be considered to be that value is created through interaction within an environment where artefacts with technology and humans who use products have been mutually interacting. Therefore, it is important to ascertain the mechanism of how value is constituted through interactions in a society. To treat such an issue, this paper first explains key concepts of emergent synthesis, co-creative decision-making, and value creation models as a basis for co-creative manufacturing. Then an approach integrating game theory, experimental economics and multi-agent simulation is proposed. Finally, this paper presents a research example using the approach, focusing on electric vehicle development.

1. Introduction

New technologies frequently spur innovation and support the long-term growth of an economy, thereby bringing wealth to life. Especially in recent decades, innovations centering on information communication technology are proceeding rapidly, thereby producing lifestyle changes continuously. However, products with high functionality do not always become diffused and do not necessarily create value or welfare for our society. Accordingly, it is not easy to ascertain or forecast how technological changes produce value in society and how

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products with new technologies permeate and alter our lifestyles. These questions are related to the manner in which products are exchanged in markets and the manner in which products show emergent function by their use, and are related to an individual's intrinsic sense of value. In other words, along with product functionality itself, value is created through interaction in an environment where artefacts with technology and humans who use products have been mutually interacting: that environment is "society". Conventionally, when designing products or developing new technologies, designers do not consider such a wider area including interaction within a society.

Most people would agree on the importance of value in a society. However, it is generally difficult to clarify its mechanism. That is even more true now that we confront globalization of business, diversification of culture, individualization of lifestyle, environmental problems, and short product life cycles: the social value of products is embedded in products in a complex manner. Although marketing research has long been conducted mainly using questionnaires or interviews for capturing potential demand for upcoming products, such approaches cannot completely elucidate the mechanism of value, especially in our complicated society. The important point is *interaction* between artefacts and humans in a society. Therefore, the mechanism of how value is constituted through interactions must be ascertained to realize the value of *co-creative manufacturing*. For that purpose, the knowledge accumulated in the social sciences should be necessary. Interdisciplinary studies are desirable. In other words, it is important that the framework able to handle issues of socioeconomic systems should be connected to the problem of artefact design or manufacturing.

An academic field considering such an aspect is now being established, the name of which is "artefactual engineering," as proposed by Yoshikawa.[1] Artefactual engineering addresses issues such as *artefacts that provide welfare might also menace human life*. For example, artefacts such as motor vehicles bring about greenhouse gas emissions and cause many deaths and huge artefacts such as nuclear plants can cause widespread accidents under some circumstances. That kind of problem does not arise from the outside but does arise from our daily activities, particularly because we produce and use artefacts. In artefactual engineering, this problem is referred to as "the evils of modern life". Researchers in artefactual engineering try to study and establish a new methodology of artefactual design that can resolve some "evils of modern life". In this spirit, the idea I describe in this paper can be characterized as a part of artefactual engineering.[2]

To demolish the conventional view of technology-centred manufacturing, this paper presents a proposal of a concept and its methodology for connecting the interaction in a society with manufacturing activities. This paper is organized as follows. Section 2 explains some basic concepts related to the problem. Section 3 proposes an approach to treat it actually. Then, as an example, Section 4 presents one study that has been pursued to date. Finally, we conclude matters in Section 5.

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[1] H. Yoshikawa, "Proposal of artefactual engineering: Aims to make science and technology self-conclusive". *Illume*, Vol. 4, No 1, pp. 41–56 (1992) (in Japanese).

[2] Actually, the author now belongs to Research into Artefacts, Center for Engineering (RACE), which was set up in 2002 inside the University of Tokyo to pursue the study of artefactual engineering.

2. Basic concepts related to synthesis

Activities of the design or production of artefacts can be characterized as part of synthesis in a broader sense. From the viewpoint of synthesis, several basic concepts are advocated. The ideas summarized in this section constitute a key issue for the consideration of co-creative value manufacturing.

2.1 *Emergent synthesis*

When designing an artefact in general, it is necessary to satisfy the required specifications of the artefact. That can be reworded as an inverse problem, thereby meaning that it is a problem of determination of the system's structure for performing its function to achieve a purpose under environmental constraints.

Figure 1 depicts the concept of emergence,[3] which represents the idea that a global order of structure expressing a new function is formed through bidirectional dynamic processes, where local interactions between elements engender global behaviour, which imposes new constraints on the behaviour of the elements. In the figure, the left diagram represents the process of generating global order from local interactions among elements. The centre diagram shows that there exists feedback of global behaviour into the environment of local elements. The right diagram signifies that by repeating those processes, a new global order is formed, expressing a new function.

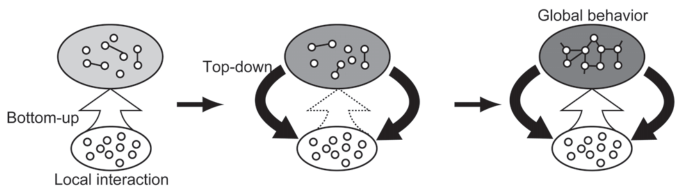

Figure 1. The concept of emergence.[3]

A problem of emergent synthesis,[4] as shown in Figure 2, is whether a function meets a specific purpose in the process of emergence. In problems of traditional product design and production, analytic and deterministic approaches based on optimization are mostly used. Instead of such top–down approaches, the methodology of emergent synthesis adopts the ideas of both bottom–up and top–down features. Ueda et al. (2001) classified emergent synthesis problems into three classes:[4]

Class I—Problem with a complete description: if information related to the environment and purpose is given completely, then the problem is described entirely, but it is often difficult to find an optimal solution.

Class II—Problem with an incomplete environmental description: the purpose is complete, but information related to the environment is incomplete. The problem is not

[3] K. Ueda, "Emergent Synthesis". *Artificial Intelligence in Engineering*, Vol. 15, No 4, pp. 319–320 (2000).

[4] K. Ueda, A. Markus, L. Monostori, H.J.J. Kals, T. Arai, "Emergent synthesis methodologies for manufacturing". *CIRP Annals—Manufacturing Technology*, Vol. 50, No 2, pp. 535–551 (2001).

described completely. Therefore, coping with the unknown environment's dynamic properties is difficult.

Class III—Problem with incompleteness: the environmental description and the purpose are incomplete. Problem-solving must therefore start with an ambiguous purpose. Human interaction becomes important.

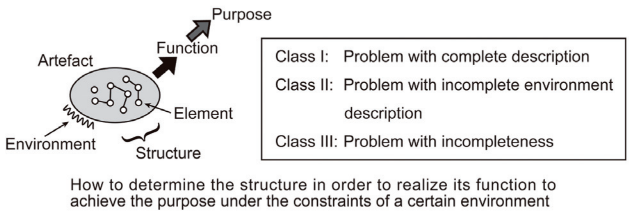

Figure 2. Problems of the emergent synthesis of artefacts.[4]

2.2 *Co-creative decision making*

According to Ueda et al. (2009),[5] co-creative decision-making is defined as collective decision-making that creates an effective solution as a whole system through mutual interaction among various agents. A main difference from a simple emergent system is that the elements are agents that have their own purposes and which make decisions autonomously. Figure 3 presents the importance of co-creative decision making.

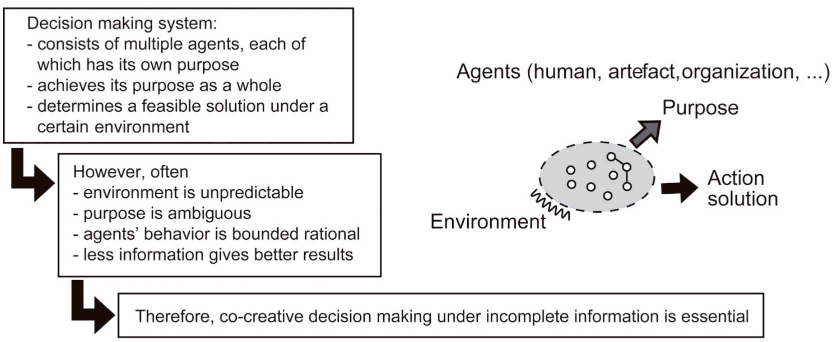

Figure 3. Co-creative decision making.[5]

For example, the study by Ueda et al. (1998),[6] which addresses an interactive production system that specifically examines human interaction based on biological manufacturing systems, is regarded as an early prototype study within the context of co-creative decision-making. Márkus and Váncza (1998)[7] studied interaction between customer preferences and reallocation of manufacturing resources, which is also a study considering an aspect of co-creative decision making.

[5] K. Ueda, T. Takenaka, J. Váncza, L. Monostori, "Value creation and decision-making in sustainable society". *CIRP Annals—Manufacturing Technology*, Vol. 58, No 2, pp. 681–700 (2009).

[6] K. Ueda, J. Vaario, N. Fujii, "Interactive manufacturing: Human aspects for biological manufacturing systems". *CIRP Annals—Manufacturing Technology*, Vol. 47, No 1, pp. 389–392 (1998).

[7] A. Márkus, J. Váncza, "Product line development with customer interaction". *CIRP Annals—Manufacturing Technology*, Vol. 47, No 1, pp. 361–364 (1998).

2.3 *Value creation model*

Corresponding to the emergent synthesis classification presented in Section 2.1, value creation models are discussed here. Figure 4 presents proposed system models of three kinds: Value Providing Model, Adaptive Value Model, and Co-creative Value Model; producers, customers (consumers), and products and services considered are treated as agents. Each model is explained by Ueda et al. (2008) as follows:[8]

Class I value creation model (providing value): The value for the product or service provider (producer) and receiver (customer) can be specified independently and the environment can be determined in advance. The model can be described as a closed system. The problem to be addressed is the search for an optimal solution.

Class II value creation model (adaptive value): The value for the product or service provider and receiver can be specified, but the environment changes, making it difficult to make a prediction. The model is a system that is open to the environment. The problem that must be addressed is the adaptive strategy.

Class III value creation model (co-creative value): The value for the product or service provider and the value for the receiver cannot be determined independently. The two interact. Therefore, they cannot be separated. The provider enters the system. The problem that must be addressed is value co-creation.

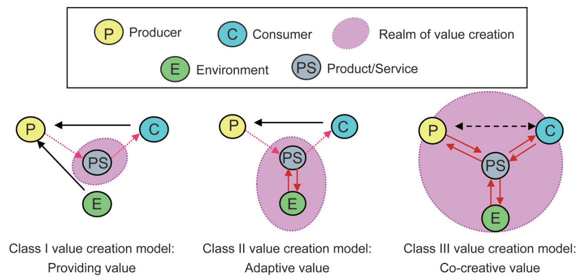

Figure 4. Value creation model.[8]

These extremely important concepts form the basis for considering a social system mechanism towards co-creative manufacturing. The next section presents an actual approach.

3. Proposed approach to address social systems aiming for co-creative value manufacturing

This section presents a proposed approach integrating game theory, experimental economics, and multi-agent simulation to address social systems in which artefacts and humans mutually interact with each other and create value.

3.1 *Game theory*

Game theory usually addresses decision-making problems, particularly in an interdependent situation using a definite mathematical method. In the simplest formulation, only players, actions,

[8] K. Ueda, T. Kito, T. Takenaka, "Modelling of value creation based on emergent synthesis". *CIRP Annals—Manufacturing Technology*, Vol. 57, No 1, pp. 473–476 (2008).

and payoffs are included in a game-theoretic situation. For example, Table 1 presents the widely known prisoner's dilemma game, which well describes a dilemma interrelationship between two players. In addition, with several equilibrium concepts, game theory can predict the decision that players with perfect rationality will take. For example, in the prisoner's dilemma shown in Table 1 one can use the concept of Nash equilibrium to predict that both players take the action of "Defect". As such, game theory can provide the theoretical basis of the social system we target.

Table 1. Payoff matrix (of the rewards accruing to the two prisoners) for the prisoner's dilemma game.

		Player 2	
		Cooperate	Defect
Player 1	Cooperate	3, 3	0, 5
	Defect	5, 0	1, 1

3.2 *Experimental economics*

In the field of experimental economics, researchers conduct experiments with human subjects to analyse an economic system or human economic decision-making by constructing a virtual economy in the laboratory. Just as engineers and scientists do in other fields, economists also do experiments using a controlled environment: information is controlled by desk partitions, as shown in Figure 5. Decisions are made with a networked computer. In addition, a remarkable point is that subjects can actually receive a monetary reward according to their performance in the economic experiment. By such arrangements, as well as giving real economic incentives, subjects' preferences are controlled. This point owes much to the "induced value theory" proposed by Smith (1976).[9] Therefore, taking the approach of experimental economics, we can examine interactions between artefacts and humans in a socioeconomic situation.

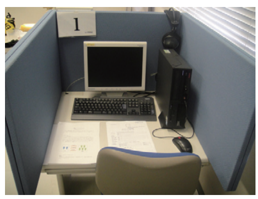

Figure 5. Laboratory for economic experiments. On the left, a laboratory for economic experiments. On the right, an individual desk for a subject.

3.3 *Multi-agent simulation*

Nowadays multi-agent simulation is much used in various domains. According to Russell's definition,[10] an agent is anything that can be viewed as perceiving its environment through

[9] V. Smith, "Experimental economics—induced value theory". *American Economic Review* Vol. 66, No 2, pp. 274–279 (1976).
[10] S. Russell, P. Norvig, *Artificial Intelligence: A Modern Approach* (2nd edition). Prentice Hall (2002).

sensors and acting upon that environment through effectors, as shown in Figure 6. Multi-agent simulation involves multiple agents and presents global behaviour through an emergent process arising from local interactions among agents. This kind of simulation technique enables precise insight into decision-making in a socioeconomic system. For example, multi-agent simulations enable us to perform easy modelling of mutual interactions in local behaviour. Therefore, multi-agent simulation can address several aspects such as dynamic processes prior to reaching equilibrium, which game theory does not usually deal with. The method is also useful for analysing social systems.

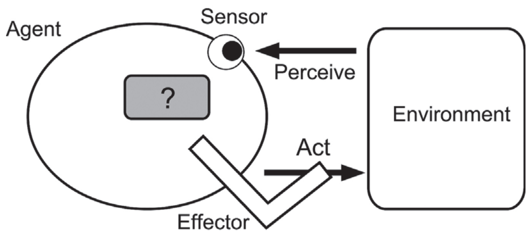

Figure 6. The basic agent model as conceived by Russell.[10]

3.4 *Integrating the three approaches*

By applying the concept of emergence to a social system in which humans and artefacts mutually interact, emergent processes of the social system can be described as depicted in Figure 7. It does not matter whether it is synthesis in social systems or synthesis of artefacts; the basic idea is common among them. The point is that global behaviour emerges as an output through interaction between humans and artefacts. Whether this output satisfies the *purpose* of the entire system is important. Consistency between the purpose of the entire system and output behaviour is closely linked to the problem of value creation in society. Hence, the social system mechanism must be elucidated if we want to connect it to the issue of artefact production.

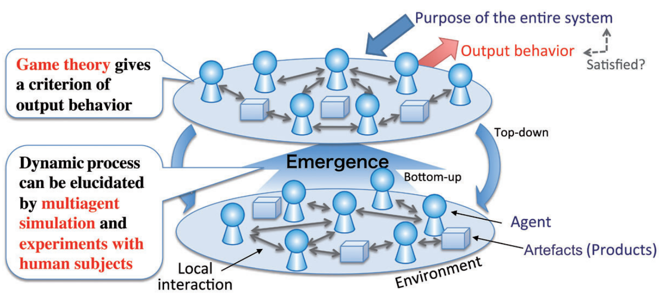

Figure 7. Emergence of a social system and the integrated approach.

Formulation of interdependent decision-making among players using game theory implicitly means in this context of emergence that the nature of the relationship between players can be described in a definite mathematical manner. Therefore, it can be regarded as a simple formalization of interaction between humans and artefacts, especially in an extreme case in which all players have perfect rationality. However, game theory mainly addresses the equilibrium state, disregarding dynamic processes until a converging state is reached. Therefore, the equilibrium solution obtained by game theory could be used as a criterion for the result obtained for global behaviour when all players behave rationally with complete information.

Experimental economics provides the possibility of the direct observation of dynamic processes. Therefore, this approach is useful to elucidate the mechanism of emergence with interaction among humans and artefacts in a society. As described above, because the experimental economics method controls human subjects' preferences by induced value theory, experiments can clarify the emergent process under the controlled condition in which a subject's preferences are given by an experimenter. This point is extremely important for addressing synthesis problems concerning artefacts and their value in society. We can also conduct experimentation of artefact synthesis problems in a hypothetical society.

Multi-agent simulation can freely model interactions among humans and artefacts in a society. Although experiments with human subjects are restricted in terms of the number of subjects who participate at any one time because of the limitation of laboratory capacity, multi-agent simulation can be readily conducted with thousands of agents. Moreover, in addition to preferences, behaviours or strategies can be flexibly controlled. Therefore, multi-agent simulation should be used for clarifying the dynamic process of emergence, especially together with the complementary use of experiments with human subjects.

4. Research example

Along with the ideas proposed in this paper, we have studied several related topics. This section presents an example related to electric vehicle development.[11]

Electric vehicles are widely anticipated to be introduced because of their potential contribution to resolving environmental problems such as global warming and energy consumption. They have therefore been developed by many automobile companies. However, because electric vehicles require new infrastructure such as plug-in stations, it is not easy to shift society towards using electric vehicles. Vehicle producers would have insufficient incentive to develop electric vehicles if infrastructure were not constructed and if consumers did not want to buy them. On the other hand, infrastructure providers would also have no incentive if electric vehicles did not appear in the markets. Therefore, there is an interdependent relationship. This poses a difficult problem of value creation in society. The study modelled interdependent decision-making among vehicle producers, infrastructure providers, and consumers. Additionally, the study conducted experiments with human subjects and multi-agent simulations to elucidate the mechanisms that affect their decisions.

The study constructed a decision-making model in which a producer makes a decision related to the development of electric vehicles and a decision to introduce them into markets. An infrastructure provider makes a decision related to whether to construct plug-in stations. Consumers can choose to purchase an electric vehicle (EV) or a gasoline vehicle (GV). In this context, the four scenarios to be analysed are prepared as presented in Figure 8.

[11] N. Nishino, T. Iino, N. Tsuji, K. Kageyama, K. Ueda, "Interdependent decision-making among stakeholders in electric vehicle development". *CIRP Annals—Manufacturing Technology*, Vol. 60, No 1, pp. 441–444 (2011).

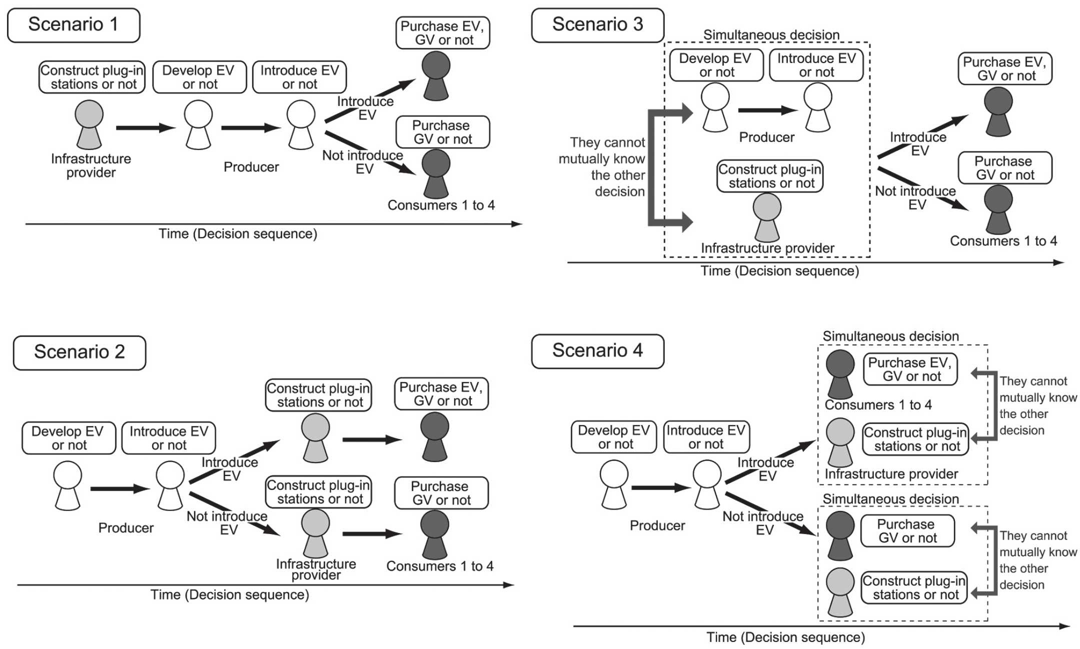

Figure 8. Four scenarios of the electric vehicle (EV) development model.[11]

Using those four scenarios, we conducted experiments under conditions of incomplete information, which means, in game theory, that players do not necessarily know all the game-related information such as the game rules, possible actions, and their payoffs. It was assumed for this study that players know their own respective payoff matrices, but they cannot know other payoff matrices. This situation is more realistic than the ordinary assumption of complete information. Figure 9 shows the average profit of each scenario in experiments. The remarkable point in the figure is that the profits in Scenario 2 are high, independent of information completeness, which implies that the situation of Scenario 2 presents robustness in attaining the state in which the social surplus is maximized. In other words, this social system structure can create high value.

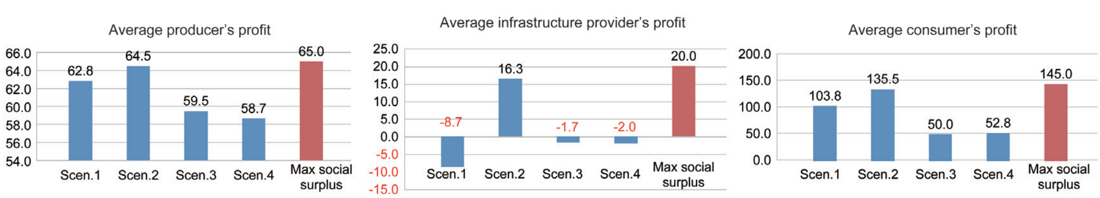

Figure 9. Experimental results from the electric vehicle development model (Figure 8).

From the results of this study, it can be concluded that if the producer wants to develop electric vehicles and launch the business, then a decision-maker structure resembling that of Scenario 2 is important to diffuse the products. Therefore, from the technology development stage, the producer ought to consider the relation between other stakeholders to create value in a society with electric vehicles.

5. Concluding remarks

This paper emphasizes the importance of interaction among artefacts and humans in society, presenting some concepts such as emergent synthesis, co-creative decision making, and a value creation model. To treat this problem, this paper proposed a methodology integrating game theory, experimental economics, and multi-agent simulation. An example of the actual research pursued to date was presented. Approaches that incorporate social interactions are very few in the field of engineering. This article will, hopefully, contribute to the future expansion of this avenue of inquiry.[12]

[12] Acknowledgments. The content of this paper derives partly from the discussion that took place during a seminar held at Cranfield University, UK on 22 September 2011. I thank the organizer of that seminar, Dr Benny Tjahjono, and the other participants. I also thank Prof. Jeremy Ramsden, who invited me to submit this manuscript after the seminar. I appreciate this opportunity to present my interdisciplinary ideas in this paper.