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Editorial

Open Innovation Engineering—Preliminary Study on New Entrance of Technology to Market

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Received: 6 May 2020; Accepted: 7 May 2020; Published: 11 May 2020

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Abstract: As engineering is required to answer directly and more heartily than before the requirement of society and markets, we want to answer the following questions. *What kind of open innovation channels exist, and how can these channels operate as a knowledge funnel to conquer the growth limit of capitalism in the 4th industrial revolution?* At first, we built up the concept model of open innovation engineering from a conceptual experiment and attempted to prove this model by literature reviews. Second, we applied this open innovation concept model at the papers of Society of Open Innovation: Technology, Market, and Complexity (SOI) 2019 Special Issues of *Electronics* as a preliminary study. Additional field researches on each open innovation engineering channel in addition to research on finding out more open innovation engineering channels are required.

Keywords: open innovation engineering; open source computing; TRIZ; open SCM; system dynamics; mechanism design; big data

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1. Introduction

In the 4th industrial revolution, so to say in the 2nd information technology (IT) revolution, engineering is required to answer directly and more heartily than before the requirements of society and market [1,2]. Furthermore, world capitalist economies are approaching their growth limits, despite artificial intelligence (AI), driverless vehicles, blockchain, precise medical IT, and a lot of new technologies, with high unemployment [3–5]. Open innovation has become the dominant paradigm to connect between technology, and markets, and to arrive at new combination of the creative destruction [6–9]. In this situation, we want to answer the below research question.

What kind of open innovation channels exist, and how can the channels operate as a knowledge funnel to conquer the growth limit of capitalism in the 4th industrial revolution?

At first, we tried to develop the open innovation engineering model which includes open innovation engineering channels, and determining ways of operating the channels through conceptual experiments, and proven first through literature reviews.

Second, we collected ideas from papers of Society of Open Innovation: Technology, Market, and Complexity (SOI) 2019 special issue of Engineering to answer the research question and to prove the concept model of open innovation engineering.

2. Concept Model Building of Open Innovation Engineering

Open innovation engineering concept model includes diverse open innovation engineering channels such as open source computing, theory of solving inventive problem (TRIZ), open supply chain management (SCM), system dynamics, mechanism design or big data, as shown in Figure 1. Open innovation engineering channels have two major functions such as (1) expanding the knowledge funnel vertically; (2) making holes at the knowledge funnel for the motivation of inbound and outbound open innovation. Open source computing and TRIZ are located at the near -side of the research parts of the knowledge funnel. Open SCM and system dynamics are located in the inside of knowledge funnel, and mechanism design and big data are located near-side of market and society at the knowledge funnels.

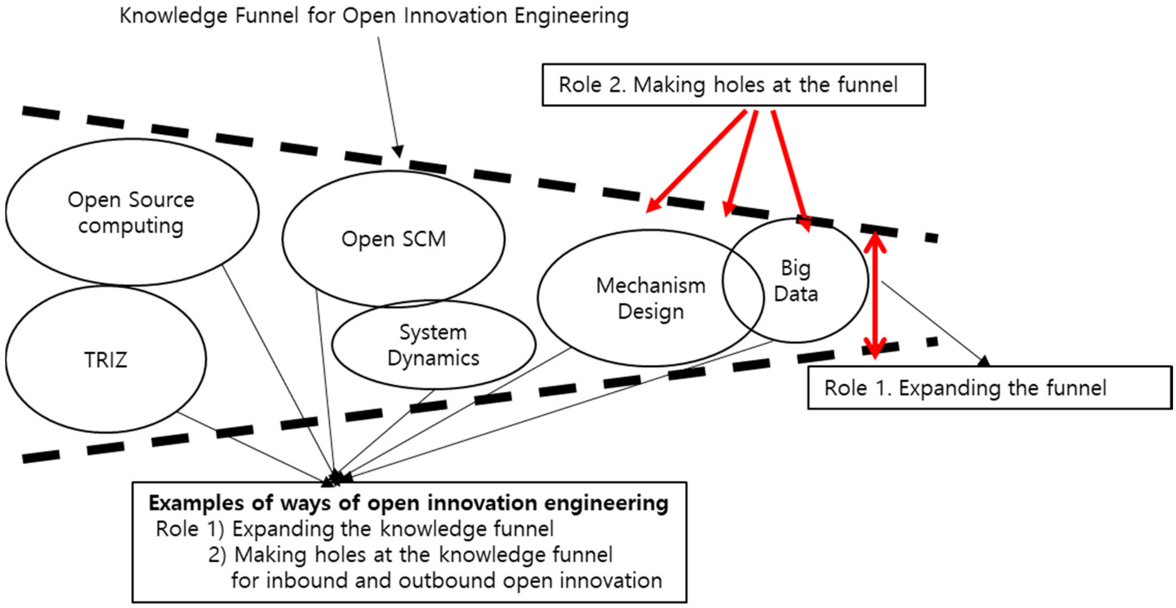

Figure 1. Open innovation engineering at the knowledge funnel.

The first function of open innovation engineering channels is to make holes at the knowledge funnels to motivate inbound or outbound open innovation of firms. The second function of open innovation is to expand the knowledge funnel vertically, which means the expanding of new markets.

3. Ways of Open Innovation Engineering in Research with Open Source Computing and TRIZ

Open source computing enables users to collaboratively create artifacts using creative development processes by utilizing computing methods and technologies to develop computational artifacts for the realization of ideas or solutions to a problem [10]. A computational artifact refers to any object made by human beings using a computer and includes, but is not limited to, software or hardware. In developing artifacts in collaboration with the outside or outsourced, these processes employ mixed techniques developed in various fields, combining, modifying existing artifacts, or creating new artifacts, or expressing curiosity and creativity of individuals. The processes of creating computational artifacts undergo iterative steps or try things repeatedly to get the targeted results from initial ideas. Open source software seems poised for rapid growth in the future, and its processes could also be similarly applicable to solving problems [11].

Open source computing has its origin in the cooperative structure of the history of software development even though traditional vendors of proprietary platforms attempted to combine the advantages of open source software while retaining control and differentiation [12]. Open source software has been a great success recently with network externalities of diverse open source platforms [13]. Open software is free for anyone to obtain, use, modify, and share it.

Such open source computing can be a powerful tool or conceptual basis for open innovation engineering in the following ways [14,15]. First, in terms of dependency, each country tries to reduce dependency on other countries in terms of technology. Additionally, in each country's protectionist trend, each country tends to close its own market, but open source technology breaks through this protectionist market and encourages innovation to pioneer the market. Second, open source is safe in terms of security because anyone can know what kind of source code of computing they use. Third, open source avoids the situation where one side monopolizes information, so competition is possible, and competition lowers prices and promotes innovation. Fourth, open source reduces development time by preventing duplicate development of already developed ones. In addition, it increases the possibility of introducing technologies in other fields, thereby increasing opportunities for convergence through the expansion of fields of study.

TRIZ is an acronym for Russian phrase, meaning theory of solving inventive problems [16,17]. TRIZ is a logical method or a procedure to find innovations. The process of the TRIZ lets users identify and analyze their specific problems, search for the general innovation patterns which are present in TRIZ to match with the specific problems and adopt the solutions to similar problems [18]. Thus, organizations who do not have their own experience and knowledge of the technologies and the fields could have the ability to solve problems and develop products creatively by using TRIZ. This approach allows organizations access to well proven know-how with less cost and time. It also allows organizations to have new intuition and insight for their future innovation projects.

Before the selection of appropriate solution methods for the specific problem, analysis of the problem to grasp the collective knowledge of the situation that causes the problem is required. TRIZ tools let the solver see through the problem situation and devise innovative solutions to the problem. These tools utilized in TRIZ include the ideal final result (IFR), function analysis and trimming, contradictions, and trends of evolution [19]. The IFR describes a situation in which a complete solution is applied that does not consider any practical or implementation constraints. The ideality is defined as benefits divided by the sum of costs and harm. Evolution occurs in the direction of increasing benefits and decreasing costs and harm, and ultimately aims to reach the IFR. When the IFR is reached, the deficiencies of the original system are eliminated, the advantages of the original system are maintained, and no new disadvantages are introduced. The IFR ensures that a moderately improved solution rather than a radical innovation, is not presented.

Function analysis of TRIZ is a methodology originally utilized in systems engineering [20]. In this method, the relationship diagram between the elements is drawn first, then it is checked if the elements of the system can be removed. This analysis is undertaken at the beginning of the process in the TRIZ because it makes the system simplified. In the zone and resource method, zone means roughly the time and space where the problem occurs. This method is intended to understand the root cause of the problem. When used with function analysis, cause-and-effect analysis can be possible. The basic principle of TRIZ is that all problems arise due to contradictions, “physical” and “technical” [21]. Physical contradiction occurs when a requirement requires values that are in conflict with each other. Technical contradiction is a common occurrence in engineering and managerial trade-offs. The inability to achieve the desired state occurs in situations where something in the system interferes with it. Without contradiction, there is no problem. The advantage of applying TRIZ to solving a specific problem is that the types and principles of contradiction that the problem has are already analyzed and solved by TRIZ. TRIZ provides 40 basic principles and 76 standard solutions that can be used immediately [22]. This benefit is even more valuable when the organization trying to solve the problem has no internal knowledge and experience in the field. These characteristics are in line with the strategy of open innovation that introduces knowledge and experience from the outside.

In addition, the TRIZ provides predictable patterns in terms of time rather than types of problems to be solved based on these 40 principles and 76 standard solutions, so they can be used as a strategic decision-making tool in open innovation engineering [19]. When the TRIZ trends of evolution are used as a strategic decision-making method, it can help to identify the shortcomings of innovation efforts so far, to predict the future direction of the product’s evolution, and to prepare an innovation strategy for their products and systems. In the classic TRIZ, eight general evolution patterns have been proposed. Since then, many TRIZ practitioners have voluntarily evolved TRIZ further by adding new patterns or improving the ease of use. This feature makes TRIZ an example of open-innovation applications. As such, the methods and processes of problem solving provided by TRIZ are applicable in all cases regardless of closed or open innovation problems. In particular, TRIZ's principles and solutions are based on the philosophy of open innovation that enables everyone free access and encourages collaboration to improve the system, making it a powerful weapon for open innovation engineering.

4. Method of Open Innovation Engineering in Development with System Dynamics and Supply Chain Management

The power of open innovation engineering could be utilized for better development with System Dynamics (SD) modeling and Supply Chain Management (SCM). Computer modeling and simulations have an important history in science and engineering. Good modeling comprises diverse aspects to engineering challenges including subject matter, analytical and numerical mathematics, computer science, data analytics, artificial intelligence, and other techniques incorporated therein. While the diversity and complexity of open innovation, engineering and modeling need a unified and simplified methodology such as SD. System Dynamics (SD) methodology is proposed by MIT professor Jay Forrester with a foundation in decision-making, dynamic relationships, feedback analysis, and simulation [23]. In the past decades, SD has been comprehensively used to analyze many complex systems. The modeling of dynamical systems is applicable for any imaginable field and engineering topics.

SD modeling efforts can improve understanding of the relationships between feedback structures and dynamic behaviors of a system so that solutions for improving performance may be developed. SD modeling and analysis generally includes (a) system identification, (b) conceptualization, (c) model formation and validation, and (d) engineering and decision analysis. System identification is the process to firm up the understanding and mental model for the modeler with relevant information about the system for open innovation engineering. System conceptualization means that the system is described in a qualitative language to show the dynamics of variables involved in the system. The result of the conceptualization is normally represented in the form of a causal loop diagram, which serves as a primitive form of the final SD model. In the model formation and validation step, stock-flow diagrams can be developed to have quantitative attributes. By providing numbers and equations for the diagrams, a simulation model can be developed. The model then needs to be properly tested or validated. Finally, the developed SD models are applied to analyze the research subjects and simulation techniques can be utilized for testing and optimizing the engineering results.

The characteristic of open innovation engineering and development came from the nature of cross-discipline and out-of-the-box thinking. We need both local optimization in the systems and global optimization between the systems for open innovation engineering. Therefore, it is important to incorporate the concept of open business innovation into open innovation engineering.

Open business innovation is an effective strategy for enterprises to develop competitiveness and market potential globally [24]. However, the execution of innovative business models and dynamic management decisions requires scientific models and a systematic understanding of strategic planning and dynamic capability. The importance of dynamic capability to firm performance in the changing business environment has been recognized, especially for an innovative business model and in early stage entrepreneurial business developments [25–28]. From a systems perspective, the connecting flows between technological innovation, business model development, market performance, and investment for continuous improvement as an innovation ecosystem have been identified as a critical driving force for open business innovation and sustainable development [29].

With the increasing development of information and communication technology (ICT) and diverse applications, electronic markets and e-business related industries are characterized with an open competition and fast-changing environment that requires companies to rapidly innovate products and services as well as effective operations management [30,31]. Furthermore, the new development of technology in the digital era is also a driving force to sustain competitiveness [32–34]. Open innovation could help companies capture new ideas form external resources and has been referred to as one of the most effective but inverted U-curve shaped, fluctuated and diverse approaches depending on several factors [35]. Yun et al. argued that e-businesses with open platform business models which take advantage of open innovation should focus on quick and dynamic changes over time instead of taking static approaches [36]. Teece has suggested an integrated approach to dynamic capabilities and systems theory that could facilitate dynamically holistic views and enhance prospects for sustainable high performance for a longer time [37].

In electronic markets, an e-business platform normally requires diverse products and innovative visual presentations with different types of IT-supported tasks, such as programing, computer image design, processing and editing. Each type of tasks could be simultaneously supported by the various IT teams, within or across organizations. The IT teams not only should assure their capabilities to fulfil the volume of tasks but also the demand for the quality of project tasks, as well as the process of strategic e-business and IT alignment with other teams [31]. These interrelationships between the demand from e-business and the supply from dynamic IT engineering management initiate the feedback structure requiring scientific simulation techniques and operational models from a holistic and dynamic viewpoint. Based on real cases and real data, SD simulation could enhance the effectiveness of researchers' conceptualizations towards a studied reality [38]. The strength of SD methodology is its capacity to deal with accumulations and feedback processes that are well connected to inherently and dynamically complex characteristics of engineering management which cannot be effectively managed by human intuition alone [31,39].

There are many open innovation engineering topics in supply chain management (SCM). Working towards a sustainable economic development and workable business model would rely both on the awareness of consumers' choices from the demand side and the practical improvements of production from the supply side. Yan et al. proposed a framework for the evaluation of horizontal and vertical supply chain collaborations (SCC) to examine the shared risk for cost effectiveness and reduced variations in supply line efficiency [40]. The horizontal collaborations with different suppliers, for example, can be considered as a company collaborating specifically with one supplier but while in competition with other suppliers competing to supply the quantity ordered. In contrast, the vertical collaborations consider a company focused on the cooperation with one specific supplier and developed different stages of procurement collaborations (e.g., improved forecast, orders, and negotiated price of raw materials).

The modeling of supply chains consists of sequentially connected stocks and flows, each receiving orders and adjusting production and production capacity to meet changes in demand. Each link in a supply chain maintains and controls inventories of materials and finished products. Previous studies have identified the instability and oscillation in manufacturing supply chains as a systems problem. A generic supply chain model and simulation functions have been proposed by MIT SD Group [41]. The concepts of supply line, inventory, and collaborative procurement strategies can be considered for the development of an engineering model [40]. The "Inventory" represents the stock of components to be managed. The "Supply line" represents the stock of orders for components but not yet received, including orders in transit to the supplier, the supplier's backlog, and those goods subject to shipping delays. There are delivery delays and shipping delays between three stages of component supply chains, supply line, inventory, and OEM components. In terms of open innovation engineering, SCM requires extensions to supply chain collaborations (SCC) and sustainable supply chain management (SSCM), from the local optimization of identified systems to global optimization between systems. It points the way for further research such as studying extensive collaborations among suppliers, manufacturers, distributors, and retailers. In addition, a broader framework of the quantitative measurements for SSCM might also be a worthy topic for future studies that inspire more comprehensive considerations for operational research and business decision making in accordance with the multiple objectives of business economics and sustainability.

5. Ways of Open Innovation Engineering in Socio-Market with Mechanism Design, and Big Data Analysis

Mechanism design attempts to explain how incentive schemes and organizations can be designed with the goal of inducing agents to behave according to the designer's or principal's objectives with the manifest of tacit hypotheses of bounded rationality of economic agents [42,43]. Mechanism design theory has been expanded to a linear programming approach to an analytical framework for thinking clearly and carefully about exactly what a given institution can achieve when the information necessary to make decisions is dispersed and privately held [44]. Eric Maskin, Nobel Laureate in economics in 2007, stated in a book foreword "Game theory and mechanism design have come a long way for more than thirty five years from fringe subjects to at the center of economic theory, and have become an important part of engineering disciplines such as computer science and electronic commerce" [45].

William Vickrey, winner of the 1996 Nobel Memorial Prize for Economics, proposed several mechanisms in public economics which have high meaning until now such as Auctions and Bidding Games; An Integrated Successions Tax; Responsive Pricing of Public Utility Services; Pricing in Urban and Suburban Transport; General and Specific Financing of Urban Services; Design of a Market Anti-Inflation Program; Necessary and Optimum Government Debt, or Mechanism on the prevention of Gerrymandering, et al. Several Bayesian mechanism design such as Single Unit Auctions; Incentive-Compatible and Individually Rational Direct Mechanisms, or dominant strategy mechanisms such as Dominant Strategy Incentive-Compatible and Ex Post Individually; Characterizing Dominant Strategy Incentive Compatibility and Ex Post are being discussed as current day mechanism designs in economic societies [46].

The 2007 Nobel Prize in economics honored a subject, mechanism design, fundamental to the study of incentives and information [44]. The effects of this mechanism design are being expanded to diverse creative designs of experimental economics, and new business model designs from open innovation and Schumpeterian new combinations [47,48]. Business model design compass, which is based on open innovation, can also be sourced from mechanisms of bounded rationality, and Schumpeterian new combinations [49]. Mechanism design with connections to markets or society will provide more chances for developing creative open innovation and business models.

With the Google Flue Trends (GFT) announcement in February 2013, many people have asserted that there are enormous scientific possibilities in big data, and one can ignore foundational issues of measurement and construct validity and reliability and dependencies among data [50]. Big data on one hand holds great promises for discovering subtle population patterns and heterogeneities that are not possible with small-scale data; on the other hand, the massive sample size and high dimensionality of big data introduce unique computational and statistical challenges, including scalability and storage bottleneck, noise accumulation, spurious correlation, incidental endogeneity, and measurement errors [51].

Extracting valuable information from big data requires innovative approaches that efficiently process large amounts of data as well as handle and, moreover, utilize their structure in numerous domains, from engineering sciences to social networks, biomolecular research, commerce, and security [52]. Simply put, because of big data, managers can measure, and hence know, radically more about their businesses, and directly translate that knowledge into improved decision making and performance even though we accept that big data's power does not erase the need for vision or human insight [53].

Big data about society and markets will give us a new combination between technology and markets that crosses the boundaries of firms, particularly if you keep in mind joy's law: "Most of the smartest people work for someone else." This lets us open up some of our data sets and analytic challenges to interested parties across the internet and around the world [53]. Indeed, companies that learn to take advantage of big data will use real-time information from sensors, radio frequency identification and other identifying devices to understand their business environments at a more granular level, to create new products and services, and to respond to changes in usage patterns as they occur [54]. As such, big data can motivate open innovation and new business model building by introducing new information about markets and society.

6. Editorial of SOI 2019 Special Issue of *Electronics*

We published five papers at the Special Issue of Society of Open Innovation; Technology, Market, and Complexity (SOI) 2019 conference through *Electronics*.

The first study showed that, as the uses of conversational agents increase, the affective and social abilities of agents become as important as their functional abilities in the open innovation engineering channel and system dynamics approaches [55]. Consequently, by building networks to harness innovation synergies, open system approaches can motivate sustainable development and creative collaboration based on both online and offline learning systems [56,57].

The second study showed that user innovation grows in a firm, according to the Korean smart media industry, with a change from the closed to the open innovation engineering channel and open SCM [58]. Therefore, exploring the innovation ecosystem such as user innovation from the perspective of sustainability, is required to survive in situations of productivity slowdown, exhausted opportunities and harness the power of human ingenuity [59,60].

The third study analyzed the UK and Indian sectorial system of innovation of M-Payments with the integration research model of open innovation and Ogle's idea of the closed and open innovation engineering channels, TRIZ [61]. Technology convergence, and open innovation in the M-Payments sector were dynamically analyzed from the perspective of Schumpeterian dynamics of open innovation, and creating shared value [2,4,62,63].

The fourth study analyzed digital government policies which were focused on E-government acts in Korea and the United States in terms of the closed to the open innovation engineering channel, mechanism design [64]. This study suggests the way to achieve knowledge-based, smart and sustainable digital government including smart cities with the development of ICT and E-government [65,66].

The fifth study analyzed development of the road pavement deterioration model based on the deep learning method at the close to the open innovation engineering channel, big data [67]. The study partially used comparing data-driven methods for extracting knowledge from user-generated contents which are potentially based on an ethical framework for designing autonomous intelligent systems [68,69].

7. Conclusions, Implications, Limits, and Future Research Goals

In this study, we built an open innovation engineering concept model which can be useful to motivate engineering research which can increase the development of open innovation and new open business models. By defining the role of open innovation engineering channels at the diverse location in the knowledge funnel, we expect the expanding of open innovation and new business models which are triggered from engineering in the future research.

At the current stage, this study is focused on the concept building of open innovation engineering and just applied it at a Special Issue of *Electronics* from SOI 2019. Additional field researches on each open innovation engineering channel in several aspects such as dynamics or success factors, should be studied in future researches. Lastly, additional studies to discover more open innovation channels are also required as future research topics.

Author Contributions: J.J.Y. built this paper framework and wrote abstracts, Section 1, Section 2, Sections 5–7. D.K. wrote Section 3. M.-R.Y. wrote Section 4. And J.J.Y. as managing guest editor with co guest editor D.K., and M.-R.Y. organized Special Issue of SOI 2019 Special Issue of *Electronics*. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the DGIST R&D program of the Ministry of Science and ICT(20-SC-01).

Acknowledgments: This work was supported by the DGIST R&D Program of the Ministry of Science and ICT(20-IT_10-02).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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