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Simulation-based prediction for 5G mobile adoption

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Abstract

South Korea launched the world's first nationwide 5G mobile services on 3 April 2019 and rushed in the race to roll out the latest wireless technology. It is necessary to perform a preliminary estimation of the new mobile market to take advantage of its huge opportunity. This study proposes a customer adoption model based on system dynamics combined with agent-based model to understand the evolution of 5G service better taking into account 5G adoption forecasts under categories with three alternative scenarios. The most important conclusion is that the 5G adoption curve is faster than 4G at the introduction stage.

Keywords: 5G adoption; System dynamics; Forecast

1. Introduction

The world's first mobile 5G commercial services were launched in South Korea on 3 April 2019. Numerous industry stakeholders and analysts are considering migration from 4G to 5G networks a profound technological change that will reshape the broadband market [1]. 5G service has not yet matured, and it is therefore difficult to determine its future outlook. However, it is necessary to perform a preliminary estimation of the new mobile market to take advantage of its huge opportunity and find ways to contribute to the establishment of strategic policies based on such demand prediction. In the past, even if demand prediction was performed in 4G, the prediction accuracy was low since South Korea has recorded a rapid market growth rate owing to 4G technical development promotion, active network investment, and high service adoption. As a result, many difficulties have arisen in spectrum plan, excessive competition, network management, and telecommunication policy.

The aim of this research is to estimate new technical service adoption as 5G mobile. The focus will be on *System dynamics* (SD) combined with *Agent-based model* (ABM). Macro-based SD paradigm suggests thinking in terms of aggregates and feedback loops. Micro-based ABM describes the system from the point of view of individual objects that may interact. This combined Multimethod-based model is utilized in complex problems because it can take advantage of both SD and ABM. Generally, ABM approach is able to capture more real phenomena than with SD. In the system being modeled contains active objects (people, vehicles, or products, etc.) with timing, event ordering or other kind of individual behavior. Especially in the case of word-of-mouth (WOM) and marketing is more efficient by ABM in terms of what it can do with supporting partial migration from stock and flow diagrams as well as developing agents behavior. At the bottom agents live in an environment whose dynamics is described in SD terms.

The first step in this study involves gathering market stochastic data on mobile customers and relevant fields. After understanding their characteristics, we selected analytical tools with the suitable model. In the second step, a customer adoption model of 5G was developed using influence variables from relevant statistics on similar 4G and appropriate parameters based on system dynamics. System dynamics is a methodology and mathematical modeling technique that is used to investigate the nonlinear behavior of complex systems over time [2]. The third step describes Word-of-mouth and marketing are based on the concept of agent-based models. This is a bottom-up approach to analyzing the macroscopic

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Table 1
Extraction factors for 5G diffusion.

Common group	Innovator group	Imitator group
Population	Innovative coefficient of 4G	Imitative coefficient of 4G
Launching time	Innovative coefficient of 5G	Imitative coefficient of 5G
Saturation of 5G QoS effect	Marketing effect Coverage effect	Word-of-mouth effect Tariff effect

structure of a system by modeling the behaviors of individual actors that make up the system. The fourth step involves applying the features of the mobile ecosystem into a model. The main categories of simulations were performed with three alternative scenarios.

The last step yields the results of empirical analysis and insight into the dynamic relationships between policy, diffusion rate of adoption, and effectiveness of the model to guide market strategy for future development of 5G services. The findings of this study will also be useful for government, the industry, customers, and society in general.

2. Simulation model development

2.1. Simulation model overview

The basic theoretical framework used in this study is the customer adoption model of diffusion with system dynamics for 5G mobile development and technological innovation.

A mixed form of system dynamics with the Bass model of diffusion in network have also been developed, which aims to capture how the complexity within social networks affects product and technology adoption [3]. Milling modeled the diffusion process using system dynamics [4], while Maier applied system dynamics to assess the policy effects of multi-generational products [5]. According to Sterman [6] and Baran [7], the basic diffusion model of Bass can be expressed as a system dynamics model. This model comprises two stock variables (potential adopters and adopters) and one flow variable (adoption rate). The adoption rate is determined by the interaction between two auxiliary variables, namely advertising, which induces the adoption of the innovator group, and word-of-mouth, which induces the imitative adoption of the majority.

The aim of this study is to develop an appropriate prediction model for 5G adoption, and analyze different results of alternative scenarios. As the 5G service sector is so diverse, the analysis target was limited only for eMBB (enhanced mobile broadband), which is the main axis of 5G. This includes most enhanced smartphone users, and also targets new technologies such as augmented reality (AR) and virtual reality (VR) usage. New technologies and services will be affected by coverage, marketing, and innovation, which take into account unforeseen affect from previous 4G. To define the scope of the study and ensure that the model is tractable, a few simplifying assumptions were made as follows:

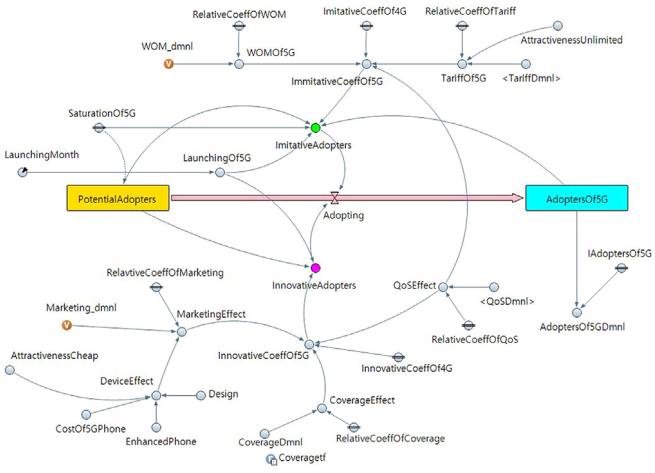

Fig. 1. Implementation of customer adoption model with 5G.

(1) Important variables such as launching time and saturation were set under scenarios,

(2) A statistical method was used to determine some input variables based on the technical characteristics,

(3) Other variables were inferred from reasonable assumptions to develop the model.

5G adoption is a large complex system to model, since the system can be decomposed to smaller subsystems, that are interconnected to each other on different levels. Some models of Word-of mouth and marketing as an integrated ABM-SD model with internal structure have been developed.

2.2. Growth pattern of existing 4G services

In South Korea, 4G service was launched in 2011 and the number of 4G subscribers is 56.3 million as at March 2019 [8]. In particular, its competitiveness was raised in the early period by network extension, carrier aggregation, spectral efficiency improvement, and additional spectrum allocation in response to the surge in the number subscribers as well as data traffic. The actual growth of 4G subscribers can be estimated using statistical data of several years. Results obtained from performing ordinary least squares (OLS) show that the innovative coefficient was 0.0164013, while the imitative coefficient was 0.0267025 for 91 months from September 2011 to March 2019. 5G customer diffusion factors can be extracted using the relative value of 5G compared to 4G. These were utilized as the diffusion coefficient of simulation modeling for 5G demand prediction.

2.3. Extraction and design factors

Various factors result in an increase in the number of mobile users: policy, marketing, device, price, and socio-cultural aspects. These factors were combined with the feedback structure of the 5G service market by examining previous studies to construct the simulation model. Each will be examined in detail as described below.

The most important parameters are the launching time and saturation of 5G. First, the launching time of 5G was set in April 2019. Second, the saturation was considered based on the estimated population of 52,941,342 in the year 2030 [9]. Based on these policy decisions, the factors affecting the diffusion of 5G are summarized in Table 1. Here, the diffusion coefficient of 5G was affected by the diffusion coefficient of 4G and related variables such as coverage, QoS, marketing, WOM and tariff. In other words, the relative parameters of 5G compared to 4G were estimated and the result was substituted for the diffusion coefficient.

2.4. Simulation model development

The customer adoption model was constructed based on the diffusion model with system dynamics; thus, it is necessary to create a causal loop diagram of the basic components and their interactions. A causal loop diagram is a visual method of displaying the system's structure and behavior. These related variables affect the number of 5G subscribers. That was developed using AnyLogic 8.4 software that enables a user to capture the complexity of social systems.

Fig. 1 illustrates the 5G customer adoption model, which includes new and cumulative subscribers, and is used to simulate the difference in the market under several scenarios. Stocks are represented as squares, while flows are represented as double arrows with valves. Dynamic variables are represented as empty circles, while parameters are represented as circles with two black lines. The arrows indicate the dependencies between the variables.

The stock of potential adopters declines as they adopt the innovation. Adoption moves people from potential adopters to the stock of adopters, which accumulates the adoption. The initial number of potential adopters is given by the total population. Adoption comes from both Innovative and Imitative adopters. 'Dmnl' is a dimensionless variable, that is without unit such as length, width, or height.

2.5. Formulas and data

The demand for innovation is affected by potential adopters and the innovative coefficient of 5G, which is composed with coverage, innovative coefficient of 4G, QoS, and marketing etc. The demand for imitation is affected by potential adopters and the imitative coefficient of 5G, which is composed with imitative coefficient of 4G, Word-of-mouth of 5G, Tariff of 5G, and QoS etc. Besides these, common-input option comp rising the launching month is applied to both sides. The formulas and types of variables necessary for developing the model are presented in Table 2. These equations as like 'Innovative Adopters' and 'Imitative Adopters' are used to describe variables that can be accumulated (stocks) and their increasing and/or decreasing (flow). Stocks continuously change their values over time, and generate information for all decisions and actions of incoming and outgoing flows. Flows are the directly change the value of stocks. Dynamic variables as like 'Innovative Coeff of 5G' and 'Imitative Coeff of 5G' can be defined to change their values instantly.

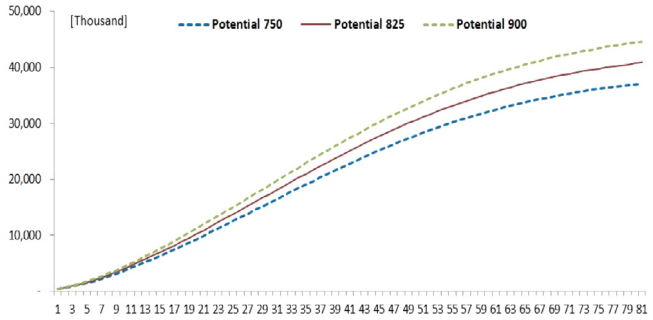

Fig. 2. Prediction results of adjusting potential adopters.

Table 2
Formulas for models.

Variable
Innovative Adopters = time() < LaunchingOf5G ? 0 : PotentialAdopters * InnovativeCoeffOf5G
Innovative Coeff of 5G = CoverageEffect * InnovativeCoeffOf4G * QoSEffect * MarketingEffect
Imitative Adopters = time() < LaunchingOf5G ? 0 : PotentialAdopters * ImmitativeCoeffOf5G * AdoptersOf5G / SaturationOf5G
Imitative Coeff of 5G = ImitativeCoeffOf4G * WOMOf5G * TariffOf5G * QoSEffect

3. Results and discussion

3.1. Scenario definitions

Scenario analysis is a process of analyzing decisions and future events by considering alternative possible outcomes [10]. In this study, scenarios were utilized on the model to present several alternative future outcomes for different parameters. These scenarios do not rely on exact data, but on reasonable estimation or sample data to highlight possible results and how the model works.

As discussed above, the important policy decisions are the launching time and saturation of 5G in potential adopters. Regarding the launching time, it was set for April 2019, to ensure adequate supply of equipment and smartphone devices.

For the saturation of 5G in potential adopters, the technical characteristics of 5G should be considered. The provision of 5G eMBB service will focus on hot spots in urban areas. Furthermore, it needs to coexist with the existing 4G network in the early phase. Therefore, the maximum number of 5G eMBB subscribers would not exceed 100% of the estimated population at market maturity. The population structure was statistically analyzed in terms of urban and rural areas, age distribution, and the estimated population. According to the Korean Statistical Information Service (KOSIS), people aged between 10 and 69 accounts for approximately 75% of the population, between 10 and 74 accounts for approximately 82.5%, and rural population represents approximately 90% [9]. 5G eMBB services will focus on hot spots in urban areas with population proportion, except for rural population, of 90% in Korea; thus, potential subscribers are a reasonable criterion for

Table 3
Definition of simulation scenarios.

Variable name	Scenario definition
Launching month	April 2019
Saturation of 5G	Potential 750 (75.0% of the estimated pop. in 2030)
	Potential 825 (82.5% of the estimated pop. in 2030)
	Potential 900 (90.0% of the estimated pop. in 2030)

5G service. Therefore, the saturation of 5G can be categorized into three scenarios as potential 750, 825, and 900 based on the estimated population in 2030. These scenarios are summarized in Table 3.

3.2. Simulation results

This section presents 5G adoption forecasts under three alternative scenarios with the launching month set as April 2019. The results of the adjustment of potential adopters is presented in Fig. 2, which shows a ±9% difference in the potential 825 scenario in the first 81 months after the introduction of 5G service. Adopters forecast respectively are 37.1 million, 40.9 million, and 44.6 million at the end of 2025.

A comparison of the time series observation of actual 5G service after its commercialization and the predicted 5G reveals for the empirical analysis. After second month May reached 784,215 subscribers which are 90 thousand slightly higher than forecast. Furthermore, 5G is progressing faster adoption curve than 4G at the introduction stage in the statistics. After commercialization, 4G was 696,404 after four months, but 5G reached 784,215 after two months.

4. Concluding remarks

Mobile communications have continuously evolved generations according to technological advancement, and they play an important role in the growth of the economy and quality of living. As the mobile industry progresses to 5G around the world, South Korea will form part a leading group in 5G commercialization. However, prospects for the future are still vague and demand forecasts for 5G are uncertain. To address the uncertainty of the future and support reasonable and efficient policy decision-making, this study investigated an appropriated prediction model for the demand for 5G service.

In this study, a customer adoption model was proposed based on system dynamics and integrated ABM-SD model to examine the evolution of 5G, taking into account the adoption of new customers focused on 5G eMBB. The Bass diffusion model was modified to forecast the adoption under reasonable assumptions and scenarios.

The most important conclusion is that the actual 5G subscribers are slightly higher than that of 5G prediction in the early stage for two months. Besides, 5G proceeds faster adoption curve than 4G at the introduction stage in the statistics. It is noteworthy, but this is just a test for the first few months. It will be necessary to keep track of the differences between actual and prediction at each growth stage. If 5G is more expensive to support existing applications, and network coverage is deployed in cities and not in rural areas, then the 4G network can be left in a bull market until excess capacity and data rate are used up.

The model shows the 5G adoption forecasts under categories with three alternative scenarios. The scenario of adjusting potential adopters was performed by categorizing the saturation of potential subscribers into 75.0%, 82.5%, and 90.0% compared to the estimated population in 2030. The launching time was set as April 2019. The adopter forecasts were compared with the corresponding scenarios.

This study makes several contributions at different levels. First is the development of a modified Bass diffusion model with system dynamics to take proactive and predictive steps for 5G adoption. A mechanism that uses the dynamic value of the diffusion coefficient according to the passage of time was developed, which is different from other feedback loops reported in social network. Second, the development of alternative methods for multiple plausible scenarios can be compared with different possibilities in the future. Finally, the developed model can be utilized in similar models to support policy decisions regarding similar systems in the future, for instance, in new technologies, such as autonomous vehicles and Internet of Things (IoT), which are specialized services of 5G. The iterative process of model construction will be encountered in different stages where understanding of the dynamic complexity is needed.

Declaration of competing interest

The authors declare that there is no conflict of interest in this paper.

Acknowledgments

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