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RESEARCH ARTICLE

Impact Analysis of Telecommunications Technology Based on Usage Scenarios: The Case of 5G Low-Latency Technology in V2X

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ABSTRACT The telecommunications sector has experienced enormous advances with technological evolution, and various alternatives for technology development toward 5G technologies have been proposed. To achieve effective research and development (R&D) management, these alternatives should be evaluated. Although cost–benefit analysis, which can help facilitate a technology with the most benefits and the least costs, is generally applied, technology related to public goods should consider both market and nonmarket perspectives. Since many telecommunications technologies have social impacts as well as market profitability, e.g., 5G, the economic feasibility analysis of such technologies needs to apply market and nonmarket approaches. Therefore, this paper presents an R&D impact analysis based on particular usage scenarios that reflect the characteristics of a telecommunications technology. We investigate how the target technology will be employed in a product or service, what costs and benefits the technology will produce, and what methods can be used to measure the costs and benefits. First, scenarios are constructed to identify different types of benefits while avoiding overlaps between them. Detailed guidelines are developed to link the most appropriate methods among various economic-feasibility analyses to assess costs and benefits for each usage scenario. Then, the proposed framework is applied to the case of 5G low-latency technology used in vehicle-to-everything (V2X) and validated. The case study findings indicate that the framework is useful in converting the direct and indirect benefits of telecommunications technology into a single economic value and is thus expected to be employed in technology evaluation.

INDEX TERMS Technology impact analysis, technology feasibility analysis, usage scenario, 5G technology, vehicle-to-everything (V2X).

I. INTRODUCTION

In the era of accelerated technology convergence and the emergence of disruptive technology, it has become essential for organizations to evaluate new available technologies to survive and prosper in the market. Accordingly, technology evaluation has recently gained considerable importance, enabling effective research and development (R&D) investment and reduced R&D risks. In particular, the telecommunications sector is expected to experience enormous advances with the technological evolution from fourth generation (4G) to fifth generation (5G). Various new technological options based on 5G wireless communications technologies have been proposed. With significant improvements over 4G, 5G technologies could accommodate several innovative services that require high speed and reliability, revolutionizing other related sectors. Therefore, with a focus on emerging 5G technologies, the costs and benefits of technology

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development have been analyzed to determine the technologies to be pursued or prioritize technologies to be developed, and the rollout of 5G technologies has been explored for effective policy making [1]. Moreover, South Korea is leading in 5G technology, where they have distributed a nationwide 5G network and commercialized 5G-based services as a frontier [2].

One of the most commonly used methods to evaluate technology options is cost–benefit analysis (CBA), in which a technology with the most benefits and the least costs is determined to be the best option. For a single technology, its adoption is recommended when its benefits exceed its costs. However, some technologies such as healthcare and telecommunication cannot be assessed by CBA, which is a market-based valuation method, because they are used for public goods. Accordingly, other methods have been developed to tackle this issue. For example, cost-effectiveness analysis (CEA) compares the relative costs for the same level of effects from different options. Further, the contingent valuation method assigns monetary value to public goods according to individual preferences; a questionnaire is provided to the respondents for making an economic decision on goods for which no market exists. In previous studies, these analyses have been applied to the telecommunications sector, which is one of the most capital-intensive, high-tech industries and thus requires careful decision-making with respect to investment, for example, cost analysis in rural areas [2] and future benefit analysis of broadband access [3].

However, despite the utility of the existing methods, a single method can scarcely capture the complexity of contributions from 5G technologies to society. First, although no market exists for 5G technologies, a wide range of mobile services have become possible and are expected to be delivered in the market through those technologies [4]. Such indirect benefits should be considered in the investment decision for network deployments as argued in an existing work [5]. The contribution of 5G technologies to the development of such services needs to be considered in their valuation, being measured by a market-based approach. Second, the benefits of telecommunications technologies are more visible in the form of noneconomic values, such as user satisfaction, rather than economic values, which necessitates the use of a nonmarket valuation approach. Accordingly, the characteristics of telecommunications technologies as an enabler of other businesses as well as an enhancer of user satisfaction need to be considered in the valuation of 5G technologies. On the one hand, a market-based approach is needed to evaluate the contribution of technology to the development of other businesses. On the other hand, a nonmarket-based approach is also required to consider the contribution of technology to society as public goods. Nevertheless, few attempts have been made to integrate the heterogeneous benefits systematically for measuring the total benefits on the basis of monetary value.

In other words, the technical characteristics of 5G can be extended to related products and services after establishing communication infrastructure in advance. Therefore, it is necessary to analyze the impact of 5G technology from a macro-socio-economic perspective, such as a country, along with related companies and users. In previous studies, when performing CBA related to 5G, analysis at the minor level and benefit from the technology owner's viewpoint were analyzed; thus, there was a limit to interpreting the cost and benefit from the macroscopic point of view of establishing R&D planning [6]. In this study, we performed impact analysis from a macroscopic perspective to evaluate the type of effect that the new technology of 5G will bring at the national level, considering the technical characteristics of 5G.

To meet the needs of an integrated framework, this study proposes an R&D impact analysis based on usage scenarios that reflect the characteristics of telecommunications technology. Such a scenario analysis helps users investigate how the target technology will be employed, what costs and benefits the technology will produce, and what methods can be used to measure the costs and benefits. The scenarios are constructed to identify different types of benefits while avoiding the overlaps between them; detailed guidelines are developed to link the most appropriate methods to assess the costs and benefits for each scenario. Finally, the proposed framework is applied to the case of 5G low-latency technology used in vehicle-to-everything (V2X) and verified. Case study findings indicate that the framework is useful in converting the direct and indirect benefits of a telecommunications technology into a single economic value and is thus expected to be employed in technology evaluation. The rest of this paper is organized as follows. Section II reviews the existing approaches to technology impact analysis, economic evaluation analysis, and usage scenarios analysis. Further, Section III explains the proposed approach designed for telecommunications technologies. Then, Section IV introduces the case study on low-latency technology applied to V2X. Finally, Section V discusses the contributions and limitations of this study.

II. BACKGROUND

A. TECHNOLOGY IMPACT ANALYSIS AND SCENARIO ANALYSIS

When a government plans national research agendas, the impact of technology should be analyzed to mitigate the uncertainty of technology policy. Thus, many administrations and research institutes have devised up-to-date frameworks for technology impact analysis (TIA), and simultaneously, various studies have been performed to develop accurate and relevant approaches for the analysis. In general, TIA can be defined as a process to evaluate the impact of technology on the economy, culture, society, environment, etc. in advance. This is beneficial in minimizing the negative effect that can be caused by a future technology and reinforce the responsibility of technology. In particular, TIA is a systematic research for policy making by investigating social impacts that can occur in developing, diffusing, and using new technology [7]. TIA can be divided into three categories: instrumental, participatory, and constructive. Instrumental TIA focuses on the analysis of the risks of technology development by domain experts. They perform a quantitative analysis for TIA, investigating the causality between technology and society. However, as the analysis has the limitation of reflecting numerous stakeholders, participatory TIA has been devised to consider the opinions of various players, advertising government policies, and promoting public debate on technology policy. Finally, constructive TIA aims at discussing the impact of technology on society, including both users and stakeholders. Instrumental and participatory TIA concentrate on finding an agenda to minimize the negative aspects of technology development in the process of legislation, while constructive TIA attempts to change the directions of technology development in the beginning stage of a policy-making process.

Because TIA deals with the evaluation of technology, many researchers have suggested appropriate evaluation indices, including the importance of social agreement, utilization possibility of the results, publicity of R&D investment, social/cultural impacts, and characteristics of technology [8]. In terms of methodology, both qualitative and quantitative approaches have been actively applied to TIA. Various methods such as trend analysis, Delphi, simulation, and scenario analysis are applicable to TIA [9]. In [10], a quantitative TIA approach to investigate the impacts of technology on society employing a system dynamics technique was proposed. The impacts of nanotechnology on diesel demand were analyzed by examining the dynamic changes of related variables over time. In particular, patents are a useful data source for TIA because many patent applicants are eager to register their inventions and patent offices rigorously evaluate the patentability of technology. Thus, many studies related to TIA use patent data to estimate the impacts of technology. Moreover, the number of patent citations is actively analyzed to calculate the impact and value of a given technology [11], [12]. In addition, various models and methods for TIA using patent data have been developed. In [13], a patent-based cross-impact analysis approach was proposed to investigate cross impacts across technology fields, and in [14] an analytic network process was developed to identify core technologies in a patent citation network. Further, a Hawkes process-based method was proposed in [15] to assess future technology impact by using the future citation counts of patents. Because technology impacts are complex to analyze, qualitative analysis is often employed to estimate the future impacts of technologies. In [16], multiple case analysis was used to develop an explanatory model for the interaction of actors in the field of blockchain technology.

Scenario analysis has sometimes been employed to conduct TIA because it can accurately investigate the impacts of new technology by considering various possible future scenarios. The uncertainty that is associated with technological development has convinced many companies to employ scenario analysis [17]. Scenarios can be defined as plausible representations of the future based on sets of internally consistent assumptions about relationships and processes of change [18]. The concepts are very important in analyzing technology impacts because technological and business impacts are strongly affected by various factors such as policy changes, new regulations, and natural disasters. Thus, many studies have proposed new TIA approaches based on scenario analysis. In [19], a new TIA approach combining intervention analysis and scenario analysis was suggested to generate all possible scenarios and assess technology impacts. In addition, a neural-network-based approach was employed in [20] for forecasting the baseline scenario to improve the performance of TIA. Furthermore, scenario analysis and life cycle approach were applied in [21] to assess the environmental impacts of thermal energy substitution and electrical energy efficiency. Because the scenario technique can implement the outlined objectives such as technological and nontechnological drivers and barriers or considering social challenges and needs, it has many advantages in performing TIA. Moreover, scenario analysis can show how the future may develop and evolve, rather than making predictions about the future [22]. Therefore, it is practically employed in analyzing technology impacts that should reflect many technological and nontechnological factors.

B. ECONOMIC EVALUATION ANALYSIS

The economic feasibility analysis of public R&D programs is performed to evaluate beforehand how much value a public activity can provide to the public. Although such public R&D programs generally pursue economic profitability, they can sometimes be proposed to meet social needs and anticipate the potential effects for future generations. Thus, when R&D programs are evaluated, we should consider both benefits and costs as well as understand who pays the cost and who can gain benefits from the programs. Therefore, the purposes of the economic evaluation of R&D programs can be divided into two categories: value creation and cost reduction. Various methods have been proposed according to the available data and the characteristics of programs. Representative approaches for economic evaluation include CBA and CEA. CBA is used to evaluate economic feasibility by estimating the costs and benefits of an R&D program. In particular, this analysis measures all the benefits and costs in monetary terms with net present value (NPV) [23]. By contrast, in CEA, the effects of R&D programs can be calculated when the benefits cannot be derived from a monetary value. The costs are estimated from a monetary value, while the effects are drawn as a result of program execution independently, without calculating a monetary value [24].

CEA can be conducted in two ways: focusing on the comparison between alternatives or calculating the value of benefits. In [25], CEA is defined as an analytic study that is designed to support a process for selecting the best

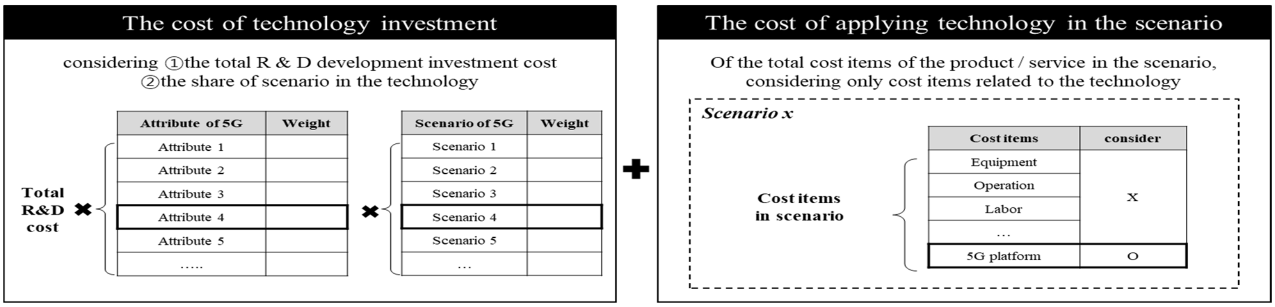

FIGURE 1. **Cost estimation process by scenario (5G example).**

alternative. In addition, in [26], CEA is defined as a method to compare various alternatives in terms of implementation costs and the intended results of programs. By contrast, in [24] the cost was calculated with the monetary value but the effectiveness was evaluated by analyzing the result itself, without conversion into monetary value in performing CEA. In another study, CEA has been discussed with at least one alternative being calculated and expressed as the ratio of incremental cost to incremental effectiveness [27]. A CEA can evaluate the cost of an R&D program as a key outcome or benefit [28]. Although most studies consider CEA to be replaceable by CBA, there exist several differences between the two methods. Effectiveness is measured in physical units, rather than monetary value. This analysis is useful when it is difficult to quantify the benefits and the results of the analysis are not shown as economic benefits. In particular, the discounting process is applied not to the benefit side but to the cost side when the NPV is calculated [29], [30], [31]. A comparison between alternatives can be performed using a fixed-cost approach or a fixed-effect approach. In the fixed-cost approach, the criterion for selection is the amount of effectiveness in a given cost, while the fixed-effect approach compares the costs of programs to obtain a certain level of effects.

Most studies related to economic feasibility analysis have focused on the application of the analysis to specific technology fields or industry sectors to assess the feasibility of R&D programs. For example, in [32] CBA was used to analyze the sustainability of bioethanol promotion in Thailand. Many researchers have used CBA as a tool to investigate feasibility in various fields such as food waste management [33], healthcare management [34], and a recycling system for end-of-life tires [35]. In addition, CEA has been applied to many cases in which the monetary value of programs is scarcely estimated, including medicine development and information technology development [36], [37]. The two approaches are sometimes combined together to enhance the performance of economic evaluation [38], [39]. Several studies have attempted to suggest new approaches to apply economic feasibility analysis to the evaluation of programs. In [40], a probabilistic CBA was proposed, where economic variables such as purchasing cost and tax were used as random variables, and the Monte Carlo

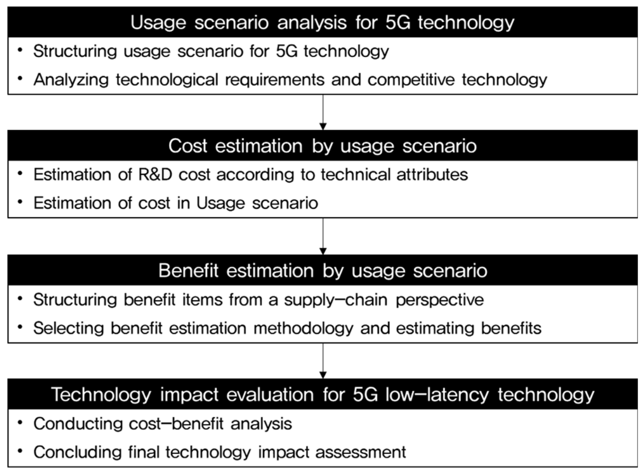

FIGURE 2. **Research framework.**

method was applied in the process. Furthermore, a social CBA to investigate the empirical trials from the Smarter Network Storage project to evaluate investments in grid-scale electrical energy storage was presented in [41]. In CEA, not only cost but also effect should be considered to help decision makers examine the efficiency of given programs. Thus, incremental cost-effectiveness ratios are calculated by dividing the cost per unit by the program's effectiveness [42].

III. SCENARIO-BASED R&D IMPACT ANALYSIS

This study proposes a scenario-based R&D impact analysis method for systematically analyzing the impact of 5G mobile communication technology. The proposed scenario-based R&D impact analysis method is designed to adapt the conventional technological feasibility process to the intricate impacts of 5G technology. In particular, this study focus on the low latency of the main strengths of 5G, which applies across multiple products and services such as virtual and augmented reality, autonomous driving, and the internet of things (IoT). The main research idea is to reflect the usage scenarios of 5G in the technology impact assessment process. Figure 1 shows that the suggested framework is composed of four processes. First, usage scenarios of 5G low-latency technology, which is an analysis target technology, are constructed, along with the understanding of technical requirements and competitive technologies. Next, the estimation of cost and benefit for each scenario is constructed. For cost estimation, cost items related to technology R&D and usage scenarios are considered according to the technology attributes. The benefit is estimated by structuring the benefit items from the supply chain perspective, selecting an appropriate methodology according to the purpose of the scenario. Finally, the results of the TIA are presented considering cost and benefit. In this study, multiple choices appropriate to the characteristics of technology scenarios to which 5G is applicable were adopted. The benefit estimation method is presented in Table 1, and the cost–benefit estimation method is summarized in Table 2. The approach adopted in this study can overcome the limitations of a unified approach in conducting R&D impact analysis in previous studies.

A. USAGE SCENARIO ANALYSIS FOR 5G TECHNOLOGY

The definition of usage scenario is a functional description of how external agents use products or services. In this study, scenario analysis based on evaluation target technology was performed to estimate benefits according to the stakeholders, process, and relationship with the target technology. In scenario analysis, usage scenarios are organized for each application field of the target technology, and the scenario overview for each usage scenario, technical requirements for the target technology to be evaluated, and competition technologies are analyzed. When constructing a usage scenario, it should be analyzed from various viewpoints, such as application fields by industry and application fields between convergence technologies. In particular, in the case of the fundamental technology and public technology, it is possible to converge with various industries and technologies, but not with the technology fields that include detailed technical performance and functions in a specific field; therefore, it should be configured with this consideration. Furthermore, it should be configured to be mutually exclusive and collectively exhaustive to avoid duplicate calculation of technology development impact analysis. It is desirable to use the existing scenario analysis results of technical analysis reports conducted by international organizations, such as the United Nations and the European Union (EU), to adjust and configure them according to the domestic industry and research environment.

B. COST ESTIMATION BY USAGE SCENARIO

The cost defined in this research is the sum of the total cost required to achieve the target for each scenario and is estimated by summing the costs of technology investment and applying technology in the scenario (Figure 2). The technology investment cost is estimated by considering the total R&D development investment cost of the technology to be evaluated and the share of scenarios in the technology. First, among scenarios of the technology, the sum of technology R&D costs is calculated, followed by the proportion of technology properties used in scenarios among technology

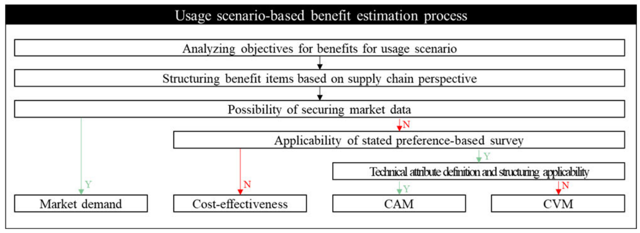

FIGURE 3. Scenario-based benefit estimation process.

properties and the proportion of scenarios to be evaluated. Then, the multiplied values are estimated as the technical R&D cost for the scenario. In addition to the R&D cost, the cost required to apply the evaluation technology within the scenario is added. Of the total cost items of the product/service in the scenario to be evaluated, only cost items related to the technology are estimated and added to the cost.

C. BENEFIT ESTIMATION BY USAGE SCENARIO

The estimation of benefits based on the usage scenarios is derived from the definition of benefit items, selection of benefit estimation methodology, and benefit estimation. The first step of benefit definition analyzes the purpose of the target technology scenario to derive a benefit item that has a direct effect and systemizes the benefit items by reflecting the beneficiaries of technology and the process of the scenario. Benefit items are classified as ''value creation'' and ''cost reduction'' according to the purpose of technology development. This study reflects the perspective of the supply chain, such as technology beneficiaries, stakeholder analysis, and the technology development process to further structure the benefits. The derived benefit items for each detailed process are used to estimate the total benefit by estimating the contribution to technology development considering the relationship with the technology to be analyzed.

The benefit estimation methodology is selected as shown in Figure 3 by examining the benefit type and data availability with the segmented benefit items for each technology scenario. For the benefit estimation model, a scenario-based benefit estimation model is proposed according to the model of the selection process for benefit estimation in the preliminary feasibility study developed in [43]. The method of estimating benefits is selected considering the possibility of securing market data, applicability of the statement preference survey, and the possibility of defining and classifying technical attributes.

In this study, existing models for benefit estimation, including the market demand approach, contingent valuation method (CVM), and conjoint analysis method (CAM), were used. In the market demand approach, the value creation benefit type was estimated by reflecting the contribution rate, success rate, and so on for the predicted future market size; further, the cost reduction benefit was estimated by reflecting the contribution rate and success rate in expected unit cost reduction after new technology development. To estimate the

TABLE 1. Benefit estimation methodology.

Approach		Estimation equation for benefits
Market demand analysis	Value creation benefit	$(future\ market\ size) \times (business\ contribution\ rate) \times (R\&D\ contribution\ rate) \times (R\&D\ commercialization\ success\ rates) \times (ratio\ of\ value\ added)$ (1)
	Cost reduction benefit	$(total\ cost) \times (cost\ reduction\ ration) \times (R\&D\ contribution\ rate) \times (R\&D\ commercialization\ success\ rates \times ratio\ of\ value-added)$ (2)
		$\big((current\ production\ cost\ per\ unit) - (future\ production\ cost\ per\ unit)\big) \times (domestic\ production\ scale))$ (3)
CVM		$\sum_{y,z}[\mathrm{U}(y,z,h) \mid y+z \le m]$, (4) $y_i^* = x_i\beta + u_i$, (5) where V denotes the indirect utility function, y is the income, p is a vector of prices faced by the individual, and q0 and q1 are the alternative levels of the good or quality indices, with q1 > q0, indicating that q1 refers to improved environmental quality.
CAM		$MWTP_x = -\frac{(\delta U_{n,j}/\ \delta x_{j,t})}{(\delta U_{n,j}/\ \delta x_{j,price})} = -\frac{\beta_t}{\beta_{price}}$ (6)

TABLE 2. CBA indicators.

Indicators	Equation/Pros and cons	Results
BCR	$BCR = \frac{\sum_{t=0}^{n}\frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n}\frac{C_t}{(1+r)^t}}$ (7) • Considering the size of the project and directly displaying the ratio of benefits to the size of the investment. • Possibility of errors in the selection of mutually exclusive alternatives, and inappropriate figure if the distinction between cost and benefits is not clear. • Considering the direct net value of the investment, providing a clear standard for alternative selection/prospective benefits, and considering the marginal NPV. • Possibility of errors when deciding alternative priorities.	BCR ≥ 1
NPV	$NPV = \sum_{t=0}^{n}\frac{B_t}{(1+r)^t} - \sum_{t=0}^{n}\frac{C_t}{(1+r)^t}$ (8) • Considering the direct net value of the investment, providing a clear standard for alternative selection / prospective benefits, and considering the marginal NPV. • Possibility of errors when deciding alternative priorities.	NPV ≥ 0
IRR	$\sum_{t=0}^{n}\frac{B_t}{(1+R)^t} = \sum_{t=0}^{n}\frac{C_t}{(1+R)^t}$ (9) • Measuring the profitability of the task, easily comparing the results with other alternatives, and interpreting results. • Only adaptable when the discount rate is clear, and when the possibility that multiple internal rates of return can be derived simultaneously.	IRR ≥ r (r: discount rate)

economic value of nonmarket goods, CVM and CAM were used as the methods for estimating benefits through surveys.

Because of its flexibility and ability to estimate total values of technology, CVM has been widely used as a valuation technique [44]. CVM can quantitatively evaluate the value of technology by asking respondents regarding their willingness to pay (WTP) for specific technology or products. Unlike CVM, which queries a direct monetary amount, CAM is different in designing a questionnaire by providing options such as ranking and score based on various attributes of the technology. Therefore, it is used to estimate the benefits for scenarios that are difficult to express in terms of monetary value. Table 1 summarizes the formula for benefit estimation for each methodology applied in this study.

D. TECHNOLOGY IMPACT EVALUATION FOR 5G LOW-LATENCY TECHNOLOGY

The final step of technology impact assessment is derived through CBA, which compares the expected profit and cost. Table 2 summarizes the CBA indicators. In this study, the benefit–cost ratio (BCR), which is suggested as the basic indicator in the preliminary feasibility study, was used. BCR has the advantage that it is possible to consider the scale of technology R&D; thus, it directly displays the ratio of benefits to the size of the investment. The total cost and total benefit values are obtained and evaluated through a cost–benefit ratio (B/C) that calculates the ratio of cost and benefit according to the cost and benefit analysis results. Finally, a technology development scenario where the sum of the present values of future benefit flows is greater than or equal to the sum of the present values of future cost flows is selected.

IV. CASE STUDY: V2X FIELD BASED ON LOW LATENCY OF 5G TECHNOLOGY

A. TECHNOLOGY IMPACT EVALUATION FOR 5G LOW-LATENCY TECHNOLOGY

5G technology, the next-generation communication technology, is a communication technology having a transmission speed of 20 Gbps or higher. The 3GPP defined the attributes of 5G as ultrahigh-speed, high-efficiency, ultra-connectivity, and low-latency technology through 5G technical reports prepared in Release 14. Among the abovementioned attributes, low-latency technology, which is the main performance index of 5G, was selected as the analysis target technology in this research. Unlike 4G mobile communication, which focused on improving transmission speed and transmission efficiency, 5G technology emphasizes superconnectivity and low latency [45], [46]. Moreover, communication technology is a fundamental technology used in other industries and societies, and

TABLE 3. Reconstructed usage scenario of the 5G usage scenario.

	Usage scenario	Detailed scenarios
1	V2X	V2V- and V2N-based collision prevention
2		V2V- and V2I-based vehicle flow management and cooperative driving
3	Smart grid	Power supply and management based on smart grid network
4	Telesurgery	Telesurgery using robotics
5	Smart factory	In-factory and inter-factory communication
6	Immersive media	Virtual reality-based office
		Augmented reality-based games and entertainment
		Virtual reality-based microassembly
7	Telecommunication in special situations	Disaster communication
8		High-speed or high-altitude communication
9		Robotics and telepresence (dangerous environments such as the Moon and nuclear power plants)

TABLE 4. V2X scenario requirements.

Attribute	5G	4G (LTE-A)	WAVE (DSRC)
Data Rate	suitable (<20 Gbps)	suitable (<100 Mbps)	unsuitable (<54 Mbps)
Reliability	suitable (URLLC)	suitable	unsuitable
Latency	suitable (1 ms)	unsuitable (<100 ms)	unsuitable (<100 ms)
Density	suitable (106/ km^2: mMTC)	suitable	suitable
Mobility	suitable (<500 km/h)	suitable (<160 km/h)	suitable (<200 km/h)
Positioning	suitable (<0.1 m)	unsuitable (<50 m)	unsuitable (<50 m)
Coverage	suitable	suitable	suitable [(250–350) m]
V2I and V2N	suitable	suitable	suitable

it is difficult to evaluate its impact using existing methodologies. Therefore, to show the validity of the impact analysis framework proposed in this research, we intend to conduct an impact assessment of 5G low-latency technology. However, as 5G technology has not yet been implemented in Korea, it may be premature at this time to evaluate its impact. Therefore, we intend to evaluate the impact of 5G technology in Korea in 2030, when it is expected to be completed.

B. 5G LOW-LATENCY TECHNOLOGY SCENARIO ANALYSIS

First, we analyze the technology scenario of 5G low-latency technology. Because there is no clear usage scenario for the 5G technology field, related studies have been conducted (two telecommunication policy papers). Furthermore, international organizations such as METIS 2020, a 5G mobile communication network technology standardization promotion organization, and International Telecommunication Union Telecommunication Standardization Sector (ITU-T) are publishing reports that analyze technical scenarios and requirements for 5G, the next-generation communication platform [47], [48]. The present research reconstructed the usage scenario of 5G low-latency technology on the basis of reports published by METIS and ITU-T. The usage scenario of the reconstructed 5G low-latency technology largely includes autonomous vehicles (V2X), smart grid, telesurgery in the healthcare field, smart factories, virtual reality- and augmented reality-based media, and special situations such as communication at high speed or disasters. Table 3 presents the details of each usage scenario. In this research, among the various scenarios, the V2X scenario, including vehicle-to-vehicle (V2V)- and vehicle-to-network (V2N)-based collision prevention scenario, and V2V- and vehicle-to-infrastructure (V2I)-based vehicle flow management and cooperative driving scenario, were selected as target scenarios.

After defining the scenario, it is necessary to analyze the scenario-specific overview, technical requirements, and competitive technology. V2X communication refers to the process of transmitting information about a vehicle and objects affecting the vehicle. V2X is a high-level concept of a vehicle communication system that includes V2I, V2N, V2V, and vehicle-to-pedestrian (V2P). It is also a core technology for autonomous vehicles. V2X communication has the attribute that a vehicle moving on a road has predictable mobility in terms of technology. In addition, it has rapid network topology change due to a high-speed vehicle and has a network configuration according to a limited communication range restricted to roads. Further, it has relatively less sensitive power consumption for data processing [49]. The "5G low-latency technology-based V2X" field is one of the sub-fields of V2X and is defined as a technology field that uses 5G's low-latency technology to connect with other vehicles, infrastructure, networks, and pedestrians related to autonomous driving through a communication network [50]. Competitive technologies for 5G mobile communication include 4G and WAVE technologies. However, 4G- and WAVE-based V2X are unsuitable for the required latency (low latency of 100 ms), and 4G-based V2X is unsuitable for the positioning of requirements (precision of 0.1 m). Table 4 lists the requirements and suitability.

C. COST ESTIMATION BY SCENARIO

The cost of a scenario is calculated by adding the technology R&D cost considering the weight of the scenario and the technology application cost of the scenario. First, the total technology investment cost is estimated by reflecting the weight of the "low latency" attribute, which is an attribute to

TABLE 5. 5G low-latency V2X technology R&D cost estimation.

Item	Value	5G low-latency V2X technology R&D cost
Technology R&D cost	10,400,000,000,000 won	330,158,720,000 won = 10,400,000,000,000 won × 1/7 × 2/9
Attribute weight	1/7	
Scenario weight	2/9	

TABLE 6. Estimation of the application cost of low-latency-based V2X technology.

Millimeter wave-based mobile communication RF module price	Total number of autonomous vehicles to be produced in 2030
3507 won	23,800,000 units
The estimated value of technology application cost to be evaluated in the usage scenario	
83,466,600,000 won = 3507 won × 23,800,000 units	

be analyzed, and the weight of the "V2X," which is an analysis target, among the total cost of applying the 5G technology to be evaluated. The total cost of applying 5G technology was 10 billion won, which is the sum of the 5G network investment amount by the three major Korean telecommunication companies, namely, SK Telecom, KT, and LG U+ [51].The proportion of technology attributes was estimated to be 1/7 = 0.142857, assuming the proportion of the seven data rates, coverage, mobility (speed), positioning accuracy, reliability, density, and low latency of 5G technologies proposed by 5GPP to be the same. Lastly, the weight of 5G scenarios was estimated to be 2/9 = 0.2222, assuming the weights of the nine 5G low-latency scenarios defined in this research to be the same. By multiplying all of these, the final R&D cost was estimated as 302 billion won; this calculation is summarized in Table 5.

Next, to estimate the application cost of the technology to be evaluated in the usage scenario, only communication-related cost items were estimated among the total cost factors of the products/services in the analysis scenario. The cost elements of the V2X service include equipment purchase cost (car purchase cost), maintenance cost, labor cost, V2X communication platform construction cost, and communication cost. In this work, only the cost related to communication was estimated. In particular, only the cost of constructing the V2X communication platform, which is the initial cost, was estimated, excluding the communication cost, which is the monthly operating cost. The V2X communication platform construction cost is based on the assumption that an existing vehicle is built, and only items that enable 5G, not 4G, are considered as a cost. Therefore, the cost of applying the technology was calculated by multiplying the sum of the radio frequency (RF) modules and the number of autonomous vehicles to be produced by 2030. The number of autonomous vehicles estimated by KT Economic Management Institute to be produced by 2030 was 23.8 million units [52]. To use the 5G communication network in an automobile device, it was assumed that a millimeter-wave-based mobile communication RF module that processes and communicates with an antenna was used. The price of the RF module produced by Wisol, the only RF model-manufacturing company in Korea, was estimated to be 3507 won (www.wisol.co.kr) as the millimeter-wave-based mobile communication RF module price. Thus, the application cost of the technology to be evaluated in the scenario was estimated to be 83.5 billion won as given in Table 6.

The total cost was calculated by adding (1) the estimated R&D cost of the technology to be evaluated and (2) the estimated cost of applying the technology to be evaluated in the usage scenario.

D. BENEFIT ESTIMATION RESULT

We estimated the benefits related to autonomous driving based on the low-latency technology of 5G communication technology. First, the benefit items were structured as given in Table 7 by analyzing existing studies related to the supply chain perspectives that are articulated by producers and consumers according to the purpose of the R&D scenarios of value creation and cost reduction. Most of the 5G-based autonomous driving scenarios have been researched to provide new services, commercialize them to provide new business opportunities, and expand existing revenue models. In [53], a performance evaluation to support high-end IoT device-related delay-sensitive applications under a 5G environment was presented. Further, a 5G low-latency-based method to support real-time route planning by constructing a 3D high-resolution map and real-time traffic data transmission was proposed in [54]. Additionally, examples of cooperative autonomous driving between vehicles using V2X technology were discussed in [55], and the technical requirements for safe and efficient operation were analyzed. In [56], the possibility of providing 5G-based localization of auxiliary driving applications through 5G network design in autonomous driving situations that require precision-based positioning in centimeters was studied. Furthermore, through real-time traffic data analysis, benefit items of cost reduction type were structured considering the reduction of traffic accidents. In [57], safety applications such as traffic control, pedestrian collision, and speed on the curb by utilizing V2I technology were proposed, and the advantages in terms of traffic flow and safety were analyzed. In [58], a collision prediction algorithm based on V2P technology was proposed to reduce the risk associated with the use of smartphones and minimize potential risks.

For each benefit item derived above, the estimation methodology was determined by checking data availability according to the model of the process of selecting the benefit estimation method. The type of value creation from the

TABLE 7. Structuring benefit items from a supply chain perspective.

Benefit items	Structuring benefit items from a supply chain perspective		Expected effects
Value Creation	Producer perspective	Providing new vehicle management service	New business opportunities, and expansion of existing revenue models
		Providing new infotainment services	
		Providing real-time traffic and surrounding information	
		Increasing production volume by data management and utilization capabilities	Reduction of production cost in the automotive industry
	Consumer perspective	Using remote vehicle management service	Convenience
		Improving road safety	Stability
		Using infotainment services	Enjoyment
Cost reduction	Consumer perspective	Remote vehicle management service	Traffic accident reduction
		Providing real-time traffic and surrounding information	
		Improving road safety	

producer's perspective applied the market demand approach according to the data provided in the existing market analysis report. Although there is difficulty in terms of the lack of direct market data related to 5G-based V2X, it is possible to refer to several reports that estimate the future market size related to the overall fields of 5G. Among them, the future market data of the technology to be analyzed can be estimated by reflecting the weight of 5G-V2X technology. The second type of value creation is psychological stability and comfort from the consumer's perspective, which, like producers, presents difficulties in securing market data directly. CVM was selected by setting a virtual market for 5G-based autonomous driving technology and conducting a questionnaire on stability and convenience to determine whether data could be secured. Finally, it was judged that the benefits of reducing the cost of damage to human, physical, and social institutions could be estimated by acquiring data that included the demand for 5G-based V2X technology, costs related to traffic accidents, and proxy market data.

Each benefit item was estimated using the benefit estimation methodology derived above. The producer-oriented benefit of the autonomous driving market based on 5G low-latency technology was estimated to be a value improvement following the evolution of telematics, including vehicle management services, infotainment services, and real-time traffic and surrounding information provision services. As in the EU socio-economic analysis, 50 % of telematics value is expected to be added when 5G is introduced, and the current value of telematics is based on the price of the Chevrolet infotainment system of GM Korea (KRW 550,000, based on 2019.02). The estimate of the value increase of 275,000 won per vehicle was reflected. The number of connected vehicles was estimated by using the yearly number of vehicle registrations at the Ministry of Land, Infrastructure, and Transport. From the analysis results of the "5G Socio-Economic Impact Analysis Report" published by KT Economic Management Research Institute, the rate of introduction of connected cars was assumed to increase by 5 % per year [52]. The 5G contribution was estimated as 32.2 % by 2030 through calculation as a percentage of real-time connection capacity increase, reflecting the proliferation of ultrahigh-speed and ultralow-latency networks. The benefit of productivity increase from the producer's point of view was derived to be 301 billion won. According to the socio-economics analysis of the EU, the benefits in the automotive industry following the introduction of 5G technology are expected to serve as a catalyst in future industrial automotive production owing to improved data management and exchange capabilities in the automobile manufacturing process. According to the Korea Automobile Manufacturers Association, the domestic automobile production in 2017 was approximately 4.1 million, and Kia Motors' "All New Morning (2017)" was applied as the lowest-priced car of 9.45 million won in Korea. The 5G contribution increase was estimated to generate at least 55 billion won in productivity contribution annually by applying the 1 % figure of 5G production increase when analyzing EU socio-economics.

The value creation benefits of consumer convenience (remote vehicle management service), stability (road safety improvement), and enjoyment (information service) were estimated by the CVM approach. A questionnaire was designed through the double-bounded dichotomous choice method to derive WTP for the annual service fee for each item and the ratio of intention to use it. A survey was conducted on 200 sample groups, including both nonexperts and experts, where 5G-based V2X expected users were set as the population for the target. The following analysis was conducted on 46 valid responses out of 47 responses. For the basic statistics of the survey responses, the proportion of respondents was 31 males (65.96 %) and 16 females (34.04 %), and 10 driving experiences (21.28 %) and 37 cases (78.72 %) were found. In the case of prior knowledge related to driving, there were 19 cases (40.43 %) and none (59.57 %). For the WTP analysis, the analysis package DCchoice of statistical software R was used [59], and the Kaplan–Meier analysis of survival function was used to estimate the average value through the Spearman–Karber member at a confidence level of 95 %. We derived around 9726 billion won of benefits for consumer value creation by applying WTP and the number of connected vehicles from the previous analysis results.

Finally, the benefit of reducing the damage cost was estimated using the ratio of accidents caused by driver negligence among the types of road accidents, assuming that all traffic accidents caused by driver negligence could be eliminated. Among road traffic accidents, the ratio of traffic accidents caused by the negligence of drivers and pedestrians was 85.2 %. It was estimated that 55.3 % could be reduced to 29.9 %, assuming that all accidents caused by driver negligence could be eliminated, among accidents caused by driver and pedestrian faults. Considering the government investment amount by technology classification in the automobile industry announced by Korea Institute of Science and Technology Evaluation and Planning (KISTEP), the government R&D cost of smart car technology was estimated to be 45 billion won. Among total investments in smart cars, the government R&D cost of 5G low-latency technology-based smart cars was estimated as 9.5 billion won, including In-vehicle Networking (IVN) technology, connected car technology, and V2X-based safety system technology. Therefore, the 5G contribution of the effect of reducing the cost of damage to human, physical, and social institutions by traffic accident reduction was estimated to be 21.0 %. According to the Traffic Accident Comprehensive Analysis Center of Safety Headquarters of The Road Traffic Authority, the cost of physical damages was approximately 10.1 trillion won and human damages were 18.9 trillion won, resulting in a total of around 29 trillion won, and the cost to social institutions due to traffic accidents was estimated to be 1.5 trillion won for one year. The final loss of 506 billion won was derived by multiplying the total loss cost due to the annual traffic accidents with the 5G-based accident reduction rate and the contribution of low-latency technology. The estimated results for each benefit category totaled KRW 1.84 trillion as given in Table 8.

TABLE 8. Benefit estimation results.

Benefit items	Estimation method	Estimation equation for benefits	Result (billion won)
(Producer) Business model expansion and creation	Market demand approach	Value Creation Benefits = Value increase amount × Number of connected cars × 5G contribution rate × Contribution rate of low-latency technology in 5G = 275 thousand won/vehicle × (36.62 million × 65 %) × 32.2 % × 1/7 = 301 billion (2030)	301
(Producer) Output increase		Production cost reduction benefit = Annual vehicle production increase for 5G contribution × Lowest vehicle price × Contribution rate of low-latency	55
		technology in 5G = 4.1 million × 1 % × 9.45 million won × 1/7 = 55 billion won	
(Consumer) Convenience, stability, and enjoyment	CVM	Number of connected cars × $\sum$(an annual service fee of WTP_i × user $ratio_i$) = (36.62 million × 65 %) × ((7.2011 × 0.1739) + (6.7663 × 0.1087) + (4.0217 × 0.5217)) = 972.6 billion	973
(Consumer) Reduction of human, physical, and social institution damage costs	Calculating damage cost reduction	Benefits of reducing damage costs = Cost of human and material losses for annual traffic accidents × 5G contribution accident reduction rate × Low-latency technology contribution rate in 5G = (1.5 trillion + 29 trillion) × 55.3 % × 21 % × 1/7 = 506 billion	506

E. RESULTS

A CBA based on the cost and benefit results estimated in the previous chapter was performed to derive the results of technology development impact analysis in the 5G low-latency V2X technology field. From the cost analysis, the total cost was calculated to be approximately 4136 hundred million won, considering the R&D cost and the usage scenario of the technology to be evaluated. Furthermore, the calculated estimation of benefits was 1.84 trillion won in total by reflecting the benefits related to business model creation and increased production in the automotive industry from the producer's and consumer's viewpoints, convenience, stability, and enjoyment benefits, and benefits to reduce damage costs were totaled. From the derived B/C of 4.437 (>1), it was judged that economic feasibility was high. Many researchers and business decision makers recognize the necessity of transitioning to 5G/6G with the advancement of technology. Although this transition is already underway independently of the results of CBA, the goal of the present study is to aid in a more detailed understanding and prediction of the impact of such transitions on business operations. By utilizing the results of this study, companies can effectively perform strategic decision-making considering the various economic and technological advantages and disadvantages that such transitions can create. This study focused on low latency among the technical characteristics of 5G. Usage scenarios aimed at low-latency 5G were presented, and the results of impact analysis were derived for V2X, the most representative scenario among them. As presented in Table 4, V2X technology must satisfy technical requirements such as data rate, reliability, density, mobility, positioning, and coverage as well as low latency. In addition, to secure the low latency of V2X, mobile edge computing (MEC) is being presented as a new paradigm [60], [61]. In other words, the low latency of V2X focused on in this study reflects new technological trends, including MEC.

V. DISCUSSION AND FUTURE WORK

The discussion compares the results of existing reports with those of this study to analyze the validity of the proposed framework. In addition, we examine the pros and cons of the proposed framework and the possibility of its use. In this study, a report analyzing the ripple effects of 5G technology in the Korean market was used for comparison [52]. This report showed the possibility of 5G technology as a general-purpose technology by estimating the socio-economic effect of 5G for the first time in Korea and analyzed various use cases of 5G technology. In particular, this report evaluated the impact of 5G in 2030, the same time as this study, in terms of amount. In 2030, convenience in 10 industries, including automobiles, manufacturing, and healthcare, was assessed to be 42.34 trillion won, of which 7.29 trillion won was for the automotive industry. In detail, the total benefit was calculated by dividing it into four benefits: strategic benefit (2.11 trillion), operational benefit (0.39 trillion), consumer benefit (4.28 trillion), and third-party benefit (0.51 trillion).

The producer model's business model expansion and creation benefits from this study are similar to the strategic benefits of the report, and the output increase benefits are similar to operational benefits. Furthermore, the report defined consumer convenience as a combination of convenience, stability, and enjoyment benefits and the reduction of human, physical, and social institution damage cost benefits in this study. In addition, the report defined the benefits of third parties such as insurance companies. Except for the third-party benefit that quantifies the additional impact rather than the technology itself, the strategic and operational benefits are similar, considering that in this study, the contribution of low-latency technology was set to 1/7. However, in the case of convenience from the consumer's point of view, in this study it differed by more than three times compared to 1.5 trillion won. This study segmented consumer benefits in more detail compared to that in previous reports and calculated benefits by reflecting the opinions of consumers in the actual market through CVM.

The academic contributions of this study are as follows. A technology impact evaluation system was established to reflect both the characteristics of the R&D project and social values. By focusing on technology R&D projects, the results of detailed benefits and costs can be presented to supplement the results of the analysis based on higher concepts such as economy, society, culture, ethics, and environment, presented by the existing technology impact assessment methods. In particular, the result of the impact evaluation based on the actual use of the product and service was presented by analyzing the usage scenario of the technology. We presented a methodology to evaluate technology impacts considering not only the existing direct R&D performance, such as patents and papers, but also the ripple effects of the industry through R&D. This study has practical as well as academic contributions. The evaluation results of this study can be used as basic data for technology planning and policy establishment by governments and research institutes. The feasibility assessment of the national R&D project is performed for large-scale R&D projects in Korea, where the proposed framework can be applied. In particular, it is useful to evaluate new growth-engine technologies that are difficult to apply from a cost–benefit perspective. In other words, the proposed framework can be used as an objective practitioner's guide by proposing a systematic process.

However, in the methodology proposed in this study, only four alternatives of market demand, CVM, CAM, and cost-effectiveness were considered when estimating the benefits; thus, other alternatives need to be additionally considered. In addition, the knowledge of relevant technical experts is required to analyze the usage scenarios for each technology. When evaluating the impact of technology, verification through accurate evaluation is difficult because the expected cost and benefits are analyzed through estimation. The study also has limitations in that the field of the case study is restrictive. This study is centered on the V2X case, which takes latency into account among various application scenarios related to 5G. However, owing to the nature of the technology, there exist many 5G application scenarios beyond the selected V2X case, and these may entail different technical characteristics and economic benefits.

Furthermore, not only low latency but also other characteristics of 5G, such as transferability and generalization, can be considered. Conducting case studies on various features of 5G and comparing their economic impacts can also be a meaningful research endeavor. Therefore, future research could consider applying the framework presented in this study to various 5G application scenarios to evaluate the technical characteristics and economic benefits suitable for each situation. For example, usage scenario 3 in Table 3 is, namely, smart grid services, represents an advanced form of the existing power grid system. Because there is an existing market for this scenario, it allows benefit estimation using the market demand approach. Furthermore, within the approach of market demand analysis, estimating cost reduction benefits is particularly appropriate. Other examples are usage scenarios 7 and 8. Telecommunication in special situations highlight situations where communication was previously impossible but has been overcome with the new technology of 5G. Therefore, as there is no pre-existing market for these scenarios, the market demand approach is not applicable. Although preference surveys can be conducted, given the close connection to societal services, it is challenging to assess them in monetary terms. Hence, the CAM approach is the most suitable evaluation method.

VI. CONCLUSION

This study suggests a framework for usage scenario-based R&D impact analysis to reflect the characteristics of telecommunications technology. These technologies are considered infrastructural technologies, which contribute to the creation of new businesses by promoting a wide range of mobile services that have been unavailable with the previous generation of technology. In addition, they are developed for public goods; no market exists for them, but they affect the degree of customer satisfaction for the goods. In particular, as the users of telecommunications services can be both organizations and individuals, the benefits of offering better services can be expressed as the creation of other businesses, where a market exists but for another sector, and/or improving user satisfaction, where no market exists. To consider such heterogeneous benefits of technology development in the telecommunications sector, this study proposes the use of scenarios, where the possible applications of the technology are described, along with its impact on businesses and user satisfaction. Accordingly, on the basis of these scenarios, the benefits are divided into several categories according to the type of organizations and users that are likely to be affected by the target technology. Then, the benefits for each scenario are merged into a single monetary value for comparison with the total costs. The proposed approach suggests a systematic process to decompose the total benefits into a smaller, homogeneous, and thus more measurable unit, applying the concept of usage scenarios, which enables the cost and benefit analysis for telecommunications technology. Thus, it contributes to the existing studies on R&D impact analysis and helps decision makers to determine in practice whether to invest in a particular technology.

Despite the valuable contribution of this study to the technology evaluation of the telecommunications sector, it has several limitations. First, the proposed framework can be elaborated in terms of methodologies. For example, more detailed guidelines to develop usage scenarios can be developed. Second, the proposed framework was applied only to a single case. Accordingly, further case studies are needed to ensure its generalizability. This study delves into the technological characteristics and economic advantages of 5G, placing particular emphasis on V2X. Although in this work we conduct a case study confined to the V2X scenario, the findings contribute to a deeper comprehension of the evolution of 5G and subsequent network advancements. Further research is needed to broaden the utility of the framework presented herein by applying it to a diverse range of 5G application scenarios.

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