External Environmental Analysis of Technical Systems for Establishing R&D Strategies

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Abstract: Analyzing the external environment of technical systems emerging from objective patterns of technical system evolution is essential for predicting future technological development and for establishing R&D strategies. However, STEEP, a typical environmental analysis tool (involving social, technological, economic, environmental, and political aspects) and qualitative investigation method, is not easy for researchers in science, technology, and engineering to use effectively without having expertise in the relevant area. This study aims to develop a method that can be easily used by non-specialist researchers in R&D. To achieve this, the external environment was divided into the macro environment and the micro environment by applying multi-screens, a systematic analysis method of the theory of inventive problem solving (TRIZ). Specifically, macro environmental factors are defined as STEEP while micro environmental factors, which have a direct effect on the survival or success of a technical system, are defined as five supersystems based on Porter's five forces framework. For analyzing the macro environment, a wide range of the existing STEEP factors were systematically sub-categorized around the key concepts. These concepts were defined according to the analytical purpose of market-oriented technology development and topic of analysis for each field of STEEP. Based on this classification system, the STEEP analysis template, a practical tool for macro environmental analysis, was developed to derive the core STEEP keywords. Similarly, a template for supersystem analysis was developed to analyze the relationship and influence of STEEP keywords on the five supersystems. This STEEP factors classification method and the templates are expected to provide a guideline for quickly and easily analyzing the influence of STEEP factors on a technical system.

Keywords: STEEP, Five Forces Analysis, TRIZ, Multi-screens, R&D Strategy

1. Introduction

As technological progress is accelerating and product life cycles are decreasing in the era of the Fourth Industrial Revolution, objective prediction of future technology development is extremely important in R&D planning centered on product development. Widely used prediction methods include Delphi, Text Mining, Analysis Hierarchy Process (AHP), and Technology Roadmaps. These methods, based on extensive data, including patents, surveys, and assessments of several experts from various fields, are not only costly and time-consuming, but also dependent on experts' decisions, which can be

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subjective[1]. In an effort to address these limitations, researchers are attempting to apply technology evolution trends and the theory of inventive problem solving (translated as the abbreviation TRIZ), which was proposed by Russian scientist Genrich S. Altshuller[2], to further develop prediction technology. Since this prediction technique presents several potential future development directions for a given technical system, selecting the right direction is part of the R&D planning and product development. The choice is made by considering various selection criteria, of which external environmental factors are most significant. In this study, an external environmental analysis focuses on the social, cultural, economic, and political factors and trends that influence the success and selection of technical systems in the market.

Tools commonly used to analyze the external environment, including STEEP (social, technological, economic, environmental, and political aspects), PEST (political, economic, social, and technological aspects), and PESTEL (political, economic, social, technological, environmental, and legal aspects), have the advantage of classifying the changing factors of enormous and complicated external environments in various categories. However, as qualitative basic investigation methods, they are generally used together with quantitative methods, including Delphi, big data analysis, and AHP, to predict future development in specific areas[3-6]. This means that external environmental analysis requires the involvement of many experts from various fields, and an enormous amount of money and time. Consequently, individual researchers or those from small and medium-sized companies, with limited resources, personnel, time, and budgets, find it difficult to take advantage of the external environmental analysis methods in R&D planning or product development.

Against this backdrop, this study aims to develop a method and a user-friendly tool that can be used to analyze the external environment, which influences the development of a technical system.

This study focused on STEEP analysis, one of the most commonly used tools for external environmental analysis. The goal is to develop a method that enables non-specialist researchers and engineers without expertise in environmental analysis to use STEEP analysis to aid R&D planning and product development. To do so, key indicators were derived, and the relationship between the indicators and a specific technical system was analyzed based on the systematic method of TRIZ.

2. Research Methodology

2.1 Main Tool in Systematic Thinking Method of TRIZ: Multi-screens System Operator

The essence of the TRIZ method of systematic thinking is based on the analysis of a system from various perspectives; that is, the basic function, changes in time, components of the system (subsystems), and its relationship with external elements of the system (supersystems), providing a minimum of nine directions[7]. This is the first step in a systematic analysis. The Nine Screens System operator (also called as multi-screens), suggested by Altshuller, is used as a tool in this study, because it can be expanded to more than nine directions (screens) of thinking according to the research scope[8]. A systematic approach using the multi-screens system operator is shown in [Fig. 1]. In this figure, a tree system is presented at different system levels from the entire tree (system), to a leaf (subsystem), to a forest (supersystem), and so on, along with the same variants from the past, present, and future (line of evolution)[8].

In this study, the basic concept of the systematic analysis method of TRIZ is applied for the external environmental analysis of a technical system. The supersuper-systems of a given system are defined as macro environmental factors and the supersystems are defined as micro environmental factors directly related to the technical system.

[Fig. 1] Tree Analysis Using the Multi-screens System Operator of TRIZ

2.2 Supersuper-system Analysis: Macro Environmental Analysis Using STEEP Method

STEPP analysis is used to analyze the main indicators in five areas—social, technological, economic, environmental, and political—to identify key trends in each area. The quality of the analysis relies on the amount and level of relevant data as well as the indicators[1]. The classification methods and indicators differ slightly depending on the organization. This study examines the indicators used by six organizations and researchers in the fields of business management, science and technology, and marketing. These indicators are largely divided into two categories: listing by area [1][9-11] and sub-categorization by specific subject[12][13]. In the classification by area, researchers identify the main indicators for each area. However, there are many indicators, and most importantly, it is difficult for non-experts to reach a meaningful interpretation using the relevant indicators. In the classification by subject, it is relatively easy for non-experts to interpret the meaning of the indicators, but there are times when researchers have to find the indicators themselves. Take the example of demographic indicators in the social area. In the first classification (listing by area), the indicators are presented as birth and death rates, and percentage of the population in economic and social segments[9]. In the second classification (sub-categorization by specific subject), demographic indicators are specified under the category of factors that influence demand and supply[12], where specific demographic indicators can be driven only if the purpose and scope of the analysis are clearly defined.

In this study, to improve the usability of the environmental analysis method (STEPP) among non-experts, the selection criteria for indicators and data was established as follows: reducing the time and cost required to obtain and interpret data; ensuring publicness, objectivity, and accessibility of the data; and providing guidelines for non-experts to interpret the data and understand the relationships more easily.

Accordingly, as shown in [Fig. 2], the sub-factors were categorized and data for each area of STEPP were selected so that even non-experts can easily identify the necessary indicators and find relevant data by themselves.

[Fig. 2] Process of Extracting Key Indicators for each STEEP Area

[Table 1] shows the classification criteria and description of indicators related to the main factors in each area of STEEP, defined according to the process outlined above.

[Table 1] STEEP Key Indicators Classification Criteria

Indicator Group	Classification Criteria	Description	Data Type	Main Sources
Factors Level 1	Status data	Basic statistics related to basic conditions and structure formation in the field	Quantitative data, statistics	Statistics Korea, KISTEP Science & Technology Policy Support Service, IITP, Korea Development Institute, Institute of Foreign Affairs and National Security (IFANS)
Factors Level 2	Main trends	Key to changes in each area based on the Level-1 indicators	Qualitative data, report, text	Statistical Research Institute, Ministry of Science and ICT, Korea Institute for Industrial Economics & Trade (KIET), IFANS, Korea National Environmental Technology Information Center (KONETIC)
Factors Level 3	Global trends	Global-level main information for Levels 1 and 2	Qualitative/quantitative data, report	UN, World Bank, OECD, S&T GPS Global Science & Technology Policy Support Service, KIET, IFANS, McKinsey Global Institute

2.3 Supersystem Analysis: Extraction of Supersystem Elements Using Five Forces Analysis Method

Porter's five forces, a very useful framework for analyzing competition among existing companies in the market, divides the business environment into different levels, and thus, indirectly analyzes the impact of macro environmental factors on companies by using the competitive forces of the industry to which a company belongs[12]. Competitive forces include industry rivalry, suppliers, buyers,

substitutes, and new entrants in the traditional classification of economics and business management. In the field of marketing, they are defined as micro environmental factors—suppliers, resellers, customers, competitors, and the public[14]. Most importantly, five forces analysis seeks to predict the probability of survival and success of a company (or a product) in the market, and defines the factors with a direct impact on it.

For market-centered R&D planning, the external environment is divided into *Supersuper-system*, a common macro environment, and *Supersystem*, a micro environmental factor that has a direct impact on the products in the markets, according to multi-screens, the systematic analysis method of TRIZ, and the interrelationship of the two systems is analyzed. The five aspects of the five forces analysis are applied to define the supersystem and its five factors (mentioned above) more precisely.

3. Method and Tool for Analyzing the External Environment of Technical Systems

3.1 Method of Classifying STEEP factors for Supersuper-system Analysis

In this study, the supersuper-system analysis method is intended to facilitate a systematic sub-categorization of extensive conventional factors for each area of STEEP. This method is also useful for extracting necessary indicators, and understanding the relationships between the indicators. There are three steps to systematizing the classification of STEEP indicators. First, the purpose (market-oriented technology development) and analysis topic for each field of STEEP are established. Second, the contents for each of the social, technological, economic, environmental, and political areas (large category) are sub-categorized according to the analysis topic to define the key concepts (medium category) corresponding to the topic. Finally, the indicators used by six organizations in the fields of science & technology, business management, and marketing [1][9-13] are classified in detail (small category) based on the key concepts. Based on this, [Table 2] shows the specific factors derived for each area of STEEP.

[Table 2] Classification of Sub-factors for Each Area of STEEP

Large Category	Medium Category		Small Category
	Key Concept		Main Factors
Social	Level 1	Population (households) and income structure status	Main demographic (household) indicators, GNI per capita, household consumption expenditures, total savings rate, ratio of women workers
	Level 2	Changes in domestic demographic and consumption structures	Population (household) projection analysis; household income and consumption changes; generation classification, distinction, and characteristics; digital life changes; list of changes in trendy products
	Level 3	Changes in global demographic and consumption structures	Population by country indicators, global population forecast, GNI per capita in each country, global digital life changes
Technological	Level 1	New technology trends	Emerging technologies, ICT issues
	Level 2	R&D policy changes of government and companies	R&D investment, R&D human resources, R&D laws and bills, technology industry support and regulation policies
	Level 3	Global R&D policy changes	R&D investment by country, R&D policies by country
Economic	Level 1	Macroeconomic and industrial status	Main domestic and foreign macroeconomic indicators, analysis of domestic and foreign economic trends, domestic and foreign economic outlooks
	Level 2	Industrial structure changes and economic support policies: regulatory changes	National economic stimulation policies, new industry policies, technology and industry regulation policies
	Level 3	Changes in global economic and industrial structures	Global industrial structure status, economic policies by country
Environmental	Level 1	Environmental issues	Resources, energy, climate change

	Level 2	Changes in environmental policies (support and regulations)	Environmental regulatory laws
	Level 3	Changes in global environmental issues and policies	Sustainable industry trends, global environmental regulations and laws
Political	Level 1	Political status	Domestic and foreign political situations and trends
	Level 2	Domestic political trends	Government state affairs (strategies and execution plans), government's foreign policy changes
	Level 3	Global political trends	Global political issues, U.S.–China conflict, China's political situation

The classification system is characterized by the division of a range of factors and data into key concepts according to the hierarchical level. This guides users to easily find the factors, indicators, and data required for analyzing the external environment around key concepts. It is relatively easy to extract keywords around the main concepts from the literature to analyze the trend in each STEEP area.

To support this process, an external environmental analysis tool based on the TRIZ's multi-screens was developed. This tool allows researchers in science, technology, and engineering to perform STEEP analysis for examining the environment of a technical system easily and quickly.

3.2 Tools for Analyzing the External Environment of Technical Systems

3.2.1 Supersuper-system Analysis Tool: STEEP Analysis Template

The STEEP analysis template was developed to use the classified indicators by distinguishing the three levels of “status—main trends—global trends” based on quantitative and qualitative data. This template is designed to easily find the necessary data and data sources according to the key concepts of each area. It can also quickly identify the trend changes through the changes in the core keywords in STEEP, from the past to the present, thus enabling users to predict the future trends.

In this study, the trend in each STEEP area is analyzed around the Level 2 key concepts. There are two main methods for deriving trends. In the first method, users investigate the data of the main factors by key concepts to analyze the pattern of changes. In the second method, users extract core keywords from the existing literature that analyzes megatrends while considering duplicates, similarities, and relationships in the search results of the key concepts. For example, to analyze the trend in a social area, core keywords can be derived using the main indicators in Level 2, namely, population, household, consumption, generation, digital, and trendy products, as search words in the literature on megatrends [15], as shown in [Table 3].

[Table 3] Core Keywords for Main Indicators in Level 2 in Social Area

Main Factors	Core Keywords for Short-term Future (1–5 Years)
Future population projection	Super-aging, increased need for elderly employment, the need for health and quality of life, increased demand for medical and healthcare technology, ultra-low birth rate, decreased school-age/youth population, worsening of imbalance between age groups, worker scarcity and declining productivity, imbalance in supply and demand of labor, increased migration between countries, use of bioengineering technology, increase in urban population, demand for smart cities, mega-urbanization
Future household projection	Single-person household, increased percentage of married-couple households, diversification of household composition, small household size, aging of single-person householders, family value change, multi-culturalism, women's social advancement

Household income/consumption change	Income polarization, worsening income disparity, worsening imbalance of income and employment, worsening conflict between social classes, online shopping, rational consumption, consumption sharing, digital platform, electronically mediated workers, gig economy, digital goods, online to offline, on-demand economy, value-oriented consumption, MEconomy (Me+Economy), Gen MZ consumers, intelligent consumption, remote consumption, focusing on high-class workers, job polarization
Distinction and characteristics of generations	Value diversification, generation conflict, worsening of social conflicts, diversification in generation composition, digital gap, emergence of new consumption generation/mobile new human species, YOLD (Young Old) generation, Generation MZ (places importance on individualism, empiricism, realism, and diversity)
Digital life change	Online shopping, remoteness, spread of telecommuting, digital social evolution, acceleration of a contact-free society, platform service use acceleration, social gaps and conflicts due to digital gaps, digital literacy, unstaffed, automation, sharing economy, various values, digital and non-face-to-face communication, digital-twin urban space, digital goods, digital currency, surrealization, real-time contents, digital bank, blockchain, TechFin, multiple digital identities, digital healthcare, digital smart city
Trendy product change	Streaming service

A statistical analysis of the content derived from the key trends in Level 2 can use quantitative data from Level 1, and an analysis to predict a trend's global dimensions can use Level 3 data.

By summarizing the analysis at different levels, a STEEP analysis template is composed based on the keywords of each area, as shown in [Table 4].

[Table 4] STEEP Analysis Template (Social Area)

Time Criteria Aspects		Main Factor	Main Source	2010s	Present	Future: Short-term (1-5 Years)
S-Megatrend		Science & technology forecasting survey	www.kistep.re.kr	Periodic Research on Future Society Forecast of the Korea Institute of Science & Technology Evaluation and Planning (5-year period)		
Social	1. Domestic population (household) and income structure status	Total population and population growth rate	www.index.go.kr	Analysis of changing trends using key statistics provided by public organizations		
		Population by age groups	www.index.go.kr			
		Number of households	www.index.go.kr			
		Household composition ratio	www.index.go.kr			
		GNI per capita/gross household disposable income per capita	kosis.kr			
		Average monthly household income and expenditure (consumption expenditure by item)	kosis.kr			
		Gini coefficient, median income (50-150 %) (market income)	kosis.kr			
		Participation rate of women in economic activities	kosis.kr			
	2. Domestic population and consumption structure changes	Analysis of future population projections	kostat.go.kr	Extraction of core keywords and analysis of keyword changes using survey and research literature provided by public organizations		
		Analysis of future household projections	kostat.go.kr			
Changes in household income and consumption		kostat.go.kr/sri/srikor/index.action				

		Classification and characteristics of each generation	kostat.go.kr/sri/srikor/index.action	Extraction of core keywords and analysis of keyword changes based on literature and statistical data provided by public organizations
		Changes in digital life	www.index.go.kr/main.do	
		Changes in trendy products	Consumer Trend Center, Seoul National University	
	3. Global population and consumption structure changes	Changes in global population structure	population.un.org/wpp/Publications	
		Changes in global consumption structure	databank.worldbank.org	
			www.itu.int/en/Pages/default.aspx	
			www.mckinsey.com/mgi/overview	

The keywords extracted by area, repeatedly appearing across the STEEP areas, include polarization, imbalance, deepening conflicts, individualization, connectivity, diversification, smartification, remoteness, digital economy, platform service, circular economy, and reorganization of the traditional global value chain. Based on this finding, researchers forecast the overall macro external environment trends for the near future.

3.2.2 Supersystem Analysis Template

The key to the supersystem analysis of a technical system is to identify the relationships between each STEEP factor and the five supersystems that have a direct impact on the survival or success of a product or technology in the market. This analysis is done by using the core keywords in STEEP. These relationships define the external environmental factors that affect the future development of the technical system. The supersystem analysis template was developed as a tool for conducting this analysis.

The supersystem analysis template is designed to systematically analyze the impact of the key trends in each area of STEEP on each of the five forces of the micro environmental factors. An example of a social area is shown in [Table 5].

[Table 5] Supersystem Analysis Template (Social Area)

Forces		STEEP Factors—Short-term				
Category	Target and Characteristics	Field	Factor Group	Main Factor	Core Keyword	Impact of Factor (Description) and Strategy
Suppliers/ Consumers/ Substitutes/ Competitors/ New Entrants		Social	L-1 Domestic population (households) and income structure status	Total population and population growth rate		
				Population (ratio) by age groups		
				Number of households (increase rate)		
				Household composition ratio by generation		
				GNI per capita/ Gross household disposable income per capita		
				Average monthly household income and expenditure		
				Median income (50–150%, market income)		
				Participation rate of women in economic activities		
			L-2 Changes in domestic populations and	Analysis of future population projections		
				Analysis of future household projections		

		consumption structures	Changes in household income and expenditure		
			Classification and characteristics of each generation		
			Changes in digital life		
			Changes in trendy products		
		L-3 Changes in global population and consumption structures	Changes in global population structure		
			Changes in global consumption structure		

Users can specify the five supersystems of a given system and identify their impact on it, as well as understand the relationship with core keywords by the level in each area specified in the STEEP analysis template. The frequency of the words related to the core keywords in each STEEP area indicates the degree of impact on the system.

4. Conclusions

A practical external environmental analysis method and tools based on TRIZ's multi-screens were developed that can be easily used by science, technology, and engineering researchers and researchers from small- and medium-sized companies to establish their R&D strategies for product development.

The tool was used to divide the external environmental factors of the technical system into macro environmental factors (supersuper-systems) and micro environmental factors (supersystems). By using the STEEP method, the trends and core keywords for the five macrosystems were derived. The five microsystems were defined by applying the five forces analysis method. Also, a guideline was provided to analyze the impact of the main factors of social, technological, economic, environmental, and political areas on the supersystem by using the STEEP and the supersystem analysis templates.

[Fig. 3] summarizes the prediction method for technical systems based on TRIZ's multi-screens method.

[Fig. 3] Future Prediction Method for Technical Systems Using Multi-screens System Operator

It is expected that the external environmental analysis tool will be used to define external environmental factors that significantly affect the technical system of the R&D planning and development. This study provides a theoretical basis for developing a convenient external environmental analysis method and tool to use in the market-oriented technology R&D field. Case studies are needed to analyze their accuracy and appropriateness in predicting future technology development and

establishing R&D strategies. Therefore, a follow-up study is needed to verify this assumption by applying the tools to specific technical systems and deriving future prediction results.

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