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DATA-DRIVEN DERIVATION OF PROMISING FUTURE DEFENSE TECHNOLOGY

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Abstract. *As the fourth industrial revolution changes the whole paradigm of future warfare along with the entire national defense environment, the defense sector needs to respond with innovativeness and creativity. As technological life cycles are shortened due to the advancement of cutting-edge technologies, it is essential to consider technological development trends in the field of defense technology planning. Additionally, whereas technologies by nature do not have boundaries such as "civilian" or "military", the existing technology-derivation methodology has been limited to the defense science and technology sector. This paper introduces a data-driven derivation method for prediction of promising future defense technology. The present study developed a systematic approach to the derivation of creative and unprecedented weapons systems via both data mining analysis and the establishment of a defense science and technology acquisition road map for long-term development trends. The special contribution of this study is that it not only supports prediction of promising future technologies but also enables those in the defense sector to view and consider possible applications of those technologies in the forms of weapons systems.*
Keywords: Text mining, Future weapon system, Technology prediction, Environment analysis

1. **Introduction.** The fourth industrial revolution brings drastic transformations to society by means of core technologies in fields such as big data, Artificial Intelligence (AI), and Internet of Things (IoT). Further, these core technologies have numerous applications in terms of the development of new weapon systems in the field of defense science and technology [1]. In an attempt to predict promising future technologies, various prediction models and methodologies such as morphological analysis [2], logistic growth model [3], and Delphi method [4] have been applied in diverse fields including aerospace, medicine/biology, and management [5]. Kim et al. [6] endeavored to find new and creative ways to accurately foresee future technologies domestically by applying improved TFDEA (Technological Forecasting with Data Envelopment Analysis) to the technology prediction problem of the main battle tank. Additionally, the Defense Agency for Technology and Quality (DTaQ), a Korean national defense institute, has predicted new technologies related to autonomy in the defense sector by publishing 'Forecasting Unmanned Technology in Future Warfare' [7]. Notwithstanding the several studies that have been conducted, the prediction of future defense sector technologies and, ultimately, new weapons systems, is limited to the imaginings of future warfare scenarios. In other words, prediction of future

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technologies in the defense sector is based on experts' opinions as subject to personal experience and knowledge; as such, it has a distinct disadvantage in that it lacks objectivity. To compensate for this, it is crucial to collect as much information as possible that pertains to the most recent research and development cases and to analyze the collected data by using text mining, trend analysis, and network analysis, among other tools. In this way, the information utilized is not limited by personal experience or expertise; thus too, prediction of promising future technologies is rendered more objective and unbiased.

Kam et al. [8] analyzed chronological and annual research trend changes in the field of medicine/biology by collecting academic papers in relevant journals and by performing text mining on the aggregated data. To guarantee objectivity and expertise, they selected only the abstracts of papers that had an average impact factor of 10 or greater over the last 5 years. In another study, KISTEP (Korea Institute of Science and Technology Evaluation and Planning) analyzed 10 promising future technologies using text mining [9]. Various studies are ongoing in other countries as well, as seen in examples such as text-mining-based research of reviews of online users [10] and the prediction of stock markets by utilization of text mining of real-time news broadcasting [11]. However, the above-mentioned research and applications are limited to the civilian sector; no such work relevant to the defense industry has been done.

This paper introduces a data-driven derivation method for prediction of promising future defense technology. To that end, the present study developed a systematic approach to the derivation of creative and unprecedented weapons systems via both data mining analysis and the establishment of a defense science and technology acquisition road map for long-term development trends. The proposed approach entails the following steps: future environment analyses, mega-trend extraction, derivation of promising future technology fields, magnet word selection, related-word extraction, future defense technology selection, and prediction of futuristic/conceptual weapons systems. The special contribution of this study is that it not only supports prediction of promising future technologies but also enables those in the defense sector to view and consider possible applications of those technologies in the forms of weapons systems. The rest of this study is organized as follows: Section 2 introduces the proposed approach; Section 3 details our extraction of future core technologies in the defense sector and derivation of futuristic and conceptual weapons systems thereby; Section 4 summarizes the results and draws conclusions.

2. **Proposed Framework.**

The proposed framework consists of three stages shown in Figure 1. The first stage, selection of promising future technologies, preferentially analyzes environment changes by utilizing the environment analysis method known as D-STEEP (which has 6 categories: Defense, Social, Technological, Economic, Ecological, and Political), and then extracts the important trends for each category. Actually, STEEP (Social, Technological, Economic, Ecological, and Political) is a prevalent macroscopic environment analysis methodology that has been widely utilized in science and technology prediction research by many civilian institutes; D-STEEP (or Defense-STEEP) is the version modified for the defense sector by adding capabilities for analysis of future warfare environments and the latest weapons system development trends, etc. For example, the expansion of cyber warfare and the increased importance of long-range, precision strike systems cannot be analyzed using conventional STEEP analysis.

The second stage, data-driven derivation of promising future defense technology (core future defense technology), preferentially classifies the important trends extracted in the first stage, from which classifications it derives promising future defense technologies using a big-data-analysis-based text mining technique, and then meticulously assesses those technologies.

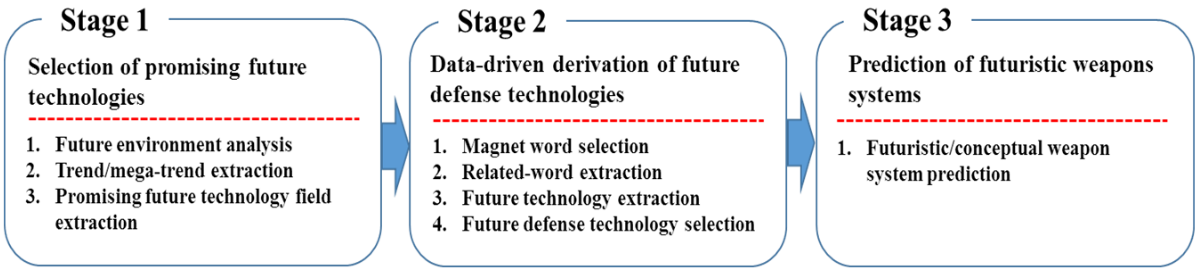

Figure 1. Future weapons system and core technology guidance process

The third stage, prediction of futuristic/conceptual weapons systems, derives futuristic weapons systems based on the promising future defense technology sorted by the second stage, and then draws out operational as well as design concepts for each system.

2.1. **Stage 1: Selection of promising future technology.** This stage consists of three steps: 1) future environment analysis, 2) trends/mega-trends extraction, and 3) promising future technology derivation. The first, future environment analysis step analyzes the environmental changes according to D-STEEP's 6 categories. The second, trends/mega-trends extraction step extracts the macroscopic trends from the results of the environmental change analysis and clusters the macroscopic trends with high relevance for extraction. The third, promising future technology derivation step identifies candidates for promising future technologies in each mega trend, and then integrates them by similarities to derive future promising technology fields. The extracted promising future technologies in this third step are representative technologies that are expected to be in the spotlight in the future, and are the basis of data (source) collection for the text mining analysis in the second stage. Preparatory to the crucial text mining analysis, it is imperative to gather data that has similar characteristics in terms of topics in creating a data pool. Thereby, each promising future technology field will have a corresponding data pool of its own in order to minimize data pool dilution and maximize technological expertise. To minimize noisy data when performing text mining, each promising future technology field will have a corresponding data pool the sources of which are prominent journals abroad such as *IEEE*, *Nature*, and *Science*, as well as news articles, such as from *Global Defense News*, on the latest defense-related issues (development trends, research, etc.).

2.2. **Stage 2: Data-driven derivation of future defense technology.** This stage consists of four steps: 1) magnet words selection, 2) related-words extraction, 3) future technology extraction, and 4) future defense technologies selection. The first step selects the magnet words, which are the key words representative of emerging technology trends, for each promising future technology selected in the first stage. To achieve this, it extracts key words from each selected promising future technology via crawling abstracts of academic papers from prominent journals and recent trustworthy news articles, and creates a data pool based on the extracted key words; subsequently, the magnet words are selected from the key words through a text mining analysis. In selecting the magnet words, the support (an indication of how frequently a particular word appears in the data pool), confidence (an indication of how frequently a particular word appears in a document of a certain technology field) and lift (an indication of how frequently a particular word appears in a document of a certain technology field compared with other technology fields) are applied as importance indicators. The second step extracts the related words for each magnet word by applying network analysis incorporating the Graphical Lasso model, which analyzes word-to-word associations. Note that the relevance of selected magnet words and extracted related words are verified by an expert forum. The third step derives the militarily applicable promising future technologies based on the magnet words with their respective related words as verified in the second step. In this third step, the verified magnet words and their respective related words are considered as basic input factors, and the technology development trends are considered as additional influencing factors. As a result, candidates for promising militarily applicable future technologies are presented. Adjunctively, the experts of each promising technology field refine the derived militarily applicable promising future technologies by confirming, deleting or modifying them. The fourth step summarizes the results of the promising technology potential assessment to select the core future defense technologies. To ensure that these technologies are selected evenly across the entire promising future technology fields, five to seven technologies are selected for each promising future technology field.

2.3. **Stage 3: Prediction of futuristic weapons systems.** The third and final stage proceeds by examining the potential applications of the core future defense technologies in order to derive futuristic/conceptual weapons systems. The derivation process holistically includes consideration of the core future defense technologies as well as their magnet and related words, the related technological fields and their applications as well as demonstrations in science fiction such as movies, and novels. After prediction of the futuristic/conceptual weapons systems, the definitions and the operational concepts of those systems are modified by conferring with military experts. Finally, the conceptual design and operational process is settled.

3. **Derivation of Promising Future Defense Technologies and Futuristic/Conceptual Weapons Systems.** As a demonstration of the proposed framework, we applied it to the derivation of core future defense technologies and futuristic weapons systems. Through D-STEEP environment analysis, 73 important trends were identified, and after the integration and modification process, 11 mega trends were selected. In selecting the mega trends and identifying promising future technology fields, official reports on emerging technologies published by government institutes such as the Electronics and Telecommunications Research Institute (ETRI), KISTEP, and the Agency for Defense Development (ADD) were utilized. This process was repeated for all 11 mega trends, and the following 13 promising future technology fields were selected: Advanced Sensor, Cyber Security, Advanced Propulsion, Artificial Intelligence, Advanced Material, 3D/4D Printing, New & Renewable Energy, Unmanned Robot, Internet of Things (IoT)/Internet of Everything (IoE), Virtual Reality (VR)/Augmented Reality (AR)/Mixed Reality (MR), High-Power Energy, Quantum Information, and Detoxication.

A total of 194 sources comprising abstracts of academic papers published in journals such as *Science*, *Nature*, and *IEEE*, as well as news articles pertaining to the most recent defense science and technology issues, were selected for analysis via text mining. Afterwards, morphemes were analyzed and sorted by importance. To execute this, 13 key-word dictionaries were built for each of the 13 promising future technology fields, respectively, to ensure an accurate text mining process. In compiling the key-word dictionaries, 180,000 words from 54 subcategories of the "science & technology" category of *Oxford Reference* and the *IEEE Taxonomy* were used.

A 6-gram model that uses 6 neighboring words was applied to analyzing the morphemes. Further, to evaluate the importance of a word, TF (Term Frequency) – IDF (Inverse Document Frequency) was utilized. When analyzing key words, Hellinger Distance, which indicates the similarity of appearance frequency, was used as a criterion for filtering of regular words that do not reflect the characteristics of promising future technologies. In the end, 186 magnet words and 1,725 related words were extracted in 13 promising future technology fields. Table 1 shows the text mining result for "Cyber Security", one of the 13 promising future technology fields.

Table 1. Text mining results for promising future technology in cyber security field

"SCADA" "Cloud Security" "ESM Security" "Mobile Security" "Smart Grid Security" "Big Data Security" "Personal Information Security" "Forensic" "Data Mining" "Machine Learning" "Cyber Attack" "Detection/Cure/Restoration" "Real-Time Self Defense System" "Integrated Circuit Tamper Prevention" "Information Leakage Prevention Technology" "Terror Risk Prediction"

The extracted representative key words were examined and modified by technology experts via a small group-discussion panel in order to determine the candidates for magnet words. Finally, these magnet word candidates were filtered by the relevance of their related words (drawn from the text mining process) to determine the magnet word selections. Related words are more detailed, subordinate concepts of magnet words, and represent specific categories and technologies of each promising future technology field. The process of selecting related words is almost the same as that of selecting magnet words. Totals of 155 magnet words and 456 related words were selected. Table 2 shows the finally selected

Table 2. Related words based on magnet words in field of Advanced Sensor

No	Magnet words	Related words
1	Contact Lens Sensor	Biological Systems, Flexible Electronics
2	Interferometry	Acoustic Imaging, Precise Positioning, Remote Sensing, Artificial Intelligence
3	Multi-Static	Radar, Imaging, Synthetic Aperture Radar, Remote Sensing, Across Track Interferometry, Along Track Interferometry
4	Quantum Sensor	Radar, Quantum, Stealth Detection, RF-Quantum Conversion
5	Biodegradable Sensor	Wastewater, Current Measurement, Nanoscale Devices, Telecommunications
6	Electrochemical Micro Sensors	Film, Absorption, Biosensors
7	Flexible Electronics	Internet of Things, Antenna, Base Stations
8	Head-Mounted Display	Visualization, Cameras, Clouds, Computer Vision
9	Interferometry	Imaging, Remote Sensing, Digital Elevation Models
10	Mems	Navigation, Gesture Recognition, Accelerometers, Kinematics
11	Pathogen Detector	Biomarker, Data Mining, Bluetooth, Voltage
12	Side Scan Sonar	Imaging, Underwater Structures, Optimization Methods
13	Imaging Sonar	Imaging, Spatial Resolution, Beams, Dynamic Range
14	Smart Dust	Global Positioning System, Compound, Precision, Location, Real-Time
15	Smart Sensor	Internet of Things, Surveillance, Wireless Sensor Networks, Security
16	Spectroscopy	Imaging, Remote Sensing, Hyper Spectral, Measurement Techniques
17	Underwater Sensor Network	Self-Powered Wireless Sensors, Wireless Sensor Networks
18	Vector Sensor	Artificial Intelligence, Acoustic, Adaptive Control, Anisotropic, Sensor Arrays

magnet words and related words for "Advanced Sensor", one of the 13 promising future technology fields.

The 248 promising future technologies were evaluated to select future defense technologies. To achieve this, evaluation categories as well as their relative weights were decided by AHP survey, and the future defense technologies were selected based on the 3 categories of future defense technology evaluation and their 6 subcategories. The weights of these 3 categories and of their respective subcategories are listed in Table 3.

Table 3. Future technology evaluation weights by category

3 categories	**Weight**	**6 subcategories**	**Weight**	**Final weight**
Economic/Social Ripple Effect	0.141	Economic Ripple Effect	0.581	**0.082**
		Social Ripple Effect	0.419	**0.059**
Technological Innovation	0.315	Technological Ripple Effect	0.462	**0.146**
		Technological Progressiveness	0.538	**0.169**
Defense Applicability	0.544	Weapons System Applicability	0.408	**0.222**
		Military Fighting Power Improvement Contribution	0.592	**0.322**

Finally, 63 future defense technologies, all of which are highly technologically promising, were selected from the 13 promising future technology fields. More specifically, 6 technologies from Advanced Sensor, 6 technologies from Cyber Security, 4 technologies from Advanced Propulsion, 4 technologies from Artificial Intelligence, 6 technologies from Advanced Material, 5 technologies from 3D/4D Printing, 6 technologies from Advanced Renewal Energy, 3 technologies from Unmanned Robot, 4 technologies from IoT/IoE, 4 technologies from Virtual Reality/Augmented Reality/Mixed Reality, 4 technologies from High-Power Energy, 7 technologies from Quantum Information, and 4 technologies from Contamination Purification were selected. Table 4 shows the sample of future defense technologies for "Advanced Sensor".

Table 4. Future defense technologies list for Advanced Sensor

Promising technology field	**Future defense technologies**
Advanced Sensor (6 Technologies Selected)	• Subminiature Sensor Implant Memory Chip Technology • Contact Lens Wearable Real-Time Bio-Monitoring Technology • Precise Location Detection Technology for Underwater Vehicle • Image Acquisition Technology for Micro Air Vehicle Swarm • Multi-Static Interferometry Synthetic Aperture Radar Technology Using Multiple Satellites and Unmanned Aerial Vehicles • Stealth Object Detection Technology Using Minimal Microwave Detection Radar

The selected future defense technologies were used to derive the futuristic/conceptual weapons system. In this stage, the future defense technologies along with their respective magnet words and related words as well as the related technology categories and even science fiction movie/novel applications were utilized in order to holistically predict the

Table 5. Futuristic/conceptual weapons system list (Advanced Sensor)

Promising technology field	Futuristic weapon systems
Advanced Sensor (3 Weapons Systems Selected)	• Remote Soldier Health Monitoring System Using Contact Lens • Micro Air Vehicle Swarm • Memory Implant Chip for Real-Time Tactical Adaptation

various possibilities for the maturations of these technologies and their military applications. A total of 40 futuristic/conceptual weapons systems were derived from the 63 future defense technologies. Table 5 shows the futuristic/conceptual weapons systems for "Advanced Sensor".

4. **Conclusion.** This paper introduced a data-driven derivation method for prediction of promising future defense technologies. For that purpose, the present study developed a systematic approach to the derivation of creative and unprecedented weapons systems via both data mining analysis and the establishment of a defense science and technology acquisition road map for long-term development trends. The proposed approach entails the following steps: future environment analyses, mega-trend extraction, derivation of promising future technology fields, magnet word selection, related word extraction, future defense technology selection, and prediction of futuristic/conceptual weapons systems. The special contribution of this study is that it not only supports prediction of promising future technologies but also enables those in the defense sector to view and consider possible applications of those technologies in the forms of weapons systems. Eleven mega trends were derived from 73 important trends. These mega trends were categorized into 13 promising future technology fields. From those technology fields, 248 promising future technologies were derived. After further assessment, 63 core technologies were selected. These selected technologies were labeled "future defense technologies". Finally, as based on those future defense technologies, 40 futuristic/conceptual weapons systems were predicted.

The future technologies derived from the proposed method could be utilized in establishing a defense science and technology acquisition road map as well as in identifying core future technologies in the technology planning process. Additionally, the futuristic/conceptual weapon systems based on the future defense technologies could be used as a reference in various requirement planning activities such as those summarized in the "Direction of Development of Long-Term Weapon Systems" of the U.S. Joint Chiefs of Staff.

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