Identification and Evaluation of Influential Factors on New Product Commercialization in the Commercial Explosives Industry Based on the Integrated Delphi-Fuzzy and BWM Decision-Making Approach

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Abstract

Currently, commercialization is one of the most critical elements for the success of new businesses. In our country, due to the presence of human resources that are both innovative and creative, good ideas are often proposed at both the academic and industrial levels; however, unfortunately, they frequently stall at the early stages and fail to move into the production phase. Moreover, due to the existing sanctions in various industries against Iran, areas such as chemicals, mining, and construction such as dam building, road construction, and tunnel construction heavily rely on the development services of the commercial explosives industry. In this study, using both library research and field studies, 24 influential factors in the commercialization of new products in the commercial explosives industry were identified and content-validated in the first step. Subsequently, based on the fuzzy Delphi method, these identified factors were evaluated and screened, with 16 factors confirmed. Then, using the BWM decision-making method, these factors were weighted and ranked. The results of this research can significantly influence the production of new products in the commercial explosives industry by identifying the most important factors affecting new product commercialization. Given the rapid competitiveness in the market, the emergence of new technologies, increasing domestic demand, and the self-sufficiency goal of the country, this study can contribute to more efficient and increased production in this sector.

Keywords: *Commercialization, New Product, Commercial Explosives, Fuzzy Delphi Method, BWM Decision-Making Method.*

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1. Introduction

The world is constantly changing, having entered a new century characterized by speed, change, and complexity [1-4]. The shortening of product life cycles due to rapid technological advancements and the modern consumption patterns of the market can lead to recurrent changes in product features and production volumes. Consequently, for companies to achieve their goals, they must adopt flexible technologies [5]. The selection of commercialization models helps companies and organizations create competitive advantages within the market environment. Choosing the right commercialization model amidst the increasing options posed by technological growth is a significant challenge. However, making the correct choice and managing it well is a vital issue for organizations, enabling them to gain business capabilities and the potential to survive in the market [6].

Therefore, commercialization can be a crucial and fundamental element in the development strategy of a company and its movement towards sustainable development. This requires attention to research centers and supportive economic and political frameworks for such activities [7]. The commercialization process transforms raw materials or university research into economically viable and practical technologies. Especially in developing countries, where there is a lack of ability to transform research ideas into applicable technologies, commercialization is of paramount importance. While Iran is a country rich in creative ideas, it struggles to efficiently invest in utilizing these ideas in industries and applied research due to inadequate valuation and motivation for creating ideas and commercializing them.

The reviewed literature highlights various dimensions and models of technology commercialization and innovation. Anbarki and Pourhosseini examined key infrastructure and practical models for technology commercialization, identifying factors such as financial resources, synergy, direct and indirect capabilities, competition, and socio-political influences as pivotal for successful commercialization efforts (Anbarki & Pourhosseini, 2020). Ghiabi utilized expert opinions to identify effective components for commercialization in technology markets, finding that marketing, consulting, and legal/financial factors significantly influence the commercialization of knowledge-based products, explaining 74.80% of variance [8]. Aliyari and Malazadeh underscored the role of value creation through knowledge businesses, particularly in defense industries, identifying weak organizational structures, lack of attention to environmental challenges, and political contradictions as major barriers [9]. Araja et al. explored how olfactory congruence with brand image positively impacts consumer perception and store atmosphere [10]. Grace et al. (2020) developed a multidimensional brand loyalty scale, emphasizing stable consumer-brand relationships driven by engagement [11]. M'Chirgui et al. (2018) highlighted the importance of government facilitation and support for student and human capital involvement in university technology projects [12]. Henttonen and Lehtimäki (2017) demonstrated that external collaborations for business process innovation enhance open innovation and performance in SMEs [13]. Baraldi et al. (2015) analyzed the influence of self-efficacy, creativity, and regulatory factors on organizational science commercialization mechanisms [14]. Finally, Lin et al. (2015) underscored the significance of strategic alliances and inter-company collaboration for fostering high-tech product commercialization, advocating for mutual functional cooperation and knowledge creation [15]. Collectively, these studies provide a comprehensive understanding of the multifaceted factors influencing technology commercialization and innovation.

According to a 2021 report by Global Industry Analysts, the global market for explosives was estimated at 22.4 million tons in 2020. The report also forecasts that by 2027, the estimated volume will reach 29.1 million tons, indicating a compound annual growth rate of up to 3.8% from 2020 to 2027 [16]. This global outlook suggests that the industrial world is giving special attention to the development of commercial explosives industries. This is due to the necessity of utilizing these materials in the development of major industries within countries and the extensive global market, along with the significant profit margins from their exports. In fact, this research arises from internal demand and is among the core issues and concerns of relevant governmental bodies in recent years. Given the current circumstances in this industry, it can be concluded that for the survival of organizations and companies developing and producing commercial explosives, they must focus on producing new products and utilizing innovative technologies as one of their primary strategic goals in the coming years.

2. Methodology

The present study is classified as applied research in terms of its objective. From another perspective, categorized according to data collection methods, this study is a descriptive-survey research. In this research, both documentary and field studies were employed to collect data and address the research questions. The documentary study utilized existing and relevant data pertaining to the research topic, while the field study employed semi-structured interviews.

One of the most effective decision-making techniques is the use of fuzzy theory-based methods. In such matters, the problem of interest is first formulated within the framework of fuzzy decision theory, and then appropriate responses are sought using available software. A notable characteristic of this technique is the assurance of finding suitable answers based on expert opinions. This method is currently recognized as the most effective managerial method for finding appropriate solutions across a vast array of issues. In this study, opinions from 10 experts from both academic and industrial fields in the commercialization of commercial explosives were utilized. Consequently, a meeting was convened with these experts to formulate a checklist of influential components, where they were asked to express their opinions using a triangular fuzzy scale. Based on the collected information, an analysis was conducted to screen indicators, ensuring that any indicator failing to meet the minimum required score (average score) was excluded from further evaluation. The process continued with the remaining indicators.

Table 1. Verbal Variables and Corresponding Fuzzy Numbers in the Delphi Technique

Verbal Variables	Triangular Fuzzy Numbers
Very Low Importance	(0.25, 0, 0)
Low Importance	(0.5, 0.25, 0)
Medium Importance	(0.75, 0.5, 0.25)
High Importance	(1, 0.75, 0.5)
Very High Importance	(1, 1, 0.75)

After collecting data, the fuzzy average of the opinions of n respondents was calculated using Equation 1. Subsequently, Equations 2, 3, 4, and 5 were employed for defuzzification and determining the significance of indicators. Indicators with values less than the average were removed.

Equation 1:

$$Fuzzy\ Average = \left[\frac{l_1 + l_2 + \cdots + l_n}{n}، \frac{m_1 + m_2 + \cdots + m_n}{n}، \frac{u_1 + u_2 + \cdots + u_n}{n}\right]$$

Equation 2:

$$x_{\max}^{1} = \frac{l + m + u}{3}$$

Equation 3:

$$x_{\max}^{2} = \frac{l + 4m + u}{6}$$

Equation 4:

$$x_{\max}^{3} = \frac{l + 2m + u}{4}$$

Equation 5:

$$Crisp\ Number = max\ \{ x_{\max}^{1}, x_{\max}^{2}, x_{\max}^{3} \}$$

Crisp Number: A definitive number.

The best-worst method for solving multi-criteria decision-making problems is introduced. In a multi-criteria decision-making problem, a set of alternatives (proposals) are evaluated based on several criteria to select the best alternative. This method was proposed by Jaafar Rezaei in 2015. Statistical results indicate that the BWM method significantly outperforms the AHP method concerning consistency rate and other performance criteria such as minimum error, total deviation, and consistency. Notable features of the presented method compared to existing multi-criteria decision-making methods include:

- Lesser need for comparative data.
- Stable and more consistent comparisons, meaning more reliable results are obtained.

The content validity of the questionnaire was evaluated using Laosh's content validity index (CVI). There are multiple methods for measuring validity, among which the content validity ratio (CVR) is one. To calculate this index, specialists in the field of test content were asked to classify each question based on a three-part Likert scale: "item is essential," "item is useful but not essential," and "item is not necessary." Then, the content validity ratio was calculated using the following formula:

$$CVR = \frac{N_e - \frac{n}{2}}{\frac{n}{2}}$$

In this formula, N is the total number of specialists, and Ne is the number of specialists selecting the essential option. Questions with a CVR value lower than the desired level according to the number of evaluators should be excluded from the test as they do not meet acceptable content validity standards according to the CVI index.

3. Findings

Based on the evaluations conducted in the field of commercial explosives, derived from library studies and in-person interviews with industry experts, the following components were identified, as detailed in Table 2. Initially, a content analysis of the components was performed, followed by their identification and screening using the fuzzy Delphi method.

Table 2. Identified Components in Commercialization of Commercial Explosives

No.	Indicator	No.	Indicator
1	Development of domestic experiential technologies	2	Development of executive infrastructure for implementing modern techniques
3	Strengthening economic stability	4	Improving administrative bureaucracy for knowledge-driven innovations
5	Ease of obtaining necessary testing permits	6	Utilizing academic experts in pre-test analyses
7	Engagement of experienced managers in modern innovations	8	Financial support during product development and prototype production
9	Managerial commitment to implementing commercialization plans	10	Competency in feasibility analysis of research parameters for final product development
11	Presence of an R&D specialist team for detailed and conceptual design	12	Managerial leadership capabilities in technology commercialization
13	Trust in domestic technical knowledge	14	Development of a national brand at the international level
15	Optimized use of intra-organizational resources	16	Improved organizational support regulations in initial plans
17	Creation of tax exemptions for technological product development	18	Precise identification of local and international markets for required equipment
19	Utilization of domestic resources and necessary executive infrastructure	20	Use of joint international investments
21	Initial evaluation of the commercialization team's ability to execute plans	22	Knowledge flow within the organization for creating lessons learned for future projects
23	Evaluation of national benefits in product development and technology commercialization	24	Comprehensive analysis of prior technical commercialization experience

Before finalizing measurement tools and utilizing them in the main data collection stage, researchers must scientifically ensure the validity and reliability of the tools. Validity refers to whether the measurement tool can measure the specific characteristic it was designed for. Validity is crucial because inadequate or inappropriate measurements can undermine the value and credibility of scientific research. Given that the identified components for commercializing commercial explosives were derived from field studies and prior research, their validity was assessed through the content analysis approach of Lawshe by gathering the opinions of 10 experts. The results are presented below.

Table 3. Content Analysis of Commercialization Components for Industrial Explosives

Index	CVR
1	1.00
2	1.00
3	0.90
4	1.00
5	1.00
6	1.00
7	1.00
8	1.00
9	0.90
10	1.00
11	1.00
12	1.00
13	0.90
14	1.00
15	1.00
16	1.00
17	1.00
18	1.00
19	1.00
20	1.00
21	1.00
22	0.90
23	1.00
24	1.00

Based on the obtained values and their comparison, it was confirmed that the identified components are valid. Following the introduction of research experts for gathering opinions, the next section uses the fuzzy Delphi method to evaluate the identified indicators.

In this section, the fuzzy Delphi method was applied during brainstorming sessions with research experts. After collecting viewpoints, the following steps were undertaken:

1. In the first step, the components in Table 2 were labeled sequentially as C1 to C24.
2. In the second step, opinions of 10 experts were gathered in two evaluation stages using a five-point Likert scale ranging from "very low" to "very high," ensuring minimal deviation (less than 0.1). Due to its length, the related table is not presented here.
3. In the third step, the collected data was fuzzified as per Table 1. The fuzzy values of expert opinions are not provided here due to space constraints.
4. Subsequently, the fuzzy average of expert opinions was calculated. To defuzzify and determine the importance of commercialization components for commercial explosives, the fuzzy mean and the crisp values of the indicators were tabulated below. Components with crisp values greater than the fuzzy mean (>0.80) were validated for further assessment.

Table 4. Fuzzy Analysis and Selection of Key Components in the Commercialization of Industrial Explosives.

Symbol	Component Description	Fuzzy Mean	Definite Value

C1	Development of Indigenous Experimental Technologies	1.00	0.85
C2	Development of Execution Infrastructure for Implementing New Techniques	1.00	0.90
C3	Strengthening Economic Stability	0.98	0.83
C4	Improving Administrative Bureaucracy for Knowledge Innovation Development	1.00	0.88
C5	Simplifying the Provision of Necessary Permits for Testing	0.80	0.58
C6	Utilizing Academic Experts in Pre-Test Analysis	0.80	0.60
C7	Involving Successful and Experienced Managers in New Innovations	0.98	0.85
C8	Financial Support During Product Development and Prototyping	0.98	0.83
C9	Managers' Commitment to Executing Commercialization Plans	0.90	0.78
C10	Capability in Feasibility Studies for Product R&D Parameters	0.90	0.78
C11	Existence of a Specialized R&D Team for Conceptual and Detailed Design	0.95	0.85
C12	Managers' Guidance in Technology Commercialization	0.92	0.80
C13	Confidence in Indigenous Technical Knowledge	0.88	0.75
C14	Development of a National Brand at the International Level	0.95	0.88
C15	Optimal Utilization of Intra-Organizational Resources	0.85	0.70
C16	Improvement of Supportive Organizational Policies in Initial Projects	0.85	0.70
C17	Establishment of Tax Exemptions for Technological Product Development	0.90	0.78
C18	Accurate Identification of Local and International Market Needs	1.00	0.95
C19	Utilization of Domestic Resources and Required Execution Infrastructure	0.85	0.73
C20	Leveraging Joint International Investments	0.90	0.78
C21	Initial Evaluation of the Commercialization Team’s Capability for Project Execution	0.88	0.75
C22	Knowledge Flow Within the Organization to Establish Lessons Learned for Future Projects	0.85	0.70
C23	Assessment of National Interests in Product Development and Technology Commercialization	0.90	0.78
C24	Comprehensive Analysis of Prior Technical Experience in Commercialization	0.95	0.88

In this section, following the identification and screening of the components for the commercialization of industrial explosives, the ranking of indicators will be conducted according to the following steps:

Table 5. Selected Components for Use in the BWM Decision-Making Method

Symbol	Commercialization Component	Symbol	Commercialization Component
W1	Development of Domestic Experimental Technologies	W9	Trust in Domestic Technical Knowledge
W2	Development of Executive Infrastructure for Implementing Modern Techniques	W10	Development of National Brand at an International Level
W3	Strengthening Economic Stability	W11	Optimized Utilization of Intra-organizational Resources
W4	Improving Administrative Bureaucracy for the Development of Knowledge-Based Innovations	W12	Enhancing Organizational Supportive Regulations for Initial Proposals
W5	Utilizing Experienced Managers in the Field of New Innovations	W13	Leveraging Joint International Investments
W6	Financial Support During Product Development and Prototype Production	W14	Initial Assessment of the Commercialization Team's Capability to Execute the Proposal
W7	Existence of a Specialized R&D Team for Detailed and Conceptual Design	W15	Assessment of National Interests in Product Development and Technology Commercialization
W8	Leadership Capability of Managers in Technology Commercialization	W16	Comprehensive Analysis of Previous Technical Experiences in Commercialization

Based on expert opinions in the field of industrial explosive commercialization, W1 was evaluated as the best indicator, while W9 was identified as the worst.

Table 6. Pairwise Comparison Vector for the Best Criterion

W16	W15	W14	W13	W12	W11	W10	W9	W8	W7	W6	W5	W4	W3	W2	W1	Weight
5.2	5	4.7	4.8	4.4	4.3	4.8	4.6	4	6.2	4.8	5.4	3	4.2	3.6	1	Most important dimension relative to W1

Table 7. Pairwise Comparison Vector for the Worst Criterion

W16	W15	W14	W13	W12	W11	W10	W9	W8	W7	W6	W5	W4	W3	W2	W1	Weight
5.1	4.2	3.3	3.7	3.2	5.2	5.2	1	4	6.2	4.7	6.2	4.2	5.1	4.3	4.2	Least important dimension relative to W9

The relationships between the criteria, based on the BWM decision-making model, are as follows:

$$
\begin{aligned}
&\text{Min } \varepsilon \\
&\text{s.t.} \\
&|w_1 - 3.6\, w_2| \leq \varepsilon \\
&|w_1 - 4.2\, w_3| \leq \varepsilon \\
&|w_1 - 3\, w_4| \leq \varepsilon \\
&|w_1 - 5.4\, w_5| \leq \varepsilon \\
&|w_1 - 4.8\, w_6| \leq \varepsilon \\
&|w_1 - 6.2\, w_7| \leq \varepsilon \\
&|w_1 - 4\, w_8| \leq \varepsilon \\
&|w_1 - 4.6\, w_9| \leq \varepsilon \\
&|w_1 - 4.8\, w_{10}| \leq \varepsilon \\
&|w_1 - 4.3\, w_{11}| \leq \varepsilon \\
&|w_1 - 4.4\, w_{12}| \leq \varepsilon \\
&|w_1 - 4.8\, w_{13}| \leq \varepsilon \\
&|w_1 - 4.7\, w_{14}| \leq \varepsilon \\
&|w_1 - 5\, w_{15}| \leq \varepsilon \\
&|w_1 - 5.2\, w_{16}| \leq \varepsilon \\
&|w_2 - 4.3\, w_9| \leq \varepsilon \\
&|w_3 - 5.1\, w_9| \leq \varepsilon \\
&|w_4 - 4.2\, w_9| \leq \varepsilon \\
&|w_5 - 6.2\, w_9| \leq \varepsilon \\
&|w_6 - 4.7\, w_9| \leq \varepsilon \\
&|w_7 - 6.2\, w_9| \leq \varepsilon \\
&|w_8 - 4\, w_9| \leq \varepsilon \\
&|w_{10} - 5.2\, w_9| \leq \varepsilon \\
&|w_{11} - 5.2\, w_9| \leq \varepsilon \\
&|w_{12} - 3.2\, w_9| \leq \varepsilon \\
&|w_{13} - 3.7\, w_9| \leq \varepsilon \\
&|w_{14} - 3.3\, w_9| \leq \varepsilon \\
&|w_{15} - 4.2\, w_9| \leq \varepsilon \\
&|w_{16} - 5.1\, w_9| \leq \varepsilon
\end{aligned}
$$

$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 + w_8 + w_9 + w_{10} + w_{11} + w_{12} + w_{13} + w_{14} + w_{15} + w_{16} = 1$$

$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 + w_8 + w_9 + w_{10} + w_{11} + w_{12} + w_{13} + w_{14} + w_{15} + w_{16} \geq 0$$

The above model was implemented and analyzed using the Lingo mathematical programming software. Upon solving, the optimal weights of the criteria were obtained, as presented in Table 8.

Table 8. Calculated Weights of Selected Components

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
0.17	0.071	0.061	0.085	0.047	0.053	0.041	0.064	0.020	0.053	0.05	0.058	0.053	0.055	0.051	0.05

Based on the evaluation, the indicator Development of Domestic Experimental Technologies (W1) ranked first with a weight of 0.17, followed by Improving Administrative Bureaucracy for the Development of Knowledge-Based Innovations (W4) with a weight of 0.085, and Development of Executive Infrastructure for Implementing Modern Techniques (W2) with a weight of 0.071. The ranking of the 16 relevant components is presented in Table 9

.

Table 9. Final Effective Components in the Commercialization of Industrial Explosives by Importance

Component	Rank
Development of internal experimental technologies	1
Improvement of administrative bureaucracy in the development of knowledge innovations	2
Development of infrastructure for the implementation of new techniques	3
Leadership power of managers in the field of technology commercialization	4
Strengthening economic stability	5
Improvement of supportive organizational laws in initial designs	6
Initial assessment of the commercialization team’s capabilities for executing the project	7
Development of a national brand at the international level	8
Utilization of international joint investments	9
Financial support during product development and prototype production	10
Assessment of national benefits in product development and technology commercialization	11
Optimal use of internal organizational resources	12
Comprehensive analysis of previous technical experience in commercialization	13
Utilization of successful and experienced managers in the field of new innovations	14
Presence of an R&D specialist team in detailed and conceptual design	15
Trust in domestic technical knowledge	16

4. Discussion and Conclusion

In recent years, with the advancement of science and technology and the recognition of knowledge as a driver of economic growth and organizational productivity, the commercialization of knowledge and its application in various production and service sectors has been proposed. Creating platforms to enhance knowledge within organizations not only generates economic value for the organization but also contributes to the economic and technical development of society. Delivering a product to the market can ensure the success and survival of the organization. Commercialization in the commercial explosives industry is a process through which an innovative idea is introduced to the market as a technology, product, service, or new process. This process encompasses all activities, from idea generation to prototype design and testing, production, marketing, and final product sales.

In manufacturing and industrial organizations, research and development (R&D) is meaningless without commercialization. Therefore, this study examined the key components influencing the commercialization of new products in the commercial explosives industry. Initially, through library and field studies and with the assistance of 10 experts in this field, 24 preliminary components were identified. These components were validated through the content analysis method of Lawshe, and all 24 identified components were approved.

Subsequently, using the fuzzy Delphi method, the identified components were weighted and screened, resulting in 16 validated components out of the original 24. These components were then valued and ranked using the Best-Worst Method (BWM). The analysis revealed that the development of indigenous experimental technologies ranked first with a weight of 0.17, followed by the improvement of administrative bureaucracy for developing knowledge-based innovations with a weight of 0.085, and the development of executive infrastructures for implementing modern techniques ranked third with a weight of 0.071.

Overall, this research aimed to identify essential components in the commercialization of commercial explosives products using a scientific approach and the experiences and insights of experts in this field. The study contributes to the improved development of new products in the commercial explosives industry, aligning with domestic trade and industrial development strategies at the sectoral, national, and regional levels.

Authors’ Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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