Int. J. Nonlinear Anal. Appl. 15 (2024) 8, 247–258
ISSN: 2008-6822 (electronic)
http://dx.doi.org/10.22075/ijnaa.2023.30682.4466

Designing a model for determining the level of technological complexity of research and development activities in knowledge-based companies

Gholam Ali Shahmoradi[a], Taghi Torabi[b,*], Reza Radfar[c], Mohammad Hassan Cheraghali[d]

[a]*Department of Technology Management, Faculty of Management and Economics, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[b]*Department of Economics, Faculty of Management and Economics, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[c]*Department of Technology Management, Faculty of Management and Economics, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[d]*Department of Administrative Science Planning and Management, Faculty of Management, South Tehran Branch, Islamic Azad University, Tehran, Iran*

(Communicated by Farshid Khojasteh)

Abstract

Today, in developed countries, the research and development department of knowledge-based companies has played a very important role in the production of new and advanced technologies and ultimately the growth of the knowledge-based economy. One of the important reasons for the success of these companies some of which have become the world's technology giants), conducting research and development activities based on global standards and having a high level of technological complexity. The current research, which is applied research, was conducted with the aim of identifying and classifying the effective factors in determining the level of technological complexity of research and development activities in knowledge-based companies. This research is a type of qualitative research that was conducted using the data-based method. The statistical population of the research was 20 research and development experts and specialists of Iranian knowledge-based companies. Data collection was done through a literature review and semi-structured interviews until theoretical saturation was achieved. By analyzing the data, the first 149 variables were extracted and during the three stages of open, central and selective coding, 98 influential factors were identified in determining the level of technological complexity of research and development activities, then, while identifying the central category, Identified factors were included in the main categories (including: causal, contextual, intervening conditions, strategies and consequences) and the research paradigm model was extracted. In the current research, during the coding process, the identified factors were classified into 6 categories. Achieving advanced technology was considered as a central category, which includes the variables of the novelty of activity, the creativity of activity, uncertainty of result, systematicity, transferability of results, speed of development, added value of technology, distinctiveness from competitors, and credibility. The result of technology is the potential of learning, and the extent of the application of technology Conclusion: Identifying related factors will provide the possibility for knowledge-based companies to help improve the level of complexity of the country's own activities.

*Corresponding author

Email addresses: gh.shahmoradi2@gmail.com (Gholam Ali Shahmoradi), t-torabi@srbiau.ac.ir (Taghi Torabi), r.radfar@srbiau.ac.ir (Reza Radfar), m_cheraghali@azad.ac.ir (Mohammad Hassan Cheraghali)

Received: April 2023 *Accepted:* June 2023

Keywords: technological complexity, research and development, knowledge-based companies
2020 MSC: 97U70

1 Introduction

The knowledge economy is one of the most important and influential fields in countries' economic development and growth. Knowledge companies are essential for the economic growth of knowledge economies, such that these companies have been recognized as the main engine of economic growth in recent years [3]. Technology has always been essential in creating wealth for Iran, with significant effects on the people's standard level and quality of life. Thus, knowledge companies' technological innovations are of great importance and advantages [6]. Research shows that global industrial innovations and developments during the last decades stem from the innovative activities of knowledge companies [1]. Knowledge companies' standard and quality research and development activities are essential to achieve advanced and innovative technologies. These companies can generally adapt to the market's changes and fluctuations, offer new products and achieve sustainable competitive advantages through efficient methods and R&D activities [12]. Today, R& D in knowledge companies is essential in increasing the knowledge economy's share. The technological complexity of knowledge companies' R&D activities in developed countries than in other countries is higher. This higher complexity improves activities' efficiency and effectiveness. In addition, it increases the technological level of innovative products such that other countries' products cannot compete with them in the world markets, which results from the growing share of the knowledge economy in these countries [8]. Therefore, developing these companies' R&D activities based on global standards and their appropriate technological complexity have increased their importance at the national, regional, and even global level.

There are many knowledge companies in Iran working in different fields. The high profitability of developed countries' knowledge companies, on the one hand, and the necessity of effective R&D activities in resistive economies, on the other hand, have provided a prominent position for Iranian knowledge companies. Despite the various supports provided to these companies, their share in the country's economy still needs to grow, and Iran's knowledge economy ranking among other countries is not suitable. In addition to inadequate support for these companies and the need for more serious support, adjusting Iranian knowledge companies' R&D activities seems to be the most important reason for their unsuitable global ranking. Despite the unsuitable raking of Iran's knowledge economy, many Iranian knowledge companies claim to perform extensive R&D activities based on global standards. Resolving this contradiction requires studying R&D activities in Iranian knowledge companies to determine whether these companies' R&D activities are actual or not. In other words, some R&D activities are just copying, imitation, or reverse engineering, which does not provide new contributions and are not actual R&D activities. In addition, we need to measure the technological complexity of these R&D activities to compare and adapt these ongoing activities based on global standards and to develop and improve them.

There are many studies on various dimensions of Iranian knowledge companies. However, few studies have identified and classified factors affecting the technological complexity of R&D activities in Iranian knowledge companies whose R&D activities are not up to global standards. The present applied research seeks to fill this gap. Domestic and abroad researches on knowledge companies are reviewed. Most research performed in Iran examines factors like performance evaluation models, critical success factors, knowledge management models, creation and development models, human resource management, technology management, technology commercialization, innovation capabilities and capacity, organizational and managerial innovation, knowledge companies' acquisition and merge models, R&D costs, organizational culture, business model, and technology transfer. There are few studies on the technological complexity of knowledge companies' R&D activities. Most abroad research on the subject has examined factors like the technology acceptance model, the managers' technological decisions risk, the evaluation of the R&D management system, and the improvement of business power. Then, we reviewed research on knowledge companies' R&D activities, including R&D evaluation, R&D globalization, R&D portfolio management, R&D projects, R&D expenses, R&D productivity growth, R&D management, R&D critical success factors, R&D technology, R&D roadmap, R&D strategies, R&D cooperation strategies, and R&D policies and capabilities. This study fills this gap to resolve challenges such as the need for better competitiveness, the lack of up-to-date technology, and knowledge companies' weak performance. In particular, if knowledge companies adjust their weak R&D activities and improve the technological complexity of their activities, they can provide innovative products to compete with domestic and abroad markets' high technology products. As a result, they can accelerate the countries' growth and the share of the knowledge economy in their economy. This research identifies factors affecting the technological complexity of knowledge companies' R&D activities and classifies them into causal and contextual factors, interveners, strategies, and consequences. In this regard, the aim of this research is to identify effective factors in determining the level of technological complexity of research and development activities in knowledge-based companies and to classify them into causal, contextual, central, intervening, strategies and consequences factors. took In this case, research has been done, and some of these researches will be briefly explained according to the topics raised.

Konjkav Monfared [10] conducted a research entitled "Evaluation of the effect of technological innovation acceptance factors and resource commitment on knowledge management capabilities in order to increase competitive advantage." The findings of the research showed that the variables of resource commitment, perceived benefits and complexity have a significant effect on knowledge management capability and increase the advantage. In addition, the findings showed that compatibility does not have a significant effect on knowledge management capability.

Keshavarz et al. [9] conducted a research titled evaluation of success factors of knowledge-based companies in Fars Science and Technology Park with structural equation modeling approach. In this research, in order to measure and rank the success drivers of knowledge-based companies from seven components of organizational culture, organizational policy, organizational capabilities, support mechanisms, environmental infrastructure, demographic characteristics and Personality traits and 32 indicators have been used. The results of the research show that all the identified indicators have been effective in the success of the knowledge-based companies of Fars Science and Technology Park, and among the seven drivers of success, the organizational culture component has been recognized as the most important component. and the indicators of infrastructure with information technology, patents and intellectual property and supporting policies of the government have obtained the first to third ranks.

Hashemi [7] conducted a research titled investigating the behavior of human resource attraction for research and development in knowledge-based companies in response to financial and tax policies. The results showed that small knowledge-based enterprises that have received one or both technology development and commercialization facilities have been able to increase their research and development manpower; While in large knowledge-based companies, none of the combinations of support tools have had a significant effect on the increase of research and development manpower.

Yahyai and Hassanzadeh [17] conducted a research titled presenting a technology commercialization model in knowledge-based companies in the field of information and communication technology. The results of the research showed that all the six factors of Pestel's model are effective on the commercialization of technology, and the most important factor is the economic factor, and the least impact on commercialization is related to the legal factor. Also, the most important factors affecting the commercialization of technology, in the order of specific laws in the information and communication technology industry, technology transfer and bachelor's degrees, technological maturity level, access to raw materials and energy, interest rates, consumer attitudes towards goods and services, how resources are allocated by the government, external Technology outsourcing, immigration, ethical issues, new product development, future policy perspectives, income distribution, the state of the domestic economy, and intellectual property are rights.

Rezaian et al. [14] conducted research in knowledge-based companies with the aim of modeling factors affecting knowledge networks as one of the components of research and development. The results of this research showed that the development of management processes has the greatest impact on the formation of knowledge networks, and the most influential factors are located at the first level of the model, which include the type of knowledge, cultural factors, organizational structures, and communication mechanisms.

Moulaei et al. [11] conducted a research to investigate the effect of personal knowledge management on culture and innovative performance in knowledge-based companies operating in Sanandaj city in 2016. The results show the positive and significant effect of personal knowledge management on innovative culture and innovative performance in the research model.

Pakniat et al. [13] conducted a research entitled Analysis of the impact of technological innovation capabilities on technology commercialization and the performance of knowledge-based companies in Isfahan province. The findings show that the effect of the five capabilities of learning, research and development, strategic planning, organization and production on commercialization in these companies can be confirmed, while this condition does not exist for marketing capability and resource allocation. Also, the results indicate a positive and significant effect of technology commercialization on company performance. Among the influencing factors of environmental instabilities, the effect of two market instability adjustment variables on the path between technology commercialization and company performance are not confirmed, but the effect of technology instability adjustment is accepted.

Su and Lee [15] conducted a research titled using the technology acceptance model in research and development. Perceived usefulness, perceived ease of use, and perceived validity have a positive effect on users' behavioral intention. The proposed technology acceptance model provides some technical and theoretical support for the application of the technology acceptance model in research and development.

Tom Brockel [2] conducted a research entitled Measuring Technological Complexity, Current Approaches and a New Measure of Structural Complexity. In this research, while examining two existing empirical measures of technological complexity, including the reflection approach and the difficulty of knowledge synthesis approach, a new approach of structural complexity is also presented and using these three approaches Five indicators for measuring the complexity of technology are presented based on the criteria of increasing complexity over time, larger research and development, collaborative research and development, and spatial concentration [2].

The findings in [16] showed that the consensus among cultural evolutionists appears to be that human cultural evolution is cumulative, which is usually understood to mean that cultural traits, especially technological traits, increase in complexity over generations. It is argued here that there is not enough valid evidence for or against this theory of technological complexity. For one thing, the few data sets that are available hardly constitute a representative sample. For another, they prove very specific and usually different versions of the complexity thesis or, even worse, fail to mention the increase in complexity.

Erasmus et al. [4] conducted a research titled structural model of technology acceptance in knowledge-based companies. The results confirmed the significant paths from the perceived usefulness of the information system to the attitude towards and behavioral intentions to use it. In addition, behavioral intention to use the system predicted actual use. Perceived ease of use indirectly affects the attitudes and behavioral intentions of use through the perceived usefulness of the information system.

The findings in [5] showed that the more complex the design, the slower the improvement speed. It also shows that the relationship between the total cost of technology and the number of innovation attempts is asymptotically a power law, which corresponds to the functional form often observed for empirical data.

2 Methodology:

This study uses grounded theory to identify and classify factors affecting the determination of R&D activities' technological complexity in knowledge companies. It is applied in terms of purpose and qualitative in terms of method. The population includes 20 R&D experts and specialists in knowledge activities. We reviewed documents and performed semi-structured interviews to collect data. In addition, we benefited from the experts' opinions and knowledge on the research topic.

The current research has two different phases. First, we systematically review the literature by searching various databases such as Elsevier, Emerald, Springer, Civilica, Iranian Research Institute for Information Science and Technology, Scientific Information Database (SID), Noor Specialized Journals Database, Humanities Research and Cultural Studies Institute, and Magiran. Second, semi-structured interviews with experts were used to extract the final components, the data were analyzed using qualitative content analysis, and the extracted factors were categorized. . Finally, the data of strategic factors obtained are ranked using the fuzzy ahp method.

Qualitative content analysis and a paradigm model were used to analyze data. The paradigm model displays the identified categories using coding in the form of a systematic pattern. As follows, qualitative content analysis is performed through open, axial, and selective coding.

As part of the data analysis process, open coding divides, compares, conceptualizes, names, and categorizes the data. It divides the data into separate parts and analyzes them to detect their similarities and differences.

Axial coding seeks to establish a relationship between the categories produced in the open coding stage. It is called axial coding because coding is realized around a category's axis.

Selective coding includes integrating and improving the categories. It seeks to finalize the selected axial codes, which is performed by removing duplicate codes and unifying the codes with the same meanings.

Many researchers consider evaluating the validity and reliability of the research results specific to quantitative research [30], but examining the accuracy and validity of the research's data and findings is also an essential part of qualitative research [31]. The grounded theory uses various methods for validation. The current research reviews the opinions of interviewees and experts who have not participated in interviews, including three experts from knowledge companies and three writers and theorists from the R&D field. Then, the necessary editions after receiving corrective comments are performed. In addition, as Strauss and Corbin suggest, this study uses criteria such as appropriateness measures, application or usefulness of findings, concepts, contextualizing the concepts, logic, depth, variability, creativity, sensitivity, and note-taking as questions to confirm the research validity [32].

3 Quality control (extracted code control)

In order for the researcher to be able to use the qualitative findings in the analysis, he must code them. Inter-coder reliability is a widely used term that refers to the degree of agreement that independent coders obtain when evaluating the features of a message or text. The specific term for consistency in content analysis is "agreement between coders". Determining validity and reliability is a critical step in the qualitative data analysis process.

The Kappa method is one of the statistical decision-making tools that examines the amount of agreement and coordination between two individuals, phenomena, or sources of decision-making, each of which is measured separately.

Kappa coefficient is a numerical measure between -1 and $+1$, the closer to $+1$ indicates the presence of proportional and direct agreement, the closer to -1 indicates the presence of inverse agreement, and the opposite and values closer to zero indicate the opposite of agreement. to give

$$k = (p_0 - p_e)/(1 - p_e)$$

In this relationship, p_0 is equal to the ratio of units about which there is an agreement, and p_e is the ratio of units where the agreement is likely to be random.

3.1 Fuzzy AHP method

Fuzzy hierarchical analysis has two well-known methods, which are Chang's method and Yager's method. Chang's method is the most famous and common method in Iran, which we teach in this section. The stages of fuzzy AHP according to Chang's method are as follows:

Step 1: Draw a hierarchy diagram

In any multi-criteria analysis, drawing a hierarchical diagram (decision tree) is one of the first and important steps. Because it is after drawing this diagram that we clearly know the goal, the structure of the hierarchy of indicators and sub-indices, and options.

Step 2: Define fuzzy numbers to perform pairwise comparisons

At this stage, it is necessary to define your fuzzy numbers, which are needed to perform pairwise comparisons, so that the experts can provide their answers accordingly.

At this stage, the questionnaires have been provided to the experts and they have answered it. So we now have the matrix of pairwise comparisons that contain fuzzy numbers.

Now the point is, what should we do when we are faced with several respondents? The safest thing to do is to look for the answer in the original source of this method, i.e. in the original article of Chang's method. Chang's Fuzzy AHP article mentions that when we have multiple respondents (which is the case in %99 of cases), we should take the arithmetic mean of the opinions, that too in only one half-matrix.
Step 4: Calculate the matrix S for each row of the pairwise comparison matrix S are triangular fuzzy numbers calculated from the following equation:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \bigotimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$$

In the above relation, M are triangular fuzzy numbers inside the matrix of pairwise comparisons. In fact, when calculating the matrix S, we add each component of the fuzzy numbers one by one and multiply the total sum by the fuzzy inverse.

Step 5: Calculate the degree of magnitude of S relative to each other In this step, the Sis are compared with each other in terms of magnitude, based on the following formula:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) = \begin{cases} 1 & \text{if}\, m_2 \geq m_1 \\ 2 & \text{if}\, l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases}$$

that in the above relation,

$$M_2 = (l_2, m_2, u_2)\,,\; M_1 = (l_1, m_1, u_1)$$

Step 6: Calculating the weights of criteria and options in pairwise comparison matrices.

In this step, it is enough to obtain the unnormalized weight vector by calculating the lowest value calculated in the previous step.

Step 7: Calculate the final weight vector.

In the last step, we normalize the weight vector obtained from the previous step, which was not normalized, to obtain the final weight vector, which is our final goal of fuzzy calculations.

Interpretive structural method

Interpretive structural modeling method is an interactive learning process. In this technique, a set of different elements are structured in the form of a comprehensive systematic model. Such a model that is formed, draws the structure of a complex issue or a problem in the form of a carefully designed pattern in the form of a diagram. This method is an interpretive model in which a group of experts decide whether and how the elements are related, and it is a structural model in that it extracts complex components based on the relationship of the structure and specific relationships through the modeling method. and explains the overall structure as a diagram model. This method is a tool to create order in the complexity of relationships between variables and is a suitable option for dealing with complex issues, especially when using systematic and logical thinking.

The various steps involved in the ISM technique are shown in the figure above. These steps ultimately lead to the creation of an ISM model, which are explained in the following steps:
Step 1) Identification of variables related to the problem: The ISM method begins with the identification of variables that are related to the problem or topic under discussion. These variables are obtained through the study of the subject literature, past studies, through receiving the opinions of experts or through questionnaires.
Step 2) Forming the structural matrix of internal relations of variables (SSIM): This matrix (structural self-interaction matrix) is a matrix with the dimensions of the variables, which are listed in the first row and column respectively. Then the two-by-two relationships of the variables are specified by symbols. The structural self-interaction matrix is formed based on the discussions and opinions of the industry, organization and university experts. To determine the type of relationships, it has been suggested to use different management techniques, such as brainstorming and nominal group techniques, etc., according to experts. The symbols in the table below are used to determine the type of relationship.
Step 3) Creating the achievement matrix (RM) or the received matrix: by converting the symbols of the SSIM matrix to the numbers zero and one, the achievement matrix can be reached. By following these rules, the initial acquisition matrix is prepared. These rules are as follows:

Step 4) Adapt the achievement matrix: After the initial achievement matrix is obtained, its internal consistency should be established. For example, if variable 1 leads to variable 2 and variable 2 leads to variable 3, then variable 1 should also lead to variable 3, and if this state was not established in the initial achievement matrix, the matrix should be modified and the relationships that were missed be replaced.

If we have n criteria as described in $c_1, c_2, \cdots, c_n$ and their pairwise comparison matrix is as follows:

$$A = [a_{ij}], \qquad i, j = 1, 2, \cdots, N$$

where a_{ij} shows the preference of element c_i over c_j, if we have in this matrix:

$$a_{ik} \times a_{kj} = a_{ij} \qquad i, j, k = 1, 2, 3, \cdots, n.$$

Then we say that the matrix A is consistent.

In this part, we want to know that if the matrix of pairwise comparison is inconsistent, what is the amount of inconsistency of the matrix and how do we measure it. Before stating the criteria for measuring inconsistency, some important facts about each pairwise comparison matrix are mentioned:

Theorem 3.1. If $1\lambda, 2\lambda, \cdots, n\lambda$ are the eigenvalues of the pairwise comparison matrix A, the sum of its values is equal to n:

$$i = n\lambda \sum$$

Theorem 3.2. The largest eigenvalue ($\max\lambda$) is always greater than or equal to n, in this case some λs will be negative.

$$n \leq \max\lambda$$

Theorem 3.3. If the elements of the matrix deviate a little from the compatible state, its eigenvalues will also deviate a little from their compatible state.

$$w \cdot \lambda A \times w =$$

where λ and w are the eigenvalue and eigenvector of matrix A, respectively. In the case that matrix A is compatible, one eigenvalue is equal to n (the largest eigenvalue) and the rest are equal to zero. Therefore, in this case we can write:

$$A \times w = n \times w.$$

In the case that the pairwise comparison matrix A is inconsistent, according to Theorem 3.3, $\max\lambda$ deviates slightly from n, which can be written:

$$\max \times w\lambda = A \times W.$$

The reason for using $\max\lambda$ according to theorem 3.3 is that it will have the smallest distance from n. Since $\max\lambda$ is always greater than or equal to n, and if the matrix deviates from the compatibility mode, $\max\lambda$ will deviate from n, so the difference between $\max\lambda$ and n $(n - \max\lambda)$ depends on the value of n, and to solve this dependence, the scale can be defined as follows, which we call the inconsistency index (I.I.).

$$\max - n/n - 1\lambda = I.I.$$

Note: according to theorem 3.1, we have $i = n\lambda \sum$ or $i\lambda = -\sum \max - n\lambda$, that is, $\max - n\lambda$ The values of the inconsistency index (I.I.) have been calculated for matrices whose numbers have been chosen completely randomly and they have called it the random matrix inconsistency index (I.I.R.), whose values for n-dimensional matrices are according to the table below:

For each matrix, the result of dividing the inconsistency index (I.I.) by the inconsistency index of the random matrix (I.I.R.) is then a suitable criterion for judging inconsistency, which we call the inconsistency rate (I.R.). If this number is smaller than 0.1, the compatibility of the system is acceptable, otherwise you should reconsider your judgments.

Step 5) Determining the level and priority of variables: In this step, using the final achievement matrix, the set of output and input for each variable is obtained. To determine the level and priority of the variables, the achievement set (output) and the prerequisite set (input) are determined for each variable.

The output set of a variable includes: components of the system from which the component originates. To determine the late set of each component, the corresponding line should be checked. The numbers ((1)) of this line indicate the directional lines from which it leaves. The input set of a variable includes: components of the system that lead to that component. To determine the advanced set and its corresponding column component, the number of ((1)) in this column indicates the directional lines that enter that component.
After determining the set of output (achievement) and input (prerequisite) for each variable, common elements in the set of achievement and prerequisite are identified for each variable.

After determining the prerequisite sets and achieving common elements, it is time to determine the variable level (elements). In the first table, a variable with the highest level of the hierarchy of the interpretive structural model is placed, whose achievement set and common elements are completely similar. After determining this variable or variables, we remove them from the table and form the next table with the rest of the remaining variables. In the second table, as in the first table, we specify the second level variable. This operation is repeated until the level of all variables is determined.

Step 6) Drawing the model: after determining the relationships and level of the variables, they can be drawn in the form of a model. For this purpose, first, the variables are adjusted according to their level from top to bottom. At this stage, according to the levels obtained from the variables and the final matrix, an initial model is drawn and the final model is obtained by removing transferability in the initial model. The relationship between the variables and the direction of the arrow is determined from the final matrix.
Step 7) Analysis of penetration power and degree of dependence (MICMAC): MICMAC or mutual influence of matrix multiplication applied for classification; The purpose of this analysis is to identify and analyze the power of penetration

and the dependence of the variables. At this stage, by summing the entries of ((1)) in each row, the power of penetration and also the sum of the entries of ((1)) in each column, the amount The dependence of the variables is obtained. Based on this, the influence-dependence diagram is drawn. In this analysis, the variables are classified into four groups according to their power of influence and dependence:

1- Self-governing (independent) variables: which have weak influence and dependence. These variables are somewhat separate from other variables and have few and weak connections with the system.

2- Dependent variables: they have weak influence, but high dependence.

3- connection variables: which have high influence and dependence. These variables are non-static, because any kind of change in them can affect the system and finally the feedback of the system can change these variables again. In fact, any action on these variables leads to the change of other variables.

4- Independent variables: they have high influence and low dependence.

3.2 Fitting the structural model

After examining the fit of the measurement models, it is time to fit the structural model of the research. Unlike the measurement models, the structural model section has nothing to do with the questions (manifest variables) and in this section, only the hidden variables and the relationships between them are examined. be made t-values and R2 values have been used to check the fit of the research structural model. R2 is a measure that shows the impact of an exogenous variable on an endogenous variable, and three values of 0.19, 0.33, and 0.67 are considered as criteria for weak, medium, and strong values.

4 Findings:

A total of 65 documents, including articles, books, and theses related to the research topic, were investigated to collect data. For this purpose, the valid databases of the relevant documents were first extracted. Then, we screened them several times, and the final documents were selected.
To extract effective factors affecting the technological complexity of the R&D activities in knowledge companies, 20 R&D experts and specialists from knowledge fields were interviewed. We performed three additional interviews to ensure theoretical saturation. Then, their data were analyzed, which did not lead to the discovery of new concepts and categories.

Finally, open, axial, and selective coding were used to analyze and code the data collected from the literature review and interviews. Strauss and Corbin's paradigm models were used to categorize the open codes.

For the open coding, the text of each interview and the finalized documents extracted from the literature were read. Then, an open code was assigned to each key point, extracting 149 codes, including 54 open codes from reviews and 95 codes from interviewing experts.

The categories of this model are causal conditions, contextual conditions, axial categories, intervening conditions, strategies, and consequences. Causal conditions (C) are related to the categories affecting the axial category. In this research, causal conditions represent events or incidents that directly affect the technological complexity, cause its occurrence or development, and have time priority. Contextual conditions (UC) are special conditions affecting strategies. They are stable patterns intertwined with specific times and places that create situations in which individuals and organizations act/react under them. Axial category (AC) is a mental form of a phenomenon that is the basis of the process. Intervening conditions (IC) are general contextual conditions affecting strategies. They refer to events changing the intensity of causal conditions' effectiveness. Intervening conditions appear contingently and unexpectedly. Strategies (S) are specific actions or interactions resulting from the axial phenomenon. Consequences (CO) result from strategies.

The current research based on this model uses the code of access to advanced technology as the axial category, and other categories are related to it. The extracted open codes are categorized as causal conditions, contextual conditions, intervening conditions, strategies, and consequences. The results of this process are presented in Table 1.

Selective coding based on the axial coding's findings complements categories needing further improvement and development and removes and merges duplicate codes and codes with the same meanings; finally, 98 codes were extracted. Table 2 presents the results of selective coding.

The integrating process of categories at this stage uses theoretical theorems based on the paradigm model, and accordingly, five hypotheses are proposed.

Table 1: Axial coding

Category	Axial code
Axial category	Access to advanced technology, including activity originality, activity creativity, outcome uncertainty, systematicity, transferability of R &D results, development speed, technology's added value, difference, technology credit, learning potential, technology application broadness, technology codability, new knowledge transfer capacity, technology uniqueness, rapid growth
Causal conditions	Sharing information, improving ability, reducing occupational classes, organizational creativity, organizational trust, job satisfaction, considering talents, encouraging ideas, advising employees, empowering the organization, skilled and empowered users, supportive policies, R&D intensity, absorbing capacity, appropriate design and budgeting, amount of investment on R&D, supporting factors, physical and structural resources, financial and capital resources, employees' motivation and commitment, specialized and qualitative workforce, problem-solving skills, workforce quality, employees' knowledge from an organizational perspective, job importance
Contextual conditions	Period type, corporate strategy, corporate culture, management convenience, technological complexity, increased complexity over time, more extensive R&D, collaborative R&D, spatial concentration, safety, environment, convenience, innovation, occupational safety and health, environmental effects, innovation source, cultural embedding, willingness and ability of the technology recipient to meet the technology owner's requirements, the technology owner's control on the recipient's use of the technology, the cooperation purpose, the cooperation terms definability, the capital sharing ability, necessity of quick access to the desired technology, structural complexity, difficulty of combining knowledge, risk management, management and leadership style, focused decision making, systemic thinking, and organizational missions
Intervening conditions	R& D limitations, technological infrastructure, guidelines and laws, technological skills, job knowledge and information, organizational recognition, participation in staff meetings, technology's environmental compatibility, job attitude to technology, familiarity with technology and market, company's size/power, employees' expertise and skill, the reference country (in terms of culture), technical infrastructure, feedback, market access, work processes, acquisition cost
Strategies	Communicating method with the company, technology dependence, level of commitments, knowledge leakage, finding research, research purpose, performance, outputs, techniques used, required qualifications, work size, time horizon, financial resources, future employment guarantee, sense of belonging, organization's interest in technology, organizational adherence, need for technology, making R&D organization more efficient, choosing the right job, organizing workshops, training courses, training and empowering personnel, job training, job promotion, information exchange, reverse engineering, continuous improvement, flexibility, open innovation, creative space
Consequences	Technology protection ability, risk level, organization's relative ability in the desired technology, competitive (strategic) effect of technology, technology life cycle, technology ease of use, technology usefulness, aligning organization's strategy with its R&D, readiness to use technology, organization's goals consistency with technology, patents and intellectual property, R&D results' commercialization, technology intelligence, technology competitiveness, research applicability, products' quality and reliability, creating new opportunities, produced knowledge complexity and broadness, globalizing R&D activities, aligning strategies, resistive economy, and business success

Identifying and prioritizing the strategic factors of model development Prioritizing variables using fuzzy AHP approach

After the introduction of the fuzzy AHP method by Saati in the 1970s, many models in the field of fuzzy AHP have been presented by various researchers. In these methods, fuzzy and hierarchical concepts have been used in a combined manner. In the first stage, a questionnaire was prepared for pairwise comparisons and given to 15 experts, and the results of the questionnaire were analyzed using MATLAB software. has been the results are as follows:

Inconsistency rate: 0.02

The inconsistency rate shows how much the collected data can be trusted from each expert's point of view. The basis of hierarchical analysis calculations is based on the primary judgment of the decision maker, which appears in the form of a matrix of paired comparisons. Therefore, any error and inconsistency in the comparison of elements affects the final result obtained from the calculations. According to the table above, axial factors have the highest priority and Consequences with a weight of 0.123 have the lowest priority. Also, the compatibility rate is equal to 0.02, so the compatibility of the criteria with the purpose of the research is acceptable. The output of MATLAB software for prioritizing development subsets according to experts' answers is as follows:

5 Discussion :

This qualitative research identifies and classifies factors affecting the technological complexity of R&D activities in knowledge companies. As a result, knowledge companies can improve the complexity of their R&D activities and provide advanced technologies and innovative competitive products at the world-class to increase the share of the knowledge economy in the countries' economies. Influential factors were identified by reviewing the literature and interviewing R&D experts in knowledge companies. The grounded theory was used to code documents and interviews in MAXQDA, which resulted in the extraction of 149 open codes. Finally, 98 factors were identified and classified

Table 2: Selective coding

Consequences	Strategies	Axial category	Intervening conditions	Contextual conditions	Causal conditions
Technology protection capability Risk level Technology life cycle Technology usefulness Aligning R&D with the organization's strategy Patents and intellectual property Commercialization of R&D results Technology smartness Technology competitiveness Research applicability Products' quality and reliability Creating new opportunities Produced knowledge's complexity and broadness Globalizing R&D activity Resistive economy Business success	Continuous improvement Flexibility Open innovation Creative space Technology dependence Commitments Knowledge leakage Information exchange Finding research Research purpose Performance Outputs Techniques used Required qualifications Work size Time horizon Future employment guarantee Sense of belonging to organization Technology necessity Making the R&D more efficient Employees' training and empowering Promotion Reverse Engineering	Access to advanced technology, including activity originality and creativity Outcome uncertainty Systematization Results transferability Evolution speed Technology application broadness Technology added value Competitive advantage Credit from technology Learning potential	R&D limitations Guidelines and rules Work processes Job knowledge and information Technology's environmental compatibility Familiarity with technology and market Company size/power Employees' expertise and skill Feedback Market access Technological infrastructure Technology skills	Enterprise strategy Company culture Increased complexity over time More extensive R&D Collaborative R&D Spatial concentration Occupational safety and health Environmental effects Innovation source Cultural embedding Structural complexity Difficulty of combining knowledge Risk management Management and leadership style Focused decision making Systematic thinking	Information sharing Improving abilities Organizational creativity Organizational Trust Job Satisfaction Considering talents Encouraging idea creation Consulting employees Organization empowerment Skilled and capable users Supportive policies R&D intensity Absorption capacity Supporting agents Physical and structural resources Financial and capital resources Employees' motivation and commitment Expert and quality workforce Problem-solving skills

Table 3: Final weights of strategic criteria with AHP approach

Consequences	Intervening Factors	Contextual Factors	Causal Factors	Strategies	Axial Factors	
0.123	0.138	0.169	0.178	0.191	0.201	Weight

Table 4: Ranking of model dimensions

rank	Weight	Dimensions	
1	0.201	Axial category	Dimensions of the model for determining the level of technological complexity of research and development activities
2	0.191	Strategies	
3	0.178	Causal conditions	
4	0.169	Contextual conditions	
5	0.138	Intervening conditions	
6	0.123	Consequences	

into six categories during the coding process. Access to advanced technology was selected as the axial category, which in turn includes variables such as activity novelty, activity creativity, outcome uncertainty, systematicity, results' transferability, evolution speed, technology's added value, competitive advantage, technology credibility, learning potential, and technology's broad application. Five hypotheses are proposed based on the research findings:

1. Causal conditions to reach advanced technology, including 19 factors of information sharing, improving abilities, organizational creativity, organizational trust, job satisfaction, considering talents, encouraging idea creation, consulting employees, organization empowerment, skilled and capable users, supportive policies, R&D intensity, absorption capacity, supporting agents, physical and structural resources, financial and capital resources, employees' motivation and commitment, expert and quality workforce, problem-solving skills, affect the axial category.

2. Contextual conditions, including 16 factors of enterprise strategy, company culture, increased complexity over time, more extensive R&D, collaborative R&D, spatial concentration, occupational safety and health, envi-

ronmental effects, innovation source, cultural embedding, structural complexity, the difficulty of combining knowledge, risk management, management and leadership style, focused decision making, and systematic thinking provide a general bed for the constant effort to achieve advanced technology, and they are influential on strategies.

3. Intervening conditions, including 12 factors of R&D limitations, guidelines and rules, work processes, job knowledge and information, technology's environmental compatibility, familiarity with technology and market, company size/power, employees' expertise and skill, feedback, market access, technological infrastructure, and technology skills provide a specific bed for the constant effort to achieve advanced technology, and they are influential on strategies.

4. Strategies, including 23 factors of continuous improvement, flexibility, open innovation, creative space, technology dependence, commitments, knowledge leakage, information exchange, finding research, research purpose, performance, outputs, techniques used, required qualifications, work size, time horizon, future employment guarantee, sense of belonging to the organization, technology necessity, making the R&D more efficient, employees' training and empowering, promotion, and reverse engineering, refer to actions and reactions leading to advanced technologies, and they are influential on consequences.

5. Advanced technology acquisition and measures to maintain and continue it leads to consequences such as technology protection capability, risk level, technology life cycle, technology usefulness, aligning R&D with the organization's strategy, patents and intellectual property, commercialization of R&D results, technology smartness, technology competitiveness, research applicability, products' quality, and reliability, creating new opportunities, produced knowledge's complexity and broadness, globalizing R&D activity, resistive economy, and business success.

6 Conclusion:

According to the model obtained from the analysis of the interviews conducted with the foundation's data approach, it can be seen that with the acquisition of advanced technology as a central category that includes the variables of novelty of activity, creativity of activity, uncertainty of result, systematicity, transferability. The results are the speed of transformation, the added value of technology, being different from competitors, the credibility of technology, the potential of learning, and the extent of the application of technology. There may be other factors in determining the level of technological complexity of research and development activities in knowledge-based companies that have not been identified. Since conducting research and development activities that have high technological complexity can lead to the provision of competitive technological products, providing a model of the relationship between technological complexity of research and development activities and improving the market performance of knowledge companies. The basis and finally increasing the share of the knowledge-based economy can be a suitable case for future researches.

Ethical considerations:

In this research, by introducing the sources used, the ethics of scientific trustworthiness and intellectual rights of the authors of the works have been respected, and other scientific principles such as confidentiality and informed consent have been observed..

Appreciation and thanks:

The authors would appreciate the cooperation of all R&D experts and specialists of knowledge companies in interviews.

References

[1] P. Azoulay, J.S. Graff Zivin, and B.N. Sampat, *Public R&D investments and private-sector patenting: Evidence from NIH funding rules*, Rev. Econ. Stud. **86** (2019), no. 1, 117–152.

[2] T. Broekel, *Measuring technological complexity-current approaches and a new measure of structural complexity*, arXiv preprint arXiv:1708.07357, 2017.

[3] F. Da Silva, E. de Araujo, and M. de Moraes, *Innovation development process in small and medium technology-based companies*, J. Innov. Manag. Rev. **13** (2016), no. 3, 176–189.

[4] E. Erasmus, S. Rothmann, and C. Van Eeden, *A structural model of technology acceptance*, SA J. Ind. Psycho. **41** (2015), no. 1, Art. 1222, 12.

[5] J.D. Farmer, J. McNerney, S. Redner, and J.E. Trancik, *The role of design complexity in technology improvement*, Atlanta Conf. Scie. Innova. Policy, Ivan Allen College of Liberal Arts, 2009.

[6] L. Ferri, R. Spanò, M. Maffei, and C. Fiondella, *how risk perception influences CEOs' technological decisions: Extending the technology acceptance model to small and medium-sized enterprises' technology decision makers*, Eur. J. Innov. Manag. **24** (2021), no. 3, 777–798.

[7] Z. Hashemi, *Investigating the behavior of research and development human resource attraction in knowledge-based companies in response to financial and tax policies: a case study of Iran*, Tehsehe Tehsil **7** (2018), no. 3, 91–124.

[8] H. Jorat, *Evaluation of knowledge management system using technology acceptance model*, Int. Conf. Electric. Engin. Comput. Sci. Inf. (EECSI), 2017.

[9] S. Keshavarz, N.M. Yaqoubi, and A. Deghati, *Assessing the success factors of knowledge-based companies in Fars Science and Technology Park with the approach of modeling structural equations*, Sci. Technol. Policy Quart. **11** (2021), no. 1.

[10] A. Konjkav Monfared, *Analysis of the impact of technological innovation acceptance factors and resource commitment on knowledge management capabilities in order to increase competitive advantage (research sample: knowledge-based companies in Yazd province)*, Organ. Knowledge **3** (2019), no. 10, 175–147.

[11] S. Moulaei, R. Shakri, and N. Yaqoubi, *The effect of personal knowledge management on culture and innovative performance in knowledge-based companies*, Manag. Res. Iran **22** (2017), no. 4, 150–129.

[12] M.F. Mubarak, F.A. Shaikh, M. Mubarik, K.A. Samo, and S. Mastoi, *The impact of digital transformation on business performance: A study of Pakistani SMEs*, Engin. Technol. Appl. Sci. Res. **9** (2019), no. 6, 5056–5061.

[13] M. Pakniat, R. Ansari, and A. Shahin, *Analysis of the impact of technological innovation capabilities on technology commercialization and performance of knowledge-based companies in Isfahan province*, Innov. Manag. **5** (2015), no. 9, 59–84.

[14] A. Rezaian, N. Nezafati, and R. Bagheri, *Formation of knowledge network in knowledge-based companies*, Bus. Manag. Explor. **10** (2017), no. 20, 213–187.

[15] Y. Su and M. Li, *Applying technology acceptance model in online, entrepreneurship education for new entrepreneurs*, Front. Psycho. **12** (2021), 713239.

[16] K. Vaesen and W. Houkes, *complexity and technological evolution: what everybody knows?*, Bio. Philo. **32** (2017), 1245–1268.

[17] M. Yahyaei and A. Hassanzadeh, *Presenting the model of technology commercialization in knowledge-based companies in the field of ICT*, Danesh Invest. **7** (2017), no. 26, 63–82.