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Research Paper

Structuring Effective Factors on Maturity of Technology Using the ISM Method

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Abstract **Due to the dynamic nature of technology, capabilities related to production technologies that have been created for manufacturing new and unique products are constantly changing. Therefore it is essential to monitor the processes and techniques used to understand whether the production of a product fits future circumstances. Leaders of organizations must decide when to switch to a new technology, to maintain and increase competitive advantages. In such conditions, evaluating the maturity of the considered technologies is essential. This article with a conclusive view at various factors affecting the maturity of technology, examines the structuring of the factors affecting the aforementioned maturity. This model is based on Interpretive Structural Modelling (ISM) methodology. The ISM approach enables groups and individuals to identify complex relationships among a multitude of elements in a complex decision-making situation; and it works as a tool for organizing and directing complexities of relationships between variables. This technique starts with identifying variables that are related to the issue, then the contextual relations between the variables are determined using the knowledge and experience of the experts; finally, the multilevel structural model is formed.**

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Introduction

In general, manufacturing companies that deal with utilizing capabilities of technologies, are faced with numerous changes and affective factors such as market demand and product life cycle. In order to overcome these numerous changes and various effective factors, companies must constantly apply techniques and processes that are effective and efficient. Manufacturers must know whether or not, the technologies they use in the making of their products are proportionate to the probable effective factors of the future. A few of these factors are: fluctuations that exist in the life cycle of a product, or the rules and regulations related to environmental law that get stricter and more serious every day. Based on Porter's opinion, technology leadership is an accessible method that helps maintain the competitive advantage in companies that are active in countries with high salaries. On the other hand finding new technologies helps manufacturers maintain their competitive advantages and work towards increasing them. Meanwhile, when it comes to choosing a new technology, by reducing the production cost, new processes affect the choices and options of the companies. Technology related risks are always accompanied by new choices. Therefore, to minimize these risks, only the technologies that have a particular amount of maturity (technology readiness level) should be used in the production environment. Technology maturity refers to the development level of a technique or a process of production. On the other hand, nanotechnology is a newly emerging technology; therefore, presenting a tool for maturity assessment can strengthen this industry. Technologies play a key role in a firm success, as they contribute positively to creating value and standing in the market leader position in a competitive environment. technology and its evaluation has always been a major challenge for business executives. paying attention to this issue is especially necessary in countries that consumes technology more than they create it (Zoleikhaei et al, 2020). This article presents an approach for structuring indexes that are related to technology maturity in order to evaluate the effectiveness of the technology maturity indexes. In this article based on the indexes obtained by experts related to technology maturity, the relationship and dependency between qualitative variables of the problem have been discovered.

Backgroud

In comparison with the life cycle of plants and trees, production technologies exhibit similar behavior, which can be explained with a concept known as technology life cycle. this curve of life cycle exhibits different behavior in different stages. Various models have been created in the scientific literature to describe these different characteristics. Each of these models have specific characteristics and examine the technology life cycle from one particular aspect. The Ryan and Ford model is one of these models that considers the strategic aspects of using a technology. According to Ford and Ryan, the probability to achieve competitive advantages is severely dependent on technology maturity. This model divides technology life cycle into four strategic roles. Therefore in a graph like this, both competitive potential, and technology maturity are kept in mind. Parallel to the lifecycle there are four stages that a technology goes through: innovative technology, crucial technology, standard technology and obsolete technology (replaced). Depending on the stage of the technology, it exhibits different characteristics. One of the important factor in the failure of the technology application to gain a competitive advantage in firm is the lack of awareness and knowledge of the level of technological capabilities of the firm and their use for comparative advantages (Zoleikhaei et al, 2020). While standard technologies have high efficiency, obsolete technologies are old-fashioned and do not have any value due to their inefficiency. Through the usage of technology and its correction by one or multiple companies, simultaneously with a decrease in competitive potential the maturity increases. Competitive potential in these conditions refers to the opportunity to obtain advantages such as process time reduction, production cost reduction, or new product development in comparison with other competitors. In order to determine the stage of technology and to evaluate it, Ford and Ryan considered a number of qualitative indexes such as the amount of time needed for further development, the duration of progress, and the sustainability of a competitive advantage. However, qualitative factors give an inaccurate estimate on the maturity of a technology. For example, most of the indexes presented by Ford and Ryan are the same in more than one of the stages. Hence, investment indexes in development of technology have the same effect on innovative, standard, and old-fashioned or replaced technologies that are related to the life cycle of technology. Finally, given that this model has no limitations regarding time, predicting its future behavior is almost impossible. Therefore, this model is not capable to determine and evaluate technology maturity.

Method

In this regard, for evaluating the maturity of technology we need to define the indexes. Thus, the maturity is defined as "a state in which we have achieved full development and growth." From the point of view of production, maturity refers to a process that has been fully comprehended, documented, there is official training and explicit knowledge about it, and it is constantly monitored and improved. Therefore, it can be inferred that the general performance and behavior of these processes are extensively predictable. Based on this definition for maturity, in this research “documenting, dynamicity and capability” in a system are defined as the three main stages that can include the subgroups for designing indexes to evaluate maturity.

Therefore, in the first step, these three groups are identified as items that can house indexes as subgroups of this categorization. Table 1 displays this categorization.

Table 1.
Process Management Categorization

Categorization	Description
Documenting	This category refers to a state, in which documenting is connected to production processes. In fact, this category represents the type of documenting that is connected to activities which are present and there is a guarantee that the process will stay active. In general, documenting in its most basic definition includes such matters, but it is not necessarily limited to scientific papers, internal reports, books, standards and etc.
Dynamicity	This category defines a level of change that exists in connection with capabilities of each of the production processes. This category includes activities that lead to improvement and change in a process.
Capability	This category refers to a consistency in achieving an output that has been previously defined, while utilizing and implementing specific production processes. This category defines a set of activities and characteristics that display, whether or not production processes can achieve predetermined goals in performance and capability in logical stability.

As it was mentioned before, for evaluation we need to identify a set of process maturity indexes that are related to each of these three categories. These indexes were obtained for each of the categories via brainstorming in a meeting with a few members of the Nano Organization. Then, they were presented to a group of experts for evaluation in the form of a questionnaire. In this stage, some of the indexes were eliminated and some that were overlapping according to the experts, were aggregated and eventually considered as a single index. The obtained indexes will be structured from every aspect as effective factors on technology maturity. Regarding the number of obtained indexes from the aspect of dynamicity, they are divided into two sections of internal dynamicity (what is related to processes and activities that are inside the limitations of the controlling company) and external dynamicity (what is related to processes and activities that their result are).

Findings

In 1997 SAGE presented the interpretive structural modelling. This method categorizes the factors and identifies the relationships between different criteria. Interpretive structural modelling is an effective approach for subjects in which qualitative variables, with different significance levels, have reciprocal effects on each other. Using this technique, makes it possible to discover the relationships and dependencies between the qualitative variables of a problem (Charles et al. 2008). In this paper, after extraction of indexes and forming matrixes, all the stages for the development of the desired model using the ISM method, are the subject of this research (Goyandan et al. 2012). After literature review of the subject, 27 criteria were extracted by the experts, which were deemed effective on technology maturity in Nano industry. And, they are displayed in the table 2.

Table 2.
Research Indexes

Index	Code	Index	Code	Index	Code
Case study	A1	Investment growth rate	B1	Process documentation and reengineering	C1
Standardization	A2	Devices and equipment failure rate	B2	Production capability	C2
Article, books and publications	A3	Sales rate	B3	Commercialization	C3

Index	**Code**	**Index**	**Code**	**Index**	**Code**
Identified and documented processes	A4	Existence of new practical fields	B4	Predictability	C4
Internationally similar and standard steps	A5	Repeatability in sale	B5	Environmental friendliness	C5
Specific method for quality measurement	A6	Multitude of supplier and manufacturer	B6	Sustained quality of the process	C6
Process registration in the data management system	A7	Dependence on workforce skill	B7		
		Constant improvement of performance	B8		
		existence of defined goals for technological improvement and optimization	B9		
		Mechanization of the process	B10		
		The capability to match a technological process with new needs and necessities	B11		
		Identification of sources of error	B12		
		Measurability of the process	B13		
		Repeatability of the results in each stage of the process			

In the following, to obtain results, self-interaction Matrixes must be formed. Considering that these indexes were designed in three groups, then three separate matrixes will form for each group of index and finally, the results will be assessed separately. In the first step, we form the structural self-interaction matrix using the responders' answers. For the formation of structural self-interaction matrix, experts consider the criteria in pairs and answer the following comparisons based on the below spectrum.

V: The agent of the row i is the cause for the realization of the agent of column j.

A: The agent of the column J is the cause for the realization of the agent of row i.

X: Both agents of column and row cause the realization of each other (the agents of i and j have a reciprocal relationship)

O: there is no correlation between the agents of column and row.

Self-interaction matrix is displayed in the table 3.

Table 3.

Structural Self-Interaction Matrix

	A1	A2	A3	A4	A5	A6	A7
A1		o	v	x	o	x	o
A2			v	x	x	x	v
A3				x	o	o	o
A4					x	v	o
A5						o	A
A6							v
A7							

In the second step, primary access matrix must be formed via transforming the structural self-interaction matrix to ones and zeros. To do this, the following principles are stated.

- If the symbol of the ij square was the letter V, in that square the number 1 and in the opposite square, the number 0 will be put.
- If the symbol of the ij square was the letter A, in that square the number 0 and in the opposite square, the number 1 will be put.
- If the symbol of the ij square was the letter X, in that square the number 1 and in the opposite square, the number 0 will be put.
- If the symbol of the ij square was the letter O, in that square the number 0 and in the opposite square, also the number 0 will be put.

Primary access matrix is displayed in the table 4.

Table 4.
Primary Access Matrix

	A1	A2	A3	A4	A5	A6	A7
A1	0	0	1	1	0	1	0
A2	0	0	1	1	1	1	1
A3	0	0	0	1	0	0	0
A4	1	1	1	0	1	1	0
A5	0	1	0	1	0	0	0
A6	1	1	0	0	0	0	1
A7	0	0	0	0	1	0	0

After the primary access matrix was acquired, its internal compatibility must be established. For example, if the variable 1 leads to variable 2 and the variable 2 leads to variable 3, the variable 1 must also lead to the variable 3. If the access matrix was not acquired in this state, it must be corrected, and these relationships must be established. This compatibility must be added to the primary access matrix using the secondary relationships which might not exist. In table 5 the cells that are marked with 1* are the relations that have been created in the compatible matrix.

Table 5.
Compatible Primary Access Matrix

	A1	A2	A3	A4	A5	A6	A7	Penetration power
A1	1	1*	1	1	1*	1	1*	7
A2	1*	1	1	1	1	1	1	7
A3	1*	1*	1	1	1*	1*	0	6
A4	1	1	1	1	1	1	1*	7
A5	1*	1	1*	1	1	1*	1*	7
A6	1	1	1*	1*	1*	1	1	7
A7	0	1*	0	1*	1	0	1	4
The amount of dependency	6	7	6	7	7	6	6	

In this step, we calculate the set of input criteria (prerequisite) and output criteria (access) for each criterion and then identify the common factors. In this step, the criterion that has an output set (access), equal to the common set, has the highest level. After identifying these variables, we eliminate their rows and columns from the table and repeat the process with other criteria. The outputs and inputs are extracted from the compatible primary access matrix (table 4-8). For this purpose, the number of ones in each row represent the outputs and the number of ones in each column is equal to the inputs. To determine the first level, the results are shown in the table 6.

Table 6.
level One Criteria

Name of the Criteria	Output	Input	Commonality	Level
A1	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-	A1-A2-A3-A4-A5-A6-	
A2	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	1

Name of the Criteria	Output	Input	Commonality	Level
A3	A1-A2-A3-A4-A5-A6-	A1-A2-A3-A4-A5-A6-	A1-A2-A3-A4-A5-A6-	1
A4	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	1
A5	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-A7-	1
A6	A1-A2-A3-A4-A5-A6-A7-	A1-A2-A3-A4-A5-A6-	A1-A2-A3-A4-A5-A6-	
A7	A2-A4-A5-A7-	A1-A2-A4-A5-A6-A7-	A2-A4-A5-A7-	1

In table 4-5, level one criteria have been extracted, which include 5 criteria of C2, C3, C4, C5, C7. Now, in order to determine the criteria of the second level, we only have to eliminate the rows and columns of these 5 criteria form the compatible primary access matrix (table 4-4) and recalculate the determination of input and output. The results are displayed table 7.

Table 7.
Level 2 Criteria

Name of the Criteria	Output	Input	Commonality	Level
A1	A1-A6	A1-A6	A1-A6	2
A6	A1-A6	A1-A6	A1-A6	2

In the fifth step, using the acquired levels from the criteria, the interaction network of ISM will be drawn. If there is a relation between the two variables of i and j, their relation is shown via a directional arrow. The final diagram is displayed in figure 1, which was formed with elimination of incursion modes and using segmentation of the levels.

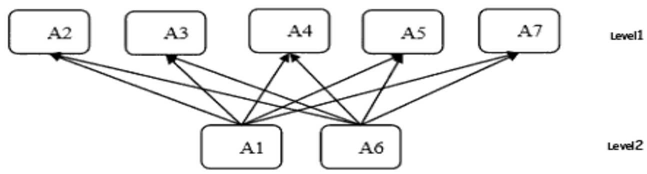

Figure 1.
The ISM model of the Documenting Group

Also, the research model can be displayed in terms of power of penetration and dependence in the form of figure 2. Based on this, all criteria are from the interface type. These variables have high dependence and high guiding power. In other words, the effectiveness and impressibility of these criteria are high and any change in them can cause fundamental changes in the system.

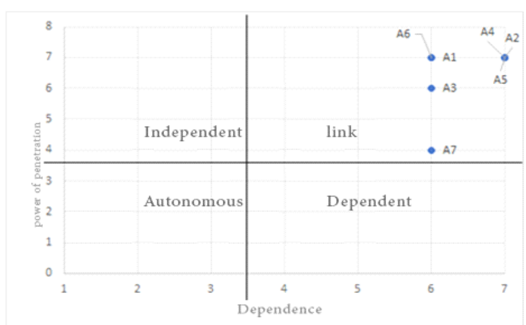

Figure 2.
Penetration Power-dependence Matrix

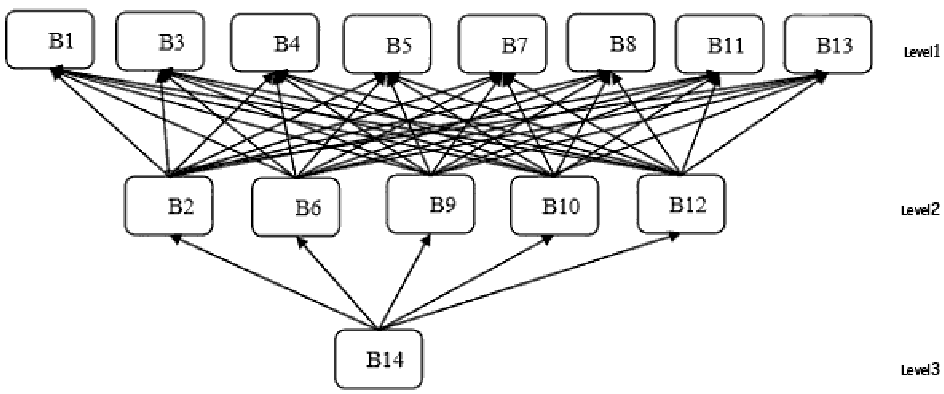

Figure 3.
ISM Model of the Dynamicity Group

In a similar way, we perform the same steps for the other two groups of indicators, and finally we draw the network of ISM interactions and obtain the power of penetration-dependence matrix for the other two groups of the indexes. Accordingly, only the B14 criterion is independent. This variable has low dependence and high guidance. In other words, high effectiveness and lower impressibility are the characteristics of this variable. The rest of the criteria are interface type. They have a high dependence and high guiding power, in other words, the effectiveness and impressibility of these criteria is very high, and any small change on these variables causes fundamental changes in the system.

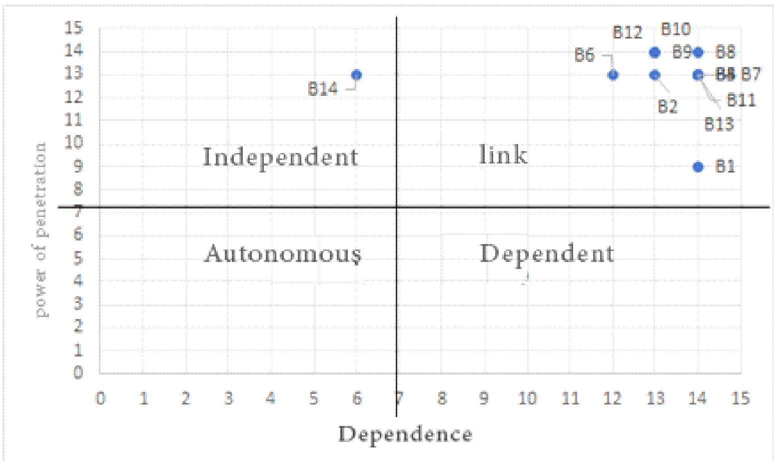

Figure 4.
Penetration Power-Dependence Matrix

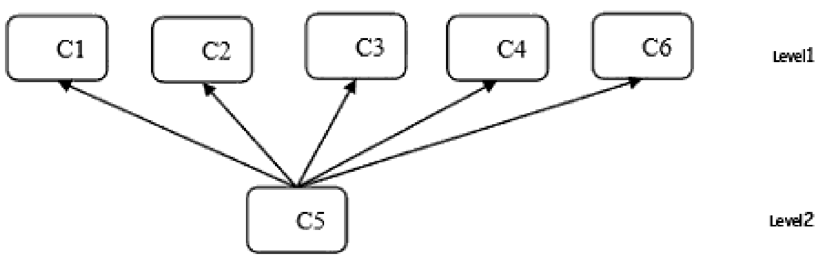

Figure 5.
ISM Model for Indexes of the Capability Group

Accordingly, only the C5 criterion is independent. This variable has low dependence and high guidance. In other words, high effectiveness and low impressibility are the characteristics of this variable. The rest of the criteria are interface type (figure 5). These variables have high dependence and high guidance. In other words, the effectiveness and impressibility of these criteria are very high and as shown in figure 6, any small change on these variables causes fundamental changes in the system.

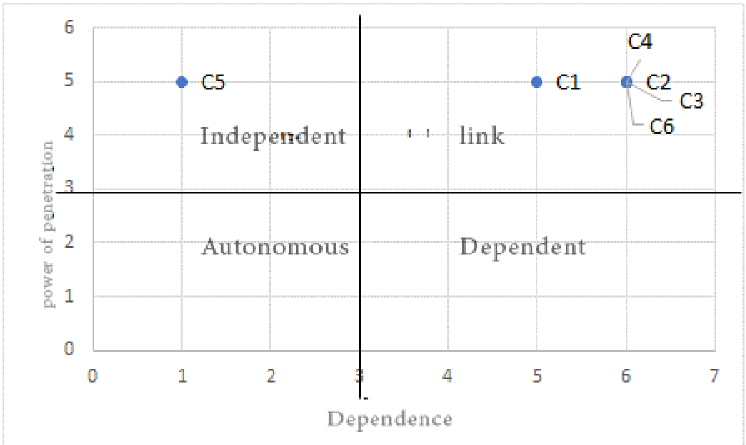

Figure 6.
Penetration Power-Dependence Matrix

Conclusions

This article, in line with assessment of technology maturity, presents an approach for structuring the indexes related to technology maturity. To this end, interpretive structural modelling has been used. Assessing the maturity of technology has always been a challenging and important issue for organizations, and its evaluation has always been a controversial topic. Interpretive structural modeling provides, organized and contextualized solutions to complex issues and provides decision makers with a realistic picture of their situation and the variables that they face. This process transforms weak and vague mental models into well-defined and transparent models. These models help to find key variables related to the problem. The ISM process involves identifying variables, defining internal links, establishing order, and explaining complex issues from the perspective of the systems. In this study, after extracting indicators related to technology maturity in three groups of documentation, dynamicity and capability, these indicators were examined through interpretive structural modeling to determine the relationships and structures between variables. The results of this model can be used to write rules in the fuzzy system and discover the relationship between variables to greatly benefit the assessment the maturity.

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