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Economic View of Maximum Reservoir Contact (MRC) Well Technology in the Drilling Industry

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ABSTRACT

The economic aspects of technological advances in the drilling industry using the maximum reservoir contact (MRC) method compared to other drilling technologies have been investigated in this study. Field and survey methods from combined implementation research methods have been performed by a dynamic approach using Vensim software. Professors, drilling and reservoir engineering professionals in the oil and gas drilling industry, or equivalent positions, comprised the study's statistical population. Finally, 120 individuals were chosen by nonprobabilistic sampling (judgment) and the snowball method. In the Vensim dynamic environment, the simulation completion time (based on the 2017 dynamics model) and the initial simulation time (based on the 2013 dynamics model) were adjusted to generate a flow diagram analyzing the economic aspects of technological improvements in this type of drilling industry. According to the causal tree results, the drilling industry's performance has the highest priority among studies of economic aspects of technological changes in the drilling industry using the MRC method. It has a significant relationship with technological changes in the drilling industry. The sensitivity analysis chart demonstrated that with a change in the variable of indicators of the drilling industry at an average level of 5.25 to 5.5, the target variable, i.e., the performance of the drilling industry, had the least sensitivity and had no particular effect on it. On the other hand, by modifying the effectiveness of the drilling industry, effectiveness indicators at the average level of 6.95, the target variable had the maximum sensitivity and had a very significant effect on it.

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1. Introduction

Understanding and using technology management in the industry increase productivity and production growth, consequently shortening time and enhancing gross domestic product (GDP). New technologies strengthen the shifting of production factors and create more product diversity. In addition, technology changes the relative cost of production and increases the comparative advantage of firms and countries. In the oil industry, as in other industries, access to new technologies increases production, improves productivity, accesses out-of-reach resources, and produces added value. Reserves of petroleum and natural gas are significant sources of hydrocarbon fluids in the oil industry, with their unique physical and chemical characteristics. When conducting an exploration, extraction, production, and exploitation process, it is vital to analyze their behaviors and their geological and formation structure to establish the activities that will be carried out to access its vast resources with a scientific perspective. After completing the exploration, the drilling operation will be carried out during all stages of the oil field development, both offshore and onshore. Drilling is one of the oil industry's most complex, expensive, and highly specialized tasks to access these vast underground resources. Anything done before drilling is useless if drilling is not done correctly, resulting in the loss of this vast oil resource and the high cost of exploration. Therefore, great importance is given to the drilling industry. In turn, the successful completion of oil wells in the continuation, production, and operation requires many different technologies and costs.

In terms of drilling paths, there are three types of drilling methods: vertical, directional, and horizontal. A vertical well is a drilling technique that involves drilling vertically into the ground to access an underground reserve of oil or natural gas. Drilling wells vertically is a more traditional oil extraction method than its modern counterpart.

Directional drilling can also be referred to as directional boring. Because most oil wells are located above the targeted reservoir, accessing them requires drilling vertically from the surface to the well below. On the other hand, directional drilling is distinct in that it involves drilling at a non-vertical angle. Directional *drilling* refers to any drilling that does not go straight down. The main advantage of directional drilling is that it allows companies to exploit multiple oil reservoirs with a single well, reducing total drilling costs and limiting environmental impact.

A horizontal well is a directional drilling technique that involves digging an oil or gas well at an angle of at least 80° to a vertical wellbore. This technique has become increasingly common and productive in recent years. Operators use it to retrieve oil and natural gas when the shape of the reservoir is unusual or difficult to access.

The production from horizontal wells was started in Iran by producing from Gachsaran Well No. 142 (December 1991) and Marun Well No. 199 (July 1992). Since 2001, 96 horizontal wells have been programmed to drill in Iran. According to production statistics in June 2001, horizontal wells produced 5% of the cumulative production of total wells.

Investigations showed that there was not any difference between the producing flow rate of horizontal and vertical wells. Despite the Ahwaz Field (Asmari), Mansori Field (Ilam), Parsi Field (Asmari), and Workover wells in the Asmari formation, excellent results were obtained in Iran. The technology of horizontal wells is applied for some *thin reservoirs* in which the vertical drilling depth is insufficient. Examples of these reservoirs are the Bibi Hakimeh reservoir and the north crest line of the Ragsefid reservoir. Among four horizontal well-completion techniques worldwide, *open hole completion* and *perforated liner* are used in Iran (Kalantari-Dahaghi et al., 2006).

The maximum reservoir contact (MRC) well method of drilling in the reservoir rock can be very cost-effective because it increases the contact area of the reservoir by more than 5 km and thus results in more production and better extraction of the reservoir, but this method requires high technology (Alyan M. et al., 2018). This contact area can be through one or more branches with different directions to get vast reservoir contact. In the present study, the main issue is what economic effects will be achieved in the drilling sector and the oil industry in general by changing the technologies in the horizontal drilling process with the maximum contact area of the MRC method. In other words, drilling technology improvements impact economic indicators in macroeconomics, microeconomics, and oil economics (Verma C. et al., 2017).

This article is organized as follows: Section 2 discusses the research background and theoretical foundations. The following section represents methodology. Section 4 argues the stages of analysis with system dynamics, and finally, Section 5 concludes the paper and gives some results.

2. Background and theoretical foundations of research

Some studies have separately examined the technological changes in oil reservoirs, the economic aspects of developing oil and gas fields, and integrated reservoir management. However, the impact of technological change on the economic aspects of the horizontal drilling industry, especially in the MRC method, has been illustrated. In order to extract economic indicators, it is necessary to explain and review the types of published economic indicators from essential sources and related databases or sites; therefore, after reviewing the concepts of indicators, the initial list is explained. However, the final list of these indicators is provided after refinements by questionnaires and expert panels. It should be noted that this study tries to identify indicators appropriate to the conditions of current and future related technologies. The background of the theoretical framework of the research is given in Table 1.

Following a review of theoretical foundations and background of the research, it was discovered that due to research gaps in the field of dynamic modeling of economic indicators related to horizontal drilling technologies (MRC process), efficiency and effectiveness indicators of the drilling industry and drilling technology economics are the leading indices to study. Furthermore, it can be proved that the MRC method may be utilized to innovate and address these gaps despite the lack of a model to aid managers in deciding on the economic elements of technological advancements in the drilling industry for future operations.

3. Methodology

From the perspective of the implementation approach, this research combines field and survey methods. This article's study population can be classified into two broad categories: The first group consisted of qualified professors with at least a bachelor's degree and experience in the oil drilling industry (reservoir engineers and drilling experts); the second group consisted of industrial engineering experts and technology managers with five years or more of experience in the drilling industry or similar positions. A total of 120 available and willing experts were selected by combining two nonprobabilistic targeted (judgmental) sampling and snowball sampling methods. In the end, 120 people gave a complete answer. Table 1 lists the theoretical framework of the research obtained as the first round of the work.

Examining the theoretical framework, reviewing the background, interviewing experts, and preparing a second questionnaire are the other steps to identify the variables needed for the dynamic modeling method. Thus, the present study identified the economic indicators related to oil processes, effectiveness indicators of the drilling industry, efficiency indicators of the drilling industry, economics of drilling technology, and horizontal drilling technologies (the MRC process) as the main variables and 13 secondary subs divided the variables listed in Tables 2 and 3. Further, Tables 4–6 present the research of the variables' descriptive information and reliability statistics.

Table 1: The background of the theoretical framework of the research

➢ **Economic indicators related to oil processes** (Abramov et al., 2018; Abbaspour et al., 2018; Pereira et al., 2015; Benes et al., 2015; Danesh and Daneshi, 2015; Hosseini and Shokorshahabi, 2014; Davari et al., 2013; Koeck, C. et al., 2019)	• Increased production in the drilling industry • Improving productivity in the drilling industry • Access to out-of-reach resources in the drilling • Value-added production in the drilling industry • Upstream oil industry (search for potential underground or submarine fields, well drilling and exploration, and well operations to bring crude oil and crude natural gas to the surface) • Downstream oil industry (refining of crude oil and sale and distribution of natural gas and crude oil products) • Intermediate oil industry (performance coverage of the downstream oil industry)

➢ **Effectiveness indicators of the drilling industry** (Song et al., 2017; Kuo et al., 2018; Reinsch et al., 2018; Wang et al., 2018; Abbaspour et al., 2018; Daghayeghi et al., 2016; Jalvani and Rafieifar, 2017; Zahedi Nasab et al., 2017; Dehghani, 2015; Rezaei et al., 2012; Mehdipour; et al., 2018)	• Drilling industry performance in terms of liquidity ratios • Drilling industry performance in terms of activity ratios • The performance of the drilling industry in terms of leverage ratios • Drilling industry performance in terms of profitability ratios
➢ **Efficiency indicators of the drilling industry** (Abramov et al., 2018; Abbaspour et al., 2018; Pereira et al., 2015; Benes et al., 2015; Danesh and Daneshi, 2015; Hosseini and Shokorshahabi, 2014; Davari et al., 2013)	• Unique study of economics, market analysis, consumer behavior, and households and firms • Study of cumulative indicators such as GDP, unemployment rate, national income, and the price index of different sectors of the economy • Planning and implementing technological changes • Reduce horizontal drilling time • Reducing the financial burden of horizontal drilling • Improving the economic aspects of horizontal drilling
➢ **Economics of drilling technology** (Abramov et al., 2018; Abbaspour et al., 2018; Pereira et al., 2015; Benes et al., 2015; Danesh and Daneshi, 2015; Davari et al., 2013; Koeck, C. et al., 2019)	• Market study • Technical feasibility • Studying the economic aspects and financial analysis (financial and economic analysis) • Drilling routes in drilling a well • Drilling methods (impact, rotary, and laser) • Types of circular drilling technologies (vertical drilling, directional drilling, diversion well drilling, and helical piping drilling)
➢ **Horizontal drilling technologies (MRC process)** (Song et al., 2017; Abbaspour et al., 2018; Kuo et al., 2018; Abramov et al., 2018; Salamy, 2005; Kazemi and Alamshahi, 2014; Mehdipour et al., 2018; Alyanet al., 2019; Alyanet al., 2018)	• Horizontal drilling • Maximum reservoir contacts area or MRC method • MRC wells ❖ Fork model (with one mother well and two side well) ❖ Fishbone model, which needs to return to the original angle with the mother well • Advantages and behavior of MRC wells ❖ Production index (*J*) ❖ Infiltration of water and oil ❖ Reduction of development cost unit

Table 2: The primary variables (endogenous)

A: Economic indicators related to oil processes	C: Effectiveness indicators of the drilling industry
B: Horizontal drilling technologies (MRC process)	D: Efficiency indicators of the drilling industry
	E: Economics of drilling technology

Table 3: The secondary variables (exogenous)

A:	A1: Micro indicators related to oil processes	C:	C1: Increasing production in the drilling industry
	A2: Macro indicators related to oil processes		C2: Drilling industry performance in terms of liquidity ratios
	A3: Prices of exported-imported goods producer		C3: Duration and speed of operation in the drilling industry
B:	B1: Drilling technologies based on fork model	D:	D1: Behavior of MRC wells in terms of production index (*J*)

	B2: Drilling technologies based on the fishbone model		D2: Behavior of MRC wells in terms of water and oil penetration
	B3: Technologies to improve the behavior of MRC wells	E:	E1: Drilling cost management
			E2: Economic study of drilling technology

Table 4: Descriptive information on the ideal importance of researching the variables

Research the variables and indicators	Number of data	Board (rang)	Minimum	Maximum	Sum	Mean	SD	Variance	Skewness Statistics
A- Economic indicators related to oil processes	120	2	5	7	708	5.90	.885	.783	.205
A1-Micro-indicators related to oil processes	120	2	5	7	669	5.57	.679	.461	.805
A2-Macro indicators related to oil processes	120	4	3	7	660	5.50	.861	.741	-.174
A3-Producer prices of export-import goods	120	2	5	7	636	5.63	0.765	0.585	.755
B- Horizontal drilling technologies (MRC process)	120	4	3	7	696	5.80	1.064	1.131	–0.310
B1-Drilling technologies based on the fork model	120	4	3	7	677	5.63	0.999	0.999	–0.061
B2-Drilling technologies based on fishbone model	120	2	5	7	692	5.77	0.817	0.668	0.470
B3-MRC Behavior improvement technologies	120	4	3	7	669	5.57	0.971	0.944	0.041
C-Efficiency indicators of the drilling industry	120	3	5	7	705	5.875	0.980	0.8	0.12
C1- Increasing production in the drilling industry	120	2	5	7	708	5.90	0.885	0.783	0.205
C2- Drilling industry performance in terms of liquidity ratios	120	4	3	7	680	5.67	1.028	1.057	–0.076
C3- Duration and speed of operation in the drilling industry	120	2	5	7	708	5.90	0.845	0.714	0.198
D-Effectiveness indicators of the drilling industry	120	4	3	7	696	5.80	1.064	1.131	–0.310
D1- Behavior of MRC wells in terms of production index (*J*)	120	4	3	7	676	5.63	0.999	0.999	–0.061

Research the variables and indicators	Number of data	Board (rang)	Minimum	Maximum	Sum	Mean	SD	Variance	Skewness Statistics
D2- Behavior of MRC wells in terms of water and oil penetration	120	4	3	7	660	5.50	0.938	0.879	0.134
E- Economics of drilling technology	120	2	5	7	688	5.73	0.828	0.685	0.551
E1-Drilling cost management	120	2	5	7	708	5.90	0.845	0.714	0.198
E2- Economic study of drilling technology	120	2	5	7	708	5.90	0.885	0.783	0.205

Table 5: Descriptive information related to the functional status of research the variables

Research the variables and indicators	Number of data	Board (rang)	Minimum	Maximum	Sum	Mean	SD	Variance	Skewness Statistics
A- Economic indicators related to oil processes	120	5	1	6	560	4.67	1.422	2.023	–1.441
A1-Micro-indicators related to oil processes	120	5	1	6	528	4.40	1.192	1.42	–0.859
A2-Macro indicators related to oil processes	120	5	1	6	544	4.53	1.383	1.913	–0.828
A3-Producer prices of export-import goods	120	5	1	6	567	4.73	1.230	1.513	–1.238
B- Horizontal drilling technologies (MRC process)	120	3	3	6	592	4.93	0.868	0.754	–0.881
B1-Drilling technologies based on the fork model	120	4	2	6	532	4.43	1.104	1.220	–1.136
B2-Drilling technologies based on fish bone model	120	5	1	6	592	4.93	1.143	1.306	–1.793
B3-MRC Behavior Improvement Technologies	120	4	2	6	560	4.67	1.155	1.333	–0.725
C-Efficiency indicators of the drilling industry	120	3	3	6	544	4.53	1.042	1.086	–0.490
C1- Increasing production in the drilling industry	120	3	3	6	544	4.53	1.042	1.085	–0.487
C2- Drilling industry performance in terms of liquidity ratios	120	4	2	6	516	4.30	1.208	1.459	–0.375
C3- Duration and speed of operation in the drilling industry	120	3	3	6	580	4.83	0.834	0.695	–0.814
D- Effectiveness indicators of the drilling industry	120	4	2	6	516	4.30	1.208	1.459	–0.375

Research the variables and indicators	Number of data	Board (rang)	Minimum	Maximum	Sum	Mean	SD	Variance	Skewness Statistics
D1- Behavior of MRC wells in terms of production index (J)	120	3	3	6	552	4.60	1.163	1.352	–0.401
D2- Behavior of MRC wells in terms of water and oil penetration	120	4	2	6	576	4.80	1.157	1.338	–1.157
E- Economics of drilling technology	120	3	3	6	556	4.63	1.033	1.068	–0.585
E1-Drilling cost management	120	3	3	6	588	4.90	1.029	1.059	–0.806
E2- Economic study of drilling technology	120	3	3	6	568	4.73	0.944	0.892	–0.734

Table 6: Reliability statistics for research of the variables and indicators using Cronbach's alpha test

Research the variables	Cronbach's alpha coefficients	Number of items
Economic indicators related to oil processes	0.876	4
Horizontal drilling technologies (MRC process)	0.860	4
Efficiency indicators of the drilling industry	0.820	3
Effectiveness indicators of the drilling industry	0.935	3
Economics of drilling technology	0.926	3

4. Stages of analysis with system dynamic

Dynamic systems are an aspect of systems theory that explains dynamic and continuous behavior in complex systems. In this study, using the system dynamics technique and Vensim software (Ventana Systems, 2019), causal relationships and the interactions between known technologies will be measured to examine the relationship between horizontal drilling process technologies and changes in economic indicators based on path analysis. According to the indicators and the dynamic system studies, it is necessary to specify the state, rate, and auxiliary variables for Vensim software, as listed in Table 7.

Table 7: The role of model variables

The variable	Role of the variable
Economic indicators related to oil processes	State of the primary variable
Drilling Industry performance	Rate – Y –The target variable
Efficiency indicators of the drilling industry	Auxiliary of the secondary variable
Economics of drilling technology	Auxiliary of the secondary variable
Effectiveness indicators of the drilling industry	State of the primary variable
Horizontal drilling technologies (MRC process)	State of the primary variable

Figure 1 shows six steps of studying the dynamic system to investigate the economic aspects of technological changes in the drilling industry using the MRC method based on the opinions of experts and datasets of the drilling industry with a dynamic approach (Song et al., 2017; Morcillo et al., 2018; Wang et al., 2018).

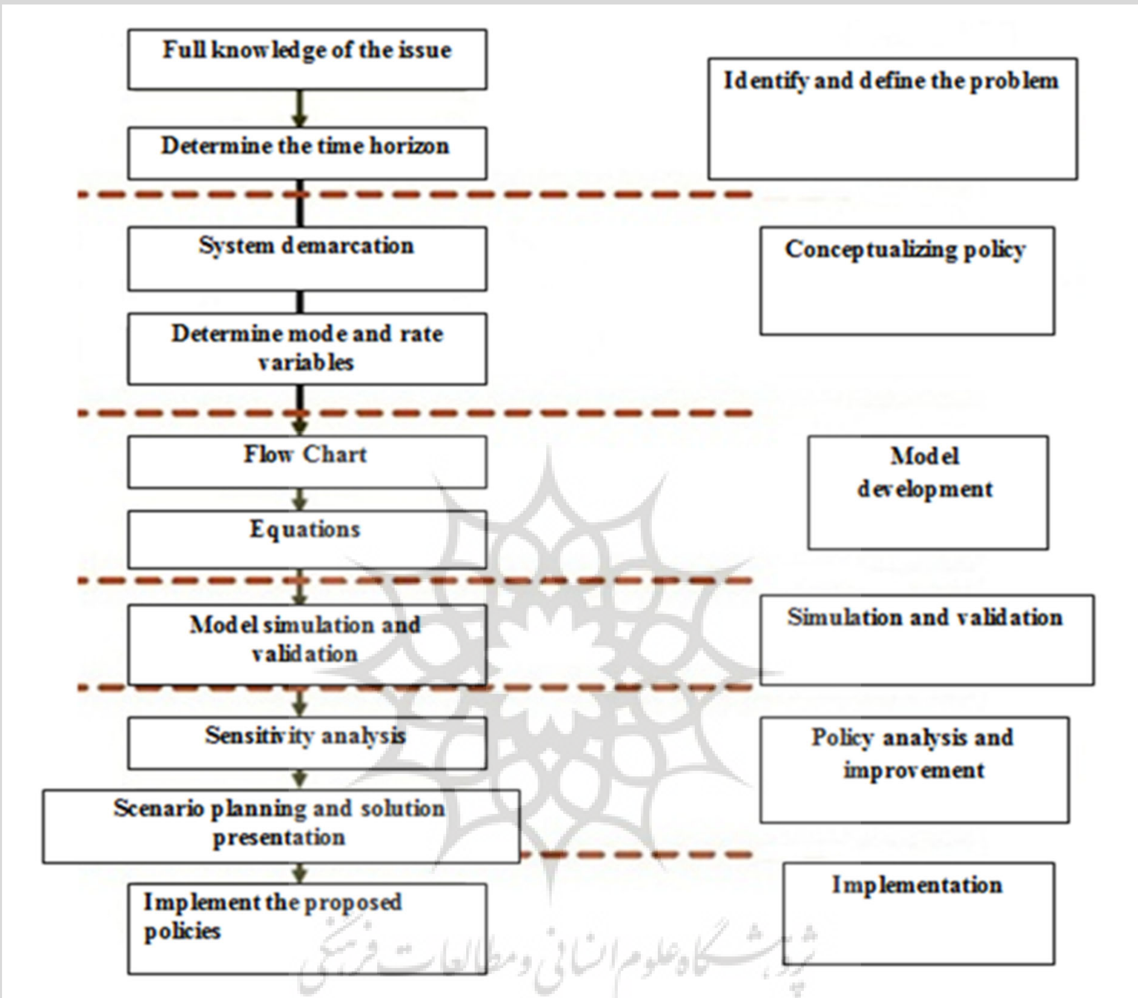

Figure 1: The steps of system dynamics designing

4.1. Data analysis

The following steps were performed to analyze the system dynamics.

1. Time horizon of the model

Based on the final conceptual model of the time horizon, the following settings were considered.

Final Time: Simulation completion time (based on system dynamics in 2017)

Initial Time: Simulation initial time (based on system dynamics in 2013)

Saveper: The time interval between storage of simulated data, which is a coefficient of time step and is 5 years for the present study.

Time: The current time of simulation was considered 2013.

Time Step: 60 times in 5 years

2. Determining the model boundary

After conducting studies and collecting information and data by interviewing industry experts and using the system dynamics method, the primary (endogenous) and secondary variables (exogenous) of the final conceptual model of this research are listed in Tables 2 and 3.

In order to determine the boundaries of the dynamic model of drilling industry performance using the system dynamics approach, as mentioned before, the endogenous and exogenous variables were first defined. This procedure makes it possible to understand a process or program and the relationship between the elements of a dynamic drilling industry performance model in its simplest form. After obtaining the flow diagram and drawing it in Vensim software, the software's accuracy of the dynamic model of drilling industry performance must be ensured. Then, to model the structural validity of the model, the model was implemented from 2013 to 2017 with the help of software, and the resulting data were compared with existing historical data from the drilling industry. Although the matching of historical trends with the data obtained from the simulation alone cannot guarantee future trends, as long as the behavior and structure of the simulated model are consistent with past assumptions, the forecasts can be expected to be consistent with future conditions. Regression analysis was also used as a statistical process to predict and recognize the relationship between independent and dependent variables and the shape of these relationships. A dimensional stability test was performed to model the dimensional equilibrium of the variables on both sides of the equation. Due to the lack of nonphysical variables in the model, the unit of these variables corresponds to reality. On the other hand, considering that the purpose of this study is to model the relationships between the rate of technological change in the drilling industry and economic indicators related to oil processes, the test of the type of sensitivity analysis and limit conditions should be used. In changing the values of the parameters, the behavior of the control model and the variables was observed.

4.2. Model causal relations

According to the definitions given in Tables 2, 3, and 7, the causal relationships of the model are shown in Figure 2.

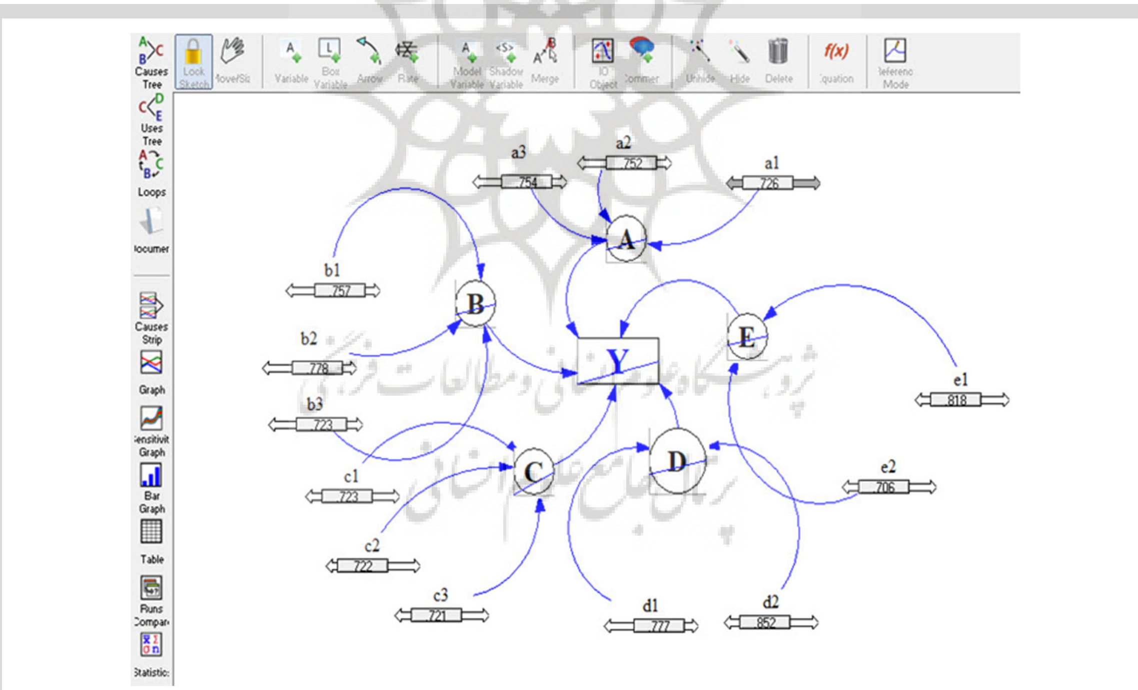

Figure 2: The causal relationships of the dynamic model

The causal relationships of the model were extracted based on the variables with an effect of more than 0.7 to study the economic aspects of technological changes in the drilling industry by the MRC method, as described in Table 8.

Table 8: The causal relationships of the model based on the variables with a high impact on the model

Model variables	Model characteristics	Symbol in Vensim	Coefficients
Economic indicators related to oil processes	Micro-indicators related to oil processes	A1	0.726
	Macro indicators related to oil processes	A2	0.752
	Producer prices of export-import goods	A3	0.754
Horizontal drilling technologies (MRC process)	Drilling technologies based on the fork model	B1	0.757
	Drilling technologies based on the fishbone model	B2	0.778
	MRC behavior improvement technologies	B3	0.723
Efficiency indicators of the drilling industry	Increased production in the drilling industry	C1	0.723
	Drilling industry performance in terms of liquidity ratios	C2	0.722
	Duration and speed of operation in the drilling industry	C3	0.721
Effectiveness indicators of the drilling industry	The behavior of MRC wells in terms of production index (*J*)	D1	0.777
	The behavior of MRC wells in terms of water and oil penetration	D2	0.852
Economics of drilling technology	Drilling cost management	E1	0.818
	The economic study of drilling technology	e2	0.706

4.3. Flow chart of causal tree

The flow chart of the final conceptual model of this research was obtained using Vensim software, as shown in Figure 3.

In the following, we face a message in Vensim software denoting the model is OK, which indicates that the model has accuracy and reliability. A dimensional stability test was performed to model the dimensional equilibrium of the variables on each side of the equation.

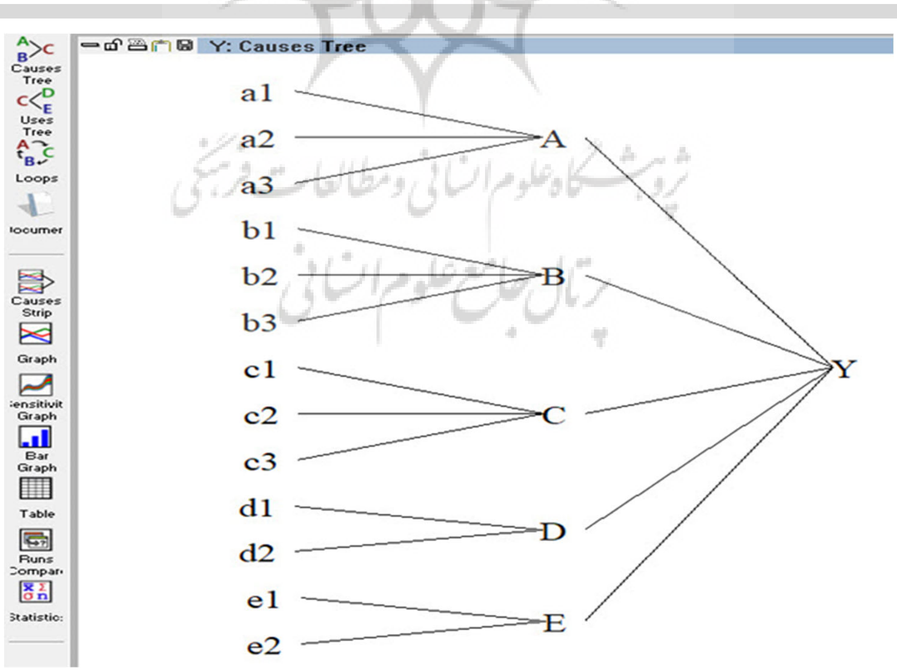

Figure 3: The flow chart of the final conceptual model

4.4. Comparative graph of the growth rate of the Vensim model of the variables

The performance chart of the drilling industry can be seen in Figure 4 as the causal relationship of economic indicators related to oil processes to the rate of technological change in the drilling industry has a significant relationship and alignment. In the drilling industry, economic indicators related to oil processes have increased in line with the rate of technological changes from 2013 to 2017.

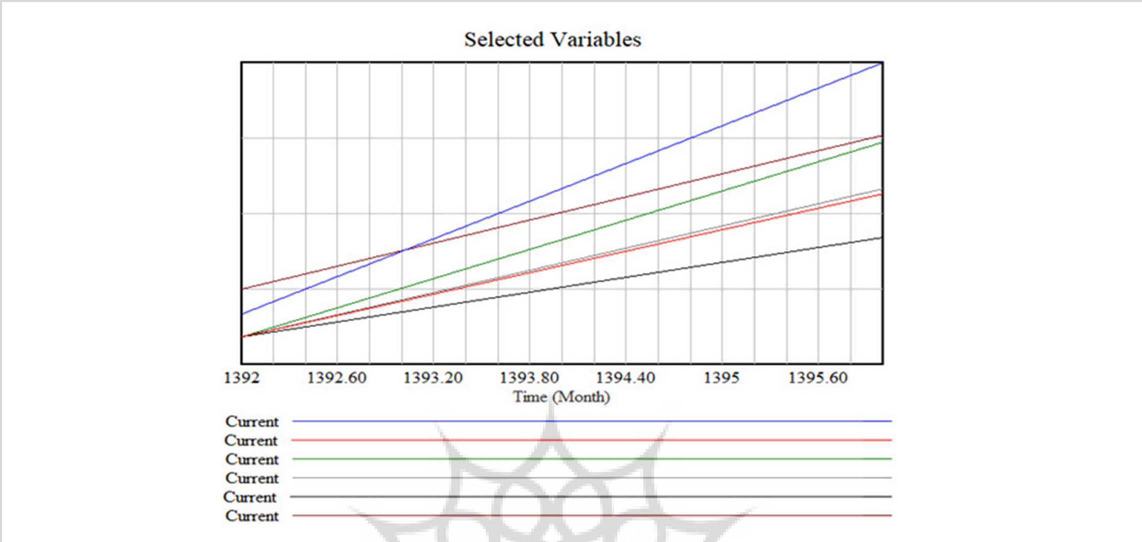

Figure 4: The comparative graph of the growth rate of the Vensim model of the variables

In fact, according to the comparative growth rate of the Vensim model the variables, the dynamic growth rate of the variable *drilling technology economics*, i.e., the black code with the code E for the target variable *drilling industry performance*, had the lowest growth rate and was the lowest in 2013. It was about 1.2% in 2013, and after experiencing a period of low growth in 2015, it increased to 2.5% and then achieved its highest rate of 4% in 2017. In addition, the dynamic growth rate of the variable *horizontal drilling technologies* (*MRC Process*), i.e., a red-coded chart with the code B for the target variable *drilling industry performance*, had a moderate growth rate and in 2013 was at its lowest level of about 1.2%. Moreover, with moderate growth in 2015 to a growth of 3.5% and medium growth in 2017, it reached its highest growth rate, i.e., 6%. On the other hand, the dynamic growth rate of the variable *effectiveness indicators of drilling industry*, i.e., a green graph with C code for the target variable *drilling industry performance*, had a moderate growth rate and in 2013 was at its lowest level of about 1.2% and with an average growth of 4.5% in 2015 and with an average growth in 2017 equal to its highest growth rate of 7.5%. The dynamic growth rate of the variable *effectiveness indicators of drilling industry*, i.e., blue diagram with code A for the target variable *drilling industry performance*, had the highest growth. In 2013 it was in a growth position of about 2%, and with remarkable growth in 2015, it grew by 6%; with remarkable growth in 2017, it reached its highest growth rate, i.e., 10% (optimal state).

Finally, the dynamic growth rate of the variable *drilling technology economy*, represented by a gray-colored D-code chart for the target variable *drilling industry performance*, had a reasonable growth rate and was at its lowest level of around 1.2% in 2013, with optimal growth reaching 3.5% in 2015 and average growth reaching 6% in 2017.

4.5. Model validation

Figures 5–9 present the validity of dynamic system models based on the Vensim model and the variables' descriptive statistics.

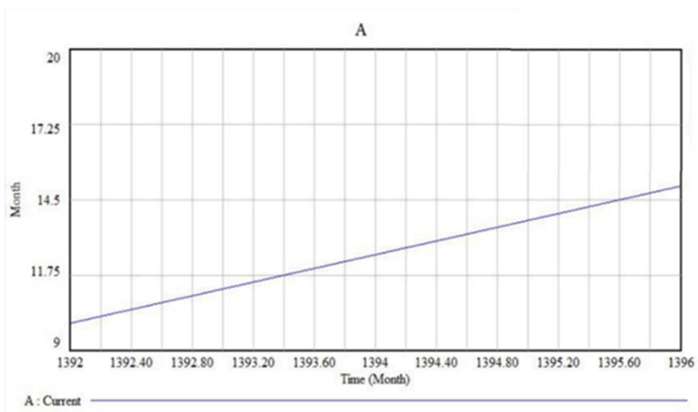

Figure 5: Dynamic changes in the variable *economic indicators related to Oil Processes* and the target variable *Drilling Industry Performance*

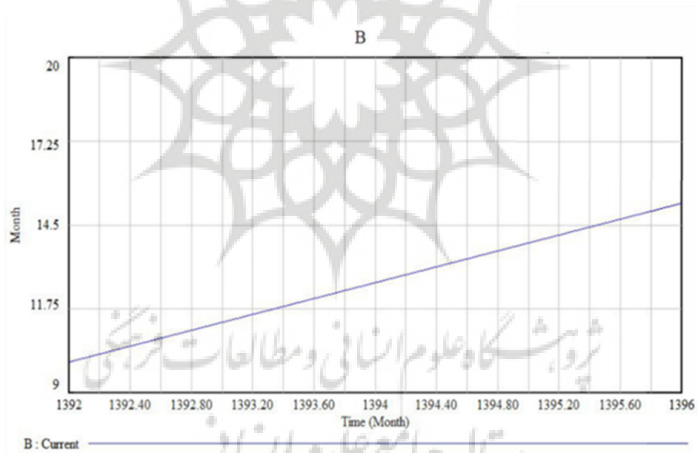

Figure 6: Dynamic changes in the variable *horizontal drilling technologies (MRC Process)* and the target variable *drilling industry performance*

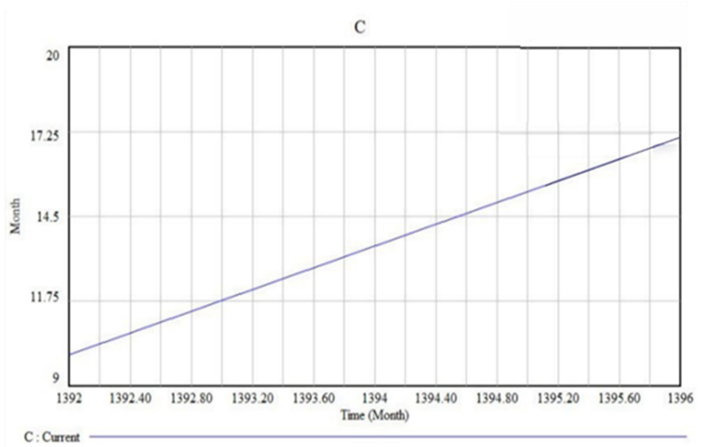

Figure 7: Dynamic changes in the variable *Efficiency Indicators of Drilling Industry* and the target variable *drilling industry performance*

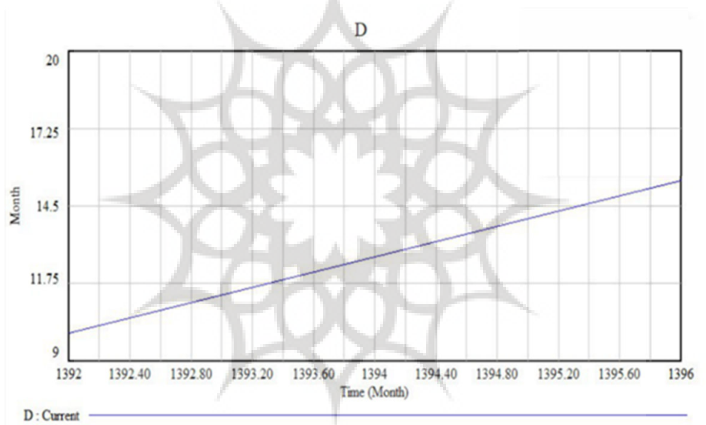

Figure 8: Dynamic changes in the variable *effectiveness indicators of drilling industry* and the target variable *drilling industry performance*

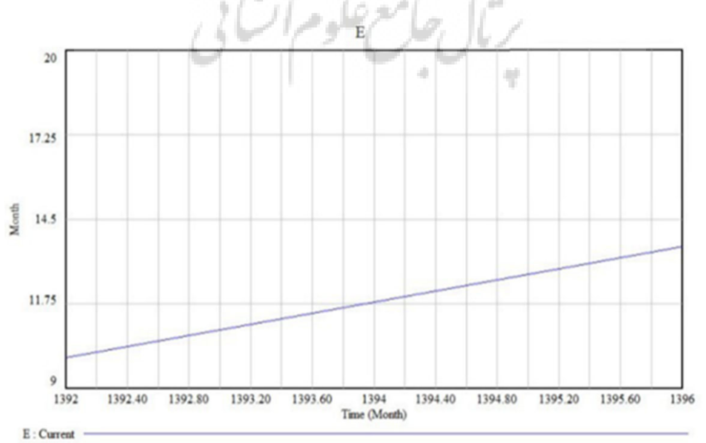

Figure 9: Dynamic changes in the variable *economics of drilling technology* and the target variable *performance of drilling industry*

In fact, according to the data of the Vensim model, the variable validation diagram, and the validation rate of the variable *economic indicators related to oil processes*, i.e., the A-code diagram for the target variable *drilling industry performance*, had the lowest validation optimization value. In 2013, it was at its lowest level, i.e., about 10%, and with low credit optimization in 2015, it reached 12%. With low credit optimization in 2017, it reached its highest credit optimization rate, i.e., 15%. The validation rate of the variable *horizontal drilling technologies (MRC method)*, i.e., the chart with code B for the target variable *drilling industry performance*, had a moderate validation optimization value and was at its lowest level of about 10% in 2013. With the average accreditation optimization in 2015, the accreditation optimization reached 12.5%, and the average accreditation optimization in 2017 reached its highest accreditation optimization level of about 15.5%. In 2013, the validity optimization value of the variable *efficiency indicators of drilling industry*, i.e., the C-chart for the target variable *drilling industry performance*, was moderate and at its lowest level, i.e., approximately 10.75%; however, with the average accreditation optimization in 2015, the accreditation optimization reached 14%; and with the average accreditation optimization in 2017, it reached its highest level, approximately 17.25% (the highest accreditation optimization mode). The validation rate of the variable *effectiveness indicators of the drilling industry*, i.e., the chart with code D for the target variable *drilling industry performance*, had the highest validation optimization and in 2013 was in the state of validation of about 10%. With the excellent accreditation optimization in 2015, the accreditation optimization reached 12.5%, and with the excellent accreditation optimization in 2017, it reached its highest accreditation optimization rate, i.e., 16%.

Finally, the validation rate of the variable *drilling technology economics*, i.e., the diagram with the code E for the target variable *drilling industry performance*, had an excellent validation optimization value. In 2013 it was at its lowest level of about 10%, and with the optimal accreditation optimization in 2015, it reached 12% accreditation optimization, and with the average accreditation optimization in 2017, it reached its highest accreditation optimization rate, i.e., 14%.

4.6. Modeling the structural validity of the model

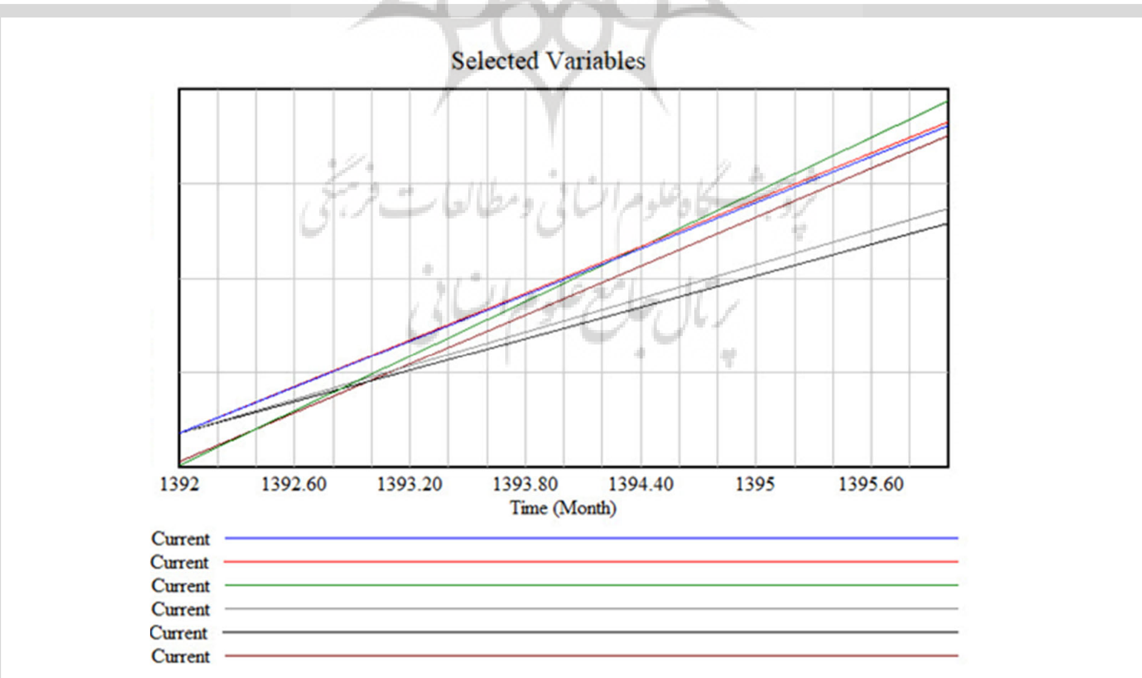

Figure 20: Change in economic indicators related to oil processes after the change in the initial level of the rate of technological change in the drilling industry

According to the information in the comparative diagram of the change in economic indicators related to oil processes after the change in the amount of the initial level of the rate of technological change in the drilling industry (Figure 10), the dynamic growth rate of the variable *drilling technology economics*, i.e., the black-coded chart with the code E for the target variable *drilling industry performance*, had the lowest growth rate. In 2013, it was at its lowest level, i.e., about 1.2%, and with low growth in 2015, it grew to 3.5%; with low growth in 2017, it reached its highest growth rate, i.e., 6%.

In addition, the dynamic growth rate of the variable *horizontal drilling technologies (MRC process)*, i.e., the red-coded graph with the code B for the target variable *drilling industry performance*, had a moderate growth rate. In 2013, it was at its lowest level, i.e., about 1.2%, and with moderate growth in 2015, it reached a growth of 5%; with an average growth in 2017, it reached its highest growth rate, i.e., 8.5%. On the other hand, the dynamic growth rate of the variable *efficiency indicators of drilling industry*, i.e., a green chart with C code for the target variable *drilling industry performance*, had the highest growth rate. In 2013, it was at its lowest level, i.e., about 0.1%, and with remarkable growth in 2015, it grew to 6%; with remarkable growth in 2017, it reached its highest growth rate, i.e., 9.5% (optimal state). The dynamic growth rate of the variable *effectiveness indicators of drilling industry*, i.e., blue diagram with code A for the target variable *drilling industry performance*, has had a favorable growth. In 2013, it was in a growth position of about 1.2%, and with tremendous growth in 2015, it grew to 5%; with remarkable growth in 2017, it reached its highest growth rate, i.e., 8.5%.

Finally, the dynamic growth rate of the variable *drilling technology economics*, i.e., a gray-colored D-shaped graph for the target variable *drilling industry performance*, had a reasonable growth rate. In 2013, it was at its lowest level, i.e., about 1.2%, and with favorable growth in 2015, it reached a growth of 4%; with moderate growth in 2017, it reached its highest growth rate, i.e., 6.5%.

4.7. Research suggestions

The most critical proposal of the present study to compare complete reservoir contact wells with other technologies in the drilling industry according to the system dynamics method from economic aspects is that with the improvement of the current situation.

1. The variable *Economic indicators related to oil processes* includes indicators such as micro-indicators related to oil processes, macro-indicators related to oil processes, and producer prices of export-import goods;

2. The variable *horizontal drilling technologies (MRC process)* includes indicators such as drilling technologies based on the fork model, drilling technologies based on the fishbone model, and technologies for improving the behavior of MRC wells;

3. The variable *effectiveness indicators of drilling Industry* includes indicators such as an increase in production in the drilling industry, the performance of the drilling industry in terms of liquidity ratios, and duration and speed of performance in the drilling industry;

4. The variable *indicators of drilling industry performance* includes indicators such as the behavior of MRC wells in terms of production index (J) and the behavior of MRC wells in terms of water and oil penetration;

5. The variable *technology of drilling technology* includes indicators such as drilling cost management and justification of drilling technology economy;

4.8. Regression analysis

The following are the factor loadings of the variables affecting the economic aspects of technological changes in the drilling industry by the MRC method.

As presented in Table 9, since the sign of the correlation coefficient is the slope of the regression line, based on the opinions of IT and industrial engineering experts in the drilling industry and academic experts, the factor loads of the variable *economic indicators related to oil processes* to the target variable (Y), i.e., *drilling industry performance*, based on the regression model calculations equal 0.914. The factor loads of the variable *horizontal drilling technologies (MRC process)* relative to the target variable are calculated at 0.751 based on the calculations of the research regression model. The factor loads of the variable *Production increase in the drilling industry* relative to the target variable are calculated as 0.822 based on the calculations of the research regression model. Further, the factor loads of the variable *drilling industry performance* in terms of liquidity ratios compared to the target variable based on the calculations of the research regression model equal 0.877. The factor loads of the variable *duration and speed of performance in the drilling industry* relative to the target variable are also calculated at 0.592 based on the calculations of the research regression model. Moreover, the factor loads of the variable *drilling industry performance indicators* compared to the target variable based on the calculations of the research regression model equal 0.592. The factor loads of the variable *Technology of drilling technology* compared to the target variable are calculated at 0.813 based on the calculations of the research regression model.

Table 9: Factor loads of research the variables relative to the target variable (Y)

Factor loads of research the variables relative to the target variable (*Y*)	**The target variable (Y)**	**Economic indicators related to oil processes**	**Horizontal drilling technologies (MRC process)**	**Increased production in the drilling industry**	**Drilling industry performance in terms of liquidity ratios**	**Duration and speed of operation in the drilling industry**	**Effectiveness indicators of the drilling industry**	**Economics of drilling technology**
The target variable (*Y*)	1.000	0.9140	0.751	0.8220	0.8770	0.592	0.592	0.813
Economic indicators related to oil processes	0.914	1.000	0.493	0.664	0.955	0.491	0.491	0.763
Horizontal drilling technologies (MRC process)	0.751	0.493	1.000	0.515	0.437	0.599	0.599	0.540
Increased production in the drilling industry	0.822	0.664	0.515	1.000	0.602	0.358	0.358	0.742
Drilling industry performance in terms of liquidity ratios	0.877	0.955	0.437	0.602	1.000	0.514	0.514	0.700
Duration and speed of operation in the drilling industry	0.592	0.491	0.599	0.358	0.514	1.000	1.000	0.407
Effectiveness indicators of the drilling industry	0.592	0.491	0.599	0.358	0.514	1.000	1.000	0.407
Economics of drilling technology	0.813	0.763	0.540	0.742	0.700	0.407	0.407	1.000

4.9. Sensitivity analysis

Graphs of sensitivity analysis of the variables to the target variable (*Y*) are presented in Figures 11–17.

The investigation of the impact of the input variables of the research model on the performance of the drilling industry demonstrates that the effects of changing the inputs of the statistical model in an organized (systematic) way can be expected in the model's output.

The graph of sensitivity analysis of the economic variables related to oil processes to the target variable shows that when the first research input (A), i.e., the variable *economic indicators related to oil processes*, is changed to an average level of 5 and 5.5, the target variable, i.e., *drilling industry performance*, has the least sensitivity and has no effect on it. On the other hand, the target variable has the highest sensitivity and a very substantial effect when the economic indicators connected to oil processes are changed at an average level of 6.75.

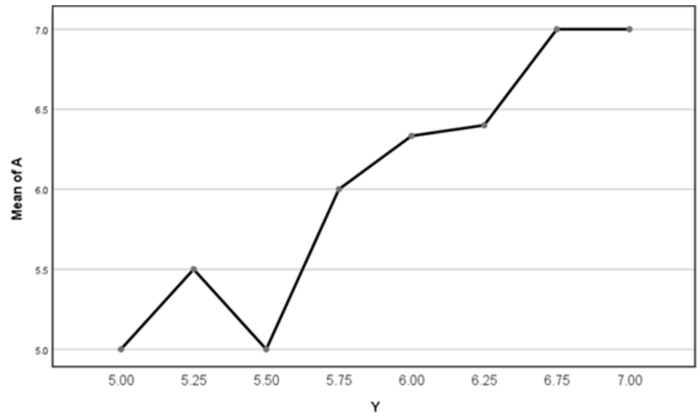

Figure 11: Sensitivity analysis of the variable *economic indicators related to oil processes* to the target variable (Y)

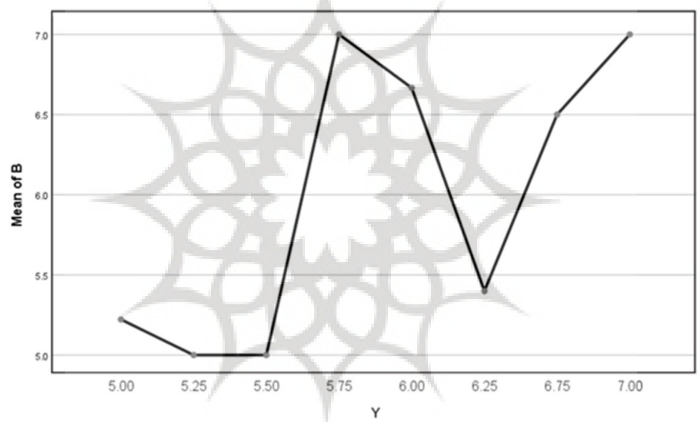

Figure 12: Sensitivity analysis of the variable *horizontal drilling technologies (MRC Process)* to the target variable (Y)

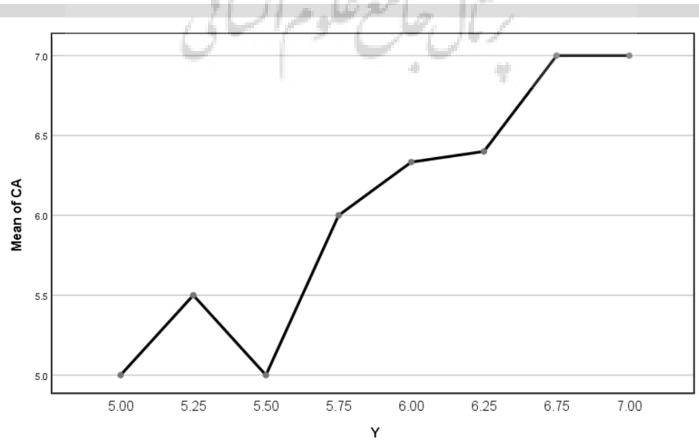

Figure 13: Sensitivity analysis of the variable *increasing production in the drilling industry* towards the target variable (Y)

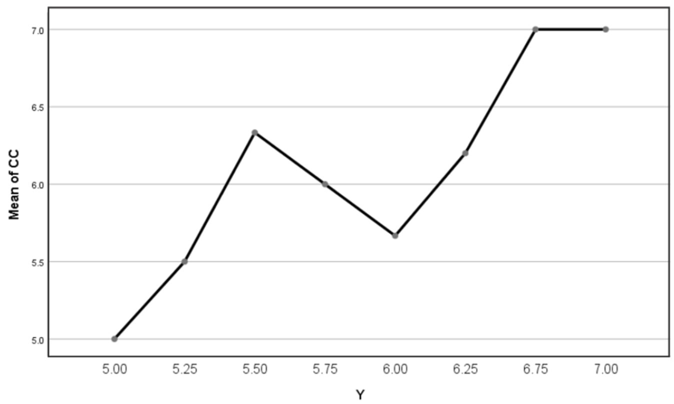

Figure 14: Sensitivity analysis of the variable *drilling industry performance in terms of liquidity ratios* to the target variable (Y)

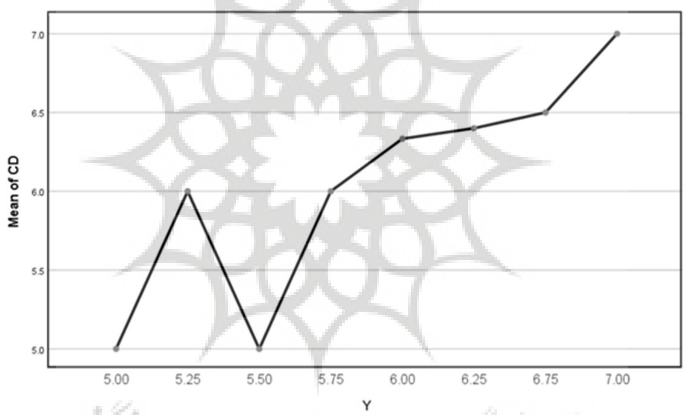

Figure 15: Sensitivity analysis of the variable *duration and speed of performance in the drilling industry* to the target variable (Y)

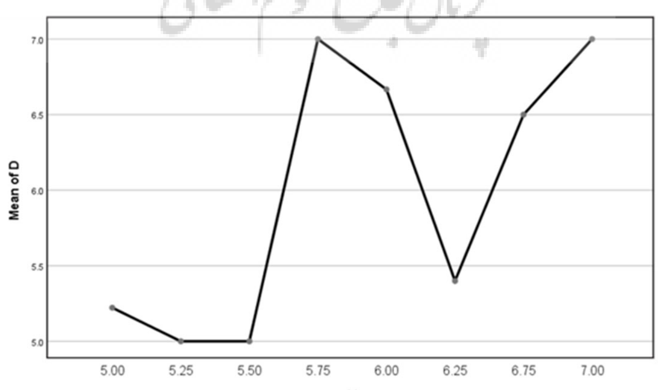

Figure 16: Sensitivity analysis of the variable *effectiveness indicators of the drilling industry* against the target variable (Y)

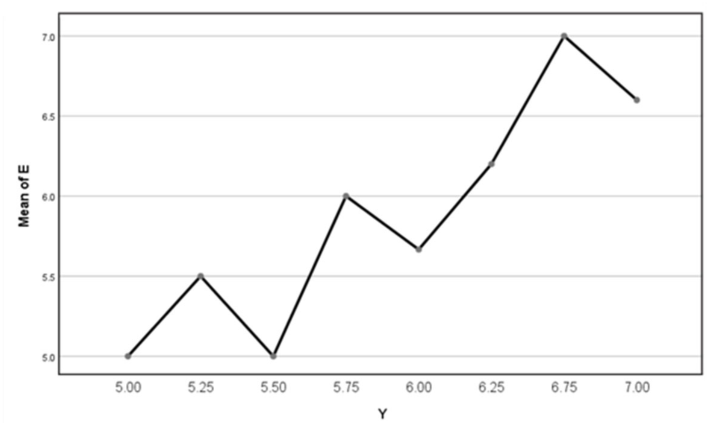

Figure 17: Sensitivity analysis of the variable *technology economy in drilling* to the target variable (Y)

In contrast, the graph analysis of the sensitivity of the variable of *horizontal drilling technologies (MRC process)* to the target variable reveals that when the second research input (B), i.e., the variable *horizontal drilling technologies (MRC process)*, is changed at the average levels of 5.25 and 5.5, the target variable, i.e., the performance of the drilling industry, has the least sensitivity and has no particular effect on it. On the other hand, by changing the variable *horizontal drilling technologies (MRC process)* at the average level of 6.95, the target variable has the highest sensitivity and has a very significant effect on it. The graph of analysis of the sensitivity of the variable *production increase in the drilling industry* to the target variable shows that with the change of the third research input (CA), i.e., the variable *production increase in the drilling industry* at the average level of 5.25 and 5.5 the target variable, i.e., the *drilling industry performance*, has the least sensitivity and has no particular effect on it. On the other hand, by changing the variable *production increase in the drilling industry* to the average level of 6.95, the target variable has the highest sensitivity and a significant effect.

Contrary to expectation, however, it turns out that when the fourth research input (CC) is changed, the drilling industry performance, measured by liquidity ratios, falls to an average level of 5, is least sensitive, and has no effect. However, changing the drilling industry performance in terms of liquidity ratios at the average level of 6.75 to 7 has the highest sensitivity and significantly affects it. The change in the variable drilling industry performance in terms of liquidity ratios at the average level of 6.75 to 7 has high and continuous effects on the target variable.

In other words, the graph analysis of the sensitivity of the variable duration and speed of the drilling industry performance to the target variable shows that changing the fourth input of the research (CD), i.e., the variable duration and speed of the drilling industry performance at an average level of 5 and 5.5 has the least sensitivity and has no particular effect on the target variable, i.e., the drilling industry performance. On the other hand, the target variable has the highest sensitivity and a substantial effect when the duration and speed of the drilling industry performance are changed at an average level of 6.95.

5. Discussion and conclusions

These findings show that the variables such as drilling industry performance in terms of liquidity ratios and indicators of drilling industry performance with an average of 4.30 are in the weakest performance. Drilling and industrial engineering experts in the drilling industry should also pay special attention to the economic aspects of technological changes in the drilling industry by the MRC method, including the following variables: A- economic indicators related to oil processes (micro indicators related to oil processes, macro indicators related to oil processes, and producer prices of export-import goods), B- horizontal drilling technologies (MRC process) (drilling technologies based on the fork model, drilling technologies based on the fishbone model, and technologies for improving the behavior of MRC wells), C1- increasing production in the drilling industry, C2- drilling industry performance in terms of liquidity ratios, C3- duration and speed of operation in the drilling industry, and D- effectiveness indicators of drilling industry (D1- the behavior of MRC wells in terms of production index (*J*), D2- the behavior of MRC wells in terms of water and oil penetration). Because of the functional status of the variables of studying the economic aspects of technological changes in the drilling industry by the MRC method, they are in a weaker position than their importance.

Based on the results from the causal tree, it can be obtained that the economic indicators related to oil processes have the highest priority and priority among the study of the economic aspects of technological changes in the drilling industry by the MRC method. This quantity has a significant relationship with the rate of technological change in the drilling industry. The graphical comparison of the rate of technological change in the drilling industry and economic indicators related to oil processes in the drilling industry in this model from 2013 to 2017 shows that the economic indicators related to oil processes have a significant relationship and alignment with the rate of technological changes in the drilling industry, according to the model validation diagrams based on the dynamic changes between the research the variable *drilling industry performance*.

In the drilling industry, the economic indicators related to oil processes have increased in line with the rate of technological changes from 2013 to 2017 after performing the final limits test of the critical variables, sensitivity analysis, dimensional stability test, and a comparative test of the simulated answer with the available documents. It was determined that the variables affecting the rate of technological change in the drilling industry and economic indicators related to oil processes are also exogenous.

Due to the lack of significant changes in these variables, the model can show a good approximation of their actual behavior. Finally, it was calculated and estimated how sensitive the behavior predicted for the system (output of that system) was to the values of the independent variables (input of that system). The graph of sensitivity analysis of the variable of indicators of drilling industry performance towards the target variable (Y) showed that with the change of the fourth input of research (D), i.e., the variable *indicators of drilling industry* at an average level of 5.25 to 5.5, the target variable, i.e., the *drilling industry performance*, has the least sensitivity and has no particular effect on it. On the other hand, by changing the effectiveness of the drilling industry indicators to an average level of 6.95, the target variable has the highest sensitivity and has a significant effect. Graph analysis of the sensitivity of the variable technology economy in drilling to the target variable (Y) shows that by changing the fourth input of research (E), i.e., the variable *economics of technology in drilling* at an average level of 5 to 5.5, the target variable, i.e., the *drilling industry performance*, has the least sensitivity and has no particular effect on it. On the other hand, by changing the variable *technology economy in drilling* at the average level of 6.75, the target variable has the highest sensitivity and significantly affects it.

Using the results of the present study to investigate the economic aspects of technological change in the drilling industry by the MRC method can help improve the performance of a subset of a drilling rig, i.e., rig power generation system, lifting system, mud rotation system, rotational system, well eruption control system, equipment registration system, and drilling operations. The most important results of this article compared to previous research are presented in Table 10.

Table 10: Comparing the most important results and findings of the present study with those of the most relevant research in the literature

	Research title	Source	Comparison of research findings									
			Economic aspects in the drilling industry	Technological changes in the drilling industry	Economic indicators of the oil industry	MRC method	Economics of technology	Drilling industry	Dynamic modeling approach	Vensim Dynamic Environment	Model validation	Case study
1	Investigating the economic aspects of technological changes in the drilling industry by the MRC method	Current Study	*	*	*	*	*	*	*	*	*	*
2	Feasibility study of using new low-diameter well drilling technology in Iran's oil and gas exploration operations	Mehdipour et al., 2018	-	*	-	-	-	*	-	-	-	-
3	Evaluation of multi-branch wells and MRC in oil and gas exploration and production	Kazemi and Alamshahi, 2014	-	-	-	*	-	*	-	-	-	-
4	Analysis of factors affecting the technical and economic attractiveness of core drilling projects in Iran using multi-criteria decision techniques		*	*	-	-	-	*	-	-	-	-
5	A review of the political and economic impacts caused by the recent changes in the regulatory framework of the oil and gas sector in brazil	Hosseini and Shakurshahabi, 2014	*	-	-	-	-	*	-	-	-	-
6	Boosting economic efficiency of pads drilling projects. A comprehensive study of wells groupings and localization of the global maximum	Pereira et al., 2014	-	-	-	-	-	*	-	-	-	-
7	Optimized design of drilling and blasting operations in open-pit mines under technical and economic uncertainties by system dynamic model	Abramov et al., 2018	-	-	-	-	-	*	*	-	*	-

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