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USE OF INFLUENCE DIAGRAMS FOR DECISION SUPPORT IN DRILLING AUTOMATION

Taras Mychailovych Matviykiv [*1], Vasyl Mykolaiovych Teslyuk [2]
[*1] Automated Control Systems Department, Lviv Polytechnic National University, Lviv, Ukraine
TMatviykiv@slb.com [1]
[2] Computer Aided Design Department, Lviv Polytechnic National University, Lviv, Ukraine
vtesliuk@polynet.lviv.ua, tesliuk@mail.ru [2]

Abstract: In this paper, influence diagrams are used for modeling and analysis of the decision-making process when shocks and vibrations occur while drilling oil and gas wells. Mathematical formalism of influence diagrams are based on Bayesian networks and allows combining graphical representation of a process with its probabilistic behavior. Influence diagrams allow to perform real-time analysis of possible situation scenarios and to increase decision-making confidence in drilling automation process. The decision making process is analyzed and a model of object-oriented influence diagram is build and tested for a shock and vibration decision making situation. A study shows that influence diagrams are a powerful tool for decision support and can be used in drilling automation and drilling control systems development.

INTRODUCTION

Today, global oil and gas industry is undergoing transformation from manual or semi to fully automated drilling control systems. Development of new technology and implementation of advanced information technology improved and altered traditional approach to drilling technics [1, 2]. Interpretation and synthesis of real-time data which is acquired by the rotary steerable systems (RSS), measurements while drilling (MWD) and logging while drilling (LWD)-systems [3 - 5] opens up new opportunities in the drilling process optimization and increases level of drilling automation [6].

With a help of modern technology decision-makers while drilling have access to new tools and huge amount of data that potentially allows making of high quality decisions. However, access to a huge amount of information, risk factor, and drilling uncertainty does not always lead to the best decisions. Also important role in decision making process plays highly qualified personnel, number of which is decreasing with rapid increase of drilling rig count and retirement of experienced personnel. Thus, the actual problem solution is gradual step-by-step transition to drilling automation technologies.

Many researchers have been devoted their work to the study of drilling automated control systems (ACS) development [7 - 9]. Decision support system (DSS) is one of ACS components that can improve the process of decision making under conditions of risk and uncertainty. Most real-time decision support systems are rule based. Use of influence diagrams, based on mathematical apparatus of Bayesian networks (BN) [10], allows combination of causal process graphical representation with its probabilistic nature and evaluation of a decision utility. This paper researches application of influence diagrams in automated decision-making process while drilling in the environment of downhole shocks and vibrations.

Presence of mechanical destabilizing factors, such as shock and vibration, negatively affect drilling rate of penetration, reliability of electronic components [11], and the entire bottom hole assembly (BHA). Timely detection, identification and mitigation of the mechanical destabilizing factors can significantly increase reliability of downhole tools, electronic equipment, and entire drilling ACS life.

Purpose of this paper is development of theory and methodology of intelligent real-time decision support systems design in oil-well drilling. This paper researches the use of influence diagrams for automatic diagnostics of shock and vibration occurrence and automatic decision-making support for mitigation decision making. The developed model can be used in further research and development in drilling systems automation.

ANALYSIS OF EXITING DRILLING DSS

A number of scientists and institutions around the world are researching application of information technology in drilling systems control and automation. Significant attention is given to artificial intelligence development, particular to the development of DSS [12 - 14]. Papers are devoted to solve various problems that arise at the planning stage and also directly during the drilling process.

Paper [12] is devoted to support decision-making at the planning stage when choosing right equipment for directional drilling applications. Described system operates with certain input criteria, such as economic benefit, drilling condition, borehole diameter, drilling depth, etc. to propose reasonable solution. The DSS is based on rules, taken from literature, analysis of field data, expert opinions and studies of relevant processes. Described DSS [12] does not use BN and influence diagrams apparatus and does not intended to be used as real time application. It is used at the planning stage of the drilling process.

In paper [13] a commercial product that monitors drilling process to reduce drilling none productive time is presented. This product supports real-time decision making by using information from downhole and surface sensors. The system includes certain mathematical models of the drilling processes and a range of a priori expert knowledge. Described expert DSS operates as a monitoring and recommendation system in case of emergency like stuck BHA, over pull, loss of circulation, etc. The expert system is based on CBR-methods (cased-based reasoning) [13, 15]. Although nowadays CBR-methods are sufficiently developed, they are still strongly syntactically dependent and based on identical match. In paper [14] is proposed to extend the above method to MBR (model-based reasoning), allowing the possibility of matching syntactically different but semantically / pragmatically similar cases.

Apparatus of BN and influence diagrams, which is proposed in our paper, can be as an alternative or as a complement to the methods described above. Unlike CBR/MBR-methods, apparatus of BN provides theoretical approach and mathematically proven method that is sufficiently accurate in extremely complex situations and conditions with predominant uncertainty. It also does not depend on inaccurate or conflicting information. An architecture that combines both technologies is demonstrated in paper [15] as an example of DSS in the medical industry.

In paper [16] use of BN and influence diagrams for decision-making in real-time drilling operation is described. Appropriateness of BN and influence diagrams is proved when uncertainty of data interpretation is present and synthesis of large amounts of information is required. A number of BN examples for sidetrack wells drilling decision, geo-steering challenges, picking up casing depth are demonstrated.

Analysis of drilling DSS scientific papers shows that most of existing systems are based on MBR-methods and works as an advisor. Insufficient attention is given to the use of influence diagrams, based on BN apparatus, which is more suitable in the conditions of uncertainty, inaccurate or conflicting input information and is more appropriate for system analysis.

DEVELOPMENT OF REAL-TIME DECISION MAKING ALGORITHM IN DRILLING PROCESS

Real-time decision making while drilling is driven by factors of risks and uncertainty, including: insufficient information; conflict or distorted information; high drilling cost and cost of wrong decisions; personnel competency, etc.

In oil-well drilling decision making in shock and vibration identification and mitigation can be summarized as per steps below: drilling process observation and monitoring; determining the need for situation assessment; gathering information about certain events cases. Situation update and assessment; beginning of situation assessment and decisions making.

Based on described steps flowing flowchart algorithm can be build (fig. 1).

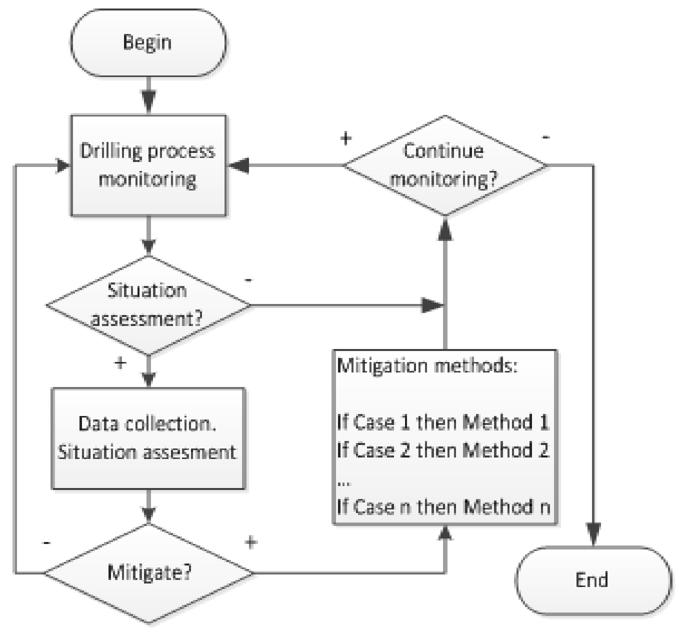

Figure 1. Flowchart algorithm of real-time situation assessment while drilling

Shock and vibration is the main mechanical destabilizing factor that affects reliability of downhole equipment. Ignoring shock and vibration while drilling, failure to identify it or misidentification of its severity can lead to serious BHA failures, such as twist-off, over torqued connections, washouts [17], etc. Presence of shock and vibration while drilling significantly reduce downhole electronic life [11] in MWD, LWD, RSS tools and it can cause permanent failures in electronic board and its components. Earlier, when MWD systems and other intelligent downhole systems were not developed or were not such advanced as they are now, it was much more difficult to detect shocks and vibration while drilling. Typically, the presence of vibration was identified by visual check on the damages on stabilizers, drill bit and other BHA components after run was already finished and BHA was pulled out of hole.

The decision-maker can identify type of vibration, its severity and decide on need and type of mitigation by assessing the current situation (geological conditions, design well trajectory, the current life of downhole tool, wellbore planned total depth, etc.) and based on his own experience. Such decisions are made under time pressure, often with insufficient information presented, factor of risk and human factor.

Functionality of “data collection, situation assessment” block was described in our previous work [18] when with the help of BN, the model of shocks and vibrations situation awareness was developed. Example below (fig. 2) demonstrates the process of vibrations type identification.

For the drilling systems automation, the decision making process has to be also automated. In this paper, we continue previous studies and we use influence diagrams to implement logic of the next blocks "Data collection. Situation assessment" block "Mitigate?" from fig.1.

DEVELOPMENT OF INFLUENCE DIAGRAM FOR SITUATION ASSESSMENT AND DECISION MAKING ON MITIGATION NEED

Earlier in this paper, the algorithm of shock and vibration decision process was presented (fig. 1). After data collection and situation awareness on type of vibration, the decision on mitigation has to be made. Timely made detection, identification and proper mitigation methods are vital in order to increase reliability of electronic downhole tools and prevent various accidents during drilling. Although, for the first look, it seems that with the first indication of vibration we should apply necessary mitigation steps, but this is not always the case. Shock and vibration mitigation requires manipulation of such drilling parameters as weight on bit (WOB) and drill string rotation speed (RPM), quite often it also requires interruption of drilling process like picking off bottom drill string and other time-consuming actions. Manipulation on drilling parameters does not always lead to the desired result and requires additional time, effort and availability of experience personnel. For example, decision for mitigation may not be made in the situation when shock and vibration severity level is low and it does not affect downhole equipment life; or when the time remaining to the end of drilling run does not exceed the expected lifetime of equipment (assuming current vibration severity). Another criterion for making decision on mitigation need is the history of shock and vibration mitigation in current geological region and depth. Now days such kind of decisions are normally made by directional driller on the well site or drilling optimization engineer, and it is based on analysis of offset wells data, his own experience and knowledge.

To solve the problem of decision making on shock and vibration mitigation need, let us form the graph-theoretical model based on the Bayesian networks mathematical apparatus, which will reflect the decision-making process. Suppose $G=(X,E)$ is directed acyclic graph (DAG) where X – set of discrete random variables with a finite number of states; E - connections between nodes, which are called arcs and represent dependencies between the variables. Bayesian network also includes a set of probability tables of transition from one state to another. Probability of each value of a node in Bayesian network can be computed when values of the other variables are known. Bayesian network [10] incorporates three components: $N=\langle V,G,J\rangle$, where V - set of variables; G - directed acyclic graph, which nodes correspond to random variables of vibration initiation; J - probability distribution of variable $V=\{x_1,x_2,...,x_n\}$.

According to Bayes' theorem probability of simultaneous occurrence of two independent events D and S is defined by the expression: $p(D,S)=p(D)p(S)$.

If events D and S are dependent, emergence of one of them gives some information about the appearance possibility of another one: $p(D,S)=p(D)p(S \mid D)$, where $p(D,S)$ - probability of the event S, if event D has already occurred.
A simple form of Bayes' theorem [10] can be written as:

$$p(D|S)=\frac{p(D)p(S|D)}{p(S)}. \qquad (1)$$

Influence diagrams are expanding of Bayesian networks. They are used for decision making. Actually, influence diagrams are BN, extended by the meaning of usefulness (utility) and solution (decision). Unlike BN, which contain only one type of nodes, influence diagrams contain additional nodes: decision and utility, denoted as rectangle and rhombus respectively.

Fig. 3 shows designed influence diagram of the process of decision making on shock and vibration mitigation need. Nodes of the influence diagram model are described in Table. I. Main inputs are current state of downhole tools and the current vibration level. The other input nodes contain information about shock and vibration mitigation history and expected time to the end of current drilling run. The key node is ("Vib Severity after mitigation"), which depends on current vibration severity and history of successful mitigation. Along with the node ("Time to run TD") the expected condition of downhole tool ("Tool Life at TD") is determined.

The developed model incorporates two utility nodes (*U*1, *U*2) and one decision node ("Mitigate?"). To reflect the best solution influence diagram utility nodes are linked with the network state. During decision making process probability of each network configuration is solved by the principle of maximum expected utility, the expected value of each alternative is calculated and is chosen the alternative with highest utility. Total utility function is the sum of all local utility functions:

$$F(x_1,x_2,\dots,x_n)=\sum_{i=1}^{k} f_i(x_1,x_2,\dots,x_n).$$

For developed network overall utility function takes the form: $F(x_1,x_2,...,x_g)=U_1(x_1,x_2,...,x_n)+U_2(x_1,x_2,...,x_n)$, where, F - the combined utility function; U_1,U_2 - local utility functions; $x_1,x_2,...,x_n$ – diagram nodes.

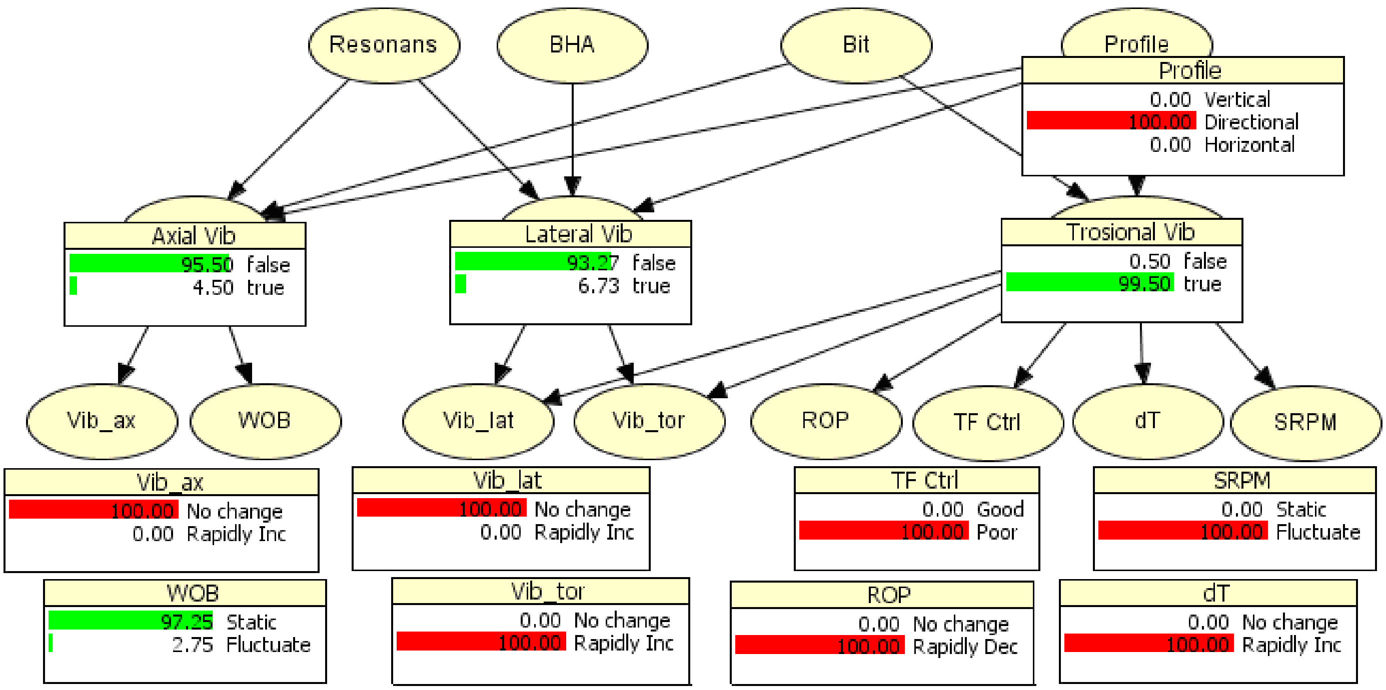

Figure 2. Bayesian Network for vibration type identification while drilling, based on real-time measurements of downhole and surface sensors

Values of utility functions are dimensionless values that reflect overall utility of the decision. U2 function depends on an expected result of mitigation and a decision which has been made. It contains a negative value of utility if inefficient decision has been made. For example, if it was decided to eliminate vibrations, knowing that in current geological conditions, most likely it will not bring the desired result. Values of utility function are defined by experts. For the described model values of utility functions are presented in Fig. 4.

EXAMPLES OF INFLUENCE DIAGRAM APPLICATION FOR DECISION MAKING SUPPORT ON VIBRATION MITIGATION

Case 1. A torsional vibration of medium severity has been identified while drilling. Successful elimination of torsional vibrations at current geological conditions is statistically defined as 90%. At the current rate of penetration, estimated time to the end of run is described with the probability of 98% as "short" (<12 hrs.). Decision needs to be made whether to start mitigation or to continue drilling with shock and vibration. Current life of weakest downhole electronic tool is estimated as “satisfactory” (expected life of 24-100 hours).

The above situation is modeled with the software package Hugin Lite 7.6. (free license for demonstrational proof of concept). Fig. 5 demonstrates the solution derived from influence diagram by using the method of maximum expected utility. Automated decision to initiate vibration mitigation is advised with 90% confidence.

Case 2. Let us continue consideration of Case 1, only with "low" actual vibration severity. In this case, after solving the influence diagrams by the criterion of maximum utility, system decides do not mitigate shock and vibrations (Fig. 6a). The decision is caused by "satisfactory" actual tool life, "low" level of vibration severity and "short" time to the end of drilling run.

Case 3. Let us modify Case 2 with "low" level of actual vibrations, but "long" (> 100 h) time to the expected completion of drilling run. In this situation, after solving the influence diagrams by the criterion of maximum expected utility, system decides to initiate shock and vibration mitigation (Fig. 6b).

Case 4. Let us continue modification of Case 3 with “unsuccessful” rate of shock and vibration mitigation in current region. Despite the "long" time before completion of the drilling run, system decides to ignore shock and vibration as attempts to mitigate, most likely, will not be successful and will only result in unproductive time and cost (Fig. 6c).

The model correspondence to real observations and to decisions taken by experts is the main criterion of its adequacy. The knowledge based expert DSS can be built based on proposed model. The knowledge base of expert DSS can be extended with income of new relevant information what will improve model adequacy. Based on acquired statistical data, new transitional probabilities are calculated and thus system is being learned.

Table: 1 Description of the nodes of influence diagram for the decision making on vibration mitigation

Variable	Interpretation	Node type	Value
Q (“Tool life actual ”)	Current actual life of a downhole tool	discrete states, (4 values)	failure, critical, satisfactory, good
M (“Vibration severity actual”)	Current actual vibration severity	discrete states, (4 values)	absent, low, medium, high
C_2 (“Success of mitigation”)	Success of vibration mitigation in current geological condition and depth	discrete states, (2 values)	successfully unsuccessfully
C_1 (“Time to run TD”)	Expected time to the end of drilling run	discrete states, (3 values)	long, medium, short
Ms (“Vibration severity after mitigation”)	Expected vibration severity after mitigation	discrete states, (4 values)	absent, low, medium, high
H (“Tool life at TD”)	Estimated tool life at the end of run after mitigation	discrete states, (4 values)	failure, critical, satisfactory, good
A (“Mitigate?”)	Decision making on need of vibration mitigation	discrete states, (2 values)	ignore mitigate
U1	Utility function which reflects level of tool “preservation”	utility	nominal units of utility (Table 4)
U2	Utility function which reflects negative effect of ineffective decision	utility	nominal units of utility (Table 4)

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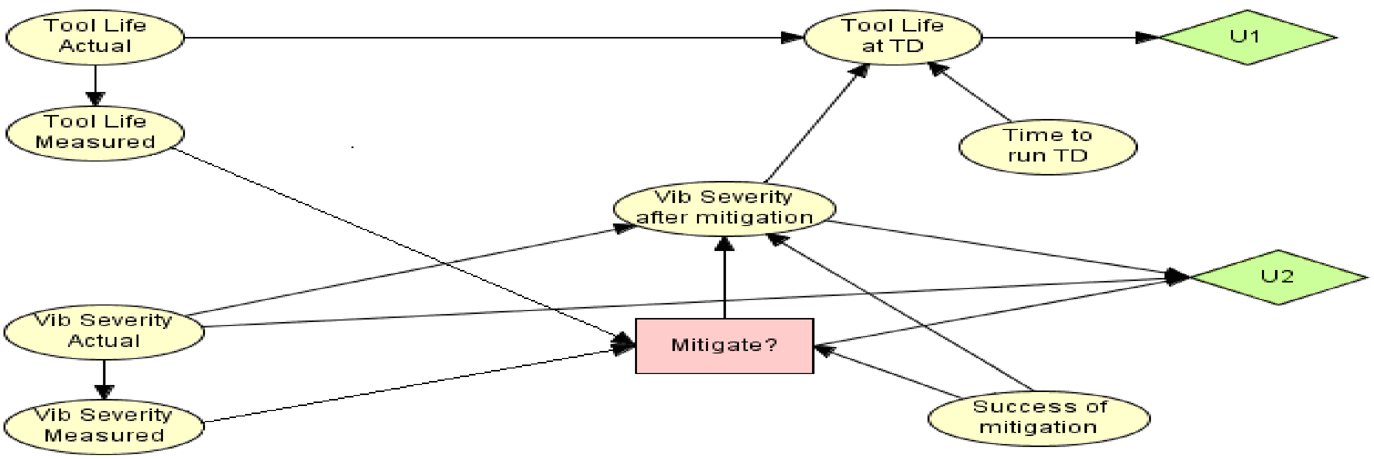

Figure 3. Influence diagram for the shock and vibration mitigation decision making

U1

H	failure	critical	statisfactor	good
Utility	-12	24	100	200

U2

A	ignore									
M	absent				low				medium	
Ms	absent	low	medium	high	absent	low	medium	high	absent	low
Utility	0	0	0	0	0	0	0	0	0	0

A	ignore						mitigate			
M	medium		high				absent			
Ms	medium	high	absent	low	medium	high	absent	low	medium	high
Utility	0	0	0	0	0	0	-10	-100	-100	-100

A	mitigate									
M	low				medium				high	
Ms	absent	low	medium	high	absent	low	medium	high	absent	low
Utility	0	-20	-100	-100	0	0	-10	-100	0	0

A	mitigate	
M	high	
Ms	medium	high
Utility	0	-10

Figure 4. The values of influence diagram utility function for the decision making on vibration mitigation

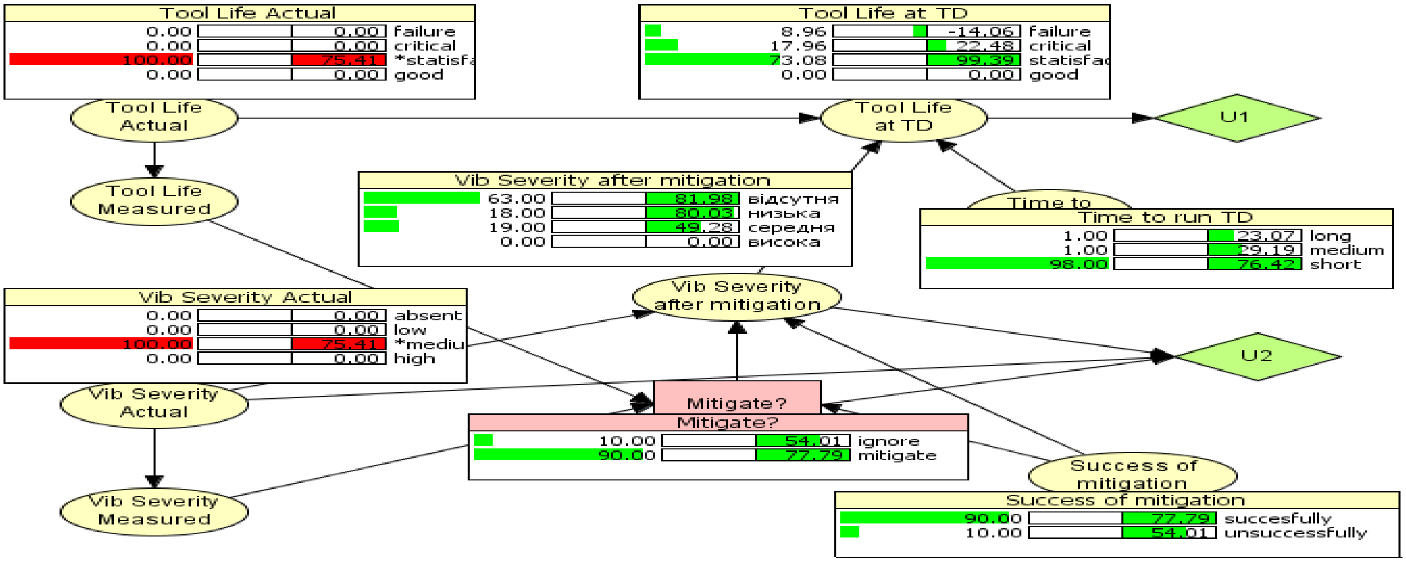

Figure 5. Example of automated decision making on shock and vibration mitigation need

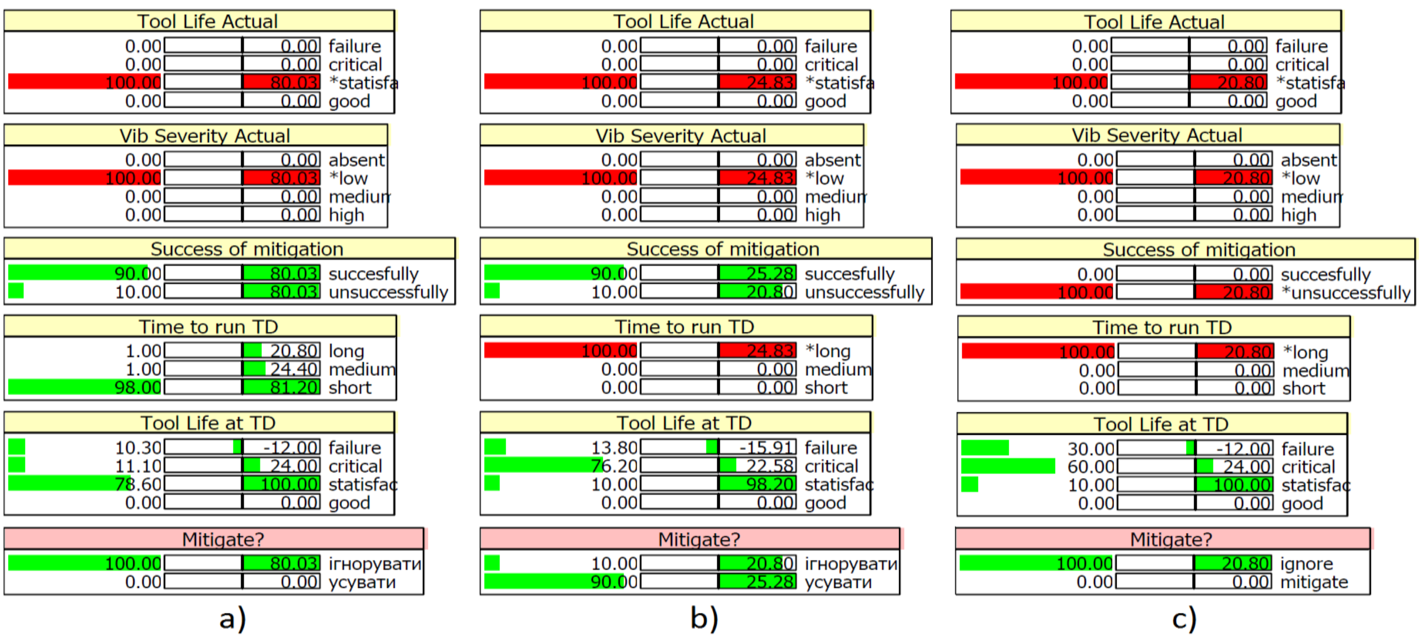

Figure 6. Comparison of the decision making on shock and vibration mitigation: a) case 2; b) case 3; c) case 4

CONCLUSION

The analysis of scientific papers of decision support systems in oil-well drilling shows that most of the existing DSS are based on MBR-methods and works in the mode of advisor. Insufficient attention is paid to the use of influence diagrams based on probabilistic mathematical apparatus of Bayesian networks, which is more suitable in the condition of uncertainties, inaccurate or conflicting input information and is more appropriate for system analysis.

It is analyzed the peculiarities of decision making in drilling process which is incorporates conditions of risk and drilling uncertainty. Main factors which affect decision making about shock and vibration mitigation had been analyzed. With the use of influence diagrams, the process of situation assessment and decision making has been modeled. Automated decision is made by solving the proposed influence diagram by principle of maximum expected utility. The process of automated decision making was demonstrated, compared and analyzed by a number of case study examples. The influence diagrams model for decision support in shock and vibration mitigation while drilling has been proposed for the first time.

The proposed model can be easily extended with additional nodes in order to reflect new information as drilling progress. Models of the decision process which are based on Bayesian networks and influence diagrams can be used for artificial further intelligence and expert decision support systems development in the direction of drilling systems automation.

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Short Bio Data for the Author


Taras Matviykiv is a Ph.D. student at Lviv Polytechnic National University, Ukraine. He has M.Sc. degree in information design technologies. His research area is applications of computer science in oil-well drilling systems. He has published several papers in scientific journals and has participated in international and national conferences.


Prof. Vasyl Teslyuk is Professor at Lviv Polytechnic National University, Ukraine. He has published more than 300 papers in international and national scientific issues and journals. His research work based on computer-aided design and modeling of microelectromechanical systems and integrated circuits. In addition, he is an author of 2 monographs and 2 study guides. 4 PhD theses were defended under his leadership. He also is a supervisor of five aspirants.