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ORIGINAL ARTICLE

P-HAZOP: A New Extended HAZOP (Hazard and Operability) Study for Risk Analysis of Pipelines

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ABSTRACT

Due to the high potential consequences of pipeline accidents, it is necessary to manage the inherited risks in the pipeline sectors. Several techniques are available to identify hazardous situations; however, it is crucial that the selected tool is tailored to the scope of work. HAZOP study is one of the most accepted techniques adopted by experts to identify hazards. Despite the wide application of HAZOP in process industries, this method is not suitable for pipelines. In this study, a new extension of HAZOP (P-HAZOP) was introduced through integrating the classic HAZOP and Kent's method. This research focused on detecting a new sort of deviation from the design intent in pipelines. A previously conducted HAZOP study for a pipeline network was re-conducted using P-HAZOP. A large number of newly detected deviations demonstrated more coverage of the P-HAZOP for the pipeline scope. Finally, it is recommended to improve the traditional HAZOP for pipeline applications.

KEYWORDS: *Pipeline risk, HAZOP, Risk identification, Kent's method, Deviation*

INTRODUCTION

Transportation of Hazardous Materials (HAZMAT) is a major source of risks, which threatens many industries as well as the public population. Pipeline networks are known as the most common way for the safe transport of HAZMATs. These networks are distributed among many industries and their clients, including the public population. Although transporting hazardous materials by pipelines seems safe, it involves its safety problems. Although the frequency of the pipeline accidents is low, the high potential for their consequences can overwhelm the low frequency. Accident databases reveal that pipelines conveying hazardous materials have the same level of risk as refinery installations [1]. The pipeline industry has experienced at least 8 major explosions and more than 55 deaths only in the year 2014 [2]. Pipelines are laid in areas where are not usually under the control of industries. In addition, the passage of pipelines through high-risk areas, such as the crowded regions, makes the situation more dangerous. Therefore, high potential consequences, lack of control, and passage through high-risk areas have made the pipelines as a serious source of damaging risks [3]. Many regulators stipulated strict requirements for managing pipeline risks. There are also several tools for identifying and assessing the risks of firms. One of the most popular techniques to identify the process risks is HAZOP (Hazard and Operability), which is employed as a powerful tool for the identification of operational and safety risks [4]. The HAZOP study focuses on procedures and aims at recognizing probable deviations from the intended design. This method is a systematic, highly disciplined, and experience-based approach that is suitable for most of the complex systems [5]. HAZOP is a commonly used hazard analysis method and many studies have focused on re-adapting HAZOP since the emergence of the process safety concept [6]. HAZOP is an intuitive technique that has been designed to inspire the inductive thinking by experts to identify hazards and operational deviations while examining a process and a system [7]. However, similar to the other risk identification techniques, the HAZOP has a specific and limited scope. This technique is a more suitable tool for complex systems with a wide range and interacting process parameters, while pipelines are relatively simple systems. The process

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parameters in pipelines are few and mainly related to the line flow. The use of traditional HAZOP for pipeline studies would be boring, and it may not be able to identify all the hazards [8]. Therefore, the common HAZOP may not be suitable enough for pipeline hazard identification. Despite this fact, many companies still insist on using HAZOP in their studies on risk analysis of pipelines. Field investigations revealed that many companies employ this technique for risk assessment of pipelines and other complex systems. Several reasons can persuade the process industries to use HAZOP for pipeline systems. This affinity may be due to "the obligation of an organization to work with HAZOP", "matching the applied technique with the risk assessment technique of other units or plants", and "familiarity with HAZOP". This research aimed at improving the classic HAZOP and making it more suitable for the use in pipeline risk assessment. To achieve this goal, Kent's method and classic HAZOP were integrated. Kent's method is an excellent and comprehensive technique for risk management of pipelines [9]. This method has shifted the pipeline risk management from the classic procedures to a new approach [9]. The specificity of Kent's method and the generality of classic HAZOP can provide a robust method for the risk management of pipelines. This research is a new extension of HAZOP, so-called P-HAZOP developed for the risk management of pipelines.

MATERIALS AND METHODS

Literatures Review: Some attempts have been made to expand the scope of classic HAZOP. As such, Dunjó et al. [5] made some efforts to extend the scope of HAZOP [5]. New approaches have developed new versions of HAZOP by expanding the scope of hazard identification, taking into account human factors, and making specific corrections. Grossmann and Fromm suggested an alternative mini-HAZOP study by excluding irrelevant and trivial questions of the full HAZOP. In their research on full HAZOP, they stated that about 90% of the questions did not provide new information on risks [11]. The main difference between the new extension and the full version of HAZOP is that this approach focuses on meaningful deviations and eliminating duplicate and redundant questions. In response to the newly emerged demands, the HAZOP technique has changed considerably. This is because of its capability to innovate new extensions for more specific applications. Some modified HAZOP versions have been developed in the past years to improve the applicability of HAZOP [12], among which can be pointed to HASPED [13], TOPHAZOP [14], Multilevel HAZOP (HzM) [15], Goal Based HAZOP [16-17], and Functional HAZOP [16-17].

Classic HAZOP: In the classic HAZOP, some known process parameters (pressure, temperature, etc.) and guidewords (less, more, no, etc.) are combined to create a potential deviation from the design intent [4]. The guidewords are generally constant and the analysis is mainly focused on the parameters. The identified high risk deviations would be analyzed in more depth as needed. The overall structure for finding the deviations is as bellow:

Process Parameter + Guideword= Deviation

Because of the limited parameters of the pipelines, the general structure of the formula is very simple.. This means that the implementation of the HAZOP study for pipelines produces a small number of similar deviations that focus mainly on the flow parameter. However, factors influencing pipeline integrity are so various that the current approach of HAZOP is unable to find all of them. Therefore, an extended new group of deviations beyond the common process parameters is required to cover more situations.

Node and Segment: In the common form of HAZOP, a complex system would be disintegrated into some nodes. Any node demonstrates a unique process within that at least one parameter changes. For example, the pressure would rise. For pipeline studies, due to the simple and long structure of the system, establishing nodes does not work. Instead, the long body of the selected pipe could be divided into some segments. The overall risk within a segment differs from the other segments. The criteria for segmentation can be changed according to the population density around the segments, soil corrosivity, and pipeline class or even surrounding environment. Each segment could be studied like a node for complex systems.

Creating the new deviations: To conduct the study, an eighteen-kilometer underground methane gas pipeline was selected in the south of Iran. The operating pressure was in the range of 8501000 psi and it is laid through the desert. A HAZOP team who previously had conducted the classic HAZOP study for the pipeline was invited to integrate the classic HAZOP and Kent's method. The team members included process engineers as the operators, safety technicians, and some other disciplines from the maintenance and instrumentation department. The parameters, which could influence the integrity and risks of the pipelines, are discussed in the Kent's manual [18]. The output of the Kent's method is represented in Fig. 1. Each component contains several sub-components. For example, the third party damage index has 7 sub-components, including soil depth, activity level, above ground facilities, line location, public education, right–of–way condition, and patrolling frequency. To innovate the new

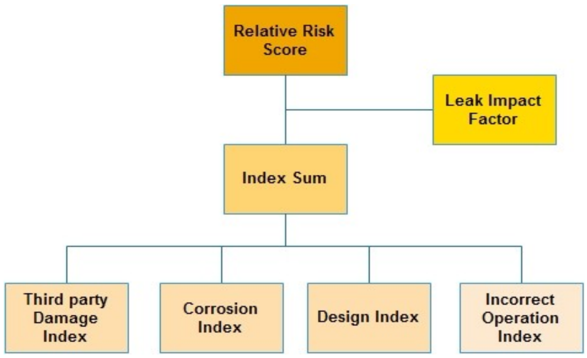

Fig. 1. Outline of Kent's method for pipeline risk assessment [18]

deviations, the components and sub-components of the index sum were analyzed and all deviations applicable for pipelines were selected. Each parameter that was noted in the manual as "an effective factor with influence on the safety of pipelines" was selected as a new deviation by the leader and the team discussed the suggested item. More than 37 parameters were found and entered into the judgment process. To accept a deviation as a novel one, it was agreed that more than half of the team members should have consensus on it. A cross table was made to mutually pair the old and new deviations. In addition, there were also some repetitive deviations, found in both the previous and the new rounds. These deviations were excluded and only the novel deviations were listed. Finally, a comparison of the previous study with the new version was done in some segments. This comparison is presented as a case study.

RESULT

The core element of the present study was based on creating a new sort of deviations from the generally accepted guide source that would be suitable for the HAZOP of pipelines. All components of Index Sum were disintegrated and the relevant parameters and deviations were detected. Table 1 shows some of the new deviations selected for the Index Sum.

The overall assessment revealed that the new deviations could be categorized in three groups:

1. The deviations that were the same as the previous deviations
2. The new deviations with some degree of overlaps with the previous ones, and
3. Quite new deviations

The team was looking for those deviations, which were new, exclusive, and supplementary for the primary deviations. Therefore, group 1 (overlapped deviations) was excluded. Most of the approved deviations belonged to the category of the novel deviations. The overlapped deviations were the clues that are expressed indirectly in the classic approach; however, the new approach pointed them directly. The repetitive deviations were the same as the first study, while the exclusive deviations were new and novel that and had not been pointed out previously. As stated before, the final evaluation of the proposed deviations showed that the most of the proposed deviations belong to the novel deviations. Fig. 2 depicts the contribution of each group of the deviations.

An Illustrative Example: A case study was conducted for a group of utility, feed, and product lines. Some of the most important lines were included in the study, namely nitrogen, oxygen, chlorine, ammonia, methane, benzene, and ethylene glycol pipeline. The methane line was underground and the others were above ground. This study was done for the methane line. After completing the new study, a comparison between the two projects was made. The team discussed the similarities, overlaps, and differences between the two studies. The newly detected deviations, regarded as the novelty of the p-HAZOP, were marked for further studies. Fig. 3 depicts the case study. Table 2 compares some of the new deviations with the previously identified deviations. Finally, the new complementary findings were added to the primary study.

DISCUSSION

In response to the constraint of the HAZOP for the use in risk assessment of pipelines, a new extension of HAZOP was developed in this study to overcome the existing limits. To this end, the classic HAZOP was integrated with Kent's method. This integration generated considerable new guidewords that reveal the need to improve the current HAZOP to cover the scope of pipeline risk management. In addition, the overlapped guidewords generated more knowledge about pipeline risks. The results demonstrated that employing this new extension of the classic HAZOP modifications revealed poor applicability of the commonly used classic HAZOP for the use in the domain of pipeline studies [19]. An outstanding feature of the new extension is its ability to enlist more details as deviations. In other words, this method can convert many failures of control systems or lack of control over the new deviations. This extension provides more (1) detailed checklist for the analysis to find the probable deviations in designs. Such a feature is especially important for those analysts with a lower level of experience. It could be said that P-HAZOP brought the publicity and comprehensiveness of the two approaches in one method. Many studies have emphasized the importance of pipeline risk management [19]. Selecting the right tools for controlling pipeline risks is crucially required. This research confirmed the previous studies on the would improve the traditional version. The new necessity of modifying the classic HAZOP to cover new applications, including pipeline risk management [5, 17, and 20]. This study highlights the need for the improvement of the current HAZOP for using in the scope of pipeline risk management. Using an integrated approach could enhance the capabilities of each technique and resolve the drawbacks of the techniques. However, it is recommended to study the integration of other pipeline risk assessment techniques in order to develop new methods more suitable for pipeline risk identification or improve the existing classic procedures by integrating with more comprehensive methods, such as Kent's method. It should be noted that these new extensions only improve the classic methods and are not alternatives for them because some classic deviations are exclusive and do not have substitutions.

Table 1. Extracted deviations from Kent's method

Parameter	Guide-word	Deviation	Meaning
Depth of soil cover	Inadequate	Inadequate depth of cover	Inadequate depth of cover is a deviation from the normal design.
Activity level	High	High activity level around pipelines	High level of activities around pipelines would rise the total risk e.g. excavation
Above ground facilities	Susceptible	Susceptible above ground facilities	Existence of above-ground facilities reflects a higher risk (pump stations, compressors, etc.).
Line location	Ambiguous	Ambiguous line location	Ambiguous line location is a deviation from the intended design.
Public education	Low/ Inadequate	Low public education	More awareness of the third parties around pipelines reduces the risks.
Right of way condition	Lack of right of way	Lack of right of way	Lack of right of way is a deviation from the normal operation.
Patrolling	No /Less	No /less patrolling	Normal operation of pipelines depends on the routine patrolling.
Environment	Harsh	Harsh environmental conditions	The impact of the surrounding environment on pipelines
Coating quality	Poor	Poor coating quality	Poor coating quality is a deviation from the intended design.
Design thickness	Less	Less thickness	It is an obvious deviation from the designing specifications.
Fatigue	Unacceptable	Unacceptable fatigue	Unacceptable Fatigue is located outside of the intended design.
Maximum operating pressure (MOP)	Exceed	MOP Exceeding	observing MOP increase integrity and safety
Surge potential	High	High surge potential	Surge effect is a sudden conversion of kinetic energy to potential energy, which is destructive.
Landslide	Destructive	Landslide	beyond the accepted design
Safety system	No	No safety system	The control system that prevents the pipeline from being over- pressurized.
Supervisory control and data acquisition	Lack	Lack of SCADA	normal transmission of information is a part of the intended design.

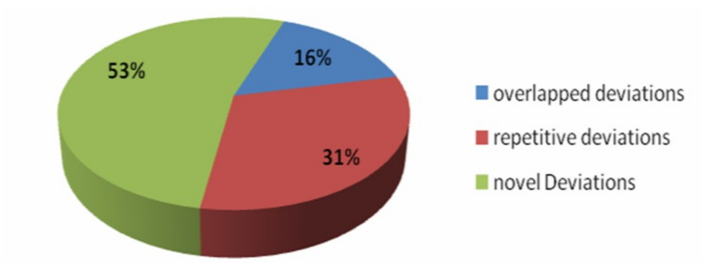

Fig. 2. Classification of the new deviations

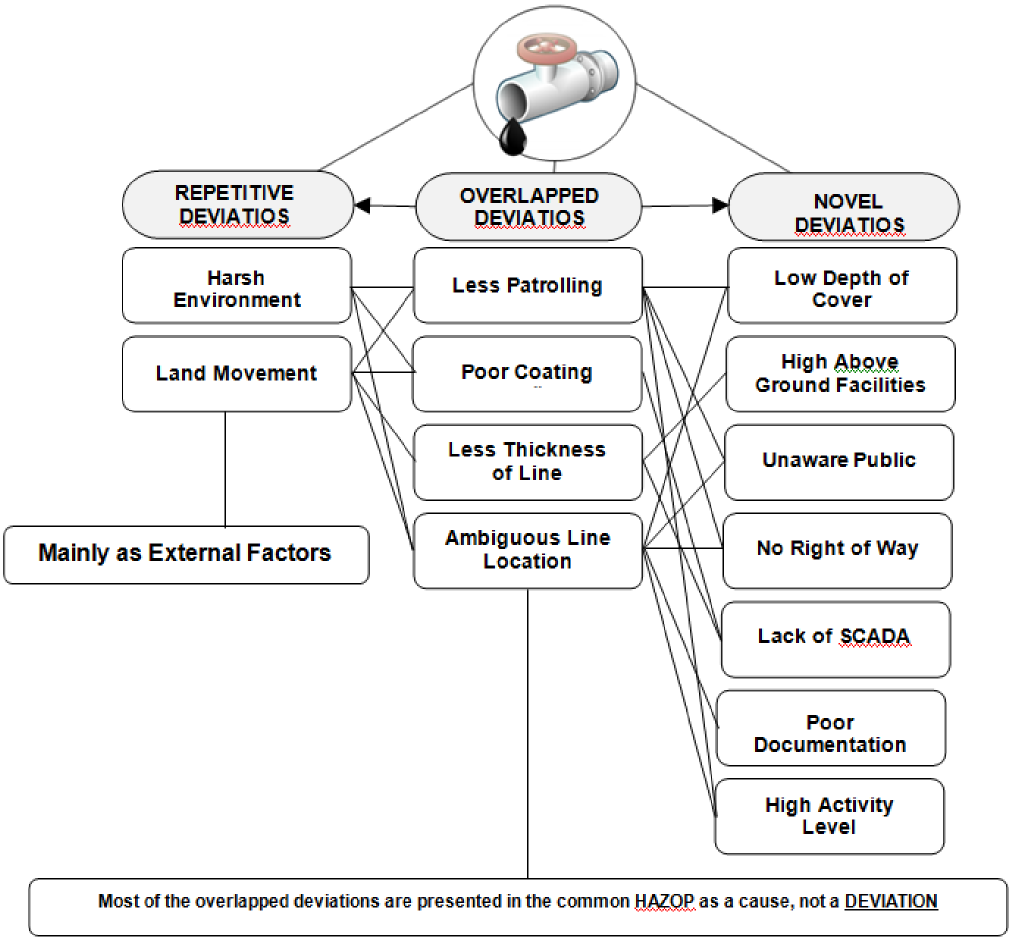

Fig. 3. Classified pipeline deviations

Table 2. Comparison of the classic and new deviations

New deviation	Overlaps with the classic deviations	Preference
High activity level	Pointed as a cause, not as a deviation, which can lead to some impacts	Unacceptable activity around pipelines is a deviation from the normal state.
Less depth of soil cover	No	Exclusive
High above ground facilities	Pointed as location of impact, not as a deviation	High above ground facilities endanger the transportation system.
Ambiguous line location	No	Exclusive
Poor public education	No	It could be a deviation from the desired status.
No / poor observation right of way	No	Exclusive
No / less patrolling	In some cases patrolling had been mentioned as a control measure	Lack of patrolling is a deviation from the normal procedures.
Harsh environment	Pointed as seasonal variations and hot or cold environment	Repetitive
Poor coating quality	Pointed as a cause for poor insulation	It could be a deviation
Less thickness	Pointed as a cause for line rupture	Considering less thickness as a deviation gives a better focus for finding its causes
Exceeded MOP	Pointed as more pressure	Considering "Exceeded MOP" clarifies which extent of pressure is allowable
Land movement	Pointed as a cause for line rupture	Applying it as a cause might lead to the ignorance of line deformation
No / poor safety system	Pointed as control measures	Considering it as a deviation would help to determine the cause of poor safety systems
No SCADA	No	SCADA was considered as a control measure not a root cause of the deviation.
No / poor documentation	No	Exclusive

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CONCLUSION

The classic HAZOP, which is used frequently by some companies to identify pipeline risks, is not a perfect technique for using in this scope. It is recommended to improve the classic HAZOP and robust it to be more fitted for the use in risk management of pipelines. It could be a good idea to integrate the classical HAZOP with other techniques to extend its scope of applicability. This was realized in this study by integrating the classic HAZOP and Kent's method in the form of a new method, called P-HAZOP.

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