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Review Article

Review and comparison of different risk assessment methods used for intelligent pigging operations in oil and gas pipelines with emphasis on the Bow Tie method

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Abstract

Considering the importance and role of process industries, including the oil and gas industry, in each country's economy and on the other hand, as the dangers and risks in these industries are high, it is very important to identify, control and analyze them in process industries. This study aims to investigate and compare different risk assessment methods used for intelligent pigging operations in oil and gas pipelines, emphasising the Bow Tie method. Various risk assessment methods were also examined in this study. Finally, it was observed that the Bow Tie method is an efficient method for assessing the risk of intelligent pigging operation in oil and gas pipelines, which has more advantages than other risk assessment methods, and by combining fault tree analysis (FTA) and event tree analysis (ETA), a comprehensive risk assessment of intelligent pigging operation in oil and gas pipelines can be reached.

Keywords: Risk assessment; Intelligent pigging; Oil and gas pipelines; Bow Tie method.

1. Introduction

How to produce from the pipelines and protect it depends a lot on the pigging operation and the pigs' efficiency. In the past, pigs were only used to clean the pipe from wax or debris and thus accelerate the flow of transfer fluid in the pipeline. Today, the pigging system is necessary for the complete cycle of maintaining pipelines, i.e. in the stages of construction, production, inspection, preservation and maintenance, repair, restoration and renovation, and during pipeline shutdown [1].

To increase the efficiency of the pipelines, they should be pigged periodically. This operation includes launching and receiving an intelligent pig, which cleans impurities and sediments by passing through the pipe. Other special pigs are also used to identify the amount of corrosion inside the pipe, geometric changes, etc., depending on the need. This operation has many potential risks that, if not detected and controlled correctly, will lead to irreparable accidents [2].

2. Problem statement

The transmission pipelines that are placed in the transmission of oil and gas, despite the refinement done on them, sometimes due to some factors, are contaminated with hydrogen sulphide gases, water vapour, etc., leaving behind acidic and corrosive conditions that make the use of the transmission pipeline unsafe and sometimes impossible. Unwanted sediments caused by waste materials inside the pipe sometimes narrow the inner space of the pipe so much that more energy is required for pumping due to the reduction of efficiency. The decrease in efficiency is caused by the two factors of increasing the surface roughness and decreasing the inner diameter of the pipe. Regular pigging makes the pipeline free of liquids, prevents the overall pressure drop and hence increases the flow efficiency. After all, the pig plays a vital role in showing the physical conditions of the pipeline. Therefore, the goal is to adopt a method that reduces these various problems and, in

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addition to increasing efficiency, guarantees the neighbouring community's safety [3].

The evaluation process of pipelines requires having sufficient assurance of the geometrical condition and dimensions inside it. During the operation, the indentation or double-widening of the pipe or other defects may naturally cause the pig to be stuck or even lost in the pipe, which can cause the flow in the pipe to be interrupted. As a result, it disturbs the entire transmission process. Therefore, the a need to use a powerful tool that can inform the user about the internal conditions of these pipelines before any accident is inevitable. This is made possible by using intelligent methods of pipeline control. Today, with the progress of knowledge in microprocessors, data storage, ultrasonic tools, polymers and computers, a new method has been created to inspect pipelines. This method is called intelligent pigging [3].

To increase the efficiency of the pipeline, the gas transmission pipelines are periodically pigged. This operation includes two independent operations of launching and receiving the intelligent pig, which cleans the impurities and sediments by passing through the pipe. Also, other special pigs are used to identify the corrosion inside the pipe, the geometrical changes of the pipeline, etc. This operation has many potential risks that, if not detected and controlled in time, will lead to unwanted outcomes [2].

The Bow tie analysis technique, which is a simple idea of combining causes and consequences, will thoroughly examine the relationship of all parameters in the analysis of accident factors with their due control measures, activities and critical tasks in two phases before and after the occurrence of the accident, which it ultimately leads to the ideal goal of every industry, which is to reduce the occurrence of accidents to zero [4].

Simultaneously with the growing attention on various aspects of safety and the need to identify risks before their actualization, multiple tools are also designed and introduced, each with strengths and weaknesses. Today, these types of tools, which are presented in the form of system safety techniques, have enjoyed such variety and breadth that, apart from the proper use and correct and accurate interpretation of the results, the valid selection of the method has become a vital issue, because the inappropriate choice of the tool is not only possible, but also is not helpful from the aspect of cost-effectiveness, but it is also hazardous due to providing misleading results. Therefore, knowledge of the characteristics and capabilities of the available tools and the ability to compare them and, as a result, choosing the most appropriate technique is considered a vital step in the safety analysis of today's critical systems. Despite the many advances in safety science and the introduction of system safety science that emphasizes identifying and controlling the risks before they become accidents, it will still be impossible to reduce the rate of accidents to zero. Therefore, accident investigation has always been considered an undeniable part of safety science, and its correct design and proper implementation will provide a basis for preventive measures regarding possible accidents in the future [5].

Considering the importance and role of process industries, including the oil and gas industry, in the economy of every country, and on the other hand, the high level of dangers and risks in these industries, the need to identify, control and risk analysis has increased. Therefore, due to the revelation of the shortcomings of risk analysis methods over time and the complexity of these processes, safety experts are trying to find new methods that perform risk analysis faster and more accurately and do not have the shortcomings of previous methods. It isn't easy to achieve such a comprehensive method with high speed and accuracy [6].

3. background research

The nature and performance of process industries such as oil and gas, while being of great importance, are sometimes hazardous. Risks have been identified and evaluated in various fields of industry, especially oil and gas, and their results have been analyzed to define and implement effective corrective and preventive measures. What is very important in the analysis of the risk assessment results is the precise identification of the operation or process under study and the investigation of the incidents in it. These studies prepare a systematic method and a model to generalize to other sectors of the industry for an acceptable level of process risks. Made using a general risk assessment model for all three parts of identifying risks and possible consequences, the effectiveness of corrective actions is never recommended. Because the consequences analysis models are not necessarily effective in the analysis of incidents, it is recommended to use models specific to that sector for all three industries [7].

Much research has been conducted regarding identifying risks and high-risk activities in industries. Also, according to the results of the existing risk assessment, corrective and preventive measures have been defined and implemented. However, a point that has not been addressed seriously in the country's vital industries is investigating and analysing the incidents and their consequences to prevent their recurrence. This is vital when providing a correct and comprehensive analysis of the risk assessment results according to global standards is possible. So far, there has not been a comprehensive review of the risk assessment methods used in intelligent pigging operations of oil and gas pipelines. In all the previous studies, only one specific risk assessment method has been examined. Therefore, the present study has investigated different risk assessment methods used in intelligent pigging operations.

In a study, Asemani studied the modelling of pigging operations in oil and gas pipelines. In this research, the dynamic modelling of pigging has been done in pipelines where gas or liquid fluid flows. All pigs are practical when travelling along the pipeline at the proper speed. It is essential to know the optimal speed and duration of the pig. This can help the operator to time the pig to the pig receiver. To model the movement of the pig in the pipelines, the fluid in front of the pig and the fluid behind the pig have been solved simultaneously with the dynamic model of the pig [8].

In another study, Kabiri et al. discussed the risk assessment of gas pipeline pigging operations using the Bow tie method in the Ten regions of gas transmission operations. The pigging operation is carried out to remove deposits from the pipelines and prevent impurities from being transferred to other gas industry facilities and damaging them. This operation includes two independent operations of launching and receiving the intelligent pig, which cleans the impurities and sediments by passing through the pipe. Also, other special pigs are used to identify the amount of corrosion inside the pipe, the geometrical changes of the pipeline, etc., in this operation, depending on the need. This operation has many potential risks that, if not detected and controlled, will lead to irreparable accidents. This article attempts to prevent accidents by carefully identifying the possible risks in this process and conducting a successful risk assessment in the Bow tie software environment [2].

In a study, Mirzaei Aliabadi et al. implemented the human error risk analysis method (SPAR-H) in the pigging operations of gas transmission pipelines. This descriptive study was conducted to estimate the possibility of human error in follow-up operations in a gas transmission company in Iran. First, Hierarchical Task Analysis (HTA) was done through field surveys, observing the tasks of the follow-up operation and conducting interviews with the operators working in this operation. Next, the human error risk assessment method (SPAR-H) was used to evaluate the possibility of human error. The results of this study showed that the SPAR-H method is a valuable and practical tool for experts to calculate the probability of human error. Based on the results of this study, some preventive measures were suggested to reduce the possibility of human error: using precise and specific instructions to perform operations and automating the processes of launching and receiving pigs [9].

In a study, Vafai analyzed the risk and reliability of human performance in the pigging operations of the 4th area of Iran's gas transmission pipelines. This research first discussed qualitative analysis tables of the PetroHRA method and quantification based on FMEA tables, operations recognition, qualitative risk analysis, risk prioritization, and identification of performance-shaping factors in follow-up operations. Then, based on the designed questionnaire and using the CREAM control style method, the probability of human error and reliability in the follow-up operations of the area were calculated. Finally, sensitivity analysis was done to improve performance and provide suggestions. According to the results obtained, fire inside the receiver, production of iron-sulfur and collision of machines with gaseous equipment are the most dangerous risks; two factors of time and training to improve performance, three factors of capability for complex work, method, and human interface and Machines work to reduce performance. Pig monitoring, presenting risks and presenting the final report have the most human error. Most errors of the cognitive function are related to the cognitive function of execution, and the control style of the area indicates that the personnel follow a specific method with little generality; therefore, modifying the technique can increase the reliability and capability for complex work. Also, with the four factors of work environment, human-machine interface, training and time remaining constant, and the improvement of three aspects of capability for complex work from inefficient to very efficient, method from inappropriate to acceptable, and teamwork from good to excellent, human error will be significantly reduced [10].

Velayatzadeh et al. studied the risk assessment modelling of pigging stations of gas transmission pipelines using the SIL method. This cross-sectional-applied research aimed to identify risks and quantitatively evaluate the risks in the gas industry's pigging operations with the help of a similar model. In this research, the methods of identifying risks and failure and success states, including the HAZOP method, fault tree analysis, event tree analysis, and analysis of protective layers, were implemented in this model. With the help of the safety integrity level method, the level of failure and success states was determined. The HAZOP method identified 9 parameters affecting the risks in pigging operations. In the fault tree analysis, two main groups of external and internal factors were identified: natural factors, human error and corrosion. The event tree analysis showed that the highest probability of occurrence related to outcome A (explosion + gas leak + heat and light + no casualties) and the lowest probability of occurrence related to outcome I (gas leak + poisoning + pollution) were obtained. In the identified events, the highest and lowest failure rates were associated with the failure of the control valve and the failure of the inlet and outlet valves, and according to the calculations, it is at the SIL2 level [11].

In another study, Hong Yu et al. discussed risk analysis and preventive measures for gas pipeline pigging operations. They stated that long-distance pigging operations in gas pipelines should be carried out regularly and according to a schedule to ensure the safety of operations. Due to the possibility of ignition and explosion of natural gas and operations on gas pipelines

under high pressure, pigging operations are hazardous. This article examines possible risks in pipeline drilling operations, such as pig jamming, gas release, valve leakage, self-ignition in hydrogen sulphide gas (H2S), natural gas explosion, and environmental pollution, and preventive measures are provided accordingly. The pigging operation also requires continuous and coordinated cooperation between groups, especially when launching or receiving a pig [12].

In a study of intelligent pigging in high pressure gas pipelines (practical problems and solutions), Nagaraj stated that intelligent pigs, or in-line inspection instruments (ILI), are electronic devices that monitor the flow inside a gas pipeline. They are typically designed to inspect the pipeline for various problems that increase the risk of pipeline failure while the line is in service. This paper describes the multiple issues pigging faces in gas pipelines even after receiving data from a conventional pipeline questionnaire following NACE RP0102. The problems and solutions start from the launching of the pig. They can be checked when passing through different pipeline parts and receiving the pig at the receiver, including recovering information from the intelligent pig [13].

In another study, Lee et al. analyzed the risk in natural sour gas pipelines during drilling. They stated that the pigging operation is a very high-risk operation. Pipeline pigs may get stuck, leading to gas leak accidents and fire and explosion risks. In addition to possible risks in natural gas pipeline pigging, there may be other risks in sour gas pigging operations that increase the risk of pigging operations. In this study, in line with the specific execution flow of pigging operations, the risks in setting up, driving, and receiving the blaster were analyzed to ensure the workers' safety and that the pigging operation was carried out and completed smoothly. According to Lee et al.'s research, more condensates and hydrates are formed if H2S is present in natural gas. Acidic gas can accelerate the corrosion of the pipeline and shorten the topping cycle. Sour gas can lead to employee poisoning, fire or explosion. The possibility of pig failure in the pigging process is high. All of the above shows that the risk increases when transporting sour gas. They also suggested selecting some anti-H2S material to make the pig and adding corrosion-resistant gas to the gas. In addition, a protective layer should be applied to the pipe, and the workers should use gas-resistant masks and personal protective equipment when receiving pigs [14].

4. Bow Tie Risk Assessment Method

The bow tie method is one of the most valuable methods in risk management, whose initial idea was presented by Hazan at the University of Queensland, Australia, in 1979. and after that, this method has been widely developed in the world. The records and experiences show that this method can manage all risks and dangers [15]. On the one hand, this model has been able to achieve the required balance through the connection between hardware and software systems, as well as the connection between the risks and the consequences of their occurrence through the required barriers and compensatory means to prevent the occurrence of accidents and the chain consequences caused by them. Establish and show them how to control them in the safety, health, and environment management system. Meanwhile, people's awareness at different levels of their influential role in managing risks and consequences significantly improves the structure and performance of safety, health and environmental management systems [16].

This method can show the components' relationship in analysing potentially damaging factors with control measures, activities and critical tasks. It is the clearest graphic representation of risk management. Presenting management solutions as a bow tie model to reduce and control the identified risks is possible. [17].

The Bow-tie risk assessment method is an integrated probabilistic method in risk management that, by finding the fundamental causes of an incident and their logical relationships, analyzes its consequences and evaluates the probabilities and paths of occurrence of different scenarios to prevent, control and reduce unwanted events. The graphical representation of this method is formed by combining a fault tree (FTA) and an event tree (ETA) [18].

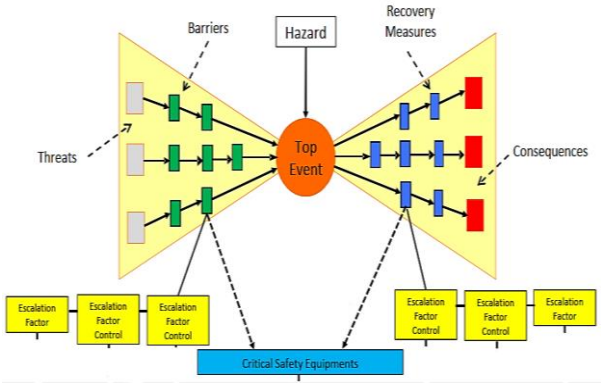

Figure 1. Diagram of Bow Tie model [19]

The Bow-tie diagram consists of five main elements: BE base events, FT fault tree, main initiating event, ET event tree and external event. The fault tree is on the left side of the diagram, and the event tree is on the right side of the diagram. Finally, by combining the fault and event tree, an important event's causes and consequences are identified, and a Bow-tie diagram is formed (Figure 1) [19].

Fault tree analysis is a graphical method that shows the relationships between a top event and the base events in a figure. This method identifies a specific adverse event

(the top event) and evaluates the causes that can lead to this event [20]. The event or consequence tree analysis method is a hypothetical modelling technique that simultaneously evaluates the consequences of a single event by creating two branches of success and failure. This technique explains the system's responses against an initiating event and allows for evaluating the probability of a favourable or unfavourable outcome [18]. Figure 2 shows the implementation steps of the Bow tie method.

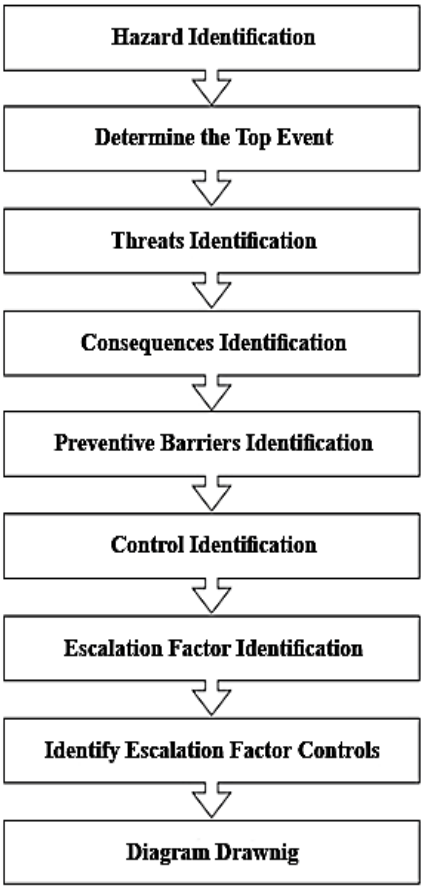

Figure 2. Bow Tie method execution steps [19]

5. Advantages and disadvantages of the Bow Tie risk assessment method

The bow tie technique is one of the most useful techniques for risk management, during which the relationship between all factors related to the risk process is shown. Also, the relationship of all components in analysing potentially harmful factors with control measures, activities and critical tasks is fully investigated. The bow tie method can evaluate the barrier's performance (such as response time, efficiency, and reliability level) and identify defective barriers or their absence. This method can be especially useful for showing the effect of safety systems and obstacles on developing accident scenarios [19].

The Bow-tie diagram depicts the risk under consideration and understandably. The power of this method is to show the possible scenarios in evaluating risk and the logical connection between its causes and consequences in a diagram. With the help of this method, the most important scenarios can be determined, and risk control and unwanted events can be reduced [18].

The bow tie technique considers both preventive and reactive elements and is used in practice as a useful method to prevent, control and reduce accidents. This method is a powerful visual tool for displaying regulatory interactions in events and incidents in an organization. In addition to showing important events, it can also show negligible events. Therefore, if this method is combined with other risk assessment methods, it is possible to identify dangerous risk factors and, as a result, the top event. In other words, you can focus all your attention and effort on identifying and controlling the factors affecting the top event and preventing the waste of energy and time due to investigating non-main events [19].

Markovski stated that among the different qualitative models used to present the accident scenario, the Bow-tie approach best represents the relationship between different risks (causes), accidents, safety systems and consequences. This research showed that this method has a relative advantage due to its high flexibility compared to other risk assessment methods [21]. The most important advantage of adopting the Bow-tie approach in risk analysis is that it provides a solid technique for comprehensively identifying all risk events and promotes understanding of their interrelationships. To communicate the basic cause and effect of more complex risk scenarios, it uses a format in the form of an easy-to-understand plan [5].

By using the bow tie model, it is possible to achieve the objectives of risk management, including applying management before the occurrence instead of after the occurrence, determining the adequacy of existing or planned controls to prevent the occurrence of an accident, determining the adequacy of existing or planned controls to prevent the occurrence of an accident, determining the adequacy of existing or planned controls for accidents after the occurrence of the accident and the ease of decision-making about the necessity and practicality of executive procedures and their relationship with existing risks. The useful features of the bow tie method are specifying the distinction between preventive and reactive barriers to eliminate or reduce the effects of the risk of a particular incident and the capabilities of the bow tie method in simplifying the determination and diagnosis of cause and effect factors, as well as summarizing and converting a large amount of quantitative data into a relatively small number of common scenarios are among the characteristics. As a result, the bow tie approach can

be considered an effective way to present and communicate project risk and its management, which is understandable for all levels of project officials and employees [17].

Using the systematic and analytical Bow-tie method while determining the root causes of accidents in determining critical tasks to ensure the integrity and effectiveness of current controls is quite effective. It plays an important role in identifying the key indicators of HSE performance and improving them [5]. Despite all the advantages mentioned earlier, the Bow-tie method is not a complete method for quantifying risk, updating old data, and modelling complex relationships between safety barriers and accidents. It cannot update past probabilities based on new information and data. Also, to include defects with common causes and to consider the relationship between causes, this method should be combined with other risk assessment methods [20].

6. Results

According to the nature of intelligent pigging operations in the oil and gas industries, this operation is considered one of the high-risk operations, and conducting a risk assessment is to implement preventive measures to prevent the occurrence of irreparable accidents, as well as control measures to reduce the consequences of possible accidents It is very important in this operation.

All risk analysis methods have their strengths and weaknesses, and combining these methods and implementing them at different levels of a risk analysis study is much more logical. This issue can be described and explained with a new insight into the Swiss cheese model. In this way, if we consider the risk analysis methods as the protection layers and assume that the risks are the lack of identification of risks and the weaknesses of the methods are the path of turning unidentified risks into accidents, the best way to control risks, especially the risks of process industries, is the combination of analysis methods. It is a risk. In other words, combining the strengths and overlapping the weaknesses of risk analysis methods will limit converting risks (non-identification of risks) into accidents [6].

The bow tie diagram is an attractive tool for risk identification and qualitative analysis that depicts the possible paths between hazards and incidents and clearly reveals the distinction between preventive and mitigating barriers. Another advantage is that it helps prioritise safety measures, which is of great value to support decision-making. All causes and consequences of an incident are depicted in a bow-tie diagram. In addition, it seems very useful to show the impact of safety systems and barriers in accident scenarios. With this method, an evaluation of barrier performance (for example, response time, efficiency, and reliability level) can be obtained. One of the important and useful features of barrier analysis is that it helps identify missing or poorly designed barriers, a key issue in management [22].

Examining the results of previous studies on the risk assessment of intelligent pigging operations shows that the Bow-tie method is a more comprehensive and accurate method than other risk assessment methods, which, in addition to examining the causes of events and their control and preventive measures, can examine the consequences The event and their controlling factors are aimed at reducing the severity of the consequences of the event, which makes it possible to carry out a comprehensive risk assessment of this operation due to the process of intelligent pigging operation and the risks of this operation in terms of activities, equipment, people, environment, etc.

7. Research limitations

According to the nature of smart artillery operations in the oil and gas industries, this operation is considered one of the high-risk operations and, unfortunately, despite the special importance of risk assessment in carrying out preventive measures to prevent the occurrence of irreparable accidents as well as control measures to reduce the consequences of possible accidents in this operation, no comprehensive and complete risk assessment has been done regarding this operation in the country's major oil and gas companies. Also, due to the specificity of this operation and its high risks, the necessary cooperation from these companies for field presence during smart artillery operations in gas pipelines does not occur, preventing the evaluation of operational risk for intelligent artillery. However, according to the studies of publications in this field, the use of pigging HSE guidelines and the use of information and experiences of the personnel of pigging and HSE groups in previous similar projects and operations, it is possible to identify the risks and assess the risk of intelligent pigging operations. Still, it is clear that if you are present in the field while performing such operations in similar projects and using the information and experiences of other people working in this field, you can identify the risks and assess the risks of these operations with more detail and focus. Another limitation we face in the risk assessment of intelligent artillery operations is the time-consuming analysis of all possible scenarios, which in most research only examines the top risk scenarios to evaluate more accurately. The results of risk assessment require that low-level risks must also be analyzed.

8. Conclusion and summary

There are more than 70 quantitative and qualitative risk assessment methods in the world, whose results can be used to manage and make decisions about risk control and reducing its consequences. The methods used in the previous research regarding the risk assessment of

intelligent pigging operations are HAZOP, Bowtie, SPAR-H, FMEA, CREAM and SIL. The results of previous studies show that to comprehensively evaluate the risks in process operations such as intelligent pigging, a combination of inferential and analogical methods should be used, and the Bowtie method is a suitable option for this purpose due to the combination of these methods.

The most important things that should be considered in choosing the appropriate risk assessment method are the type of results required, level of accuracy, time scale and financial budget. In such a way, the type of results required for managers to make decisions depends on the level of accuracy of the study, which is also affected by the available time and financial resources.

According to the research done worldwide regarding the risk assessment of intelligent pigging operations and also the dangers in this operation, conducting a complete study and using a comprehensive risk assessment method for intelligent pigging operations is considered a necessity, which can improve the level of safety in conducting intelligent pigging operations and prevent the occurrence of irreparable human and financial accidents.

Considering the emergence of 4th-generation technologies in the world and the use of artificial intelligence in risk management projects, it is suggested that artificial intelligence be used in future research for more accurate and faster risk assessment, which includes the assessment of low-level risks. Also, secondary risk assessment to measure the effectiveness of the control measures implemented in the risk assessment for intelligent pigging operations can be a new topic for future studies.

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