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STAMP Analysis of Deepwater Blowout Accident

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The aim of this study is modeling the main relationships among variables that influence the process safety of Petroleum exploration and production. To model these relationships we used the Systems-Theoretic Accident Model and Processes (STAMP) in the Deepwater Horizon accident occurred on April 20, 2010 in the Gulf of Mexico. A new holistic perspective based on systems theory, systems thinking, and resilience engineering brought by new analysis models like STAMP (Leveson, 2004) or FRAM (Hollnagel, 2012) is needed in complex socio-technical systems such as exploration and production of oil. It is a view which sees “human error is an effect of trouble deeper inside the system…[where] the focus of analysis must turn to the system in which people work: the design of equipment, the usefulness of procedures, the existence of goal conflicts and production pressure” (Dekker, 2007). STAMP incorporates three basic components: constraints, hierarchical levels of control, and process loops. Accidents are understood “in terms of why the controls that were in place did not prevent or detect maladaptive changes, that is, by identifying the safety constraints that were violated and determining why the controls were inadequate in enforcing them. The STAMP analysis of the Deepwater blowout, recognized by some authors as the largest accident in the oil history, illustrates the usefulness of the STAMP model to foster evaluation of the whole system and uncover useful levers for elimination of future loss potential, thereby making progress on process safety.

1. Introduction

Despite the recent global economic crisis, oil remains an important source of energy for economic development. However, due to its own strategic importance, sometimes production goals may conflict with the need to protect the environment, safety and well-being. As an attempt to establish constraints to ensure the productive oil exploration without threatening the health of people and the environment, the oil industry has developed guides and manuals focused on chemical process to assist in major disaster prevention challenge in complex oil exploration system (CCPS, 2007). The strategy of developing the oil industry in the aspects of chemical processes (OECD, 2008) is interesting to help improve knowledge about the processes. However, as "complex systems fail in complex ways”, a safety approach focused exclusively in chemical processes may be too reductionist, because accidents arise from the interaction between the technological and human variables. To cope with complexity is necessary that the accident prevention strategy prioritizes to understand the process as a whole and not be focused on specific human or technological aspects. The accident prevention strategy depends largely on the model chosen, because models help us to understand what happened and what to do to prevent future accidents (Lundberg et al. 2009). Unfortunately, there is no a complete model to represent perfectly the reality, but it is important that the choice of analysis model consider the complexity of the studied process and allow understand it comprehensively, considering their inter-relationships and sources of variation, and sometimes the combination of normal process variables leads to disproportionate consequences.

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STAMP - Systems Theoretic Accident Modelling and Processes (Levenson, 2014) has an approach based on systems thinking (Senge, 1990) and resilience engineering to deal with the complexity of the socio-technical system such as the exploration and production of oil. This research aims to show how STAMP can be used to analyse major accidents in oil industry. As a case study we utilize the Deepwater Horizon accident due to their importance to the oil industry (Graham et al. 2011), and the possibility of new combinations of variables and possible accidents in future similar cases.

2. Models of Accidents and Risks in the Oil Industry

The accidents and risk models usually used in the oil exploration and production industry are based on the principle that accidents occur through well-defined and linked events, which generate an unwanted result. According to this model it is possible to identify one or more causes as root, which would be responsible for triggering the unwanted event. The traditional tools of risk and accident analysis in the oil and gas industry, as HAZOP, FMEA, fault tree and "Bow Tie" are based on Chain of events or variations of this. The chain of events models are very useful for technical systems, however when we include possible human error and recombination and feedbacks over time, we turn this model inappropriate. In the context of complex systems, identify the event generator also becomes a very subjective activity, since the system is dynamic, varying combinations and creating new ones over time. Sometimes we identify human error as the cause event, when in fact we have difficulty in identifying the factors that shaped the behaviour. As the current models of the oil industry are based on chains of events, it is also difficult to include organizational and systemic factors in the current analysis, since the causality of these factors is not linear and direct. To face these limitations of current models, models like STAMP (Leveson, 2004) and the Functional Resonance Analysis Method - FRAM (Hollnagel, 2012,) were developed and applied in different complex systems, such as aviation (De Carvalho, 2011).

3. Systems Thinking and Resilience Engineering

The difficulty in understanding the process as a whole by reductionist methods becomes even more difficult when we deal with complex problems, where there is great interaction among variables and many possible combinations, including interactions between human and technological activities over time. Adding to the complexity of human decisions, microprocessor-based and software systems control the process itself, making very complex and difficult the understanding of the process models therein. The research of (Senge, 1990) uses the words of physicist David Bohm to define the strategy to see a whole by studying the parts in a complex system, in which according to Bohm, would not have utility as it would be as pick up the pieces of a broken mirror to see a true picture. The system thinking is the discipline of seeking to understand the whole and combinations thereof without isolating the parties, because they alone are not important to understand the whole. Pioneering research in this area were developed by many researchers such Bertalanffy (1969) and Forrester (1961), and methods such as System Dynamics (Sterman, 2000) were developed, as a way of representing the inter-relationship of variables by control and feedback loops. The system dynamics models have received applications in resilience engineering (Salzano et al. 2014) and safety assessments (Samadi & Garbolino, 2012) due to its holistic vision

Resilience engineering (RE) is the ability of a process to maintain control over a variable despite the inherent variability (Leveson, 2011). The main concept here is not to focus only on failure, because the process is adapting itself to variations over time, and the failure only occurs when the adaptations are not appropriate. For RE, we need to understand the aspects that enable adaptation, and studying only the failures do not allow us to understand it. Therefore accidents cannot be viewed as the result of specific events that fails, but as a control problem (Leveson, 2004). According to STAMP, variability exists and it is intrinsic to the process. However, the controls must be robust enough to keep the processes running even with the imposed variability. In this sense, safety would be the ability to keep the process running even within the normal process variations, and not as the absence of accidents and incidents. The example of Deepwater Horizon Blowout helps us to justify this approach. According to Graham and colleagues (2011) the platform was more than 7 years without the occurrence of lost time accidents when a lack of well control generated one of the biggest accident in the history of oil.

4. Deepwater Horizon Blowout

The Deepwater Horizon blowout occurred on April 20, 2010, around 21h, when the Deepwater Horizon rig exploded in the Gulf of Mexico. Deepwater Horizon was owned by Transocean and operated company in the service of BP - British Petroleum. This accident was recognized by many researchers as one of the largest environmental accidents in the history of oil. A set of decisions that preceded the explosion of April 20 resulted

in the death of 11 workers and left 17 wounded. The Well leaked for 87 days causing immeasurable environmental impacts (Graham et al., 2011). In order to understand the accident and what a blowout represent for the oil industry, it is necessary to understand some basic principles of the exploitation process, which we explain briefly below. Obviously we do not intend to exhaust the topic.

According to (Skalle, 2012), the oil exploitation process begins in prospection, in which are placed seismic surveys to detail of the rock formations and location of potential oil reserves. Based on seismic studies, the well is designed and begins the drilling work. The drilling is performed with rotating drills, which arrive with other equipment needed in the drilling location aboard a large vessel - rig. To perform the drilling a drilling fluid is injected into the well during drilling. The drilling fluid has the functions of cooling the drill, to clean the well and retain hydrocarbons within the formation. To avoid oil invasion into the well, the drilling fluid must be dense enough, but cannot be too dense in order to not fracture the rock formation. After each drilling step is performed the completion. The completion is performed by introducing a steel tube into the well and cementing of the space between the tube and the well wall. A security device called Blowout Prevention or BOP is placed at the wellhead. This device has the function to seal the well and disconnect the platform in an emergency situation. When there is a hydrocarbon invasion to the well, is called kick. If the kick is not controlled by drilling fluid or the BOP, the well becomes out of control and this is called a Blowout.

The ccident investigation report (BP, 2010) shows the following steps as the events predecessors:
• One day before the accident was performed cementing of the well by pumping a lightweight cement paste to prevent oil from invading the well. The foam of cement would need to take to reduce the pressure of the cement column on the formation. Later the research team identified the cement as a probable cause of the accident.
• The research team concluded that further hydrocarbons invaded the well through cement job,
• The negative pressure test was accepted despite well integrity was not identified properly. After testing, the crew realized that identified differences in pressure values were due to "a bladder effect."
• Unknown hydrocarbon flow was raising.
• The response actions to oil invasion failed. The first control measures were close the BOP and divert the fluids coming out of the riser to the mud gas separator instead of for the bypass line to the sea.
• Forwarding for the gas separator and the mud resulted in the release of gas to the platform.
• The fire systems and gas not prevented ignition of hydrocarbons
• BOP failed attempt to seal the well.

5. STAMP

Using STAMP, we do not seek specific component failures. The goal of the method is to understand how the control structure could not detect the variation and fix the process to ensure proper operation. The component failure is covered by the method, but by understanding the control structure. The real objective of accident investigation is not to seek human or technological component that failed, but to understand the process to prevent future accidents. It is reasonable that understanding the control loops and feedback can be established a process model that allows to adapt the changes when they occur. STAMP not intend to provide any quantitative result, because any probabilistic analysis would be based on past data or would not be enough to represent the variability and process adjustments over time According to the method, the safety constrains could be strengthened through controls, which use feedback mechanisms and seek to ensure system safety observing changes and readjusting control when necessary. The hierarchical control means it is possible to establish levels of control, in which the lower levels are closer to the physical structure where the accident occurs. Each level has mechanisms to enhance the security Constrains of the levels below and have feedback to evaluate whether Constrains imposed are being successful or failing. For the control actions are possible, the level each controller establishes a process model, which allows the identification of how the process should behave when applied to control constrains (Leveson, 2004) seeing accidents as control problem, we have the following classifications possible failures:

I. Inadequate Enforcement of Constrains (Control Action)
II. Inadequate execution of control action
III. Inadequate or missing feedback

6. CAST

The STAMP model for accident investigation is known as CAST - Causal Analysis using System Theory. To be able to understand accidents by applying the cast method are performed the steps of figure 1(Leveson, 2011).

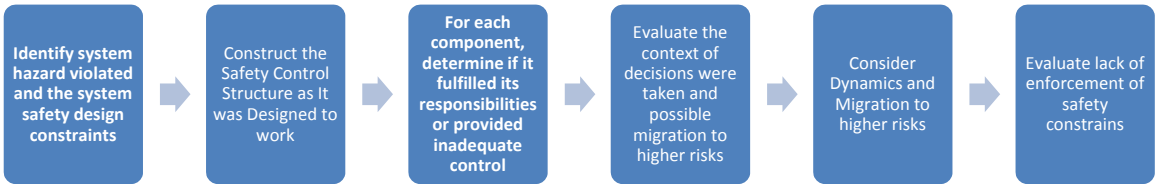

Figure 1: Steps from STAMP analysis using CAST

6.1 Identify system hazard violated and the system safety design constraints

The first step is to identify the hazard and the applicable constraints. In this case, hazard is unintentional invasion of hydrocarbons in the well and the constriction is to prevent unintentional flow of hydrocarbons to the well.

6.2 Construct the Safety Control Structure as It Was Designed to work

The next step for the accident investigation is the construction of the control structure, including control loops and feedback, considering the way it was built to work. Figure 2 shows the control structure (control loops and feedback), as it was constructed to work in accordance with STAMP and the accident description (Graham et al. 2011). The controls have the function of enforce the constraints and feedback to allow the adaptation to changes. Within each process, it is also defined a control model that allows to act in the process, according to the feedback received.

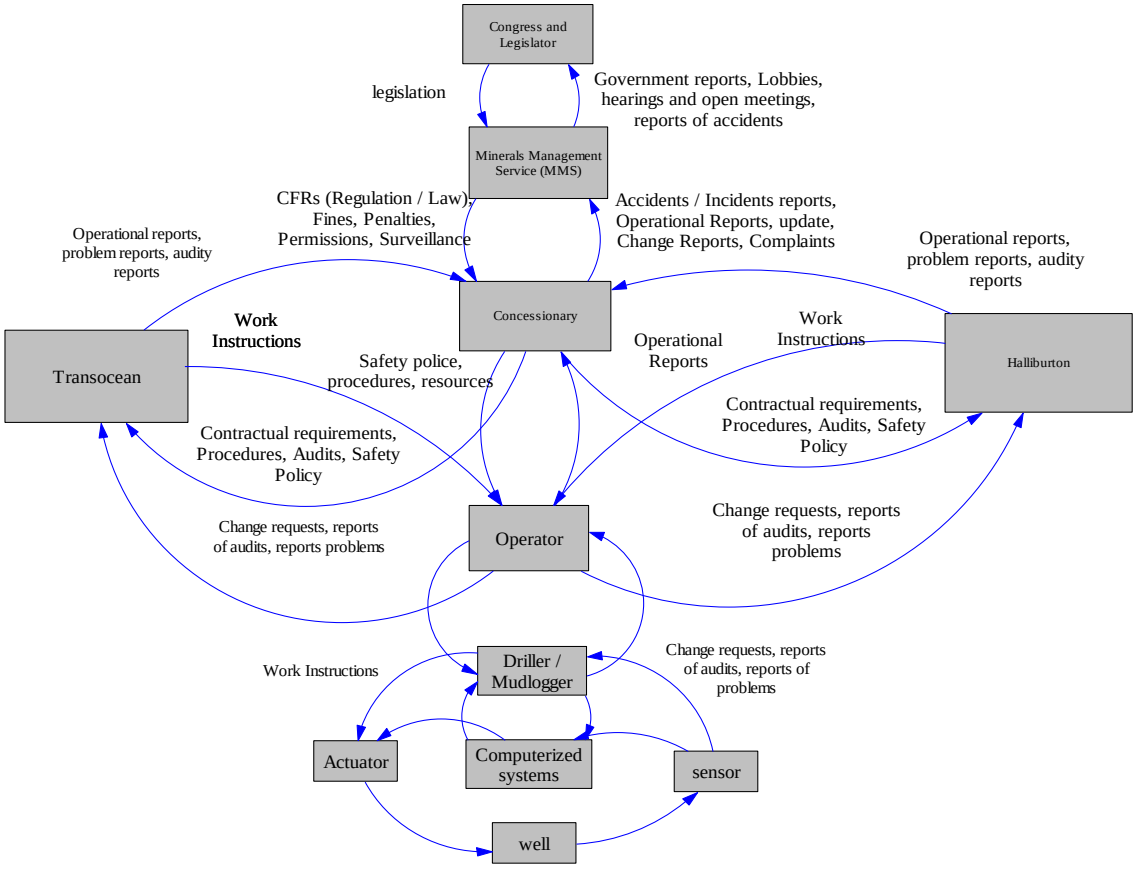

Figure 2: The Deepwater Horizon Control Structure.

6.3 For each component, determine if it fulfilled its responsibilities or provided inadequate control

The third step is to define for each main component of the control structure, the safety responsibility, the inadequate control action, the context, and why the failure occur, as shown in Table 1. The steps 4, 5 e 6 of CAST are the evaluation of results considering the context in which the decision was made and possible failures on mental models. The model (figure 2) and table of responsibilities show that difficulties in enforce the

constraints at higher levels of the hierarchy may reduce the resilience of the lower levels, because they also fail to enforce similar constrains on their levels, and this behaviour pattern passes to the lower levels.

Table1: Responsibility and Control Conditions

Component	Safety Responsibility	Inadequate Control Action	Context in which the decision was made	Process failure or mental model
Driller / Mudddloger	Ensure wellintegrity, To evaluate the information flow / pressure and operate in accordance with the procedures Operate well in accordance with the agenda management platform, Kicks detect and control during drilling,	Incorrect interpretation of signals from sensors, misdirection of the well stream to the gas separators / mud, BOP failed when triggered	shift change, delays in scheduled activities for the platform, pressure to reduce costs, lack of formal procedure for analyzing pressure information for tests	Incorrect understanding that the pressure difference of information identified in tests were caused by "bladder effect."
Platform Management	Ensure the rig agenda of compliance with, establish controls according to well conditions, operate in accordance with the work plan established by BP and Contracted Apply the BP security policies, To ensure the structural integrity of the platform	There was no provision of formal procedure for analyzing pressure information of the tests, working standards not assured operation of the BOP, cementing team release without conducting integrity tests,	Shift change, delays in scheduled activities for the platform, pressure to reduce costs,	Incorrect understanding that the pressure difference of information identified in tests were caused by "bladder effect." Understanding that were not needed cementation tests by Halliburton
Concessionary	Establish the drilling program, attend legislation send operating information to MMS, establish the work plan in accordance with the drilling conditions, evaluate suppliers, verify compliance with procedures, provide resources, conduct training, monitor operations, establish policy safety.	Failure in meeting the CFRs of MMS, no standards for integrity tests	Delays in scheduled activities for the platform, Pressure to reduce costs,	Anti-regulatory culture
Mineral Management Service - MMS	MMS	Oversee the concessionaire, provide authorizations for changes, provide regulation to the sector	There are no regulation to the specificities of deepwater BOP tests released with divergent requirements of where it would be applied	

7. Conclusions

Application of CAST for analysis of the Deepwater Horizon accident indicates that STAMP provides a different analytical approach for accident analysis, more focused on controls and ways on how they may fail. The results show that many of the decisions that contributed to the accident were perfectly acceptable when isolated, but the fragmented view did not allow the understanding of the impacts of individual decisions may bring to the overall system, changing decision patterns over the time. The analysis also indicates that there was an asynchronous evolution of the control structure and the oil industry of the United States, when comparing safety and production processes. This asynchronous evolution allowed the industry to migrate to deeper waters for higher production, but the safety controls do not adapt at the same rate. This result is particularly important because asynchronous developments can be repeated in situations of scenarios changes, as exploitation in the pre salt, or quick changes in oil prices.
The evolution of the MMS compared with industry lets also observe that the lack of reinforcement of BOP constrains may have to cause failures at physical level with the use of BOPs not suitable for deep waters.

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References

Bertalanffy, L. Von,1969,. General System Theory: Foundations, Development, Applications. (Penguin University Books, Ed.) (1st ed., p. 296). New York: George Braziller Inc.

BP, British Petroleum ,2010, Deepwater Horizon Accident Investigation Report (p. 192). Houston: British Petroleum.

CCPS, Center for Chemical and Process Engineering ,2007,. Guidelines for risk based process safety (1st ed., p. 768). Hoboken: John Wiley & Sons Inc.

De Carvalho, P. V. R. , 2011, The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience. Reliability Engineering & System Safety, 96(11), 1482–1498.

Dekker, S. , 2007, Just culture: balancing safety and accountability. Ashgate Publishing Limited (1st ed., Vol. 1, p. 166). Burlington: Ashgate Publishing Limited.

Forrester, J. W.,1961, Industrial Dynamics (1st ed., p. 484). Cambridge: The M.I.T. Press.ISBN 1614275335

Graham, B., Reilly, W. K., Beinecke, F., & Boesch, D. F. ,2011,. Deepwater - The Gulf Oil Disaster and the Future of Offshore Drilling. library of congress (p. 398). Washington, DC.

Hollnagel, E. ,2012, FRAM: The Functional Resonance Analysis Method (1st ed., p. 154). Farnham: Ashgate Publishing Limited.

Leveson, N. ,2004,. A new accident model for engineering safer systems. Safety Science, 42(4), 237–270.

Leveson, N. ,2011,. Engineering a Safer World (1st ed., p. 555). Cambridge: Library of Congress.

Lundberg, J., Rollenhagen, C., and Hollnagel, E., 2009, What-You-Look-For-Is-What-You-Find – The consequences of underlying accident models in eight accident investigation manuals. Safety Science 47 (10), 1297–1311.

OECD. ,2008,. Guidance on Developing Safety Performance Indicator. (O. for economic cooperation and Development, Ed.) Second Edi., p. 156. Paris.

Salzano, E., Di, M., Gallo, M., & Oropallo, E. ,2014,. The application of System Dynamics to industrial plants in the perspective of Process Resilience Engineering. Chemical Engineering Transactions, 36, 457–462.

Samadi, J., & Garbolino, E. , 2012,. Dynamic analysis of safety performance indicators for Co2 capture, transport and storage activities. Chemical Engineering Transactions, 26, 147–152.

Senge, P. M. ,1990,. The Fifth Discipline. (Doubleday, Ed.) (1st ed., p. 412). New York: Library of Congress.

Skalle, P. ,2012,. Pressure control during oil well drilling (4th ed., p. 145). Bookboon.

Sterman, J. D. ,2000,. Business Dynamics - Systems Thinking and Modeling for a Complex World (1st ed., p. 1008). Cambridge: McGraw-Hill/Irwin.