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Hazard Analysis and Accident Prediction for LNG Plants

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Abstract

This paper presents a qualitative hazard analysis technique for LNG plants. LNG process design and fault models are structured on the basis of POOM using fault semantic network (FSN). Previous accidents are modeled using FSN where accident steps are modeled and linked with fault propagation scenarios and related process variables. The proposed qualitative accident prediction algorithm will enable the early identification of process failures in real time plant operation by determining best match to modeled accident scenarios

Keywords: Hazard Identification, Accident Prediction, Fault Semantic Network (FSN); Accident Analysis; LNG; Gas Processing Facilities.

1. Introduction

LNG, or liquefied natural gas, is a valuable and cheap source of clean energy that can support different industrial applications. Typically, LNG is composed primarily of Methane (C_1H_4) with trace amounts of heavier hydrocarbons such as Ethane (C_2H_6), Propane (C_3H_8), iso-Butane, N-Butane (C_4H_{10}), and C5+. LNG is available from different sources like Trinidad, Algeria, Oman, Nigeria, Qatar, etc. While natural gas (NG) is often transported by pipeline, LNG is commonly transported via ships, trucks, or trains. Also LNG is used during peak shaving where a distribution point along a NG pipeline will collect surplus NG from periods of low demand and store it as LNG until it is required during periods of heightened demand (especially for seasonal demand variation) [1]. LNG can be stored in large quantities to support the operation of power generating facilities. Homes in remote areas can use vaporized LNG, i.e. as natural gas, for heating, cooking and power generation. Vehicles have also been modified to use LNG as a fuel, e.g. in California. With such potential for LNG applications, it is important to provide systematic mechanisms to identify and analyze hazards in LNG processes. There are different qualitative and quantitative methods used for hazard analysis. Fault tree analysis (FTA) is one approach that is used to analyze possible causes for any top event. FTA can be used to identify combination of causes and their propagation. However, it is mostly implemented manually where faults and their consequences should be mapped to process models. Hazard identification is also conducted using hazard and operability analysis (HAZOP). HAZOP is a systematic way to identify possible process deviations along with the possible causes and consequences [2]. However, HAZOP doesn't provide systematic fault propagation analysis from root causes to possible consequences. The accurate fault propagation scenario will support accident prediction and simulation. This paper presents a systematic solution to analyze hazards and predict accidents using qualitative fault propagation scenarios. Fault semantic networks are developed and used to represent fault propagation scenarios. Accidents are represented as sequences of events. Each event is represented using a proposed fault modeling approach where fault model includes symptoms, failure modes, causes, consequences, and degradations or deviations. The proposed hazard analysis approach enables the prediction of accidents by integrating related state variables and possible deviations and failure modes with process models. The proposed approach will enable the automatic identification of process deviations and map to accident events to shortlist possible propagation scenarios for early recovery. The following section will present the proposed process modeling for the target LNG process.

2. LNG Process Design

LNG process receives NG from the gas feed, removes impurities (such as: CO2, Sulfur compounds, Mercury, H2O, Nitrogen, and Heavy Hydrocarbons), and cools the NG to approximately -162°C.

Figure 1 shows process block diagram (PBD) of a typical (Selected) LNG process.

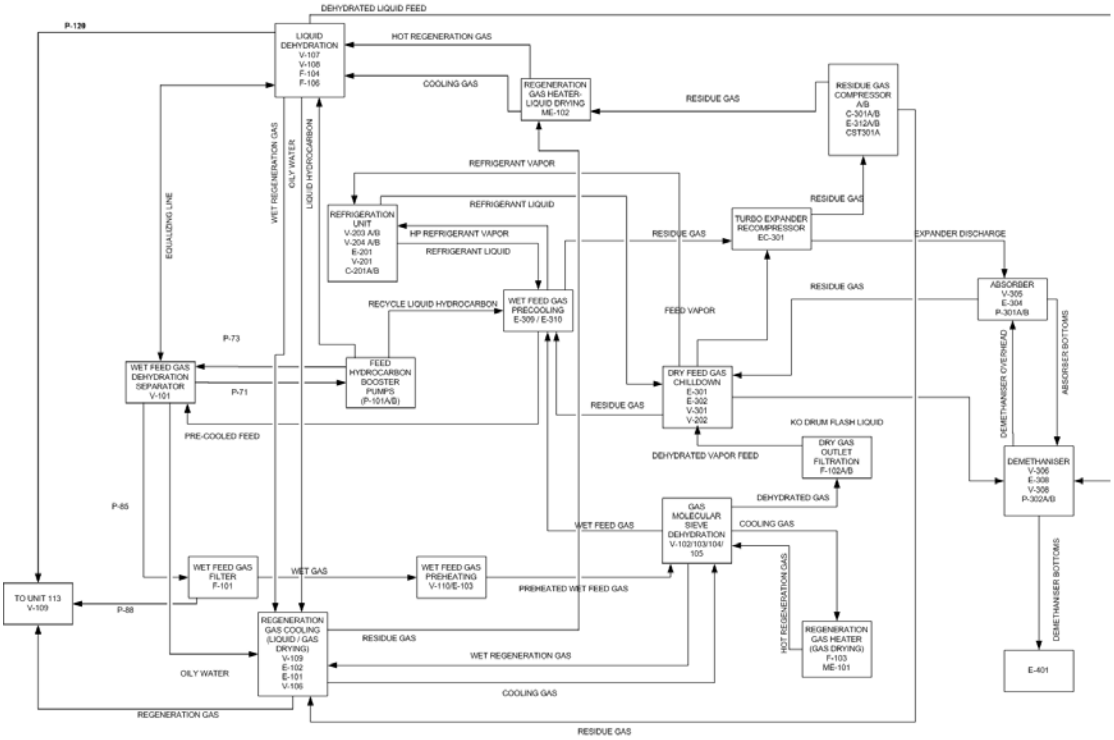

Figure 1. Process Block Diagram of Typical Gas Processing Facility

LNG process is modeled within Visio-based computer-aided process engineering tool, called CAPE-ModE. Process design models are defined as piping and instrumentation diagram (P&ID), process flow diagram (PFD), and process block diagram (PBD). Process model elements are drawn from classes stored in stencils, which represent the equipment classes. By dragging and dropping each equipment class into the drawing area, the plant equipment records are created in the database. Figure 2 shows P&ID of selected process of LNG, which includes the flash drum process.

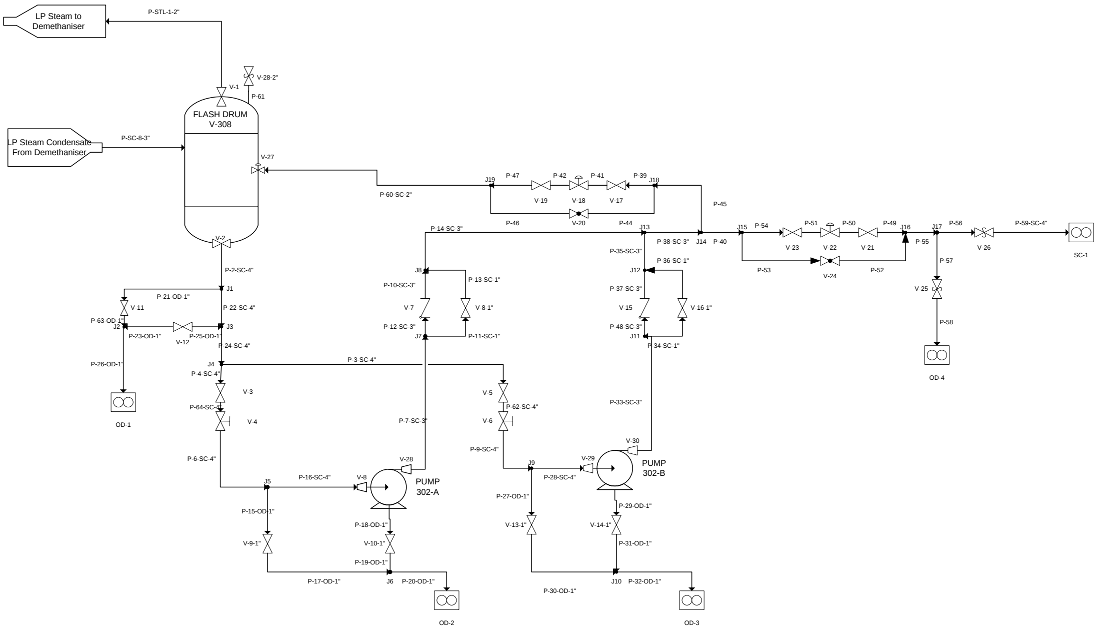

Figure 2. P&ID of Selected LNG Process, as Developed Within CAPE-ModE

3. Accident Modeling

Accidents are modeled in the form of event scenarios, which are developed from the collected accident data. In the coming sections, several accidents are analyzed using the proposed process and fault modeling methodology.

3.1 Accident Scenarios

3.1.1 Accident – 1

“October 1979: Losby, MD, USA. At the Cove Point LNG import terminal, LNG leaked through an inadequately tightened LNG pump electrical penetration seal, vaporized, and flowed through 200 ft of electrical conduit to the substation. Since natural gas vapors were not expected in this building, there were no gas detectors installed. A worker switched off a circuit breaker, igniting the gas vapors by the normal arcing contacts of the circuit breaker. An explosion killed one worker, seriously injuring a second, and caused $3 million in damage to the building.” [1].

3.1.2 Accident – 2

“January 19, 2004. Skikda, Algeria, at the Sonatrach LNG liquefaction plant. A refrigerant line leaked and vapors were drawn into the combustion air intake for a high-pressure steam boiler. The boiler fire box exploded and damaged other lines that precipitated a larger explosion outside the boiler and caused extensive damage to the facility. There were 27 workers killed, 80 injured; three LNG trains were destroyed, bringing production for 2004 down to 76% of normal for the year.” [1].

3.1.3 Accident – 3

A check valve in the piping system of one vessel failed. This caused a small quantity of LNG to be released. The main reason was the failure of a check valve in the piping system of the vessel. This led to a spill of small quantity of LNG. The spilling resulted in minor fractures of the deck plating.

3.2 Accident Event Analysis

In order to analyze accidents, discrete events are modeled in three major time steps, as shown in table 1. PV is used to represent process variable, FM is used to represent fault model, etc. Each accident step is represented using related process variables (or other state variables, e.g. environmental variable, human variables, etc.). Each state variable is described using qualitative value such as "N" for normal, "L" for low, or "H" for high.

Table 1. Three Accident Scenarios for Flash Drum Process in LNG Plant

Accident 1	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
Pump 302A Leaks through electrical seal	P-16-SC-4" Flow	N	P-16-SC-4" Flow	N	P-16-SC-4" Flow	N
	Valve V-8 Flow	N	PMP-302A Input	N	PMP-302A Input	N
	PMP-302A RPM	N	PMP-302A RPM	H	PMP-302A RPM	H
	Valve V-28 Flow	L	Valve V-28 Flow	L	Valve V-28 Flow	L
	P-7-SC-3" Flow	N	P-7-SC-3" Flow	L	P-7-SC-3" Flow	L
	P-14-SC-3" Flow	N	P-14-SC-3" Flow	N	P-14-SC-3" Flow	L
Accident 2	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
Pipe P-16-SC-4" leak	P-16-SC-4" Flow	L	P-16-SC-4" Flow	L	P-16-SC-4" Flow	L
	Valve V-8 Flow	L	Valve V-8 Flow	L	Valve V-8 Flow	L
	PMP-302A RPM	N	PMP-302A RPM	H	PMP-302A RPM	H
	Valve V-28 Flow	N	Valve V-28 Flow	L	Valve V-28 Flow	L
	P-7-SC-3" Flow	N	P-7-SC-3" Flow	N	P-7-SC-3" Flow	L
	P-14-SC-3" Flow	N	P-14-SC-3" Flow	N	P-14-SC-3" Flow	L
Accident 3	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
Valve V-28 Leak	P-16-SC-4" Flow	N	P-16-SC-4" Flow	N	P-16-SC-4" Flow	N
	Valve V-8 Flow	N	Valve V-8 Flow	N	Valve V-8 Flow	N
	PMP-302A RPM	N	PMP-302A RPM	N	PMP-302A RPM	N
	Valve V-28 Flow	L	Valve V-28 Flow	L	Valve V-28 Flow	L
	P-7-SC-3" Flow	N	P-7-SC-3" Flow	L	P-7-SC-3" Flow	L
	P-14-SC-3" Flow	N	P-14-SC-3" Flow	N	P-14-SC-3" Flow	L

3.3 Mapping Accident Scenarios to Process Design

Figures 3 – 5 show the modeling of different steps for a given accident scenario. In this case, it is accident – 1. The red lines shows the failures occurred.

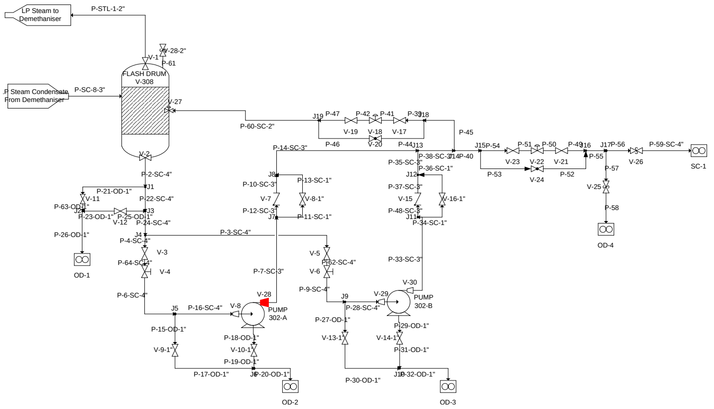

Figure 3. Accident Scenario Analysis – Event 1

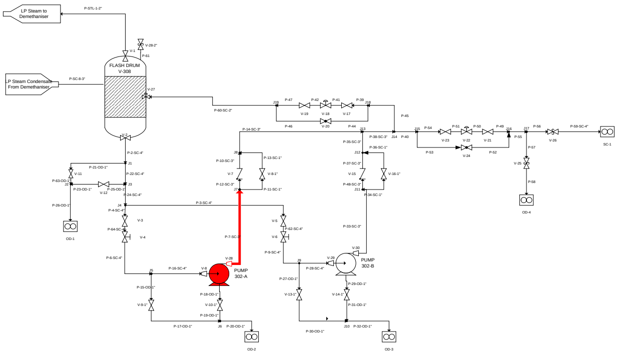

Figure 4. Accident Scenario Analysis – Event 2

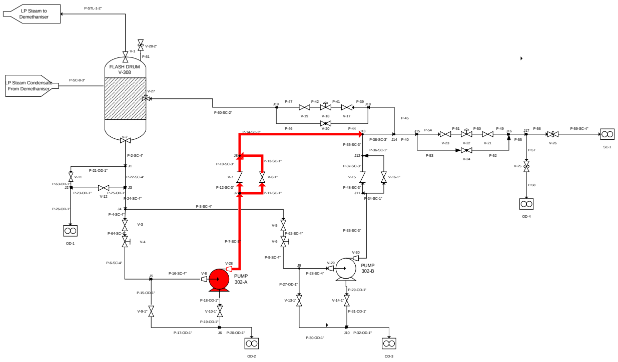

Figure 5. Accident Scenario Analysis – Event 3

3.4 Causation Modeling

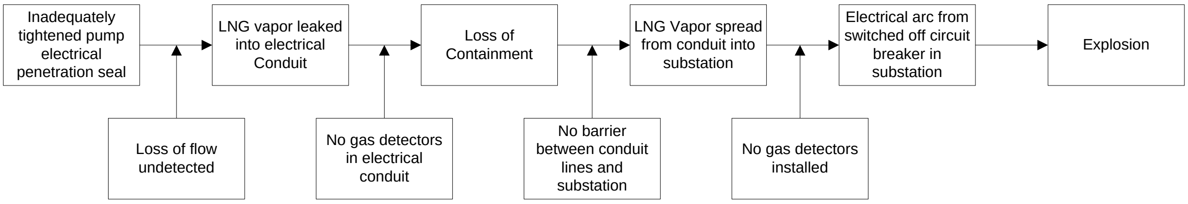

Figure 6. Causation Model for Accident Scenario – 1

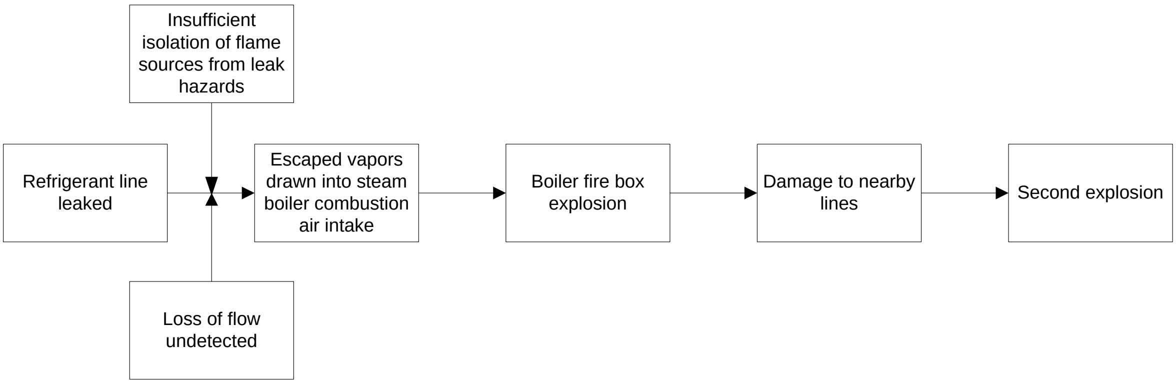

Figure 7. Causation Model for Accident Scenario - 2

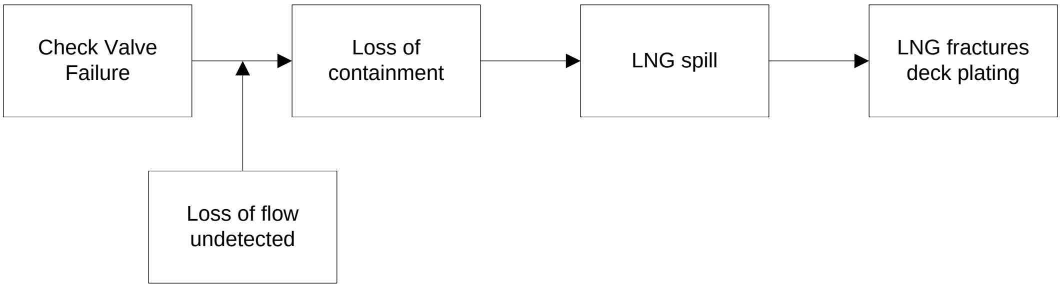

Figure 8. Causation Model for Accident Scenario – 3

4. Fault Modeling

Faults are classified as deviation or degradation or failure mode. Deviation or degradation is categorized into process deviation, material deviation, equipment deviation, environmental deviation, human deviation, or instrument deviation. Fault models are defined in generic level, called class level, and plant specific level. Faults are associated with equipment class and plant equipment records along with causes and consequences. Fault propagation is done within the same equipment, e.g. between different ports, or between adjacent equipment via connected ports. Accidents are modeled by associating fault models with each step within each accident. Table 2 shows the fault models associated with the identified accident scenarios.

Table 2. Fault Models For The Selected Accident Scenarios

Accident	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
AC 1: Pump 302A Leaks through electrical seal	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N H L L N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N H L L L
AC 2: Pipe P-16-SC-4” leak	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	L L N N N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	L L H L N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	L L H L L L
AC 3: Valve V-28 Leak	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L L N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L L L

5. Accident Prediction Mechanism

Based on the proposed fault and accident models, accidents are predicted based on event modeling of each accident step. At each step, the obtained sets of deviations are compared with each accident fault models to decide the closest accident. This process is associated with risk estimation to accurately calculate risk aggregate at each fault model and equipment levels. In order to compensate for any minor deviations, similarity matrix is used to identify the closest accidents and propose possible accident propagation scenario. For example, table 3 shows an example of a given fault propagation scenario, which is analyzed and compared versus the stored accident scenarios (i.e. history) to predict the closest possible accident scenario.

Table 3. Unknown Accident Scenario From Real Time Process Data

Accident	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
Unknown Failure Scenario 1:	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N H L L N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N H L L L

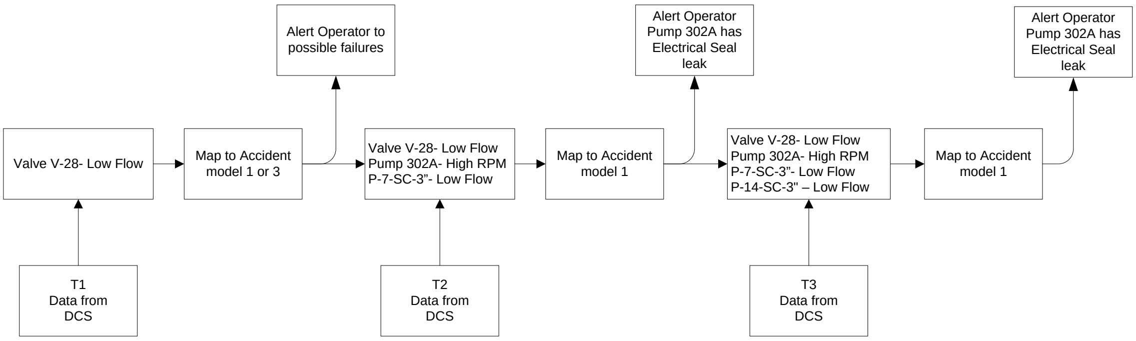

Figure 9. Causation Modeling to Analyze The Unknown Accident

The unknown accident is analyzed using the synthesized causation model, as shown in figure 9.

Another unknown accident is analyzed to predict the closest possible propagation scenario, as shown in table 4.

Table 4. Unknown Accident Described in Event Steps

Accident	T1		T2		T3	
	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value	$PV_i + FM_j$	Value
Unknown Failure Scenario 3:	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N N N L N N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	N L L L L N	P-16-SC-4” Flow Valve V-8 Flow PMP-302A RPM Valve V-28 Flow P-7-SC-3” Flow P-14-SC-3” Flow	L L L L L L

The causation model for the above accident is described as in figure 10.

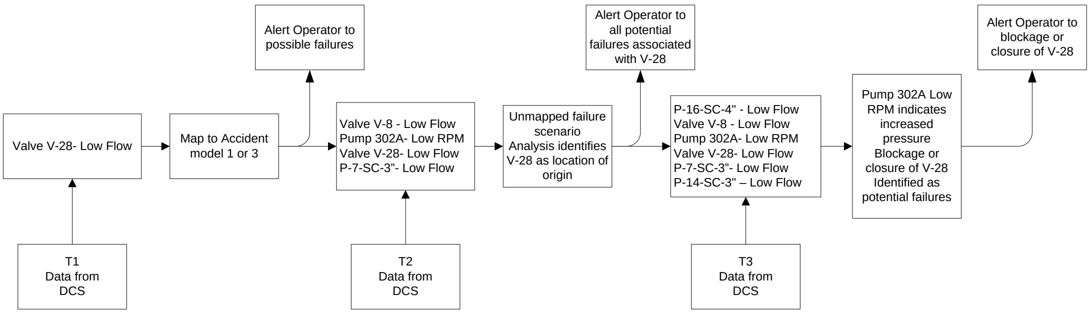

Figure 10. Causation Modeling for the Second Unknown Accident

6. Conclusion

This paper presented fault modeling and accident analysis technique to predict accidents of LNG plants. Faults are modeled as associated with process models in generic and plant specific models. Accidents are modeled in qualitative steps and described in terms of fault models. Accident prediction technique is described using qualitative approach. Unknown accident is recognized at early stages by comparing the associated process variables with previously reported accidents. Accident is identified by selecting the closest qualitative values associated with each accident step. The identified accident propagation will provide early information to plant operation to take the necessary actions.

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