Risk Assessment in LPG Loading Operations by Simulation

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Abstract

The objective of this paper is to assess the risks associated with LPG loading and especially the risks that could undergo the pump. The pump is substantial equipment that ensures and guarantees the LPG loading. A list of failure scenarios related to this equipment was conducted. The most relevance will be simulated. AnyLogic platform based on Multi-Agent Systems is used to assess the safety of this supply chain. This simulation allows the calculation of the criticality of each failure occurrence and specifies the status of the equipment (working, degraded, shutdown). The final goal is orienting responsible to the best assessment decisions.

Keywords
Risk assessment; LPG loading operations; Failure Scenarios; Simulation; AnyLogic Platform.

1. Introduction

For several decades dependability and especially its component safety have become major issues for the survival of companies. This consideration is based mainly on the concept of risk.

The risk is an intrinsic property to any decision. It is the combination of two elements: the occurrence probability of an event or combination of events leading to a dangerous situation, or the frequency of such events, and the consequences of this dangerous situation.

Risk assessment is a process of comparing the estimated risk with risk criteria given to determine the risk level. The comparison can be conducted with respect to a predetermined reference system aim to enable decision towards risk acceptance or the need for treatment. It may consider cost, benefits, stakeholder concerns, and other variables required as appropriate for risk assessment (ISO / IEC Guide 73, 2002).

LPG (Liquefied Petroleum Gas) is a low pressure liquefied gas containing one or more light hydrocarbons which consist mainly of propane, propene, butane, butane isomers, and butane with traces of other hydrocarbon gasses. Propane and butane are the main constituents. Petroleum gas can be stored and/or handled in the liquid phase under mild conditions of pressure and at room temperature (Lim, 2008; Pierini, 2015).

This article aims to assess risks in LPG loading operations. The objective is to simulate failure scenarios related to the pump that ensures loading operations in order to see the influence of these failure scenarios on the system.

This paper is organized as follows: section 2 presents loading operations in LPG supply chain. Section 3 exposes Risk Analysis of LPG loading operations. In section 4 shows and discusses the simulation results. Finally, concluding remarks are provided.

1. Case study: Loading Operations in LPG Supply Chain

The case study focuses specifically on the tanker loading operations in the bulk relay site.

The bulk relay site assures its supply by jumbo tankers from suppliers (Lavera) and distributes LPG to these customers by small carrier tankers. The site consists of a propane mounded tank, transfer equipment in the pump station area (pump/compressor/piping), a loading/unloading station of jumbo tankers and two loading post of small carrier tankers, and a parking area for tankers and bottles. Figure 1 outlines the site with its different composition.

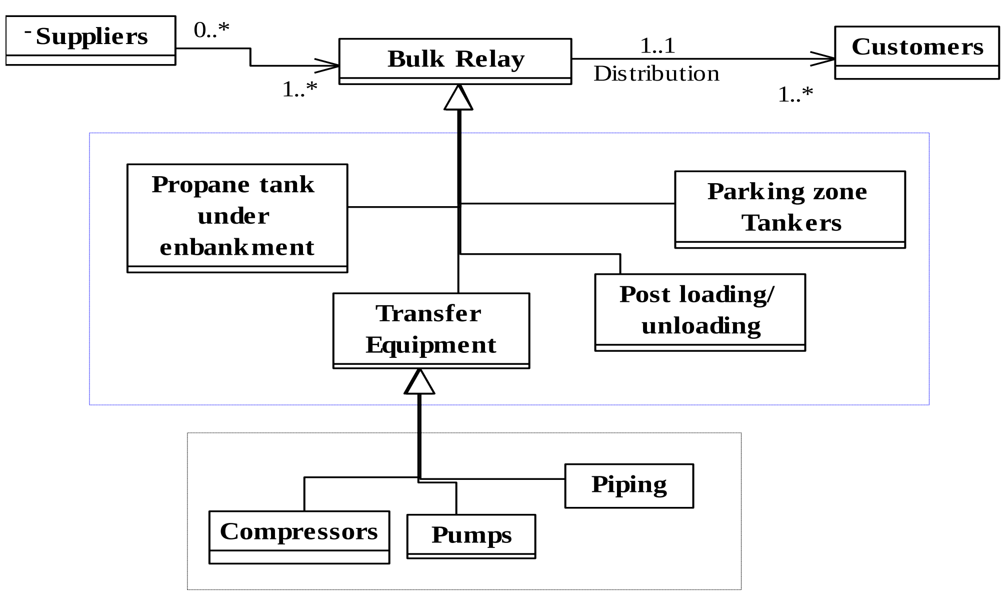

Figure 1. Bulk Relay site outline.

Loaded trucks are small carrier trucks with capacity 3.5 tons, 6 tons or 9 tons. The filling of small carrier tankers is from the tank in the loading stations. These trucks deliver propane to PRIMAGAZ customers in the region. Truck loading takes place by a liquid arm.

Loading operations are performed by a driver under the supervision of an operator Bulk Relay. Different loading operations are formalized by a UML sequence diagram as shown in figure 2.

2. Risk Analysis of LPG loading operations

During LPG loading, the equipment that ensures the load transfer is the pump. In the following, we will deal specifically with the pump, with the various failure scenarios that may arise in it.

Table 1 identifies the studied system namely, the pump, specifies the feared event, its causes, its hazards, and present safety barriers to limit its dangers.

Safety barriers put in place are:

- Pump Protection (traffic Circuit): a prevention barrier. It is an overpressure downstream of the pump causes the opening of a valve which allows the recirculation of fluid. This recirculation allows you to maintain a minimum flow which prevents the degradation of the pump.
- Pump Pressure Switch: it is a prevention barrier of mechanical failures. It protects the pump against any abnormal drop in suction pressure. The pressure switch is an organ capable of placing a contact in a certain position (role of the electrical switch) under the effect of a pressure sensing. The detection of a certain level of pressure stops the pump.

Each safety barrier is assessed with a confidence level. The confidence level is the architecture and the class probability, inspired by standards NF EN 61-508 and CEI 61-511, for a barrier, in its use environment, provides safety functions for which it was chosen. This class probability is determined for a given effectiveness and response time.

The confidence level (CL) is determined by the experience feedback reliability database of the bulk relay site, or according to the project database ARAMIS (Accidental Risk Assessment Methodology for Industries in the context of the SEVESO II Directive). For organizational barriers, the confidence level is defined by the method proposed by INERIS in the (Vallee & Dolladille, 2003) for protective barriers, and for prevention barriers, the CL is determined by the method adopted in the by INERIS (Le & De Dianous, 2008).

Several failure scenarios have been detected in the pump, the most important and are of relevance for the loading operations and throughout the site are featured in Table 2.

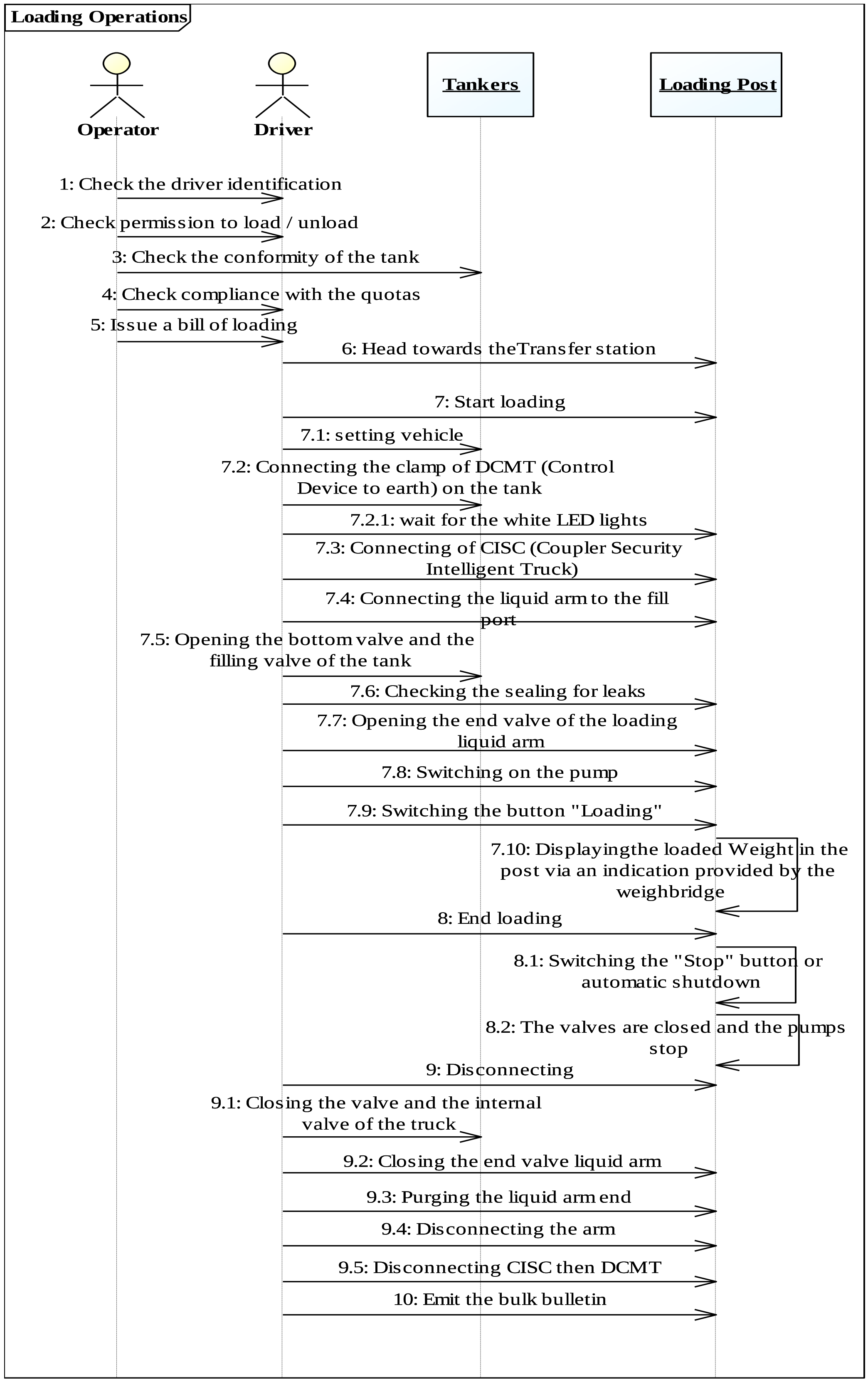

Figure 2. UML sequence diagram of loading operations.

Table 1. Risk Analysis of the studied system.

<table>
<tr><th rowspan="2">Operation</th><th rowspan="2">Equipment</th><th rowspan="2">Type of intervention</th><th rowspan="2">Periodicity</th><th rowspan="2">Who Internal/ External</th><th rowspan="2">Initial Event</th><th rowspan="2">Causes</th><th rowspan="2">Feared Event</th><th rowspan="2">Hazard</th><th colspan="3">Safety Barriers</th></tr>
<tr><th>Name</th><th>Type</th><th>CL</th></tr>
<tr><td rowspan="2">Transfer Loading Equipment</td><td rowspan="2">Pump</td><td rowspan="2">Inspection Visual Control</td><td rowspan="2">Half-yearly</td><td rowspan="2">Internal</td><td rowspan="2">-Water Hammer
-Usury.</td><td rowspan="2">- Lack of equipment maintenance.
- Material defect.
- Intrinsic failure.</td><td rowspan="2">Confinement loss on pump</td><td rowspan="2">UVCE or Jet fire with presence of an ignition source</td><td>Pump Protection (traffic Circuit)</td><td>Tech</td><td>1</td></tr>
<tr><td>Pump Pressure Switch</td><td>Tech</td><td>1</td></tr>
</table>

Table 2. Selected failure scenarios

Equipment	Failure scenarios	Consequences (Why the choice of this scenario)
Pump	Valve locked ceasing the fluid recirculation.	Pump degradation and appearance of UVCE.
	Troubleshooting the pump with a leaky seal.	The occurrence of UVCE into equipment operation with the definition of the area effects and possible jet fire as a complement.
	Misalignment of the pipe causing bearings premature usury or pumps bearings.	Maintenance failing equipment conducting to a UVCE or a jet fire.
	Cut the seal liner O-ring when reassembling the mechanical seal due to the shaft thread no-protected.	Maintenance failing equipment conducting to a UVCE or a jet fire.

3. AnyLogic Simulation for risk assessment
3.1 AnyLogic Platform

AnyLogic is a simulation platform for discrete, continuous, and hybrid type systems as well as for the development of deterministic, stochastic, or agent-based systems models (Borshchev, 2013). AnyLogic is the first dynamic simulation tool that gathers and combines these three different approaches to modeling-simulation: System Dynamics, Discrete Event, and Multi-Agent Systems (MAS). It is a tool based on the object-oriented approach. All its elements of simulation and animation are developed in Java programming language (Gallab et al., 2016).

The choice falls on the AnyLogic platform, because it is able to model more specifically industrial problems like manufacturing, logistics and supply chains (Almeder & Preusser, 2007; Jinks et al., 2010; Kim et al., 2013; Barahona et al., 2013; Felberbauer et al., 2014), as well as the maintenance field (Sabar et al., 2008; Gallab et al., 2015; 2016; 2017). In addition, the probability distributions (Weibull, Exponential, triangular distribution ...) are well defined by default in this platform relative to the other platforms that require their programming.

3.2. Simulation Results

First, the behavior of normal functioning (normal mode) of the overall system during loading operations is simulated. The normal mode allows checking all steps of loading before proceeding to the loading trucks (Fig.3).

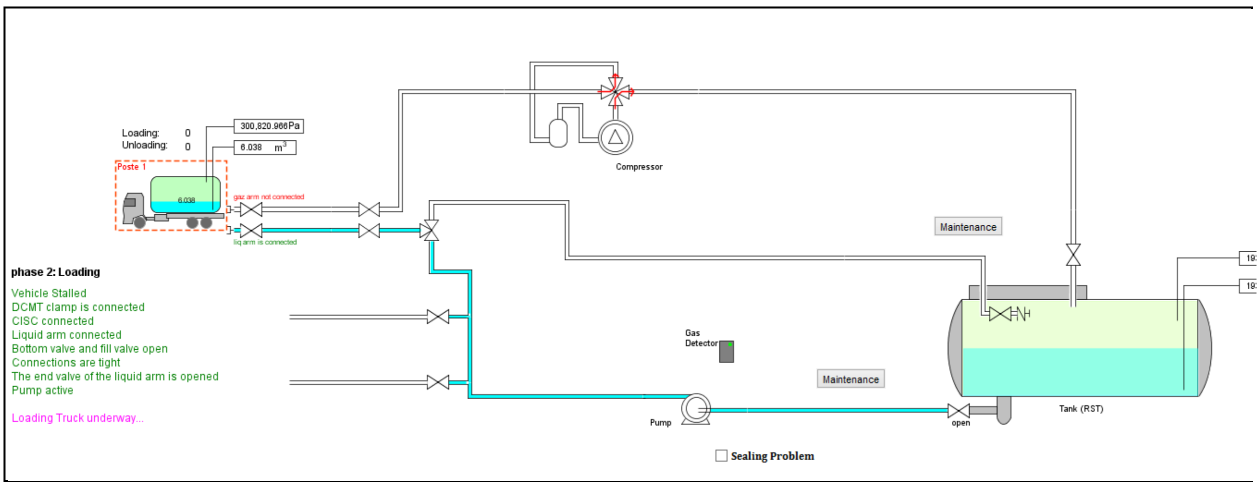

Figure 3. AnyLogic simulation for loading operations.

Figure 4 illustrates the system dynamics and how the pump operates in the global system.

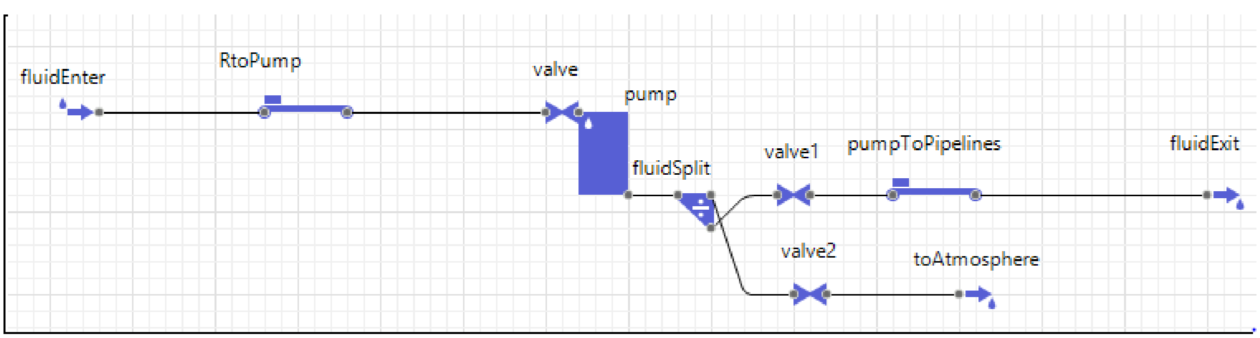

Figure 4. Simulating the pump performance.

The pump takes three operating states as depicted in figure 5:

- Normal state: the equipment functioning provides the functioning of the overall system. This is achieved when criticality is less than 2.
- State problem with the degraded state of the equipment. This state still allows the system operation but it can cause problems in the system over time. This step requires preventive maintenance to ensure proper operation of the equipment and the system overall. Its criticality varies between 2 and 8.
- Shutdown State: In this state the equipment fails, thus automatically loading operations will be interrupted. The equipment in this condition requires corrective maintenance to repair or replace the equipment. Its criticality is greater than 8.

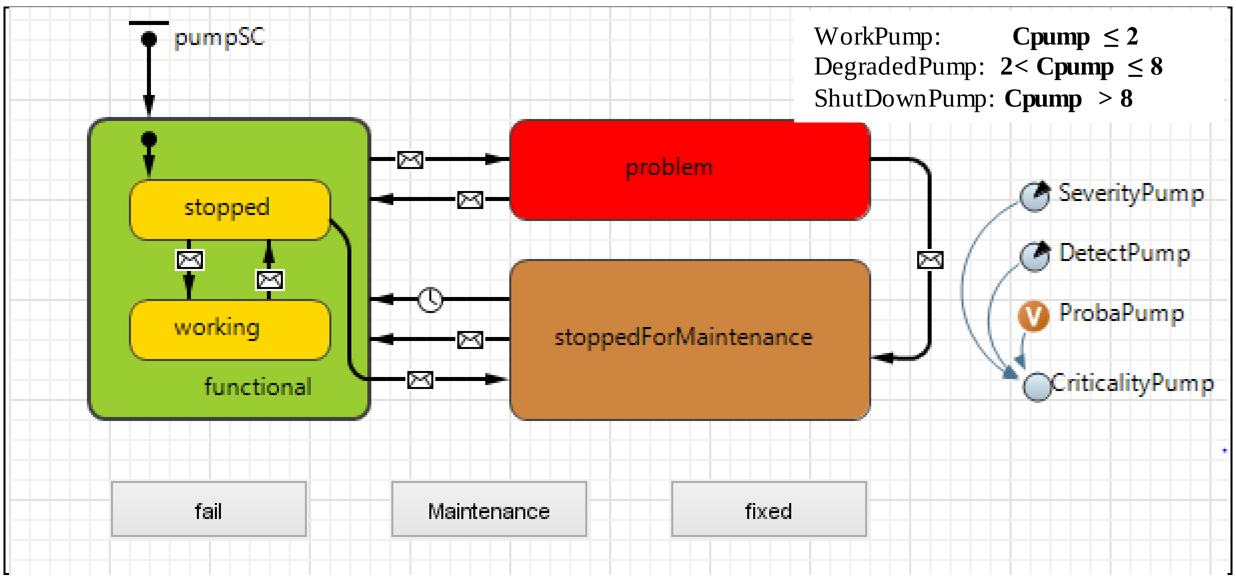

Figure 5. Pump equipment framework.

This model also simulates the failure scenarios that the pump can undergo. It calculates its criticality in each case, the number of failures and specifies the current state that can have the equipment.

Figure 6 depicts when a one failure is checking, its criticality is 2 and it is still functioning. A single fault does not affect the system operation.

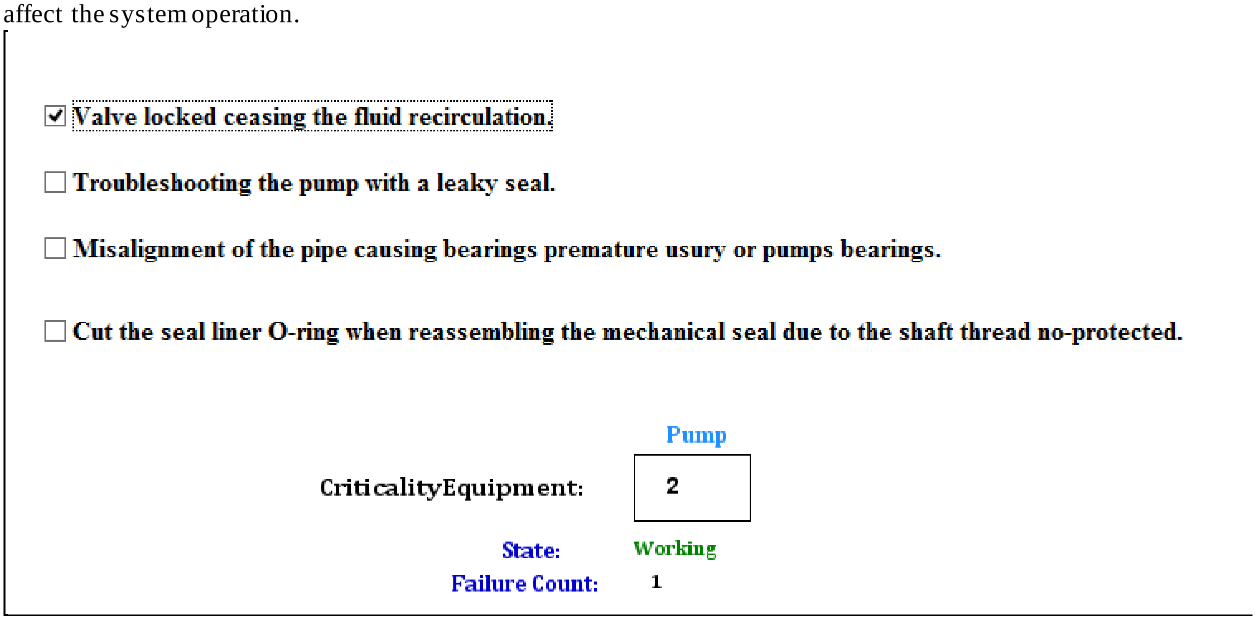

Figure 6. The output of risk assessment simulation (Working State).

When two failures are checked, the criticality increases and equipment changes its state, it requires preventative maintenance to avoid falling down (Fig. 7).

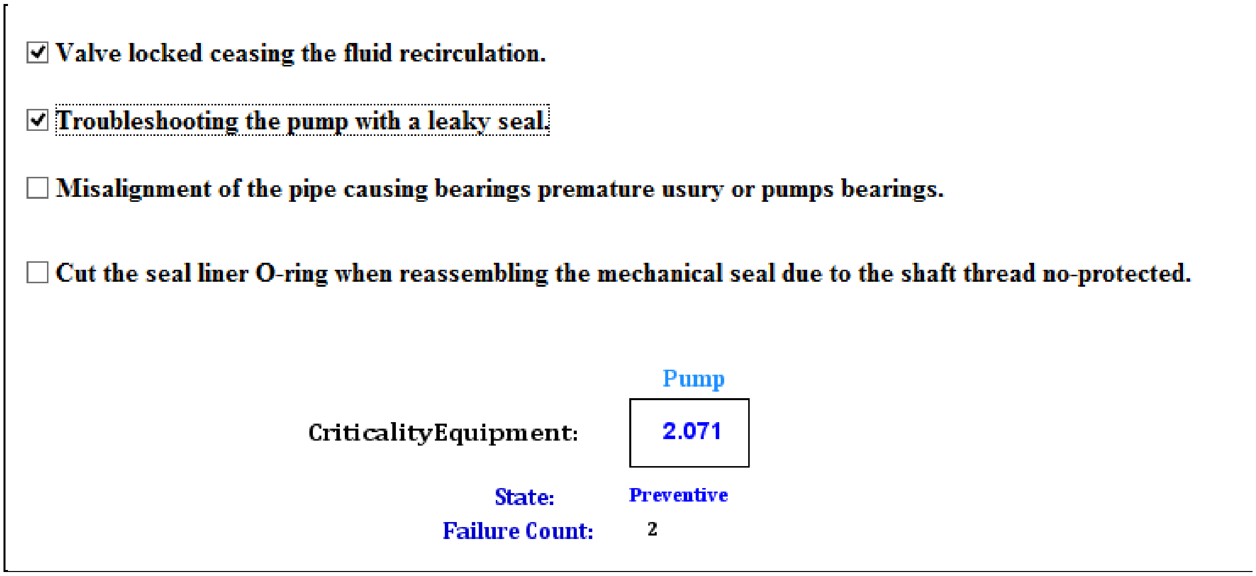

Figure 7. The output of risk assessment simulation (Degraded State).

After a significant number of failures that the pump can undergo, it breaks down. In this case, it requires corrective maintenance (Fig. 8).

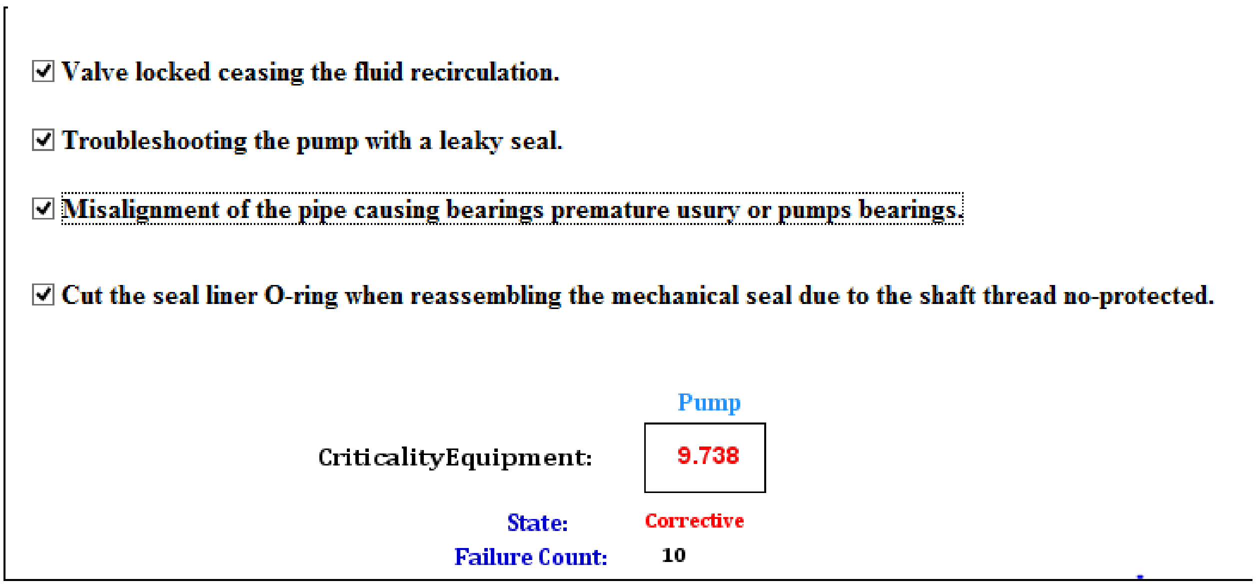

Figure 8. Output of risk assessment simulation (shutdown State).

When the pump fails, the system blinks that there is a problem with the pump and the gas sensor related to the pump warns also that there is a problem. The system stops loading operations awaiting repair of the pump as shown in figure 9.

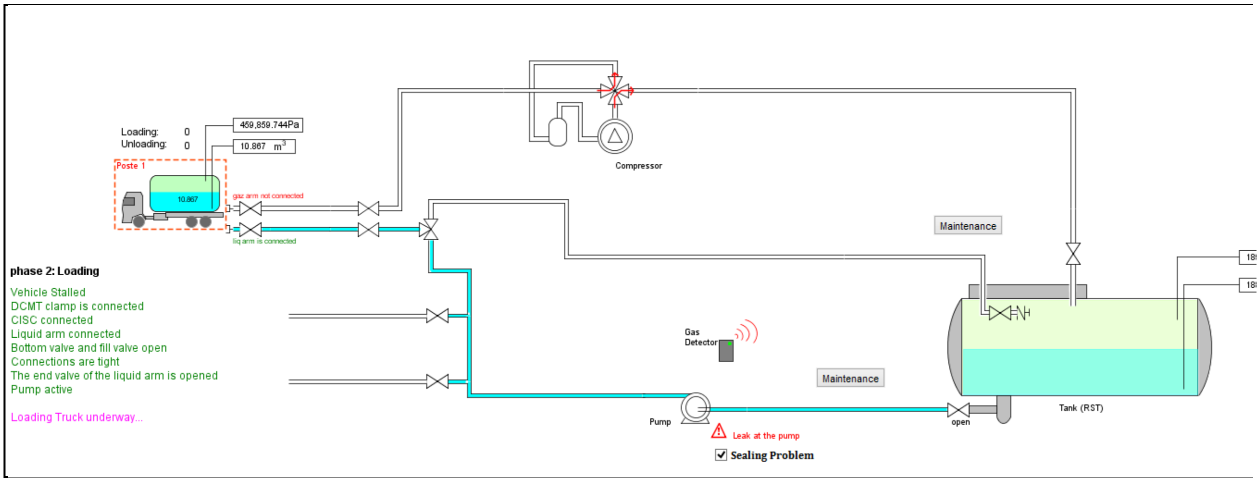

Figure 9. AnyLogic simulation when the pump is down.

The proposed model will allow the industry to have a better visibility on the risk level of the equipment (pump) using criticality calculation.

3.3. Discussion

The proposed model may provide elements for reflection to assess risks in the LPG loading operations. The aim is to simulate failure scenarios that can occur in the pump and visualizes the impact of these failures on the system.

The proposed model allows introducing the system in normal mode, showing sequence verification of various loading small carrier tankers operations.

After the simulation illustrates the degraded situation of the system, it defines the list of failure scenarios, and determines the criticality of the equipment and subsequently its state. Once a problem has been detected in the equipment, it determines its criticality, if it exceeds the defined threshold, this problem influences on all the technical installation that can lead to system shutdown.

This model allows the industry enhanced visibility on the risk level for the equipment. The industrial will know the problem and can easily intervene. In addition, this model can be considerate as a decision support tool to minimize or to avoid risks that may occur.

4. Conclusion and perspectives

This paper provides a risk assessment in the LPG loading. First, we presented the case study: the bulk relay site of PRIMAGAZ Company and specifically the loading operations. We have listed the loading operations as a sequence diagram. Then we conducted a risk analysis in loading operations particularly on the "pump" equipment that is essential equipment for loading. This analysis identifies the studied system, the feared event, its causes, its hazards and safety barriers that may limit its dangers. After, we have provided failure scenarios that may be relevant in the simulation.

The developed simulator is implemented in AnyLogic platform to show the system studied in normal mode (insurance of loading operations) and in failure mode upon the occurrence of a problem triggering calculation of criticality for the equipment and showing the influence of this failure on the system. The risk level of the equipment allows for the industry a better visibility and a decision support.

The future work is to generalize this simulation on other equipment (Compressors, Liquid/Gas Arm …) to ensure the loading and unloading operations.

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Biography

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- Vulnerability and resilience of territories and organizations.
- Assessment and prevention of technological and natural hazards, crisis management and damage assessment.