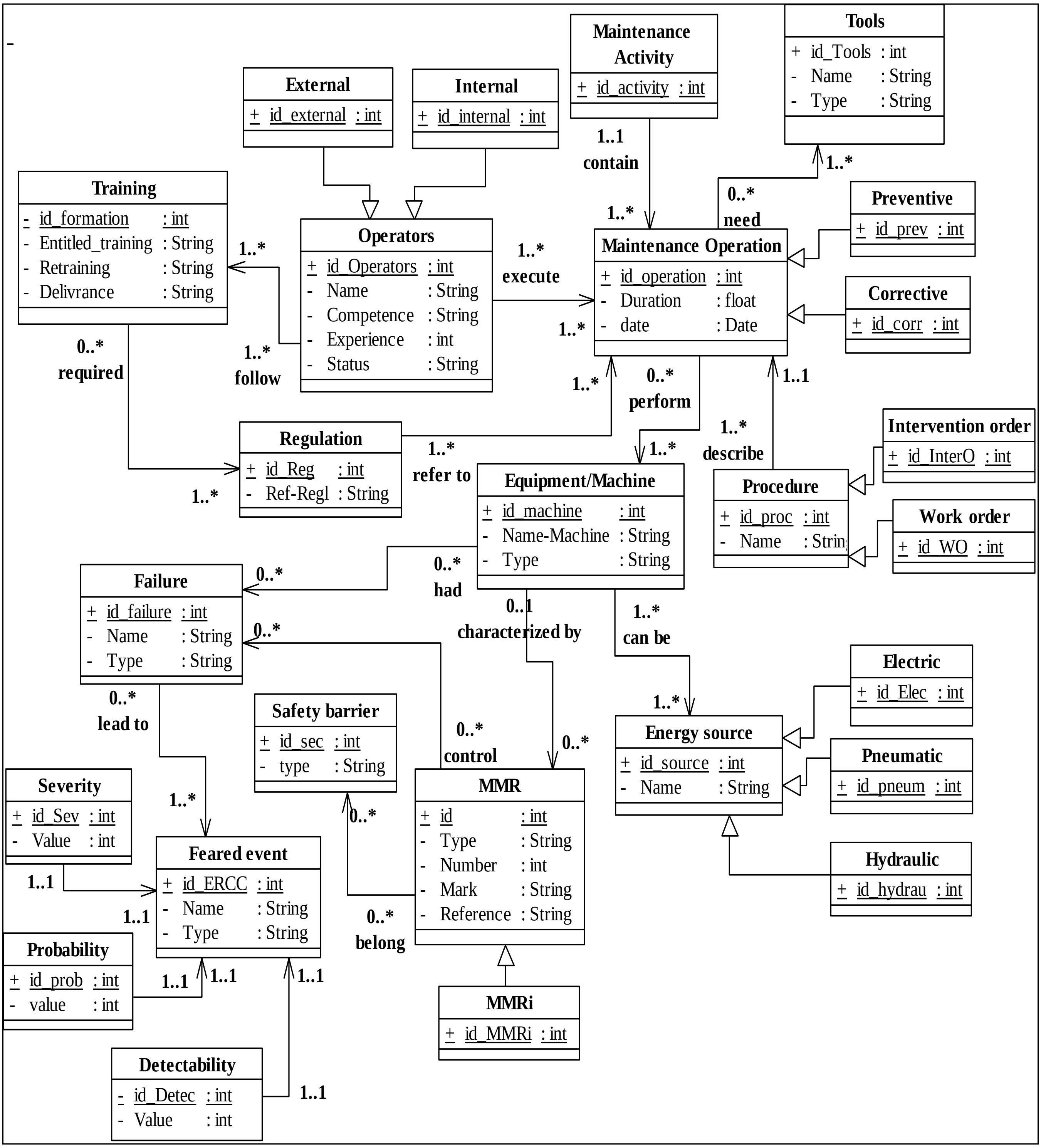

Figure 2. UML class diagram of maintenance activities within bulk relay site.

Several maintenance failure scenarios have been detected in these equipment: pumps, compressors, liquid/gas arms and detectors; the most important and relevant to the loading/unloading operations are featured in Table 1:

Table 1. Failure scenarios for equipment maintenance.

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.
Compressors	Gas compressor start-up with the isolation valves closed	Material fault or failure to apply the set-up instruction.
	Improper cleaning or non-replacement of a worn/ deteriorated relief valve;	Failure of PRIMAGAZ personnel to comply with a maintenance instruction
liquid/gas arms	Lack of attention at a lorry loading arm connecting operation by opening the manual valve	The appearance of a UVCE and jet flame.
	Failure to implement the annual wear control thread of the nut arm.	The appearance of a UVCE in material operation with the definition of the effects zone and of a possible flame jet in complement.
Detectors	Wrong calibration of the detectors	Operational failure altering the reliability of the MMRi chain.
	No verification of pre-alarm and alarm triggers.	Operational failure altering the reliability of the MMRi chain.

CONCEPTUAL MODEL OF THE PROPOSED MULTI-AGENT SYSTEM

Simulation by MAS is used to analyse and to simulate different interactions between autonomous agents of a global system. The simulation based on agents is used to model parts of the real world and Complex Systems.

MAS have shown their relevance to the design of distributed applications (logically or physically), complex and robust [14], [15]. The agent concept is now more than efficient technology; it represents a new paradigm for software development in which the agent is an autonomous entity with a goal. In fact, the agent operates in a dynamic environment and interacts with other agents using languages and protocols [16].

The main objective of MAS is to find a global solution to the global problems and modelling of heterogeneous, complex, non-linear and scalable systems with a set of entities called agents. This approach provides robust and adaptable solutions in environments that can be unpredictable.

The aim of the proposed model is to:

- Present an application of multi-agent simulation approach to control and overcome risks in maintenance activities;
- Develop a MAS to ensure safety and avoid probable failures when performing a maintenance task;
- Create a system that calculates the performance indicators related to maintenance.

Figure 3 illustrates the general architecture of MAS. This figure presents the interactions between agents: Planner Agent, Operator Agent, Tools Agent, Machine Agent, Evaluator agent and Maintenance User. The functioning and behaviour of these agents are defined and explained in our works [2], [3].

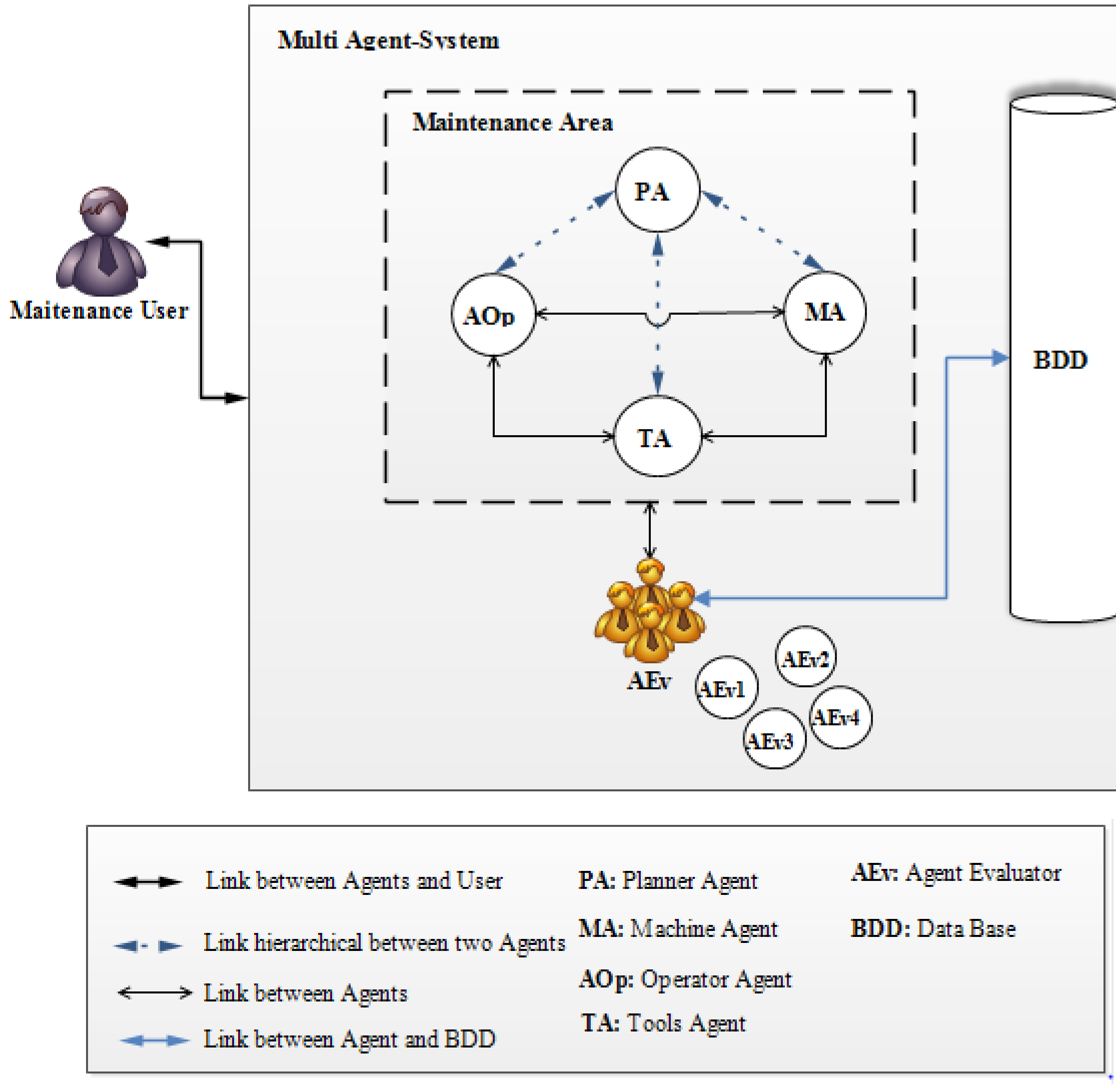

Figure 3. MAS global architecture.

ANYLOGIC SIMULATION RESULTS

AnyLogic Platform :

AnyLogic is a dynamic simulation platform for discrete, continuous and hybrid type systems, as well as for the development of deterministic, stochastic models or systems based on agents [17]. AnyLogic includes a graphical modelling language facilitating models construction. This platform allows the user to make custom simulation models through its large graphical editor, its visual representation and animation (2D and 3D) of simulation different entities. It is a tool based on the object-oriented approach, and all its simulation and animation elements are developed in Java programming language.

AnyLogic is a platform that combines the different approaches to modelling-simulation: System Dynamics, Discrete Event, Multi-Agent Systems (MAS), with all possible variations, and that using a single modelling language and within' one model development environment allowing time reduction and cost model development [18]. The flexibility of AnyLogic language allows modelling the complexity and heterogeneity of operations (common operations, economics, social, etc.) with all levels of desired details. The fundamentals of modelling language and library object AnyLogic used to model production and logistics, common processes, human resources, behaviour of consumers and patients, and the environment and their natural interaction.

The AnyLogic platform is applied to several areas such as health and pharmaceuticals simulations [19] and [20], science and education [21] and [22], energy systems [23] and [24], military, defence, security [25] and [26], industry, etc...

Interests and choice of AnyLogic platform:

AnyLogic is the first platform and the only dynamic simulation tool that gathers and combines these three approaches of different modelling-simulation: system dynamics, discrete events and MAS [17] and [18]. AnyLogic is the most appropriate platform for modelling industrial problems particularly those in the supply chain [27], [25], [28] and [29].

The choice fells on the AnyLogic platform, because it is able to model more specifically industrial problems like manufacturing, logistics and supply chains [27], [25], [28], [30] and [31], as well as the maintenance field [3] and [32]. Moreover, AnyLogic provides tutorials that are integrated into the platform and dealing with maintenance issues such as Wind Turbine Maintenance. 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.

AnyLogic Simulation Results :

Machine Agent can be a compressor, pump, arm liquid/gas, or detectors. Figure 4 represents the studied system with the different elements that compose it.

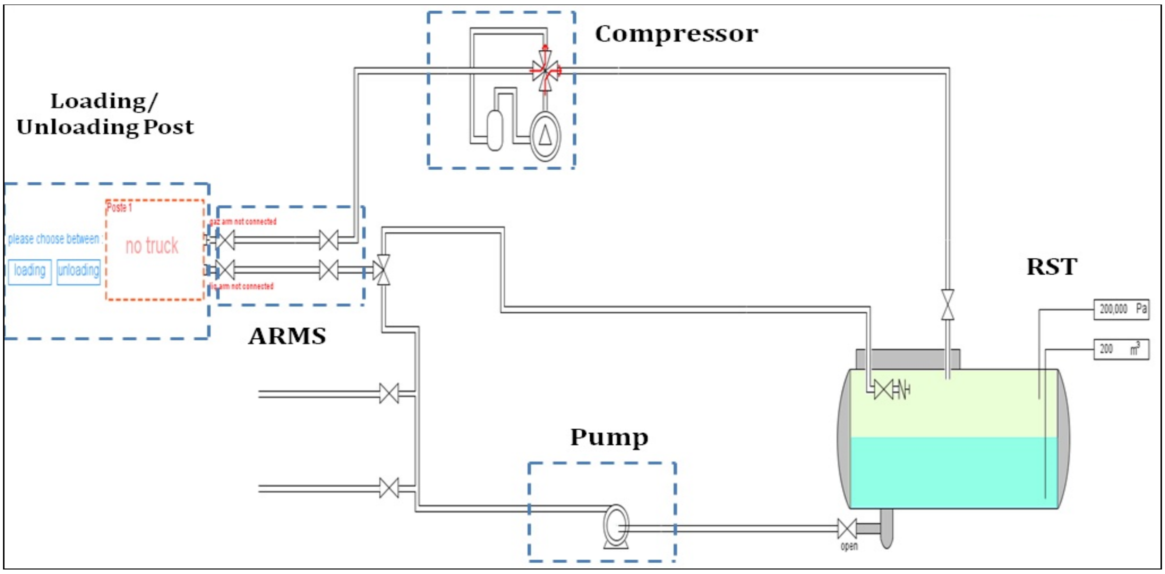

Figure 4. AnyLogic Framework of the studied system.

Simulation system during normal operation :

The normal system operation is carried out in two phases (LPG loading, or Unloading), these two phases are always preceded by the identification and verification of the truck conformity before it comes to the bulk relay site.

- Checking Truck

The simulation model provides checking truck (fig.5) before proceeding to loading/unloading operations in order to ensure compliance of trucks to prevent leaks that could create an explosion.

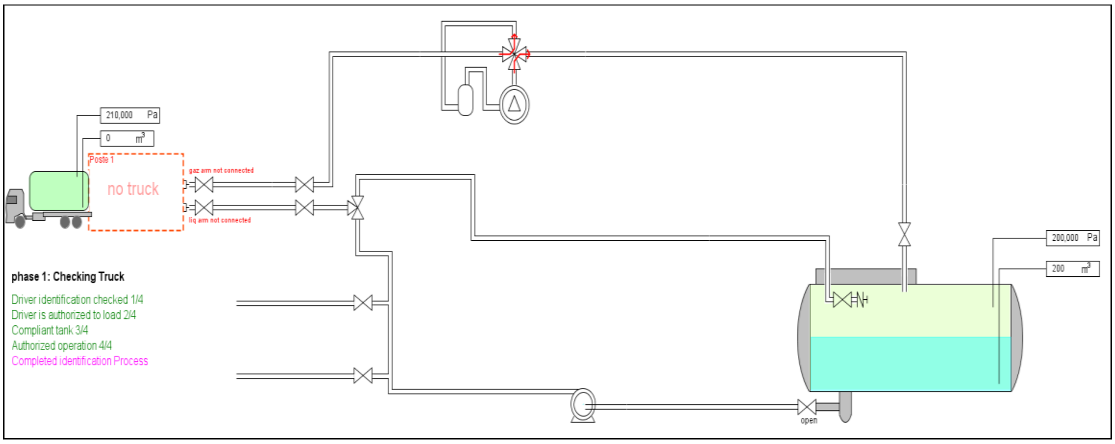

Figure 5. AnyLogic Simulation for checking the truck.

- Loading Operations

After checking the identification, the truck is positioned at the loading station for loading small tanker carrier as depicted in figure 6.

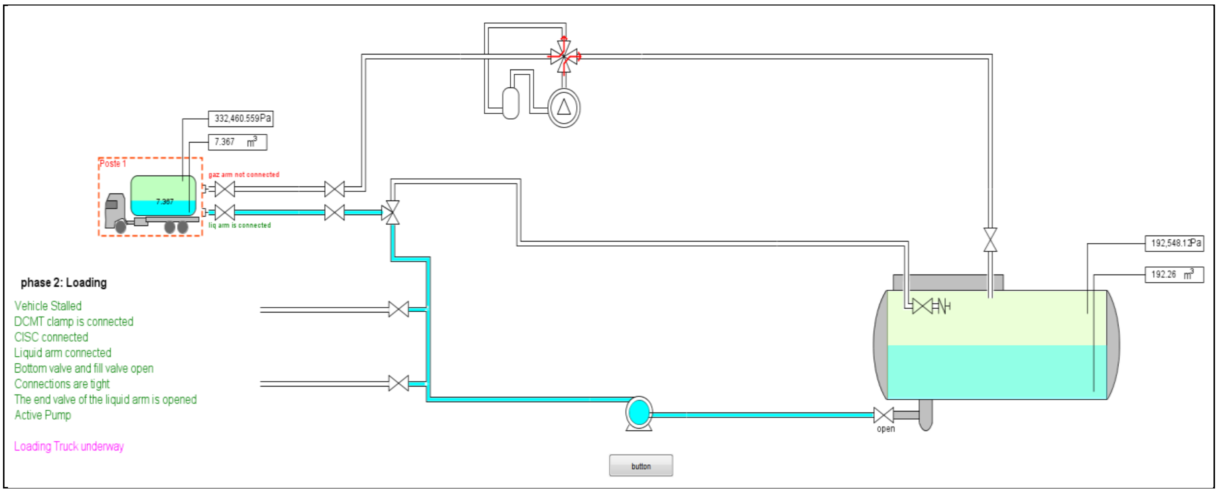

Figure 6. Loading Operations.

Loading operations are performed and ensured by the pump. The pump is essential equipment for the loading operations completion. The normal operation of the pump is outlined in Figure 7.

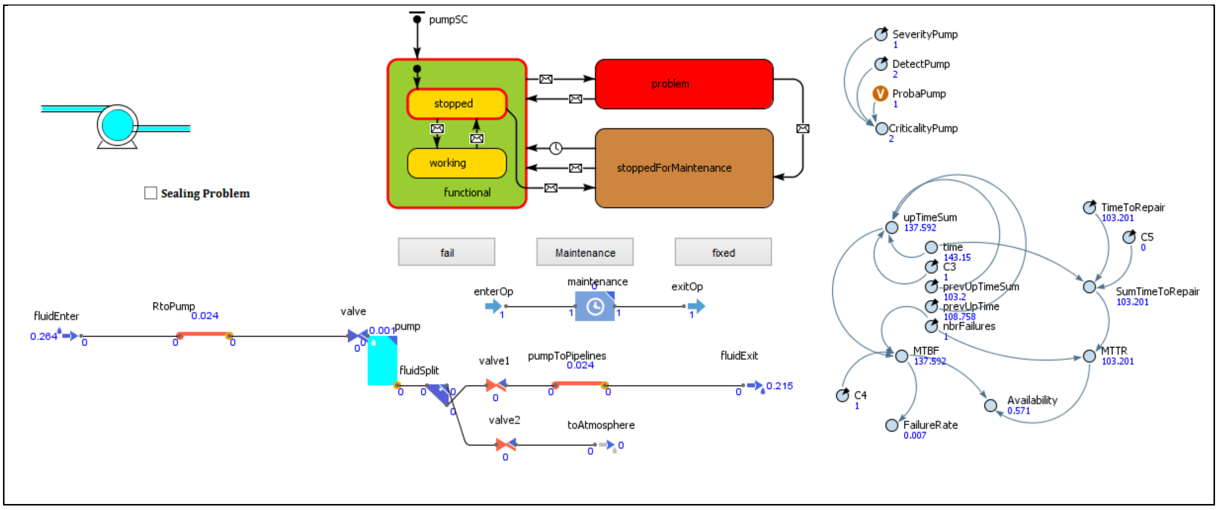

Figure 7. Pump simulation in normal operation.

- Unloading Operations

Unloading operations of jumbo tanker have taken place within the loading/unloading station. The compressor ensures the liquid (blue colour) and gas (green colour) discharging as highlighted in figure 8.

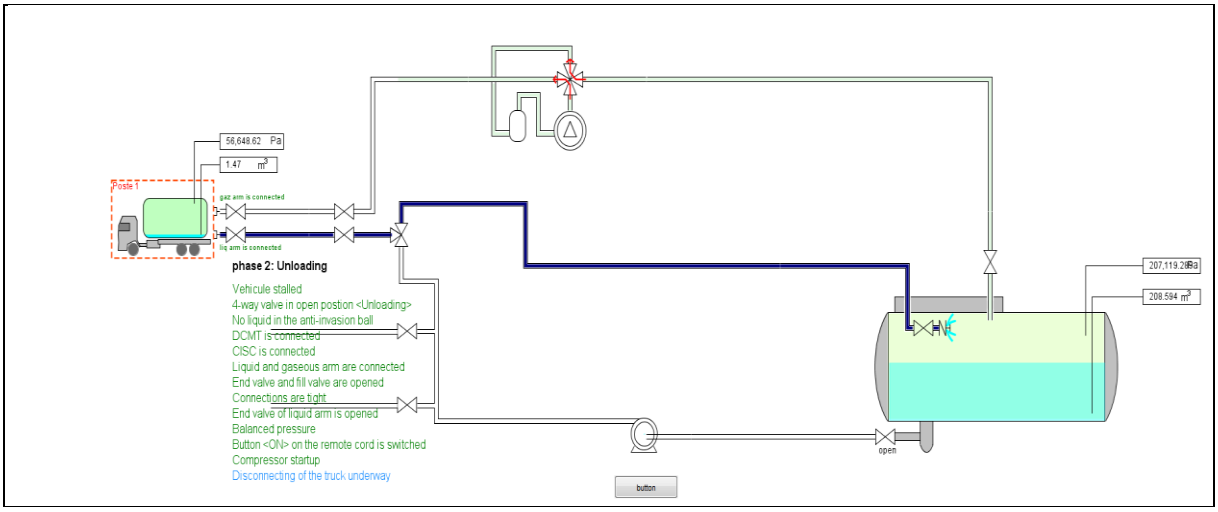

Figure 8. Unloading operations.

Figure 9 illustrates the dual compressor operation. 1st phase (green colour) concerns the fixed storage gas phase is sucked, compressed and injected into the gas phase in the tank to drain. The pressure in the tank then increases and the liquid is removed to storage. 2nd phase (blue colour) is when the entire liquid phase was transferred, the liquid valve is closed, and the compressor transfer direction is reversed by a 4-way valve. This phase allows depressurizing the tank by sucking a part of the gaseous phase to storage.

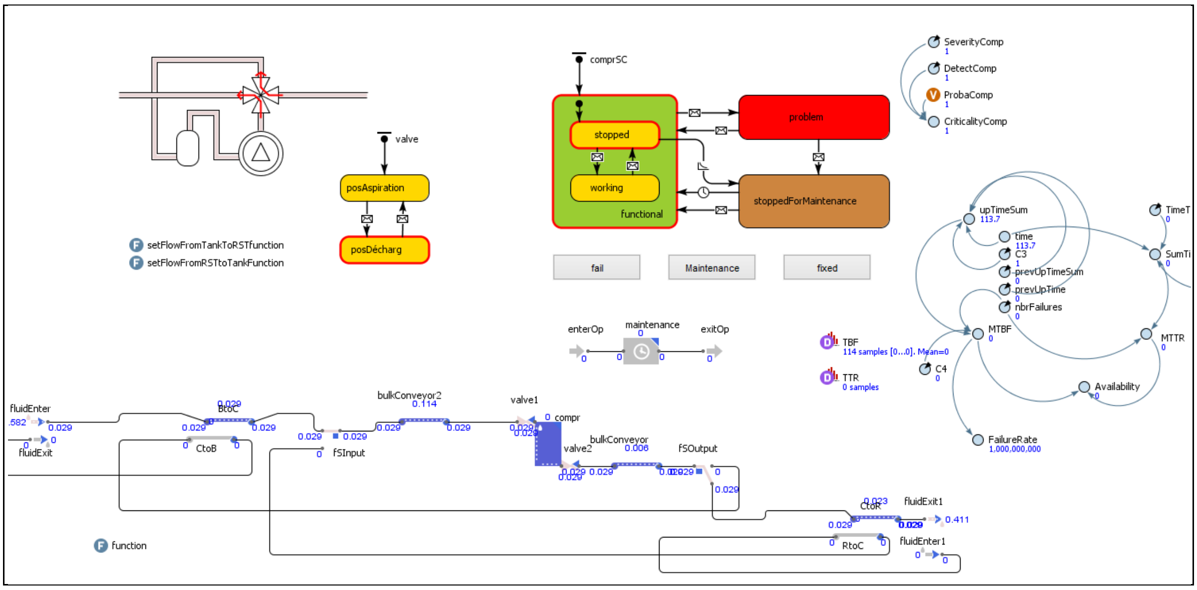

Figure 9. Compressor simulation in normal operation.

Loading / unloading operations are carried by the gas / liquid Arm. This equipment ensures the transfer of a liquid or a liquefied gas from a tank to another. The operation of the gas / liquid arm is exhibited in figure 10.

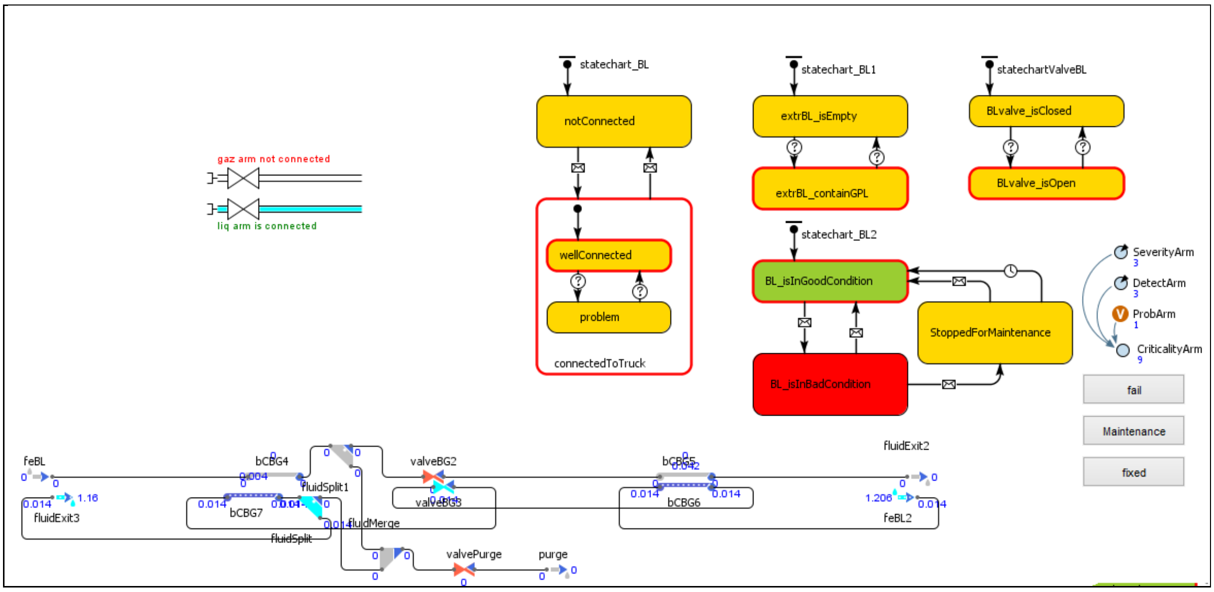

Figure 10. Arm simulation in operation.

Simulation of failure scenarios :

Each selected equipment undergoes several failure scenarios. A list of failure scenarios related to each device was made. The most important scenarios are chosen for the simulation, which aims to bring a contribution to the maintenance service, and are at risk for the service and for the entire supply chain. The selected scenarios are as follows (fig. 11).

The developed simulator will estimate the criticality for each equipment according to three parameters: probability, severity, and detectability (fig.13). The severity and detectability are given as parameters, and then the probability varies according to a probability distribution "PERT". The PERT distribution is a continuous distribution bounded on both sides. Being an alternative distribution to the Triangular, it has the same three inputs, Minimum, Most Likely, and Maximum, but is a smooth curve that puts less emphasis on extreme values. The PERT distribution is often used in risk analysis applications.

Occurrence Probability = Initial Probability of Equipment + PERT (0, 1, 0.1)

The criticality threshold depends on the state of the equipment (normal, degraded or shutdown). The threshold is defined as:

$\mathbf{C_{Equipment} \leq 2}$: the equipment is in an operating state;

$\mathbf{2 < C_{Equipment} \leq 8}$: the equipment is in a degraded state, but does not influence on the technical installation;

$\mathbf{C_{Equipment} > 8}$: if the equipment criticality is higher than 8, this equipment will cause an equipment shutdown and influence the technical installation (whole system).

The simulator also calculates the risk level of the overall system (fig.11):

Risk Level = ∑ Criticality for each equipment

= Cpump + Ccomp + Carm + Cdetectors

If Risk Level ≤ 8 ➔ The system is in working state;

If 8 <Risk Level ≤ 27 ➔ The system is in degraded mode;

If Risk Level > 27 ➔ The system is in shutdown.

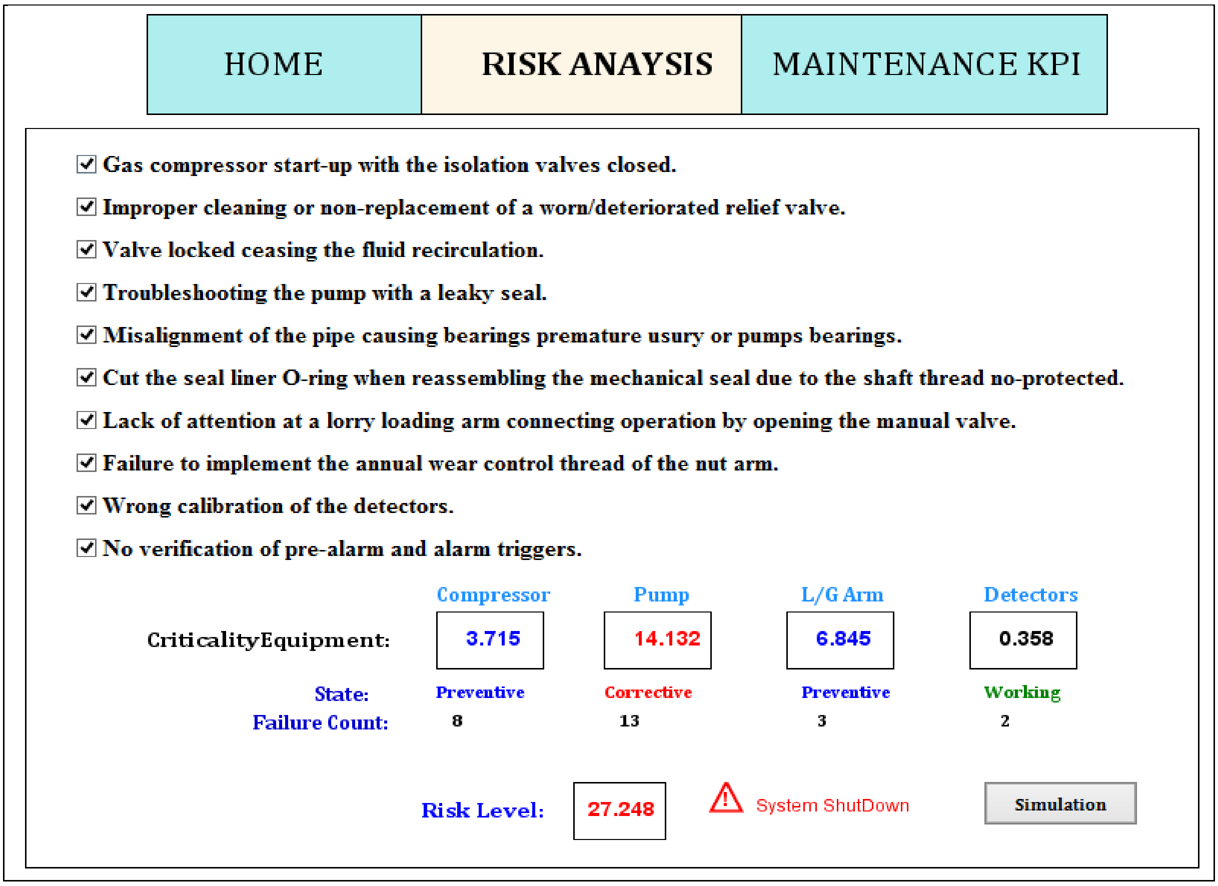

Figure 11. Risk Analysis Simulation outputs.

If a risk level exceeds 27, a flashing message the system shutdown. By clicking on the Simulation button, Figure 12 is obtained. This figure shows the truck loading shut down and the gas detector warning that there is a problem with the pump level in the first place. The gas detector's operation is illustrated in Figure 14.

When the pump fails, the valves close automatically (fig.13) and suddenly loading operations stop. Once the pump fails, it sends a message to the operator agent for performing a maintenance task.

Thus, each device is presented by a state-chart with three states: functional state, problem state and state of maintenance.

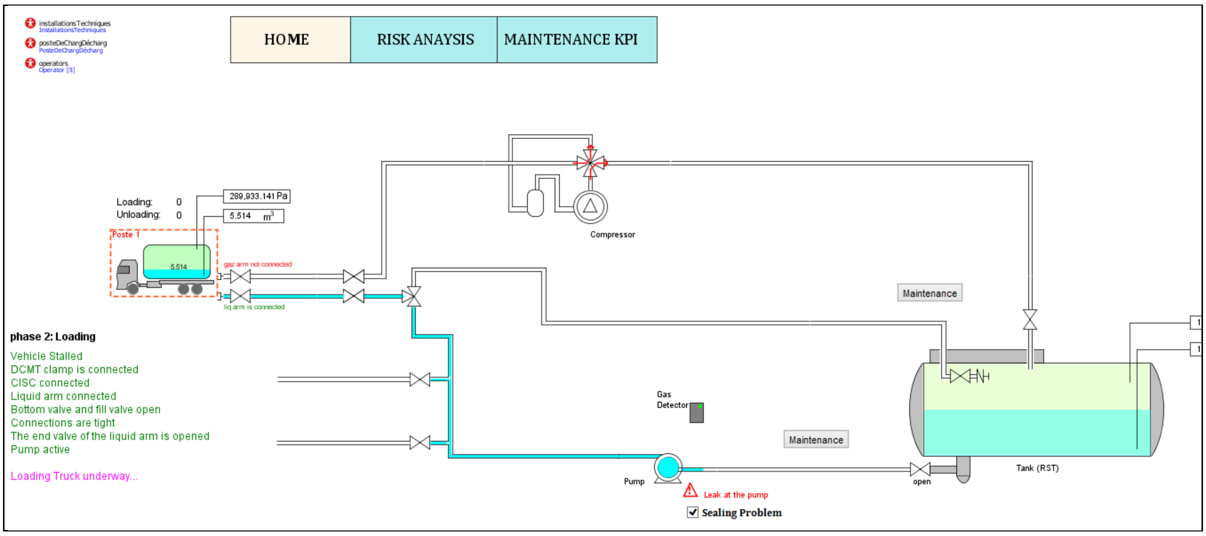

Figure 12. Off-system simulation.

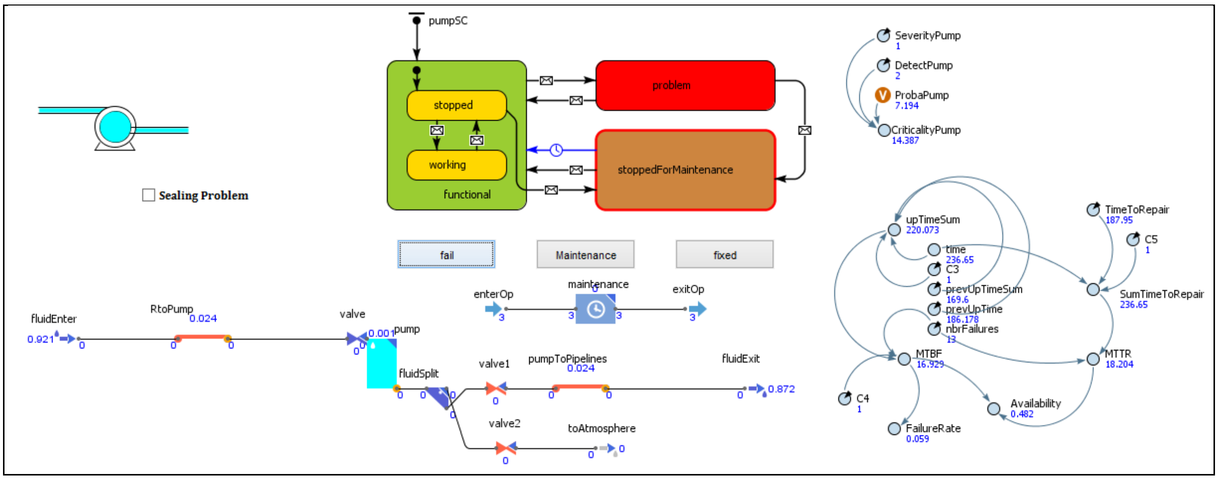

Figure 13. Pump simulation during the shutdown.

The detectors are not like other equipment, these are mitigation measures, they do not generate a risk, but they are used to reduce it, so their gravity equals to 0. Indeed, their severity lies in non-detection of a problem or leakage from other equipment. Therefore, the severity is substituted by LEL (Lower Explosive Limit).

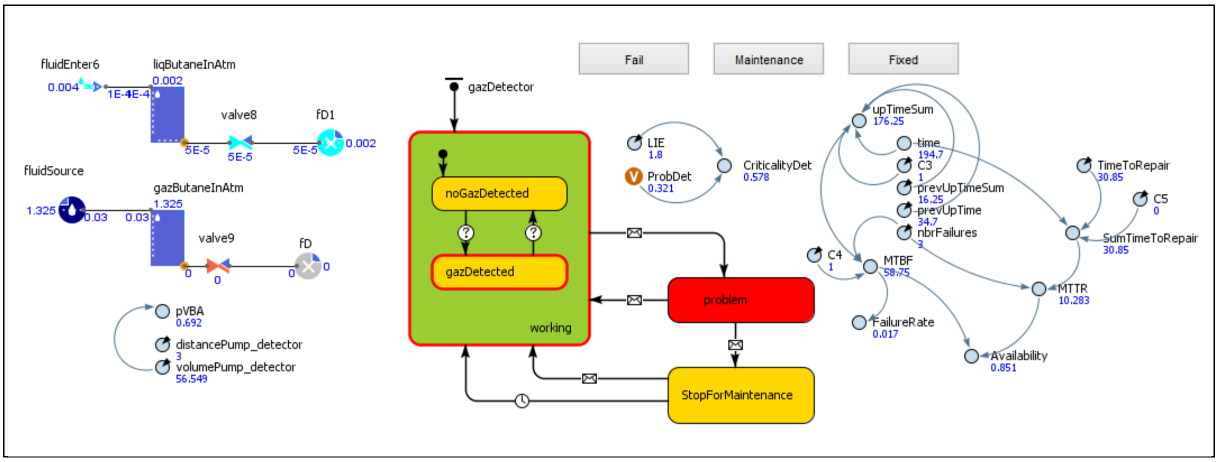

Figure 14. The operation of detectors.

KPI simulation :

Besides the risk analysis, the simulator also calculates a set of performance indicators related to maintenance. The figure 15 displays these indicators that ensuring the equipment dependability: Reliability characterized by MTBF (Mean Time Functioning), Maintainability characterized by MTTR (Mean Time To Repair), Availability and Failure Rate.

Other indicators calculated by the AnyLogic simulator about resources (operators), the simulator calculate: Operators Availability, Occupancy Rate, and Utilization Rate. These indicators include resources availability and optimization.

The goal is to get a dashboard containing these indicators for the instantaneous behaviour equipment monitors and for having visibility of the current situation in order to avoid falling into failures and keep up the operation.

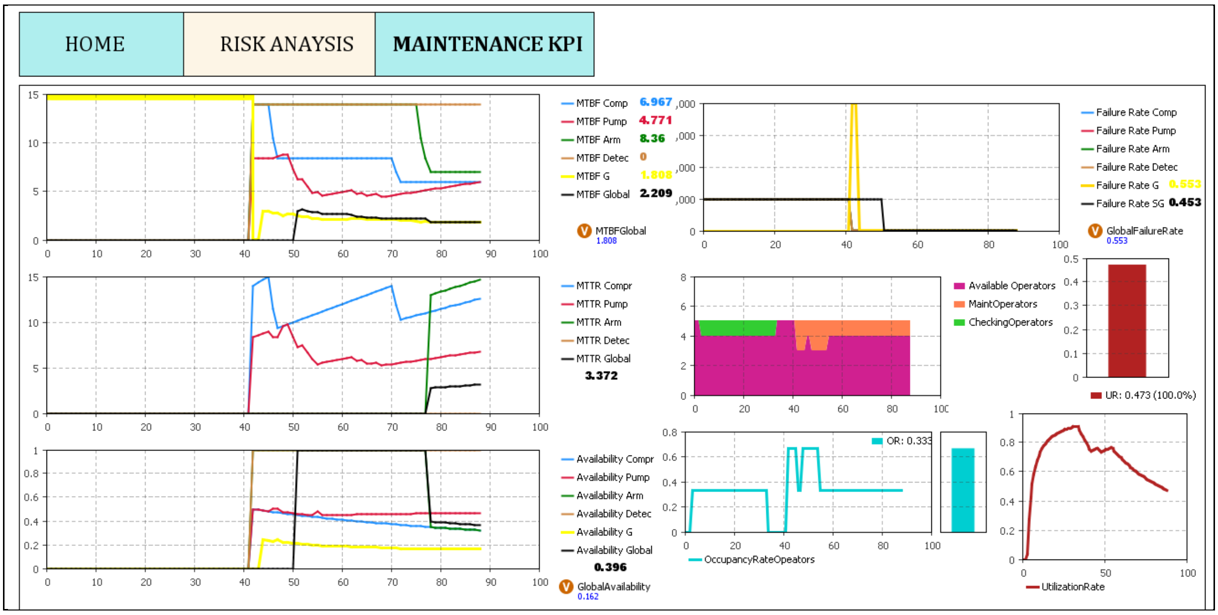

Figure 15. KPIs resulting from the simulation

Discussion :

The proposed model can provide reflection member to overcome risks in maintenance activities using MAS. The goal is to model and simulate maintenance failure scenarios (default, loss, delay, failure or insufficient maintenance) of LPG supply chain, and view the impact of these failures on the maintenance operations and the whole supply chain. Moreover, the proposed model allows managing the complexity of maintenance activities in order to optimize resources used in maintenance tasks to ensure both values for money and availability of machines. It provides knowledge on the various interactions between the elements that constitute this system in order to get instant results. These instant results are displayed as a Dashboard that collects a set of performance indicators related to maintenance which are: Reliability, Availability, Maintainability, the utilization rate, the occupancy rate...

The proposed model obvious several interests. It represents a way to support risk analysis with a system approach, taking into account the interactions between system components. According to a theoretical point of view, it provides knowledge on the field of maintenance and behaviour of different elements that make up this area to get instant results. These results are processed to compare and choose the right strategy and display performance indicators, without the need to calculate or modify the parameters every time. This model is used as a decision support by synthesizing information from different scenarios. It is a powerful tool for communication and understanding the maintenance situation, taking into account its complexity to monitor and to apprehend risks.

The simulation with this visual approach saves time by the anticipation and development planning, risk analysis, optimization, and better management of human resources. Moreover, according to the practical points of view, this work may be interested stakeholders to have a better visibility on the risk level and to take a decision regarding the right time for carrying out a maintenance operation. It is a tool that could guide industry towards the best choice to avoid maintenance failure scenarios that may occur.

CONCLUSION

The aim of our work is to manage risks that may arise when performing maintenance tasks in the LPG supply chain by using a risk analysis simulator that takes into account the complexity of maintenance and interactions between their components. Multi-agent systems prove to be the right tool to solve this problem. The goal is to simulate maintenance failure scenarios and determine the criticality of each device and of the overall system (Technical System) to achieve a risk level. The risk level will allow decision makers to have a threshold that can cause a system shutdown. The developed simulator also provides a Dashboard contains a set of maintenance performance indicators for a better visualization.

Our research, shaped by modelling and engineering, seeks to formalize and unify the knowledge to enable individuals, organizations (particularly industrial systems) to direct them to the best decisions and increase their resilience to deal with damaging disruptive events, with hazards related to the non-availability of resources and with the uncertainty of human factor operation.

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