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Development of an Asset Integrity decision support model for a fuel logistics network

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ABSTRACT

This paper explores the idea to build an objective and quantitative decision support tool, to define a useful dashboard for the Asset Integrity of a network for the distribution of fuels, necessary both to feed the vehicle fleet and to feed airport depots. The network consists of a set of physical and functional infrastructures located in space even at high distances (national and supranational level). In particular, the following are identified: the nodes, representing the fuel storage tanks, connected by complex hydraulic networks, characterized by pipes and systems for the management of the outflow and by the individual users, more or less extensive, of consumption; the links define the connections that allow the outflow of fuel from the supply, transformation, storage and consumption of the same. After a data collection phase (based on a time window of the last 3 years) and a model construction phase through the Stella Architect software, which uses the System Dynamics approach, the ”calibration” phase was developed and the next phase of ”validation” allowing to have a punctual and realistic feedback of the process implemented. Finally, the use of the technical-methodological approach to the number of nodes/repositories of the entire logistic network was tested, checking and modeling also the reciprocal interactions, in order to have a complete management of Primary Logistics both from warehouse both from resource security and environmental protection.

1 INTRODUCTION

Resource integrity is essential to ensure a safe and sustainable sector. It involves the implementation of inspections, tests, verification and other programs which are necessary to ensure that essential safety equipment is fit for purpose throughout their operational life. Keeping the hardware safe, reliable and efficient is essential not only to minimize the risk of serious accidents that all oil and gas companies in the world can have but also plays a vital role in creating a physical environment in which people feel proud to work. The integrity of the resources represents the main element that is above all part of a robust safety management system. However, it is possible to define the concept of integrity of resources also concerning the functionality, effective and efficient of a generic logistics system. In this work, the concept of asset integrity management is examined, in the fuel distribution system, concerning all the activities necessary to ensure the correct functioning of the entire system (integrity), through effective measurement of key performance indicators, and also considering aspects of effectiveness and efficiency. To do this, a quantitative tool has been implemented, based on software modelling in System Dynamics (Romano et al. 2011 and 2014), able to reproduce the behaviour of the system in its usual operation, and to implement, through a set of variables/control parameters, the asset integrity verification mechanism. The choice of modelling in the System Dynamics approach was particularly suitable, both for its evolution, which can also simulate control processes and for the ability to carry out feedback cycles, particularly interesting in the context of this work, where the analysis and evaluation parameters of the real operations of the system, can give rise to corrective actions, also about the extrapolations of dynamic behaviours (Romano E. and Iuliano D. 2018).

2 Background

The design, analysis and management of a Supply Chain constitute a relevant topic in the scientific literature of the sector, mainly for the dynamism of the environment but also for the complexity of the products and customers. There are numerous works in the state of the art that focus on the management systems of storage systems (warehouses), considering this subsystem to be critical in the operation of the entire logistics network; but also on the optimization of input/output flows or internal logistics flows (movement of materials within the same production process. The architectures of the logistic networks are characterized by complex systems that interact with each other, increasing the complexity for the analytical tractability in terms of evaluating the analysis of critical issues and for the determination of possible evolutionary scenarios that increase their effectiveness and efficiency. Large logistics networks are complex systems that are sometimes difficult to manage. To cope with the complexity of logistics networks, several specific performance measurement systems (PMS) for logistics networks have been developed in the past (Gleich and Quitt 2011; Bruns and Hegmanns 2013; Biesen et al. 2013; Gladen 2014). PMS is generally made with data warehouse systems (Bauer and Günzel 2013). In a PMS, several performance measures are hierarchically accumulated to obtain key performance indicators (KPIs). The purpose of a PMS is to provide managers with the basic information they need to improve their area of responsibility. The key elements within a completely generic logistics network are certainly the warehouse, defined as a node that can store material and help to characterize the effectiveness of the total logistic outflow. Warehouse structures can perform different functions within a network. As a result, several classification schemes are available in the literature. According to some studies, the warehouse structures should be grouped as distribution centres or as warehouses supporting production centres (Romano et al. 2007). In comparison, Frazelle (2001) classifies warehouse structures based on their function in the supply chain network, such as allocation of raw materials, products in progress, finished products, distribution, fulfilment, direct local warehouses for customer demand and value-added service. Another perspective considers the processes of a warehouse that can be classified into one of three groups:

1. loading processes;
2. service or storage processes;
3. outbound processes, which mainly include the function of shipment.

Liong and Loo (2009), for example, examined loading and unloading processes in warehouse facilities by conducting simulation experiments in various scenarios to quantify worker use and waiting times. These results have been used to identify bottlenecks and develop improvements in the system. One recommendation included increasing manual labour capacity to reduce the overuse of overtime and the delay of customer wait times. De La Fuente et al. (2019) examined the effects of workforce personnel strategies employed in the warehouse operations of a beverage distribution centre located in the Bio-Bio Region, Chile.

Understanding the management process of a warehouse structure, through a simulation approach, is important because it strongly influences the dynamics of the storage capacity in warehouse operations, but also because it allows the logistics flow to be fluidized, avoiding blocking or power failure conditions. Karakis et al. (2015) proposed a non-linear model based on the input parameters of the storage and use capacity of known machinery, technical specifications and product dimensions to determine the size of a warehouse structure. Most of the works found in the scientific literature of the management and control of a supply chain have to do with classic products: think of electronic products or products that have a high electronic content; high-tech products; to food products. On the other hand, few works deal with the optimal management of the logistic network affected by the production outflow of gas, fuels and/or oils.

The depth and complexity of the problems, in the search for optimal solutions, lead us to consider the use of simulation techniques that, at different levels, can support the decision-making process. In an attempt to build a decision-making tool for the management of all the operating flows in an oil and gas supply chain (SC), the evolutionary steps that involved each subsystem of the logistics network were considered, trying to build a systemic approach that interests both the warehouses and the delivery phases. Romano E. et al. (2012) has developed in his works, some quantitative approaches based on simulation techniques, both in DES and in SD environment, to build decision support processes in different fields, from direct and inverse logistics to modelling of health processes. The paper is structured as follows: Section 2 presents an overview of the process analyzed. Section 3 formulates the DSS problem based on the simulation and use of quantitative techniques in the context of logistics networks and describes the DSS architecture and general operating principles described in this work and provides a model of the system implementation with simulation techniques in System Dynamics which describes the logistics network of the company that provides the data for the study. Section 4 closes the document with a look at future research developments.

3 Problem Formulation

The process of the logistics network concerns the supply and distribution of fuel (in this specific case diesel). It can be considered as a single block with an input and an output. In particular, it is possible to list the states in which the logistics system that affects the diesel product evolves:

- the input of the fuel occurs with the arrival of the vessel tanker (NC) in the wharf area which, after carrying out the evolution and docking operations, begins the unloading operations;
- unloading of the product through an oil pipeline, therefore allowing the storage of diesel fuel in a ”storage tank” located in the Tanks Area which thus represents the so-called ”buffer”;
- the output of the fuel from the system is given by the ”loading lanes” located in the area through which the product is loaded to the corresponding truck tanker (ATB) which then distribute (or sell) it to the final customer (customer delivery); in details, the diesel fuel, before being loaded into the ATB, is first transferred to a ”sales tank” and, only subsequently, sold through the loading of the tankers. As part of the process, it is to be considered a link which represents the transfer of product from the ”storage tank” to a second distribution node, via a dedicated oil pipeline.

In Figure 1 we have represented the real logistic processes, instead in Figure 2, we have modelled the simplified logistic network through a series of descriptive symbols of the different stages of the process flow, from the entry of the product, until its exit.

3.1 Modelling Parameters

3.1.1 Data

All the data were collected considering a time window relating to the last 3 years of operations carried out at the logistics hub.

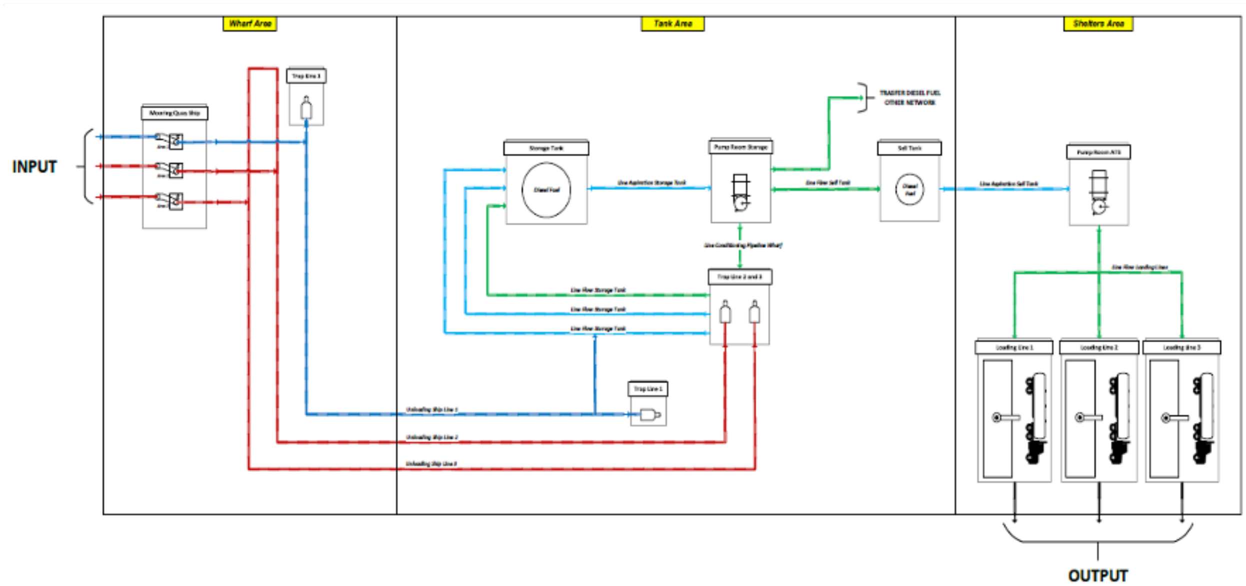

Figure 1: Process diagram of the logistic network.

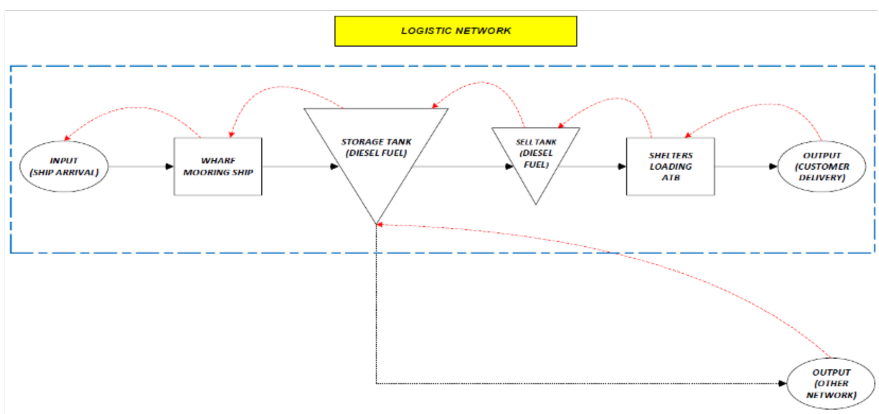

Figure 2: Schematic Process diagram of the logistic network.

3.1.2 Variables

The variables created, based on the data collected, are those listed in Figure 3, where we summarize: the state variables; the resources variables; the knobs, through which it is possible to control the outflow phenomenon and also make corrections for scenarios analysis.

3.2 Model Construction

The logic developed below is based on the logistic process already defined. This model is able to manage the supply of a certain quantity of product (diesel), that arrives by means of a vessel tanker (NC) and is subsequently discharged, stored in a high capacity tank, transferred to a lower capacity tank and finally loaded in the relevant truck tankers (ATB), or sold to the end customer. In practice, it is a ”PULL” type system, that is a system that, based on the ”X” orders received by the customer, activates the supply of the required quantities by ”pulling” the production from downstream to upstream and on schedule, so that there are never delays in delivery and/or stops in the logistic flow and, consequently, that the product is

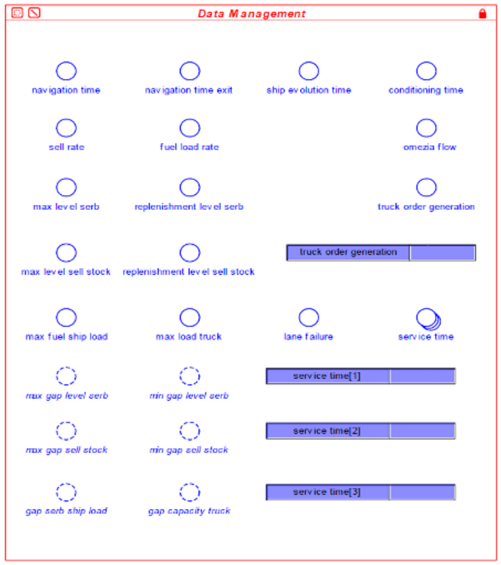

Figure 3: The variables created for the model.

guaranteed to the customer. It is noted that the two tanks (the storage one and the sale one) represent the so-called ”buffers”, which allow precisely to manage the replenishment levels based on the planned outputs, allowing thus to the system of homogenizing and programming its production capacity. The modeled logic can be summarized through the following scheme (Figure 4) which relates the logistic flow as a function of time T.

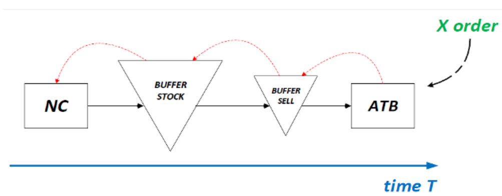

Figure 4: Process scheme based on the PULL type system.

The model was designed in Stella Architect 1.9.5, and is implemented in sub-models interact each other (Figure 5) The model was developed featuring 5 main blocks, each of which contains the constructs that define the processing logic.

These blocks, specifically, are:

- the External Logistics block;
- the Internal Logistics block;
- the Resources Management block;
- the Order Management block;
- the Line Maintenance block.

Each block is explained in detail below, describing its operating principle based on the modelled process.

3.2.1 External Logistics block

The External Logistic block is able to manage external logistics by modelling two processes, which are:

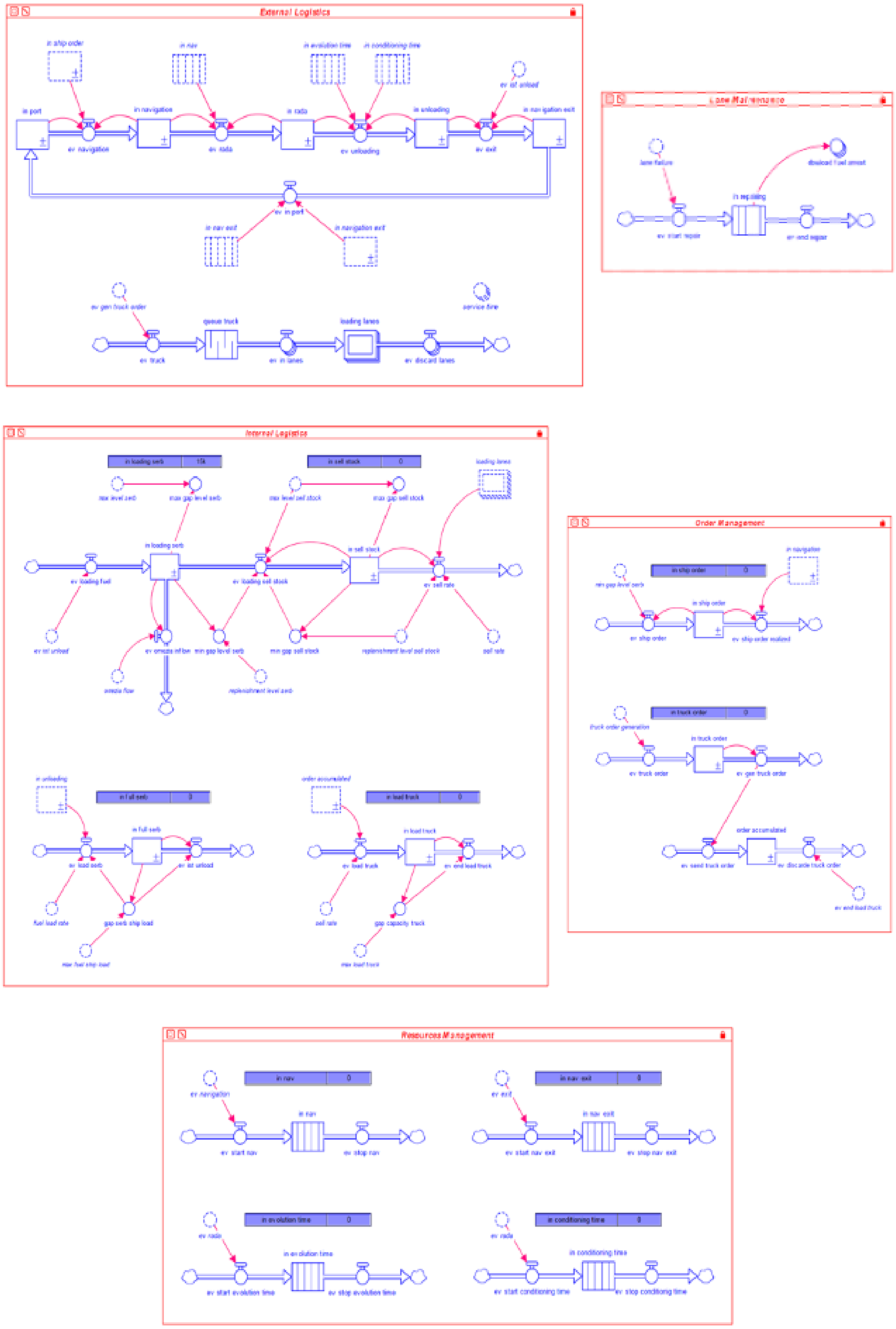

Figure 5: System Dynamics model related to the logistics network.

1. management of the vessel tanker (NC cycle);
2. the management of the loading of truck cars (ATB cycle);

The process begins with the issue of the order of a tanker, which allows receiving a quantity of the product to guarantee the supply of the node based on the consumption required downstream of the logistics process, or based on the orders received by the end customer. Once the order is received, navigation of the ship starts from the loading port with the quantity to be transported on board and then transferred to the destination pier. This process has a predefined time duration, simulated by a conveyor module in the Stella software. When the tanker ship arrives at the destination port, starts the evolution operation in the port basin. This process also lasts a predefined interval of time, depending on the ship type. At the same time that starts the evolution ship process, starts another process (hydraulic conditioning) involving ground hydraulic systems that connect tanker buffers. This operation is preparatory to the upload fuel in the network (from the ship), and consists of the displacement of the water that flows inside the pipelines. Once completed, both activities (i.e. evolution and conditioning), the ship starts to download fuel in the pipeline and to filling the central buffer tank. If one of the operations, or evolution or conditioning, will not be completed it's impossible to introduce fuel into the lines. At the end of downloading fuel from the ship, begins the un-mooring manoeuvres. The ship thus begins navigation to the loading port. The end of this cycle time the ship enters in the origin port and becomes again available to receiving another order of a fixed quantity of fuel. The same ship cycle will be, therefore, repeated for each order received. The ATB cycle (tanker) it supplies product from the ”sales buffer”. In this case, the modeled process begins with the generation of orders by the end costumers based on the request for a specific quantity of product. Once the order has been issued, the tanker makes the reservation that is managed through a queue simple model: if the resources ”loading lane” are busy, the ATB will has to wait until one of the resource is available.

3.2.2 Internal Logistics block

The Internal Logistic block allows to manage the internal logistics of the network, modelling three processes, which are:

1. the fuel management process, both in the storage central tank and in the sales tank;
2. unloading of the tanker;
3. the withdrawal of fuel for sale, by truck order.

The first process simulates the loading and unloading cycles between the two tank systems: the centralized one, connected to the ship; the sales one, connected to the ATB tankers. The refuelling of the centralized tank is managed through a suitable ”gap” which allows checking the maximum level threshold to avoid exceeding it and, consequently, the ”overflow”, ie the overflow of the product. In particular, based on the consumption required downstream of the process, the storage tank is discharged to perform two main operations, which are:

1. the supply of the sales tank;
2. the power supply of another network.

In the first case, i.e. the filling of the sales tank, two controls were implemented in the model on the levels of the storage tank relating respectively, one to its filling phase and the other to its emptying phase; all this was obtained by the construction of two ”gaps” that control the differences between the capacity of buffer tanks and the replenishment level. Based on this variables we have implemented the logic that regulate both the buffers management and replenishment orders, able to avoid stock out.

3.2.3 Resources Management block

The Resources Management block allows you to manage the resources of the logistics network, modelling four processes, which are:

1. the navigation phase of the tanker ship (outward);

2. the navigation phase of the tanker ship (return);
3. the evolution phase of the ship;
4. the conditioning phase of the lines.

The first two processes reproduce the navigation of the ship, from the origin port to destination port. The other two processes reproduce the time spent in the evolution ship phase and the hydraulic conditioning of the ground pipelines. Both logic are implemented in Stella with the conveyor construct, sets, respectively with the evolution time (ie the manoeuvre time useful for the ship to complete the mooring and docking operations on the quay) and with the conditioning time (ie the time interval for the displacement of the water flows in the ground pipelines, by introducing the product of the same type as that discharged from the ship).

3.2.4 Order Management Block

The Order Management sets in:

1. product order generation transported by ship;
2. product order generation requested by tanker.

The order of ship is generated when the central tank level reachs the replenishment level. The costumer order (at the end of supply network), instead, is generated continuously in function of costumer needs, established by analysis of real data.

4 Simulation Resuts

The simulation was performed considering the real process which is carried out over 1 week, which is made up of 6 working days and where, in turn, every single day is 10 operating hours. In particular, six simulations were performed considering 1 day, 1 week, 2 weeks, 1 month, 2 months, 3 months and 6 months as activity times, to highlight both operations that require a longer period (for example the arrival at the pier and the consequent unloading of product from the ship tanker or the filling of the storage tank with subsequent refuelling of the sales tank) both to activities that instead require a shorter period (for example the management of orders and the subsequent loading of the tank cars or the daily management of the loading lanes). Below, the graphs of the results obtained following the simulations carried out on the model implemented. The following Figures 6 and 7 show the patterns, that reproduce the real situation, relating to the management of the quantity of product over time (6 months) both in the central tank and in sales tank.

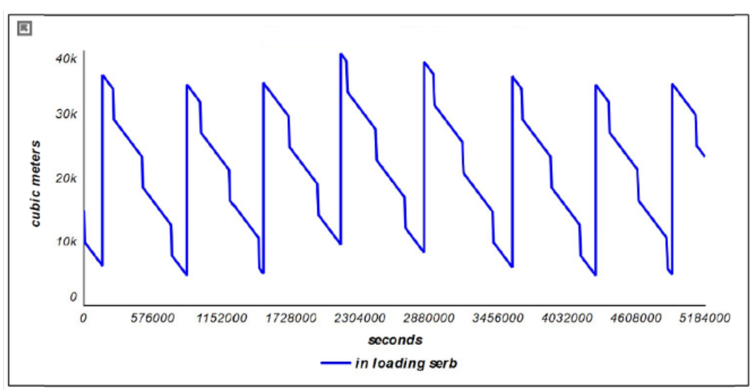

Figure 6: Management in the Central Tank .

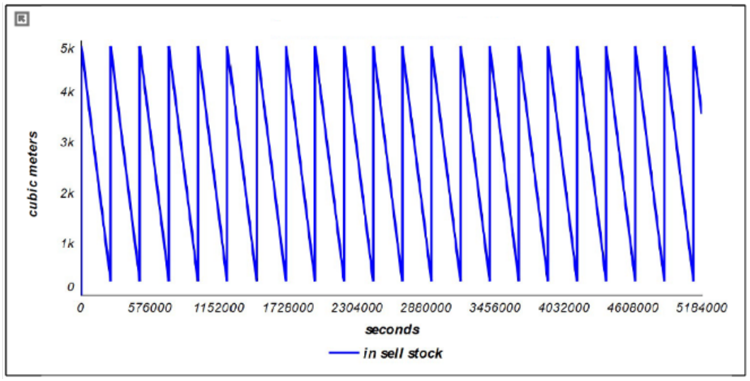

Figure 7: Management in the Sales Tank .

The Figure 8 shows, instead, the state over time (1 day) relating to the loading process of the tank cars in each of the loading lanes.

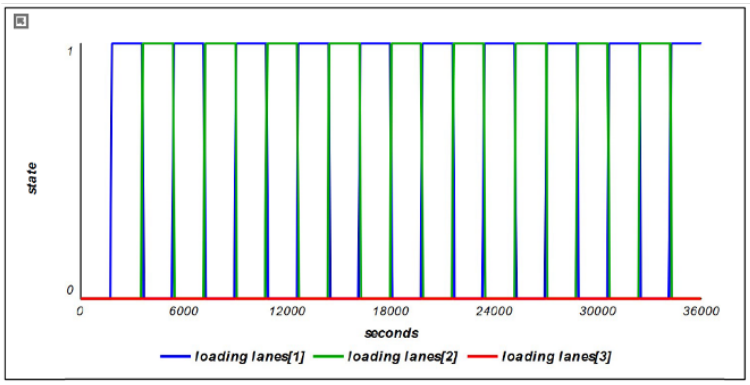

Figure 8: Loading Process in each lane.

5 Lane Maintenance block

About the possibility of using the simulation model as a decision support tool, a management policy for the loading lanes of the tankers was tested, about scheduled maintenance operations on the same. The simulation results showed that the loading lanes of the tankers are redundant: only 2 out of 3 are used; the third is discharged, for the entire operating time of the logistics process. In this regard, the operation of the one-lane service interruption was first tested. Evidence has shown that the system does not create queues with only two running lanes. If a failure in a second lane should occur, at the same time as scheduled maintenance on another lane, the system, with a single lane in operation, produces waiting for queues in the activities of loading and selling the fuel. In the long run, this situation spreads to the upstream systems, generating inefficiencies on the logistics system. The Lane Maintenance block allows you to manage the Maintenance relating to the Load Lanes of the logistics network, modelling the following process: the maintenance phase or the management of the repair of the loading lane. The process implemented, therefore, is able to manage the load lanes from their maintenance due both to possible failure and to the normal checks to be performed to keep all the components in use productive. If it should be necessary to stop one of the operating lanes either for the programmed maintenance or for the unexpected failure in the fuel loading system, the stopping of the one of the 3 lanes is managed for a deterministic time (Figure 9).

For the same period, the lane blocked is replaced by the free one (spare) to allow the normal loading of product into the tankers. This allows not to stop the production process and, therefore, to ensure that

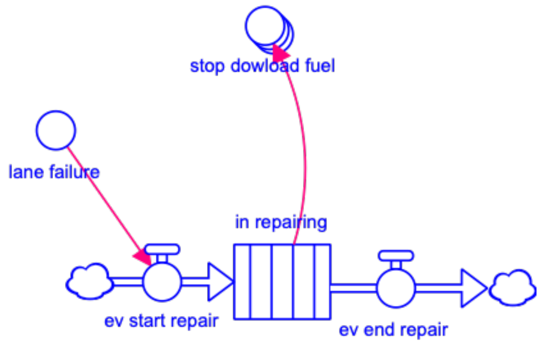

Figure 9: Maintenance sub model

the logistics flow has no interruptions or to achieve the goal of optimization, both in terms of efficiency and in terms of effectiveness, of the whole logistics network.

The Figure 10 shows the loading state over time (1 day) relating to the presence of a tanker car in lane 1 when maintenance is performed.

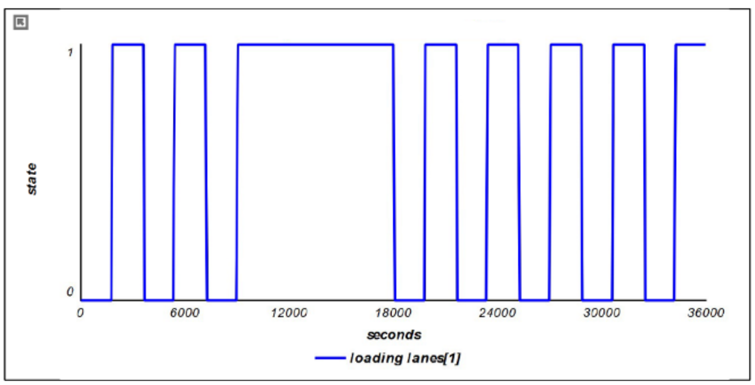

Figure 10: Loading Process during maintenance.

The Figure 11 shows the status over time (1 day) relating to the presence of a tanker car in lane 3 when maintenance is performed in lane 1.

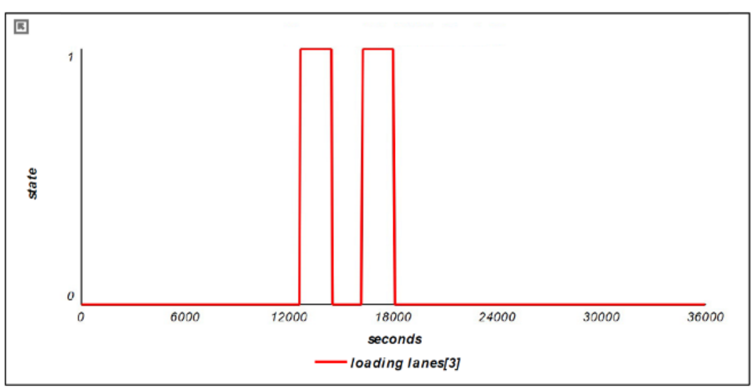

Figure 11: Loading Process in the lane 3 during maintenance.

These results allow us to verify how the process is optimized both from resource management and from warehouse management (incoming and outgoing) as there are no particular situations of possible lack of product and/or possible redundant of the same. From this, it is clear how this process is fully ”capable” and, therefore, as modelled in the logistic network, it is completely efficient. As final results of this phase of the study, we have implemented a dashboard that summarizes the results and that allows to perform checks on the output variables as well as to ”move” knobs that allow to building system scenarios evolution (Figure 12).

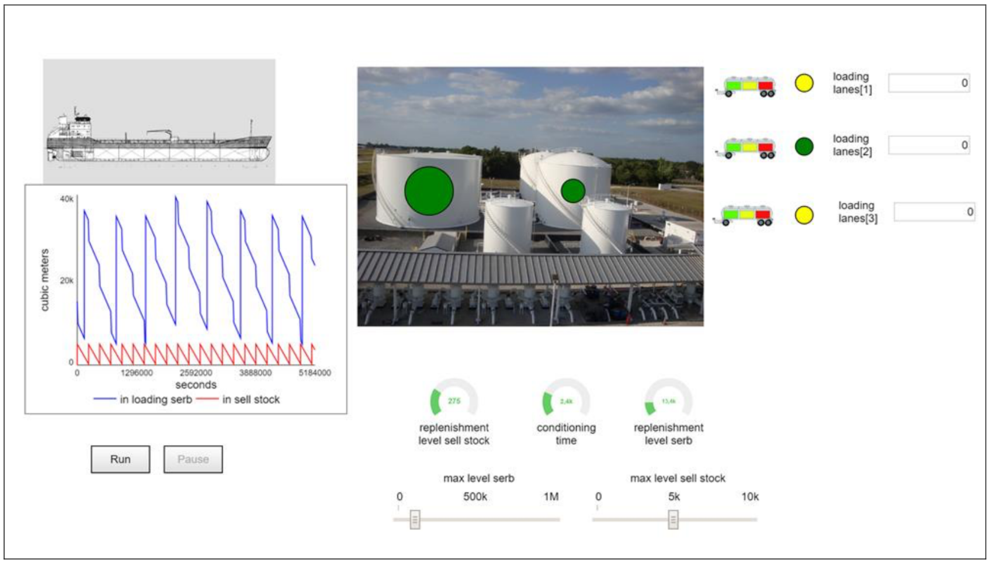

Figure 12: Dashboard of the logistic network.

6 Future developments

As illustrated in this document, among the many applications of System Dynamics, there is certainly that of analysis and Logistics management (both internal and external), a Supply Chain and Stock Management (or material management). This methodology, in fact, for each of these issues, is proposed as the basic method used for modelling (and consequently simulating) logistic environments, trying to estimate costs, performance, the efficiency of the various management logics, through the development of a series of models with which, subsequently, the effects of all possible modifications are tested. Therefore, it has been shown how it is possible to simulate different scenarios, study their changes in terms of efficiency, savings, warehouse level, delivery times and propose some changes to the management policies currently in use. Furthermore, System Dynamics' model can be a valid tool in the field of Operation Management not only as a support for strategic choices or as a method of analyzing logistical processes but also as a support for decisions at an operational level or for evaluating the performance of management logics of a warehouse including the production process and maintenance of a Supply Chain. Among the many strengths of this method, there is certainly to underline, in addition to the flexibility and versatility that this tool has, also the fact that the analysis can be carried out indifferently in terms of costs, time and performance. thus making this methodology a very effective tool to evaluate the systems, structures, procedures and processes present in the logistics sector. The project, which began with the present work but which will continue to develop in the future, is set on two different levels: the first level, already implemented in this paper, concerns the more conceptual approach based on development and in the creation of the main model that supports the Primary Logistics Asset Integrity; the second level, on the other hand, will extend not only to the management of the process relating to a single logistics node but to the entire Supply Chain Management. In particular, about the second area, three fundamental steps can be characterized and represented: the first step will be to extend the model created, through the approach to modelling the vector paradigm, to other types of product (therefore not only Diesel) which they can affect a single node; the second step will be to determine and evaluate, within the model, all the ”critical elements” identified (such as tools, equipment, components, etc ...) which, in a certain sense, are directly or indirectly linked to the issue relating to the ’Asset Integrity, thus introducing also the concept of ”maintenance”, which will prove useful for the continuous improvement of Asset Integrity Management; finally, the third step will be precisely to make the model itself complete and extendable to the entire Primary Logistics, thus applying the technical-methodological approach to the number of nodes located throughout the national territory. Finally, this work thus constitutes the first step towards the final objective, that is to optimize the entire Supply Chain Management and this through experimentation with a series of Asset Integrity Management Simulation (AIMs) and, therefore, through the development and implementation of the various phases of analysis, calibration and validation of the model which are entirely aimed at maintaining the integrity of the resources; this will be useful, not only for the protection of assets in terms of health, safety and the environment but also for maintaining the efficiency of the entire production process.

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