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Strategic Engineering for Marine Logistics for Chemical Plants

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Abstract

Industrial Plants related to Chemical Products such as Ethylene are crucial and requires to properly design dynamic Logistics solutions dealing with Technical Issues, Safety, Risks, Market Demand. This paper focuses mostly on properly define a solution to manage the Marine Logistics between chemical production facilities and the Industrial Plants using it as source material. The paper identifies the crucial aspects of this problem as well as the way to use Modeling and Simulation in this sector in combination with other innovative smart techniques within the framework of the Strategic Engineering.

Keywords: Industrial Plants, Chemical Tankers, Logistics, Discrete Event Simulation

1. Introduction

Strategic Engineering is a new discipline applied on several different fields by combining Modeling, Simulation (M&S), Data Analytics and Artificial Intelligence (AI) in closed loop with Big Data from the field to support decision making (Bruzzone et al., 2018). Strategic Engineering as new discipline has a great potential in being applied to Logistics and Industrial Plants, supporting design, planning, management, service and refurbishment (Bruzzone & Sinelshchikov 2020a). From this point of view it is important to outline that the planning and optimisation of the logistics networks is crucial especially when dealing with big quantities and high costs respect dangerous material.

Indeed, the Chemical Production is strategic at national level and represent a quite challenging aspect considering the volumes, values and risks connected and require to adopt innovative solutions for being competitive and sustainable in wide sense, considering economic, social, technical and environmental issues (Hübner, 2007). Due to these reasons, the current paper focuses on the analysis of a specific industrial problem related to Supply Chain Management of chemical product and related Plants, Tanks and related Logistics.

In this case the focus is on optimisation of the logistics networks for the specific case of Ethylene that include properly design and management of the industrial flows, storage infrastructures and consider the case of plants located in different locations supported by marine logistics through special ships: chemical tankers.

2. Chemical Plants and Logistics over the Sea

Indeed, maritime bulk logistics is one of the workhorses of chemical logistics due to its quantities and distances (Marcadon, 2004; Dal-Mas et al., 2011). In facts, most major chemical corporations have plants distributed all over the world and the flow of chemical materials often require marine logistics in order to be flexible and competitive (Ronen, 1993; Karimi 2009). In these cases, often the production flow from a production plant turns to be the intermediate product and input for another chemical facility devoted to produce other element, often located several thousand miles away. In most of the cases the chemical production is quite far from the location where is concentrated the demand of finished. Operational efficiency of maritime transportation can reduce final product costs significantly. While ground transportation routing and scheduling has received much attention in the literature, relatively few papers have addressed ship routing and scheduling (Laporate & Osman, 1995). Christiansen et al. (2007) presented a detailed review on ship routing and scheduling. Al-Khayyal and Hwang (2007) classified maritime ship routing and scheduling problems into cargo routing and inventory routing. Cargo service research involves routing and scheduling ships for a set of well-defined cargoes of known quantities, loading/unloading ports and time windows. Often the objective is to maximise profit or customer service.

All the orders shall be delivered on time since production processes cannot be stopped; regulatory constrains may cause delays that generate big additional costs. The time factor shall also be considered with attention, in order to keep the profits high. The discontinuous nature of this chemical logistics adds a level of complexity to the mission that requires strategic Optimization (Mclean et al., 2015). Hazard shall be correctly assessed considering problems related to: fire, reactivity and health, therefore nowadays even sustainability and greening the processes and supply chain are major aspects to consider to operate in a competitive market (Arslan & Er 2008; Jin, 2014; Rajeev et al., 2019). For instance, reactivity issues may lead to explosions, so it is compulsory to evaluate the possible reaction that may arise in case that two chemicals come in contact. For example, in order to minimise the danger during tank cleaning operations, specific procedures need to be followed creating challenges for multi product management (Crowl & Louvar, 2001; Jetlund & Karimi, 2004).

Malfunctions are part of production and, even if not extreme, generate variance on the production flows; so, logic models need to take into account both planned maintenance and failures in terms of MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair) of plants, port infrastructures and, even ships.

3. Supply Chain by Marine Logistics

For instance, in raw chemical the production of Ethylene, Propylene and many other petrolchemical products is carry out by chemical processes (e.g. thermal or catalytic cracking) within plants associated with refineries; therefore these products serve as raw material for many other products obtained by chemical synthesis such alcohol, chlorinated hydrocarbons, polymers, etc. The locations of the raw chemical plants and the chemical synthesis facilities requires often marine logistics and usually these sites are constructed in port areas and specific ships are used to transport them. Most of these hydrocarbons are flammable and require special attention in storage and transportation in terms of equipment, procedures, while specific regulations, certificates and policies are fundamental in their handling.

In these case the supply chain management need to cover multiple aspects and it is in charge of identifying and selecting the most convenient solutions for selecting, associating and managing the logistics flows. Usually, a specific level of cost and risk could be assigned to each potential logistics network that involve compatible products and consistent flows in terms of quality. The art of dealing with uncertainty and complex systems is really important and it is fundamental due to the nature of these production flows over marine logistics (McLean et al., 2015). There are many factors that need to be considered and should be included in models to investigate the impact of different plant engineering solutions and logistics network configuration (Bruzzone & Orsoni, 2003). Several stochastic factors have to be considered affecting sea transportations, production variance, failures and even changes in market demand and/or spot orders. All these elements interact generating a complex systems that is characterized by the possible presence of strange attractors dealing with chaos theory plus strong stochasticity (Bruzzone et al.,2002); these are classical characteristics of complex systems and could result into unpredictable behaviors that requires redesign of the supply chain to mitigate the problem and make back controllable the system (e.g. increase in storage tanks, different clustering of production flows among plants, updates in infrastructures and plants). The necessity to respect small ranges of production flows, in order to guarantee the efficiency of the chemical plants and, often, also the chemical process requires very reliable plans and could introduce huge costs in case of failures even for few days (Towels & Sinnott) while, as anticipated, risks respect safety aspects and environmental impacts introduce additional constraints on this context (Rajeev et al., 2019). Looking at this context at high level, we could consider this problem in similar way to a chess game, where many possible scenarios shall be compared, in order to win the competitors and be flexible on the market guarantee. Therefore, this game is played concurrently on different time scales. As example, it is possible to consider the management problems for an existing set of industrial plants related to chemical production over a marine supply chain (Bruzzone & Orsoni, 2003): in this case, several important decisions need to be taken on daily basis in terms of accepting and negotiating request for spot orders from the market that could be disruptive on the logistics, but could be quite profitable and require to identify most convenient response and replanning; at the same time, on an year base often with a retuning after 6 months, it is necessary to aggregate production flows and to define clusters of ports to be served, as well as the characteristics of the ships to be used in terms of type, size, number and contract to be used, by the way, in most of the case the fleet could include a minor number of ship owned by the company plus several different types of chartering (i.e. time charter, voyage charter, demise charter). Last, but not least, there is a strategic planning dealing with renewal and refurbishment of the industrial plants, storage facilities and port infrastructures (e.g. piping lines, pump groups, docking) to improve the overall performance and reduce risks and extra costs (e.g. demurrages, stockouts, stock overs, production block). In this sense, the combined use of Modeling and Simulation with Data Analytics and AI results fundamental to support decision making and require to define overall architectures for the specific case (Bruzzone et al. 2020b).

4. Decision Criteria and Support System

To finalize the most effective solution it is necessary to define ship missions that aggregate the production flows over a cluster of plants/ports and to identify the ships to be used over it. In this sense, the mission cost is definitively an important factor to be considered, unluckily the cost it is not trivial to compute; in facts, the mission time depends on the sea and on the uploading/downloading operations that are influenced back from the ship selections. Another aspect it is the possibility to select ship multiproduct that are able to transport different chemical products to increase flexibility, but this choice introduces even constraints and limitations that need to be tested over simulation (e.g. a tank certified for a product requires treatment to be usable for another one and often even a specific recertification, requiring extra costs and time). In addition, the different ship chartering contracts as well as the ship characteristics (e.g. capacity, fees and speed) influence heavily the cost structure and convenience of different solutions (Lyridis et al., 2012). Among different decision elements it should be also considered the chemical risk that often affects negatively the overall mission costs.

The DSS (Decision Support System) adopted in this paper, is an architecture devoted to guarantee effective decision making in this supply chain by transforming the "knowledge" of professional logistic experts into a Strategic Engineering process involving interoperable software modules (Bruzzone et al., 2018). The smart engine proposed could be trained by collecting information, 24 hours a day: tank levels in the different ports, production flows in the plants, weather conditions, ship position and ETA (estimated time of arrival), etc.

The DSS avails of a digital twin that allows to simulate and predict best response over the different alternative decisions (Bruzzone & Bocca, 2012): the strategic planner generates online the different possible scenarios to be simulated in fast time in order to selects the best one and to recombine the alternative solutions looking for a new high performing solution. At any time the decision maker in charge on planning is entitled to adopt changes as well as to fine tune the proposed strategy by changing optimization criteria of the DSS and rerunning the process.

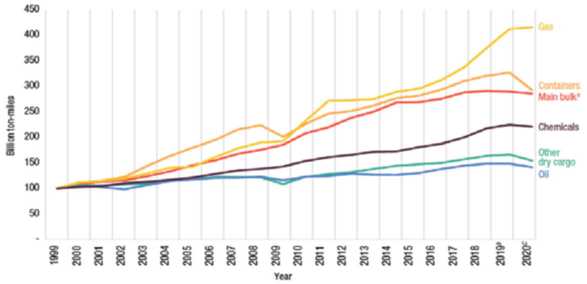
The use of simulation guarantees the big advantages, being able to consider and evaluate simultaneously the impact of different interconnected elements; this global approach deals with all the information recorded as a single “structured object". For example, the estimated arrival time is influenced by a large number of variables. As anticipated in this case, there are researches that adopted the theory of chaos to evaluate complex events and opportunities to simplify the management; in facts, a continuous measurement of the simulation results, compared with the real achievements allows to correctly fine tune the simulator and obtain an up-to-date estimate of its confidence band (Montgomery, 2017). In this case, the simulator is able to suggest the correct number and capacity for the ships to be used, guaranteeing to minimise costs, ships waiting time and the production losses due to blocks (i.e. stock out and stock over). Indeed, the ships have the challenging task to keep constant the factory tanks levels. Using in the loop the real data from the field through statistical analysis and correlations based on AI solutions, the simulator estimates, with a good approximation, how the ship cycle time, the frequency of ships arrival, the correct ship size are affected by uncertainty and variable elements. Also, the risks related to the mission, such as tank overstock and stockout, is evaluated to finalize decision even respect risks. As anticipated the costs are big and optimization could be necessary to have sustainable solution considering the high costs of chemical tanker chartering as well as the stoo costs for the industrial plants running out of raw material or unable to proceed due to the completion of their finished good tank. Transportations over ships and filling up of onshore tanks involve also risk for fires and explosions that require to respect time, procedures and clean up in case of substitution of the chemical product. So, in this scenario, the simulation of strategic logistics plays a fundamental role. The proposed DSS, like an aircraft autopilot, allows to identify, define and refine winning scenarios able to reduce operational and extra costs, increase resource use coefficient and profitability with low risk and safely.

In this article, concepts of strategic engineering is addressed and its application to the problem of marine logistics for chemical industry by engineering analysis of the problem, Chemical Bulk marine transport modelling and proposing the DSS architecture. The proposed case study related to ethylene transport is presented to highlight its complexity even in most simple case moving from simplified deterministic fleet dimension assessment up to the impact of stochastic elements.

Chemical plants have continuous production over time, with small seasonal variations in product quantities and other stochastic variations. For the continuity of production processes, theoretically, the best system for transporting the product is pipelines, therefore these solutions are often blocked by the costs and constraints in constructing these infrastructures due to the terrain and in case volumes does not justify this investments, it is necessary to use alternative solutions; in addition to long time-pay-back-period of these investments, obviously this solution is characterized by very low flexibility that involve hard limitation in reorganizing the flows and serving new customers

(Basak & Nebol, 2016). To cope with variations of production processes, plant failures, supply chain issues and latency in deliveries, the plants use big tanks to store the products that are a crucial element of the supply chain (de Swaan et al.,2004; Papageogious 2009).

The plants are characterized by continuous production that is supposed to stop just due to preventive maintenance and failure , therefore extra stops could occur due to logistics problems: full storage of output tanks (stock over) and lack of materials in input tanks (stockout) block the production with prohibitive costs and must be avoided considering their economic impacts (Bruzzone et al, 2011). This problem is connected not only to the direct costs, but even to technical problems such as damaging the reactors, long time for the start up, etc. So, it is evident that these kinds of processes require a reliable and regular flow of supplying and also an available storage for chemical reaction products; therefore, it's very critical to design appropriate inventory management systems to guarantee the process continuity (Longo et Mirabelli. 2009).



Source: Clarksons Research, 2020a, *Shipping Review and Outlook*, spring.

Figure 1. Development of international maritime trade by cargo type - REVIEW OF MARITIME TRANSPORT 2020

For Chemical Bulk transport, the choice of the transport mode depends mainly by some major aspects: quantity to be transported, distance to be covered, timing delivery respect tank capacity, operational constraints, safety regulations and directives. Obviously in chemical bulks the extensive use of special ships with tanks designed for transportation of specific products introduce complexity in terms of operation, constraints and additional stochastic elements even dealing with sailing and arriving in time into the ports. This mode of transport is characterized by flexibility due to its independence from nodes to serve and morphological conformation of the land and by cost-effectiveness due to the economy of scale of large capacity of ships. However, marine transport has a large number of technical (port infrastructures, site tanks) and commercial (contracts, taxes, etc.) constraints (Karimi, 2009).

Despite these open issues, the International maritime chemical trade in cargo has a quite positive continuous trend, expressed as ton-miles, as shown in Figure 1. This research focuses on creating a smart solution for Marine Logistics applied to Chemical Bulk and proposes a DSS for the clustering the plants and harbours to be served by a fleet of tankers; in addition the DSS should be able to define the port sequences to be visited and the configuration of the fleet including ship capacity, type, chartering solution, etc.. Availability of different types of ship chartering contracts in the bulk shipping industry provides charterers with a great flexibility in meeting their sea transportation requirements and allows shipowners to utilize their fleet in providing sea transportation services at most convenient rates, despite the high variance in ship fees; due to this reasons, even very large petrochemical companies are used to own a quite limited fleet and use extensively chartering to serve the marine logistics; as result it is necessary a continuous replanning of fleet configuration to get advantage of market evolution both in terms of ship costs and product demand. The chartering contracts vary in terms of agreement and type of service and are generally classified into different types: Voyage Charter (VC), Consecutive Voyage or Contracts of Affreightment (CoA), Trip-Charter (TC), Time- or Period- Charter (PC), and Bareboat Charter (BC) contracts. The main differences among these contracts are the operational modes, absolute value of the fees, duration of the contract, method of freight rate calculation, cost allocations and commercial and operational responsibilities (Alizadeh and Talley, 2011).

5. Model of Ethylene Logistics

This system topology consists of many ports and related industrial plants and tank farms. Each port has a production plant in its vicinity. In our analysis we decided to concentrate on supply chain of consistent chemical production flows (i.e. Ethylene); based on this model there are two groups of production plants: the first group consists of the facilities that generate the products (export plants alias producers) that are used as raw materials by the facilities of the second group (import plants alias users). Obviously for multiple materials and multi echelon case of supply chain management this approach could be extended easily due to the fact that the tankers and tanks in charge of handling the different products are not interchangeable, while inside the proposed case there are transversal constraints (inventory in tanks, ships, port infrastructures, plant capabilities). So, basically the ships are used to transport the products of the plants in the first group to the plants in the second group. The products transported are bulk chemicals that are stored in the onboard tanks (Figure 2).

The proposed approach is based on previous researches and it is summarized in the following (Bruzzone & Orsoni, 2003; Bruzzone & Bocca, 2012; Bruzzone & Sinelshchikov, 2020a):

- the production and consumption plants are in close proximity to harbours, usually inside port areas.
- the production plant loads the product QP+ in the same onshore storage system from which the ship loads the product (Q+); such storage solution is considered as a cumulative single virtual tank

- the ship unloads the product (Q-) into the same onshore storage tanks from which the customer plant takes it as raw material to produce (QC+), also in this case considered as an aggregated capacity tank.

Flow is the amount of product to be transferred by sea (Q+; Q-), following a prefixed **Sea-link**, in a certain time **Period**, from a producer plant to a consumer plant (Figure 3).

Figure 2. A schema of the main elements in the modelled system.

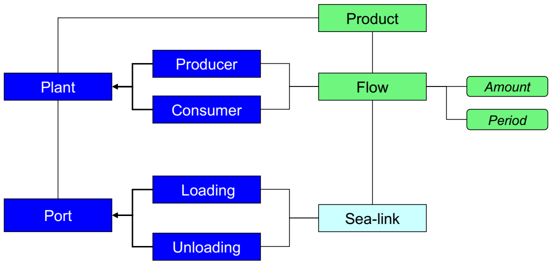


Figure 3. Main characteristics of the *Flow* object

The logistics is regulated based on Missions that represent the aggregation of a set of ships over a route among a network of plants/port respecting a specific sequence to optimize the logistics efficiency and effectiveness. Indeed, a Mission is a predefined set of Flows (of one or more products) to be realized in a prefixed time Period, comprising one or more Sea-links, using one or more Ships, with Costs and Times to be determined.

A **Mission** is divided into **Tactical Mission** and **Ship Mission** (Figure 4). A **Tactical Mission** consists of several **Ship Missions**, which together fulfil the requirements. A **Ship Mission** is the part of the **Tactical Mission** that is assigned to a particular Ship, which fulfils a subset of Flows following an assigned Route.

The mission, defined in Figure 5, refers to two **Tactical missions** that serves the two ports by different set of ships (Ship Set for Mission 1 and Ship Set for Mission 2), as shown in Figure 6.

The definition of a **Tactical Mission** requires the assessment of a port sequencing and fleet configuration, usually done by equivalent ships in terms of capacity to simplify the management in steady state condition.

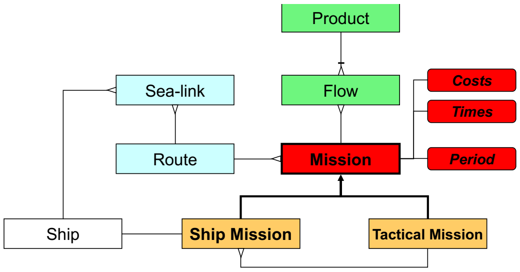


Figure 4. Main characteristics of the *Mission* object

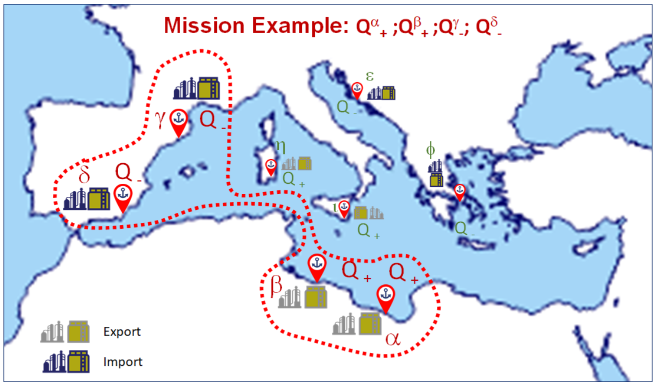
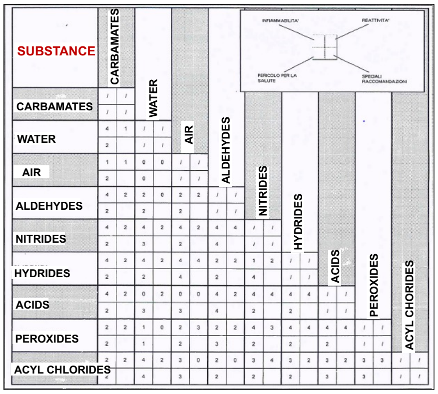


Figure 5. An example of *Tactical Mission*

Figure 6. The 2 *Ship Missions* that form the *Tactical Mission*

The goal of Port Sequencing consists of choosing the best sequence of harbours for minimizing the size of the ships avoiding peaks on a link a empty travelling on others; in this case parameters to consider are the **Ports** to be reached and the **Flows** to be fulfilled; based on these elements the model compute the a priori costs of **Tactical Missions** in deterministic conditions to be refined later on by using simulation and considering stochastic factors. The main characteristics of the mission object are shown in Figure 6. In the following, it has been assumed that the product transported by a ship on a mission is of only one type in order to provide a simplified case and put in evidence even under these conditions its complexity; in fact in this case there are not mutual coexistence constraints and extra time to clean and certify tanks; the product used for the example is Ethylene that represents a fundamental product for chemistry and requires specific operations on the handling. For instance, before the Ethylene cargo is loaded on the tanks, the following operations must be performed: inerting, gassing-up and cooling the tanks. Inerting means creating an inert atmosphere in tanks by the use of an inert gas like Nitrogen, what prevents flammable and explosive atmosphere with Oxygen (Wieczorek and Giernalczyk, 2019). The gassing-up operation consists of pushing out an inert gas from tanks by the use of cargo vapour. After an inert gas is totally removed, the introduction of cargo vapour proceeds so that tanks are cooled enough not to make cracks of tanks bottom surfaces while cargo liquid is loaded (Wieczorek and Giernalczyk, 2019).



SUBSTANCE	CARBAMATES	WATER	AIR	ALDEHYDES	NITRIDES	HYDRIDES	ACIDS	PEROXIDES	ACYL CHORIDES
CARBAMATES	/ / / /								
WATER	4 1 2	/ / / /							
AIR	1 1 2	0 0 0	/ / / /						
ALDEHYDES	4 2 2	2 0 2	2 2 2	/ / / /					
NITRIDES	4 2 2	4 2 3	4 2 2	4 4 4	/ / / /				
HYDRIDES	4 2 2	4 2 2	4 4 4	2 2 2	1 2 4	/ / / /			
ACIDS	4 2 2	0 2 3	0 0 3	4 2 4	4 4 2	4 4 2	/ / / /		
PEROXIDES	2 2 2	1 0 1	2 3 2	2 2 3	4 3 2	4 4 2	4 4 2	/ / / /	
ACYL CHLORIDES	2 2 2	4 2 4	3 0 3	2 0 2	3 4 2	3 2 2	3 2 3	3 3 3	/ / / /

Figure 7. Compatibility matrix for chemicals

Vice versa, in the case of simultaneous transport of several products, grouping of cargo products, the roles in grouping flows must take into account the compatibility matrix for chemicals (Figure 7)

The cost of a Mission is evaluated as a combination of:

- Time required by the mission cycle depending on:
  - the navigation time,
  - the impact factors typical of the ports, the sea and of the docks,
  - on the time required for the uploading and downloading operations,
  - the engaged capacity (Qmax) during this period
- Cost Coeff depends on the type of product to be transported, on its inherent risk, on the dimensions of the ship and on its costds and/or chartering contract(Spot and Time Charter, Voyage Charter)
- Qmax= Max(Qj-th sea-leg) with (j=1,....,s), where Qj-th sea-leg is the sum of the Flows pertaining to the j-th element of the path composing the mission

As it concerns the cost coefficient, it could be estimated based on the commercial classification of chemicals; indeed, products produced by the chemical industry are divided into three broad categories:

- Commodity chemicals: Chemicals produced in large quantities. They are produced by continuous plant and in general their cost is relatively low;
- Speciality chemicals: Are constituted by a mixture of different chemical substances. Are designed and produced in order to be applied to a specific application;
- Fine chemicals: They are produced in smaller quantities with respect to the previous ones; They are produced by batch (discontinuous) plant and in general their cost is high.

The Environmental risk for shipped chemicals could be assessed through the scoring method provided by the NFPA 704 System (Hakkinen et al., 2013)

6. DSS Architecture

The DSS proposed in this research is defined MARLON (MARitime LOgistic Network). This simulation model has been developed by the Simulation Team (Bruzzone et al., 2011) and has been designed in order to support decisions makers in the marine logistics. It embeds: big data analysis, simulation of processes, optimization of operative, tactical and strategic variables (Shang et al., 2017). A general view is given in Figure 8. The DSS considers stochastic variables (such as weather condition during the navigation, variability in production rates, failures, demand changes etc) that have influence on the whole supply chain; navigation time, load/unload operations time as well as ship fees and missions' costs that are in fact critical factors to identify optimal solutions over scenarios. Most traditional engineering activities have a well-defined goal and follow a tactical approach to problem solving. Today the engineer is faced with very complex problems and an interdisciplinary approach and exploitation of the availability of digitization is required, so there is a real opportunity to use the real time data about ETA, Tank Level, production planning, historical data to support decisions. Nowadays, digitization offers great opportunities for the acquisition, processing and control of data relating to industrial, logistics and supply chain processes. The data extracted in real time can be processed and stored and constitute an essential knowledge base to support high-level operations and decisions and to make appropriate changes to the resources involved and to the logic adopted. Obviously, data extraction requires the adoption of appropriate sensors and integration with Plant DCS (Distributed control Systems), Ship Automation Systems and company digital solutions (e.g. Tank Levels in ERP, Enterprise Resource Planning). All these systems as well as the consequent data analysis and simulation forecasts should be integrated into the decision process in order to create a systemic strategy in terms of object identification and pursuing them according to the canons of Strategic Engineering. In this way, the wide extensible data archive, through appropriate processing, provides useful information to the staff and a concrete basis, extracted a posteriori in the real environment of the process, for the development of intelligent algorithms to support decisions.

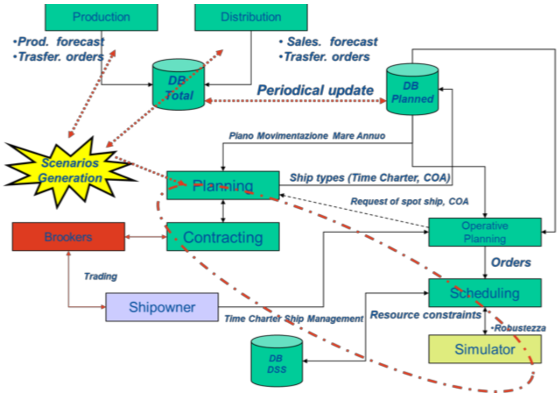


Figure 8. A general view of the DSS (Bruzzone et al., 2012)

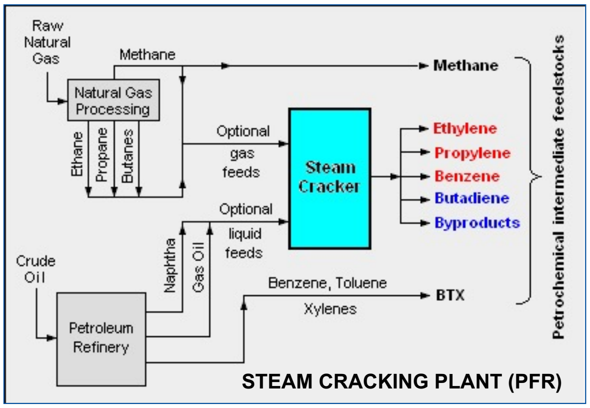


Figure 9. Ethylene production plant

In this case, DSS objectives are:

- Making the decision process independent of the role of a single expert person in the logistic sector
- Realizing a real time monitoring of the tank levels, of the ship positions by GPS and recalculating the relevant ETA (Estimated Time of Arrival) based also on weather forecasts and supply chain evolving needs.
- Supplying methods, tools and basic information to obtain:
    - Optimal fleet configuration
    - Better assessment, selection and trading of ship charter agreement
    - Better operative choices on ship Planning/Scheduling: clustering of the harbours to be served by a ship fleet, the definition of the port sequences to be visited
    - Suggestion on profitable strategic investments for improving the business

7. Ethylene Marine Logistics asCase Study

The DSS has been applied to a Ethylene marine transport problem. A schema of the production plant is shown in Figure 9. We focus on a simple logistic case that could be further generalized to more ports & flows.

Ethylene represents an important industrial organic chemical; it is a colourless gas with a sweet odour and taste. It is produced by heating either natural gas, especially its ethane and propane components, or petroleum to 800–900 °C (1,470–1,650 °F), giving a mixture of gases from which the ethylene is separated. It is highly flammable, dangerous fire and explosion risk. Because of its unsaturated nature, ethylene is very reactive and it has become one of the basic raw materials of the petrochemical industry.

The main attractions of ethylene to the chemical industry have been the ready availability of this feedstock, a reasonable cost and high purity.

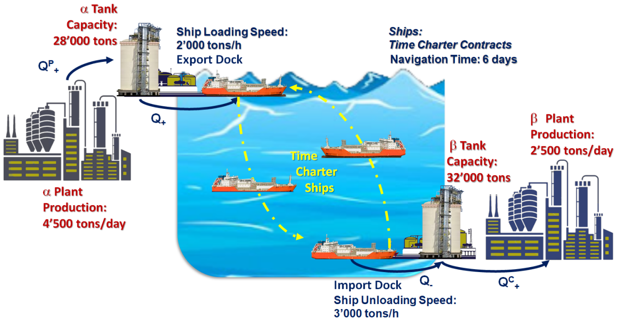


Figure 10. Supply Chain for the case study

More than two-thirds of its utilization is for the production of polymers, a fast expanding sector.

Ethylene Oxide / Ethylene Glycol – becomes polyester for textiles, as well as antifreeze for airplane engines and wings. Ethylene Dichloride – this, in turn, becomes a vinyl product used in PVC pipes, siding, medical devices, and clothing. Styrene – synthetic rubber found in tires, as well as foam insulation.

In recent years, the demand for Ethylene has grown on a huge scale. Therefore, it was necessary to transport it by sea. Ethylene carriers are special construction LPG shops, having a cascade cycle with Propylene as a refrigerant. As the optimum temperature for ethylene transport is minus 104°C, this load must be carried on semi-refrigerated vessels in tanks designed to withstand pressures up to 5.4 bar.

The supply chain addressed in this research is basic as proposed in the following and it includes two plants (Figure 10): α Plant is an ethylene production plant and β plant for the production of polymers (consumer plant). Both the plants have the same mean Production $\mu = 2'500$ tons/day and standard deviation $\sigma = 200$ tons/day. The product from α plant is stocked in the export tank, which capacity is Capacity is 28’000 tons, and from here it is loaded on a ship: the ship Loading speed is 2’000 tons/h. The ship unloads the product in the Dock Import with a ship unloading speed of 3’000 tons/h in a tank with capacity of 32’000 tons, from which the β plant takes the raw material for production.

For this simple case, the flow is unique as well as the mission and the port sequence. Autonomy of a given production plant is given by the rate between the tank capacity and the production flow. For the case study proposed based on the main data summarized in Figure 10 it result evident the necessity to balance production flow between α and β plants. In case of unbalanced flows, it is necessary to identify the quantity that could be managed on the supply chain corresponding to the minor flow (in this case 2’500 tons/h) and identify a solution for the remaining part (in this case 2000 tons/h produced by α plants) that could correspond to rerouting on another facility and/or sell on the market.

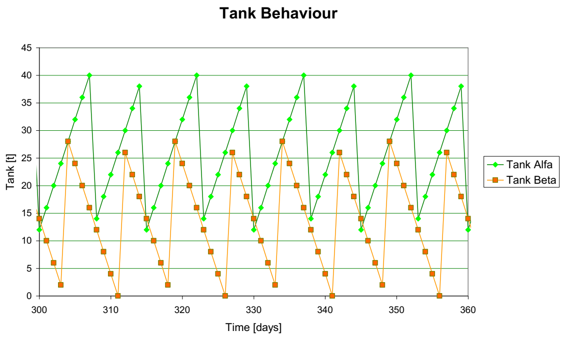


Figure 11. Tank levels over time - Deterministic model with 3 ships.

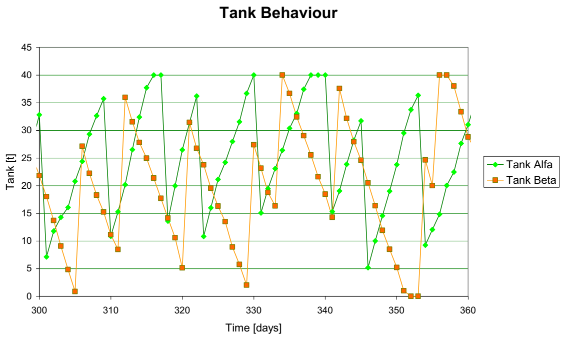


Figure 12. Tank levels– Case with 3 ships & stochastic components

In this case, the Most Critical Autonomy is the one of α plant and therefore, this is the one that determines the ship frequency. *Critical Autonomy*: $A_{critical}$ = 28’000 tons/2’500tons/day=11.2 days.

In the deterministic case, given the *Critical Autonomy*, an iterative process starts. In the first iteration to identify a preliminary basic solution under deterministic approach, we consider a ship with a capacity equal to the Export tank capacity. The *ShipCycletime* is then assessed: it is given by the sailing time + the time required to fill and empty the ship tank + the time for technical operations. Taking into account a Time Charter Contract (PC), 6 days as sailing time and 45 minutes for each of the 4 technical nautical operations (usual duration considered for regular ports), the *ShipCycletime* results in 13,10 days.

Given the *ShipCycletime*, it is possible to estimate the minimum fleet size that guarantees a time headway in the α plant not less than the *Critical Autonomy*. Little more than a ship is needed. The choice is therefore: 2 ships with 28’000 tons capabilities.

Second iteration: If 2 ships operate, the time headway in the α plant is half of the *ShipCycletime* assessed in the first iteration (where only one ship was assumed to operate). If the time headway is lower, the α plant produces less quantity of product in the time headway and therefore a ship with a smaller tank capacity is sufficient to support the supply chain.

As the capacity of the ship's tank changes, so does the time for loading and unloading it and therefore the *ShipCycletime* decreases. The time headway is now half of the new *ShipCycletime*; the α plant produces even less quantity of product in the new time headway and therefore a ship with an even lower tank capacity is sufficient. After several iterations, it turns out that 2 ships are needed each one with a capacity of 15’845 tons. These are required in order to guarantee the continuity of the production processes. Each 6,34 days, one ship loads, from the Export tank, 15’728 tons of product. Given the ship capacity, the *ShipCycletime* is 12,68 days.

A stochastic approach makes it possible to consider, in terms of risks, impact of real events that may be very relevant to the system being studied. Indeed, there possible delays in operations in ports, possible variations in shipping times due to sea conditions/weather phenomena, variations in production flows, due to seasonal or random effects, failures and demand changes, etc. This very simple system in terms of components and elements, under these additional elements is affected not only by stochasticity, but it develops even a chaotic behavior due to the high order of interactions among the different factors (Bruzzone, A. G. et al., 2004); due to these reasons the Chaos Theory could be useful to identify critical plant and supply chain configurations that result critical in these marine logistics problems. In such sense the stochastic scenarios have to be simulated and have been analyzed respect the major risks affecting extra costs: Over Stock in Export Tank; Stockout in Export Tank and Interference among Ships. An example of the impacts of these stochastic events on tank levels is shown in in the following.

Figure 11 refers to the deterministic model with 3 ships shows a regular trend of the system. Figure 12 refers to a model with 3 ships, with some stochastic components and undoubtedly, gives a more complex and realistic trend in the tank levels where it turns pretty hard to avoid stockout and stockover, even in this simple supply chain case.

In order to properly assess the cost of a Mission and considering the real complexity of the syste, the Cost Coeff should be assessed: it depends also on its inherent risks by using simulation

8. Conclusions

The proposed approach considers how to use Strategic Engineering concepts to define DSS able to be applied in the chemical product supply chain based on marine logistics. The analysis benefits from previous researches in this area and existing models and simulators. The paper highlights potential architecture devoted to face these challenges as well as the model structure to be used to face address this problem.

The reuse of previous models could lead to major benefits by adopting an interoperable approach in modeling and simulation to be incorporated into a new generation of DSS.

The proposed case, that refers to a simplified, but important, cases, is the basis for further researches dealing with the unpredictable elements related to specific configuration of the flows when the interconnected industrial plants are not balanced and on how to create solution to reduce risks and move back the whole system into a reliable and manageable framework.

The author is currently working on developing further models for being applied to real chemical logistics problems as well as to derive solutions for educational purposes.

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