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Innovative Virtual Lab for Improving Safety and Port Operations

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Abstract

Computer simulation makes it possible to reproduce real systems and processes in a synthetic environment. In this way virtual analysis turn to be possible and it complex scenarios are suitable to be simulated. In the proposed paper is presented a port system where to study the behavior respect operations and accidents and to consider interaction among multiple players. The simulation is applied to create a Virtual Lab able to evaluate and investigate the development of new procedures, contingency plans during crises. The development of models to be used in simulations is clearly a critical aspect, since the consistency of the simulation depend on the quality of the models and their interaction; in this case the authors used their experience in the field to guarantee a successful Verification and Validation. In this case study, models are used for simulations of phenomena related to port accidents and crises with particular attention to dispersion system of liquid contaminant on sea surface and dispersion of toxic gases into atmosphere. These models have been tested in the Alacres2 simulator in order to create as an effective tool to observe and study the evolution and impact of dangerous situations, as well as a decision-making support to define response plans crises.

Keywords: Simulation, Safety & Security, Extended Reality, Policy Definition, Container Terminal, Ports

1. Introduction

In recent years, marine accidents in Ports have been pretty big such as in Beirut (2020) and Tianjin (2015), therefore in Western Countries and based on the casualties reported EU Investigative Bodies, the total death toll in 2020 has been reduced by 18% compared to 2019. Obviously, this positive result should be considered in the context of the Coronavirus (covid-19) pandemic which has had a considerable impact on the intensity of the global shipment. However, considering data from a few years earlier, between 2011-2015, the situation is still serious in terms of casualties. The most evident data remains the percentage of accidents involving boats of various kinds which occurred in restricted waters and especially in port waters, around 42%. This does not take into account data on "parking" accidents, which would certainly increase the percentage. Another heavy figure is that on the percentage of accidents in coastal waters, 27%.

Data that make us understand how delicate the docking, disembarkation and station phase is in our ports and make us understand that research must also be addressed in this important area. In this the simulations that we can recreate on the computer can be very useful for research. With the ability to recreate virtual 3D environments for staging port realities and the aid of Artificial Intelligence to process the immense quantities of BigData, it is possible to provide very useful tools to the decision makers who face these adversities every day. Indeed the authors include port operation experts, simulation scientists and this mix strongly supported the Verification, Validation and Accreditation of these Models.

This article exposes mathematical and conceptual models that have been used to create the Virtual Lab of the Alacres2 Project as a solution to address port accidents (Bruzzone & Massei, 2021).

2. State of the art

In recent years, it resulted evident the importance of using simulation as effective support to study the many aspects of marine activities (Varela et al. 2007). These efforts have focused more and more, along time, on interoperability of the multiple models in this sector, such as wind, tide, buoyancy, etc. In facts, it is essential to allow these models not only to work, but also to be able to interact with each other. Like the roll of a boat, which is dictated by its weight, its shape, the wind and the current. The proposed simulation models to address port accidents embedded in ALACRES2 is focused on these important aspects, integrating them with new AI technologies, but above all we went to study concrete cases of real cases of maritime accidents in the port area. Customized scenarios of real ports were created to reproduce contamination accidents, such as the spill of chemical material following collision between two boats.

Virtual Simulation have been extensively used by the Simulation Team in order to address these scenarios including immersive solutions (Bruzzone & Longo, 2013; Longo et al. 2019, Bruzzone & Massei 2020).

Several researches have addressed the problem of modeling the diffusion of elements in the environment: several oil spill simulation models exist in the literature, which are used worldwide to reproduce the evolution of it in relation to ship accidents, petroleum productions or other sources (Keramea et al. 2021). Specifically, there are many efforts aimed at studying the related models (Gomez et al. 2021). A correct interpretation of the diffusion environment plays a key role within the modeling. As previously said, the models adopted here do not simply concern the description of a phenomenon, but the interaction of all the models with the actor and their actions, present within the scenario, potentially including both containment procedures as well as antagonists & threats. Obviously it is crucial to consider the sea and related condition as crucial elements of the models affecting the virtual world to be analyzed, including wind, currents, etc. (Serguei 1999).

The timely response to a crisis situation plays a fundamental role in limiting the damage that will come. An immediate damage assessment is essential to be able to make quick and effective decisions (Malik et al. 2022; Motorin et al. 2022).

Therefore, through the analysis of the available data and the models, it is possible to arrive at the construction of a decision support system that could offer a rapid vision of the crisis and suggest valid answers to counter it. (Bruzzone, Longo, 2009). Modeling & Simulation are crucial methodologies that greatly facilitate the process. Being able to repeat the process several times and being able to vary the parameters inside, the simulations allow to interpret reality fairly faithfully (Bruzzone & Giribone, 1998).

Due to the number of potentially available models, it is essential that the simulator adopt interoperability criteria and architecture. The main problem associated with the validation of a federation of simulation models is the necessity to conduct complete Verification and Validation on it, even if each model was previously validated independently (Bruzzone et al. 2002).

3. Models & Validation

The models described below have been developed to describe the evolution and evaluate the impact of spills of polluting materials into the environment; in particular, a spill of liquid material into the sea and the release of a gas into the air will be considered. These models are intended not only to assess the evolution of crisis events, but also to see how it is possible to intervene by adopting both preventive and mitigation solutions. These models have been integrated into the ALACRES2 Virtual Lab to analyze and develop scenarios in specific Port contexts. The accidents as well as reactions and containment procedures have been defined by port operation experts that created with simulation scientists and engineers the Champion Team devoted to conduct the Verification and Validation of these models. It is evident that within a port to simulate accidents and ways to prevent them is directly connected with the performance improvements in terms of competitiveness and operational efficiency, allowing to operating fast and safely in challenging conditions and with intense traffic. Due these reasons the proposed models could be used for multiple purposes including definition of new procedures as well as training and decision. Support.

3.1. Oil Spill Model

This model was developed to simulate the dispersion of liquid pollutants on the sea or river surface. The model takes into account the dispersion from a tank, which is damaged triggering the spill process. This scheme allows the model to be used for analyze the spill evolution.
For this reason, the dispersion should consider the continuous or spot release of fluid from a tank/ship, as well as the different aspects affecting the spill, deposit, evaporation, diffusion and transportation, all affected by the material and its conditions as well as by environmental and weather conditions.
The proposed model uses a Lagrangian approach, through the modeling of each individual subset of fluid, hereafter defined particle; in this way it is possible both to manage the physical behavior of the dispersion phase and to extend the use of the model through the development of models for the recovery of the dispersed material.

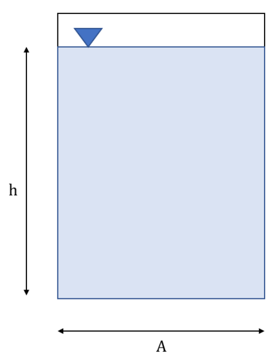

Figure 1A. Tank model initial conditions

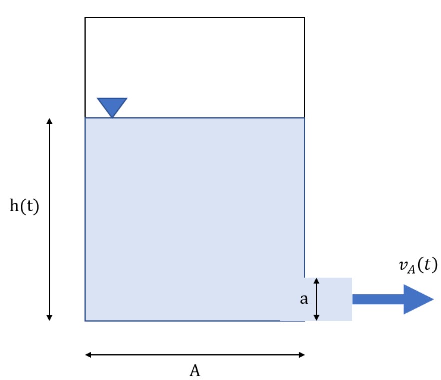

Figure 1B. Tank model with opening

The container model takes a tank of volume V characterized by its fundamental quantities, a section A and a height h associated with the height of the fluid, consistently with Figure 1A. The tank does not have an initial prestress and considers the fluid inside it as incompressible.
The physical model of the tank responds to Bernoulli's law in steady state:

$$p + \rho \frac{v^2}{2} + \rho\, g\, h = cost \qquad (1)$$

Where p is pressure, ρ is density of the considered fluid, g is the acceleration of gravity. At this point the parameters for the liquid discharge can be entered. An outlet hole with section a is therefore assumed, which causes the dispersion of the liquid contained outside the system, as shown in Figure 1B. The Bernoulli formula is then applied to define the dynamics of the fluid at the outlet between the internal section of the tank (section indicated with subscript 0) and the section near the fluid outlet (section indicated with subscript A). Since the fluid escapes from the tank, the fluid level $h(t)$ is time dependent and the Equ.(1) becomes for the points considered (unless pressure drops):

$$\rho\, g\, h(t) = p_A + \rho \frac{v_A(t)^2}{2} \qquad (2)$$

Where $v_A(t)$ is speed of output fluid according to Torricelli formula:

$$v_A(t) = \sqrt{2\, g\, h(t)} \qquad (3)$$

At this point it is possible to apply the principle of conservation of mass, in particular the incompressibility of the fluid allows to express the change in the volume of the tank at instant t as:

$$\frac{d\,V(t)}{d\,t} = v_A(t)\, a \qquad (4)$$

Where $V(t)$ is the volume of the tank and a is section of outgoing fluid. According to geometry of the tank, is now possible to update state variables of the tank.
These equations allow to describe the outflow of the fluid near the outlet hole; however, in real cases the reservoir can be placed at different altitudes with respect to the reference level considered (the level of free surface of sea). Think for example of a leakage from a tank on a ship. If the reservoir were placed above sea level, the fluid would follow a trajectory consistent with the earth's gravitational field and with an initial speed reported in the Equation (3) until it reaches the sea surface. Vice versa, a dispersion below sea level would lead to a phenomenon of buoyancy up to the reference level. Once it reaches the sea surface, the fluid forms a surface spot, assuming the contaminant is less dense than water. Dispersion and transport phenomena are reproduced by simulation models.
The surface patina has been modeled as particle system

corresponding to a subset of the spill composed of many individual particles, which influence each other.

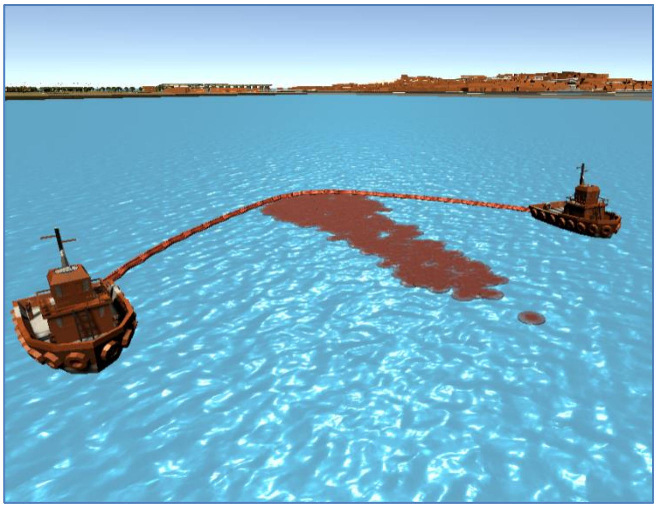

Figure 3. Containment Boom

Each particle is associated with a quantity of mass for the pollutant and an interaction radius that defines its interaction with other particles or barriers and other models and actors used in the simulation. This also makes it possible to define the specific position of each particle according to its center of gravity through a reference system; it is possible to introduce a georeferenced system that allows the model to be used in a three-dimensional environment that reproduces a real scenario. Each particle moves in space according to the equations of dynamics. Each particle is subject to the gravitational field, but at the same time it is kept on the surface according to the Archimedes thrust of the fluid in which they are immersed. For the transport of the material, the components of wind speed, currents and sea forces were considered. These last parameters can be changed according to the scenario to be implemented and allow some flexibility on the use of the model. In general, the dispersion phenomena of a contaminant depend on various factors and are dependent on the characteristics of the chemical components and on environmental factors, as well as on the residence time of the patina on the marine surface. The evaporation of volatile components, for example, is a phenomenon that can take very short times and then disappear almost completely. Conversely, other sedimentation-related dynamics can take much longer. To assess the environmental impact of the pollutant in the sea, it was considered to introduce a decay coefficient for each particle present on the surface, representing the amount of material dispersed in the water. This parameter influences the mass of the stain and its density, over time; the amount of material decayed on the seabed can also be georeferenced to draw conclusions at the end of the simulation on the environmental impact and efficiency of mitigation plans that can be compared with each other. The recovery of the material on the surface can be carried out in a timely manner thanks to the particle system adopted; in particular, as shown in Figure(3) a containment boom was developed to be able to confine the polluting material. A containment boom is a device that can be used to stem the spread of material on the surface.

These are mobile floating devices, which form a containment barrier by exploiting the mechanical action.

The deployment of the barrier takes place at sea thanks to the cooperation between two ships, which first install it, then drag it to the desired position. Thanks to the mobility of the device, it is possible to concentrate the pollutant in a smaller surface, where it can be definitively removed by skimmers, aspirators and other methods.

The model created can be used for maritime scenarios near the coast.

The confinement and recovery process can be summarized in 3 fundamental parts:

1. Initial Reaching and Boom Deployment
2. Positioning and confinement
3. Collection

During the initial phase of deployment, the two ships reach the chosen point to deploy the barrier, which generally takes place in uncontaminated waters. After the installation phase, the barrier can be dragged near the pollutant.

The collection phase is dependent on phase 2, since the arrangement of the boom can contribute to the grouping of the material to be recovered in a smaller surface area. At this point, skimmers can be used, which remove the polluting particles in their proximity.

The model is implemented according to the logic of intelligent agents, making the remediation process autonomous. The integration of this model in broader scenarios, especially with the introduction of random elements and particular scenarios, requires the use of algorithms for navigation and search for optimal routes in line with the navigation conventions.

One solution is to create a mapping system with multiple overlapping graphs, each characterized by different traversal costs.

The different graph layers can still be connected, through the nodes placed in the same position. At this point, after mapping the areas that cannot be traveled by agents, it is possible to use algorithms, such as A^*, to find the most convenient and realistic route.

3.2. Gas Dispersion Model

The model was developed to represent the release of polluting and toxic material in the form of gas.

The model used adopt a discrete approach using box grid model used for driving the simulation.

The space where you want to simulate the release of pollutant is divided into a three-dimensional spatial matrix, the smallest unit of which is a generic cube that it occupies positioned according to the coordinates within the matrix. Each cube contains virtually a certain amount of air and pollutant; therefore, within each cube the specific quantities are reported to define the physical states of the gases inside. Cubes, seen as open systems capable of relating to each other and exchanging quantities of gas, define the behavior of a moving mass of gas.

3.2.1. Conceptual Model

The space that is used is a three-dimensional space with metric units on the axes. A matrix M is superimposed on this space, of dimensions $mxmxm$, as a subdivision in volume of this space. To generate this matrix it is necessary to define a step in meters with which to divide the main dimensions. A $c_{i,j,k}$ cube positioned in the simulation space according to the chosen quantities is then associated to each cell of the matrix M. The linear dimension, as well as its relative volume, of the cube is the effect of the chosen step. For the purpose of the instrument for which it was developed, the M matrix virtually borders on 3 entities: the sea, ground and open sky. These elements are necessary to define behavior with natural obstacles / asymptotic behaviors. Sea is important for analyzing material that falls on surface, as well as ground, while open sky represents area on the border of the system where concentration becomes minimal. Each generic cube $c_{i,j,k}$ therefore corresponds in space to a volume occupied by gas, whose faces delimit the interaction with the related neighboring cube. In this way it is possible to build a network with which to model the mass exchanges and the movement of gaseous substances from one cube to another. At this point the specific quantities are associated to define the gas states during the simulation. These quantities for the contained air are temperature, pressure, contained mass, molar mass, density and are associated uniformly over the entire volume of the cube. Since each cube occupies a different region within the three-dimensional space, each size must be initialized with the correct quantities. As the altitude increases, the air tends to thin out, so a volume of air positioned at high altitude will differ with a volume positioned above sea level. Let h be the height of a cube with respect to the sea level, for the definition of the pressure the formula was used: (barometric formula)

$$P = P_{sea\ level} \left(1 - \frac{g\ h}{c_p\ T_{sea\ level}}\right)^{\frac{c_p\ M}{R_0}} \qquad (5)$$

Where: P is the effective pressure for the cube, $P_{sea\ level}$ is the pressure at sea level, g the acceleration due to gravity, c_p the constant pressure specific heat, $T_{sea\ level}$ the temperature above sea level, M is the molar mass of air and R_0 is the universal gas constant.

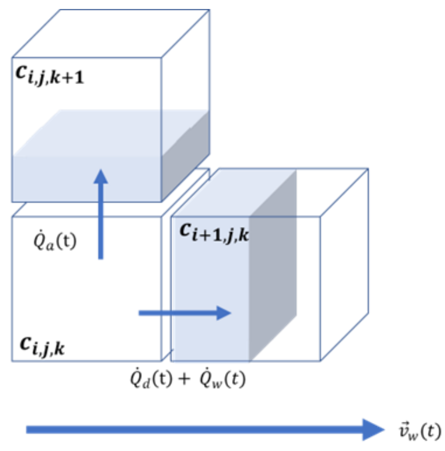

Figure 4. Diffusion Conceptual Model

Within each cube of volume V, the quantities are linked by the ideal gas equation:

$$P\ V = n\ R_0\ T \qquad (6)$$

where: P is the pressure inside the volume V, n is the amount of gas, T is temperature. This formula is reiterated for each time instant of the simulation.

3.2.2. Diffusion

The introduction of the polluting gas takes place in a chosen point of the matrix M, which corresponds to a point in space. Corresponds to a localized loss of a tank, with an injection into the system of a mass flow over time. The dispersion of the polluting gas integrates with the matrix system described above; however, the physical quantities necessary to describe the behavior and states of the new mixture originating from the air and the diffusion of the gas must be added. In particular, the molar mass, the relative temperature, the density of the new gas must be added to the variables of each cube of the matrix M.
The interaction of gas with the environment and its movement can take place thanks to the network of cubes defined previously and in accordance with the physical laws that govern these events.
Different factors are taken into account to describe the displacement of the gas:

Diffusion. Diffusion was modeled using Fick formula. Fick's formula is used to define the mass displacement based on the concentration gradient. In particular:

$$\dot{Q}_d(t) = -D\ \frac{dC(t)}{dx} \qquad (7)$$

Where: $\dot{Q}_d$ is diffusion flux, C is concentration and x is distance. D is the diffusion coefficient of the considered gas. This formula was used to define the gas shifts caused by the concentration gradient. In particular, for each cube of the matrix M it is necessary to consider the concentration of the gas with respect to the neighboring cubes (as shown in Figure 4), then move a percentage of mass towards the cubes with a lower concentration consistently with Equ.(7).

Buoyancy. In general, the buoyancy force depends on the difference between the density between two fluids. In the case in question, the pollutant is immersed in the air; the difference between the density of the air and that of the gas determine a thrust of the latter upwards, in the case of lower density, or downwards, in the opposite case. To determine the density of the polluting gas within a single cube, it is necessary to consider the mass it contains and the actual volume occupied by the mass. This volume can be found through the equation of ideal gases, since the values for that gas are known. In Figure 4 the mass flow is represented by $\dot{Q}_a(t)$, in the direction of the upper cube.

The Weather Elements such as wind an current that are defined according to the vector components of modulus and direction. The wind is responsible for moving the gas according to the direction; the displaced mass depends on the wind speed. The mass moving from a control volume of section A results:

$$\dot{Q}_w(t) = \vec{v}_w(t)\, A\, \rho_f \qquad (8)$$

Where: $\dot{Q}_w$ is the mass flux, $\vec{v}_w$ is the surface normal velocity component A of the control volume, ρ_f is the density. Similarly to the previous cases, the displacement of the mass can take place between the network of consecutive cubes.

4. Conclusions

Although the large amount of data to be processed, the proposed models represent an effective multi-scale 3D simulator, able of combining the multiple aspects of maritime and port nature, with the proposed contamination scenarios. The models presented are interoperating and represent the solid base of Alacres2 Virtual Able that is capable of conduct proper support to definition of new procedures and to assess impact of a crisis, for instance estimating the quantities of spilled material, the dispersion of multiple chemical agents and, subsequently, estimating the impact on critical port areas on people and infrastructures as well as the effectiveness of preventive and/or containment actions. This allows to identify most promising Courses of Action to counter each threat. Furthermore, in the future it will be possible to easily implement new scenarios thanks to the strong interoperability that characterized the modeling approach right from the start. The success in this case was strongly dependent on the synergy between operational people and simulation scientists and engineers; indeed, these simulations considered have a big impact on Safety and Efficiency in Harbors, while Alacres2 represents a new paradigm to support Ports and enhance their competitiveness in safe way.

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References

Asher Ahmed Malik, Mohammad Shakir Nasif, Usama Muhammad Niazi, Rafat Al-Waked, Numerical modelling of wind-influenced above sea gas dispersion and explosion risk analysis due to subsea gas release on multileveled offshore platform, Applied Ocean Research, Volume 124, 2022, 103208.

Bruzzone, A. G., & Massei, M. (2021). Strategic Engineering to Develop Strategies during a Crucial Period. In Digital Transformation in a Post-COVID World (pp. 95-128). CRC Press.

Bruzzone, A. G., & Longo, F. (2013). 3D simulation as training tool in container terminals: The TRAINPORTS simulator. Journal of Manufacturing Systems, 32(1), 85-98.

Bruzzone AG, Longo F. (2010) An Advanced System for Supporting the Decision Process within Large-scale Retail Stores. Simulation. 86(12):742-762. doi:10.1177/0037549709348801

Bruzzone A.G., R. Mosca, A. Orsoni et al. (2002), "Simulation-based VV&A methodology for HLA federations: an example from the Aerospace industry," Proceedings 35th Annual Simulation Symposium, pp. 80-85

Bruzzone A.G. and P. Giribone, (1998) "Decision-support systems and simulation for logistics: Moving forward for a distributed, real-time, interactive simulation environment", Proceedings 31st Annual Simulation Symposium, pp.17-24, doi:10.1109/SIMSYM.1998.668417.

Dmitrii Motorin, Hamid Roozbahani, Heikki Handroos, Development of a novel method for estimating and planning automatic skimmer operation in response to offshore oil spills, Journal of Environmental Management, Vol. 318, 2022, 115451, ISSN 03014797

Félix Gomez, Bruno Ribstein, Laurent Makké, Patrick Armand, Jacques Moussafir, Maxime Nibart, Simulation of a dense gas chlorine release with a Lagrangian particle dispersion model(LPDM), Atmospheric Environment, Vol/244,2021, 117791

Keramea, Panagiota, Katerina Spanoudaki, George Zorites, Georgios Gikas and Georgios Sylaios. 2021. "Oil Spill Modeling: A Critical Review on Current Trends, Perspectives and Challenges" Journal of Marine Science and Engineering 9, no. 2: 181.

Lonin, Serguei. (1999). Lagrangian Model for Oil Spill Diffusion at Sea. Spill Science & Technology

Bulletin. 5. 331-336. 10.1016/S1353-2561 (99)00078-X.

Longo., F., Nicoletti, L., Padovano, A. (2019). Modeling workers' behavior: A human factors taxonomy and a fuzzy analysis in the case of industrial accidents. International Journal of Industrial Ergonomics. Vol. 69, Pages 29 - 47