ENHANCING QUALITY OF SUPPLY CHAIN NODES SIMULATION STUDIES BY FAILURE AVOIDANCE

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ABSTRACT

An example for simulation studies of a supply chain node is developed. Highlights of failure avoidance (FA) – as a paradigm to enhance simulation studies– is given. Some cases of the application of FA to enhance supply chain node simulation studies are enumerated. It is worth exploring the potential of FA as explained in detail by Ören and Yilmaz (2009) to extend ways to avoid failures in simulation studies and to enhance their usefulness.

INTRODUCTION

According to Simchi-Levi et al. (2007), a Supply Chain is a network of different entities or nodes (i.e. industrial plants, contractors, distribution centers, warehouses, retailers, marine ports, etc.) that provide materials, transform them in intermediate or finished products and deliver them to customers to satisfy market requests (including information and finance flows). The business globalization has transformed the modern companies from independent entities to extended enterprises that strongly cooperate with all supply chain actors/nodes. Each supply chain manager aims to reach the key objective of an efficient supply chain: 'the right quantity at the right time and in the right place'.

To this end, each supply chain node carries out various processes and activities for guarantying goods and services to the final customers. The competitiveness of each supply chain actor depends by its capability to activate and manage change processes, in correspondence of optimistic and pessimistic scenarios as well as to quickly capitalize the chances given by market. Such capability is a critical issue for improving the performance of the 'extended enterprise' and it must take into account the complex interactions among the various nodes of the supply chain. The evaluation of correct trades-off between conflicting factors, i.e. inventory reduction (control policies) and fill rates, customers' satisfaction (service levels) and transportation cost (lead times), sales loss and inventory costs, is the complex task of an efficient supply chain manager (De Sensi et al., 2008).

The behaviour of real-world supply chains is usually affected by a wide range of factors. The ways in which such factors interact and the stochastic nature of their evolution over the time increase their complexity up to critical levels, where the use of ad-hoc methodologies, techniques, applications and tools is the only way to tackle problems and succeed in identifying proper and optimal solutions. Modelling & Simulation (M&S) has been widely recognised as one of the best and most suitable methodologies for investigation and problem-solving in real-world supply chains in order to choose correctly, understand why, explore possibilities, diagnose problems, find optimal solutions, train personnel and managers, and transfer R&D results to real systems (Banks, 1998). Therefore it is worth exploring new paradigms to enhance simulation studies. In the first half the article proposes, as example, a detailed simulation study for Genoa-Voltri container terminal (*Voltri Terminal Europa*). The second part of the article is devoted to Failure Avoidance (FA). Along with Verification & Validation (V&V) and Quality Assurance (QA), Failure Avoidance provides a third layer of possibilities to enhance simulation studies where the capabilities of the first two layers are exhausted.

MARINE TERMINALS AS CRITICAL SUPPLY CHAIN NODES

Marine terminals and, above all, container terminals are critical nodes of the global supply chain. Genoa-Voltri container terminal (*Voltri Terminal Europa*) is one of the most important container terminals of the Mediterranean area (see figure 1). The port capacity is about 1.0 million of equivalent containers (TEU) per year. The total berth length is 1,400 meters, the deep-water berth is about 15 meters and the yard covers more than 900,000 square ~~s~~ meters. The technical equipment in the docking area includes 10 portainers post-panamax for ships loading and unloading operations (from 40 to 50 tonnages). Connections between docking area and yard are performed by using 22 forklifts (with variable tonnages) and 60 yard tractors. Yard area equipment includes 23 Rubber Tired Gantry (RTG) for container movements (from 35 to 45 tonnages). In addition, located opposite to the berth, the container terminal is equipped with the rail service: 8 different tracks (700 meters in length) for loading/unloading operations) and 4 lead tracks. In the rail area, loading and unloading operations are performed by using 3 Rail Mounted Gantry (RMG) up to 45 tonnages. The Genoa-Voltri container terminal scenario is subdivided in 4 different parts:

- Berth Operations;
- Yard Operations
- Rail Service and Trucks Operations;
- Security Operations and Containers Inspection.

Figure 1: A view of Voltri Terminal Europe

An accurate description of the container terminal main operations (and related simulation models) is reported in the sequel. Note that one of the most important steps of a simulation study is data collections. Some of the data used in the simulation model are gathered from the website of the Voltri Terminal Europe; other data are based on subject estimation based on authors' experience (Longo and Bruzzone, 2005; Longo et al. 2005; Bruzzone et al. 2005; Curcio et al. 2007;; Longo 2010). Input data analysis follows the classic approach based on distribution fitting (Montgomery, 2003; Nist/Sematech, 2007).

Berth Operations

The ships entering the port are about 280 meters in length with capacity between 2000 and 4000 TEUs. The exact number of containers transported by each ship is inferred from uniform distribution with minimum value 2000 and maximum value 4000. Docking and undocking operations are performed by using tugboats. The amount of time for docking and sailing operations is inferred from a triangular distribution with average value 2 hours. The portainers mean productivity is 30 TEUs per hour, the mean operating time is 2 min/TEU and the standard deviation, expressed as percentage of the mean operating time, is 12-20%. After ship docking operations, unloading/loading operations begins: in both the cases containers wait in small buffers located in correspondence of each portainer.

The simulation model is developed by using Anylogic, by XjTech as seen in Figure 2. The first part of the simulation model flow chart recreates the berth operations. The arrivals process of the vessels is managed by source objects. Each *vessel* entity has specific attributes as, for instance, the number of containers to unload, the logistic company, the type of materials inside the containers. Once the *vessel* entity has been created, it is moved to the object *traffic Manager* Object that decides whether the vessel can enter the port or not (it must wait outside because of vessels traffic conditions). Each vessel entity moves then into the *Docking Operations* Object to check berth availability and select berth position. A tugboat resource (that support docking operations) is seized by the vessel entity; after seizing a *tugboat* resource and completing docking oeprations the *vessel* entity moves into the *Berth Operation* to start loading/unloading operations. Note that both the *Docking Operation* Object and the *Berth Operation* Object have multiple in/out ports used to allows the allow the flow-in and flow-out of vessels and containers in the berth area.

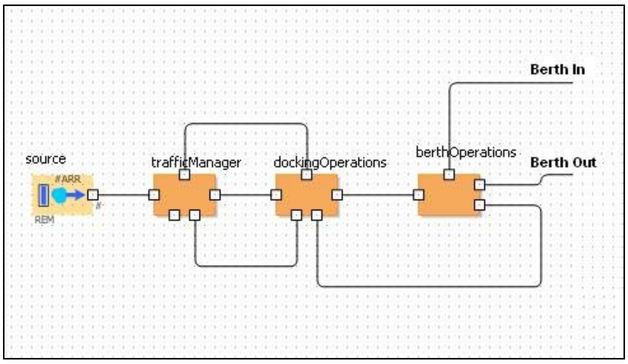


Figure 2: First part of the flow chart: vessel docking operations and berth operations

Yard Operations

Let us consider only the containers unloaded from a vessel after docking operations; in other word let us consider the modelling aspects related to the containers flow-in (the modelling aspects of containers flow-out are very similar).

At this stage, the containers have been unloaded from the vessel and wait to be moved to some destinations in the yard. Connections between buffers of portainers and yard are performed using tractors. Tractors mean productivity is 4 min/TEU and the standard deviation, expressed as percentage of the tractor mean productivity, is 35%-45%.

Tractors leave the containers in the yard; containers handling within the yard is performed by using RTGs and forklifts. RTGs and forklifts mean productivities are quite similar to tractors productivity (RTGs are characterized by smaller standard deviations, about 20%-30%). The figure 3 shows the remaining part of the simulation model.

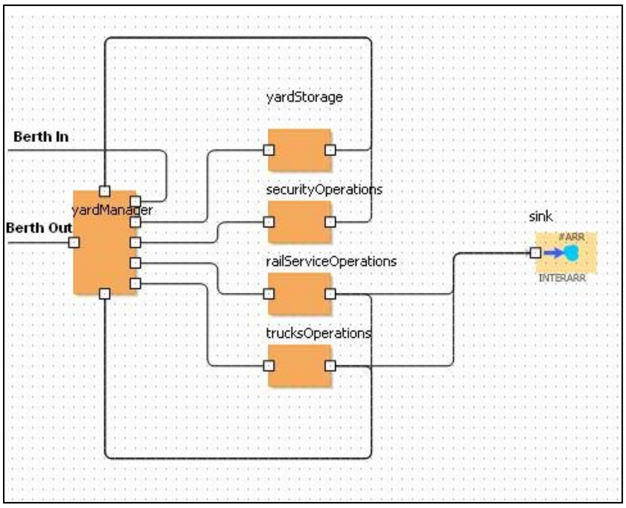


Figure 3: Second part of the flow chart: yard operations, security operations, rail service and trucks operations

Containers entities enter the *Yard Manager* object which task is to recreate yard management operations according to logic and rules used in real container terminals. Containers entities can be stored in the yard or follow another path toward *Security Operations* (discussed in the next section), *Rail Service Operations* or *Trucks Oeprations* (in the last two cases the containers leave the port respectively by train or truck). In each case the *container* entity waits for a tractors to be moved to its final destination. If the *container* entity is moved into the *Yard Storage* Object or into the *Security Operation* Object then it does not leave the port. When the *container* leaves the *Yard Storage* Object there are three possible alternatives:

- the container is moved into the *Trucks Operations* Object then a truck picks up the container and leaves the port by road transportation.
- the container is moved into the *Rail Service Operations* Object then a tractor picks up the container and moves it in the rail area (to be loaded on a train).
- The container is moved into the *Security Operations* Object then a truck picks up the container and moves it into the security area for inspection operations.

Please note that similar alternatives are available when the *container* leaves the *Security Operations* Object (in this case the *container* can move into the yard, rail service or trucks). Furthermore as previously stated, the modeling aspects related to container flow-out are pretty similar to those already described in this section, therefore they are not reported in the article.

Security Operations and Container Inspection

A *container* is moved into the *Security Operations* Object according to the value of its risk index defined as entity attribute and randomly generated before the unloading operations. Security in the container terminal is mostly related to the containers inspection operations that include different activities. First, by using a scanning equipment a digital image of the container is created (i.e., by using gamma ray). The image analysis aims at discovering container anomalies. In addition, security officers carry out container physical and visual checks and radiation inspections. In case of detection of anomalies, the officers perform additional inspection operations. If no anomalies are detected the entity is sent back to its final destination

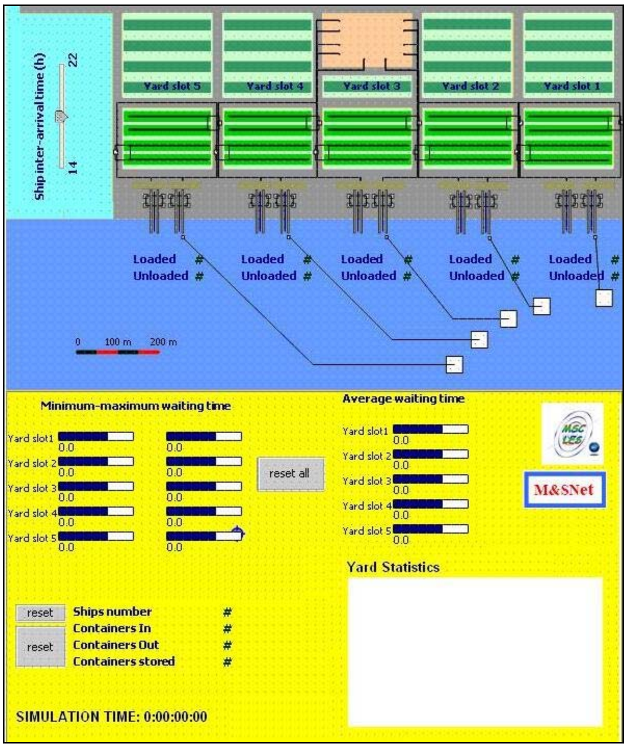
THE ANIMATION AND THE FINAL SIMULATION MODEL

The simulation model animation is based on a previous simulation model developed by authors (Longo, 2007) and use *network* objects. Network objects include

- rectangles to recreate entry/exit points, idle positions for resources, or destination points in the port;
- Lines to recreate trajectories followed by entities moving among rectangles;
- Resources to provide entities flowing in the network (i.e. containers, tractors, trucks, etc.) with different types service while moving within the network (i.e. a *container* entity seizes a *tractor* resource to move from the berth into the yard).

The *network* objects combined with the images of the terminal layout, containers, vessels, tractors, trucks, RTG, RMG, form the simulation model animation. Among others, one of the difficulties in implementing the animation was to set correctly the scale. This is required to set appropriately resources speeds and distances in the port area.. The animation is finally completed reporting information about port operations and simulated time in a display (see figure 4).

Note that in the simulation model the most important system variables are defined as parameters.



Figuure 4 – Animation and Final Simulation Model

All the parameters can be controlled from a graphic user interface (not depicted in figure 4). The graphic user interface of the simulation model allows changing the following parameters:

- Number of containers to load/unload (both from ships and from trains);
- Ships and trains mean inter-arrival times;
- Tugboats number and average speed;
- Forklifts numbers and average speed;
- Tractors number and average speed;
- RTGs number and average speed;
- RMGs number and average speed;
- Trucks number and average speed;
- Loading and unloading time for each yard, berth and rail equipment;
- Containers percentage to inspection;
- Manpower for inspection procedures;
- Tractors for inspection procedures;

Statistics and performances measures defined in the simulation models can be plotted on graphics, diagrams, histograms as well as can be exported on excel or text files. Statistics and performance measures regard number of inspected containers, inspection service time, inspection waiting time, containers daily flow entering the port, containers daily flow exiting the port, total number of containers entered, total number of containers exited, actual number of stored containers, berth cranes utilization, moved TEUs per structural unit (indicating the container terminal total efficiency).

Note that a container terminal is a non-terminating system, in other words the duration of a simulation run is not a-priori fixed. The first objective in this type of simulation model is to understand the optimal length of a simulation run. To this purpose we used the *Mean Square Pure Error* Analysis (MSpE) on different performance measures. In most of the cases the Mean Square pure Error becomes negligible after 290 days, so, such value has been chosen as optimal simulation run length.

Some preliminary analysis has been made to validate the simulation model. The results obtained show that the virtual container terminal moves, on the average 90.000 TEUs per month. Such value is similar to the statistics recorded in 2008 in the Genoa-Voltri container terminal.

FAILURE AVOIDANCE

The supply chain nodes simulation study presented in the first part of this article is a realistic study in an important logistic problem. In this second part, we elaborate on an important novel paradigm to avoid errors in modeling and simulation studies.

Similar to real systems, errors can occur in modeling and simulation. Appendix A is a list of 175 types of errors. Some relevant concepts are failure, mistake, error, fault, defect, deficiency, flaw, shortcoming, sophism, and paralogism. Brief definitions follow:

"Failure – "An event that does not accomplish its intended purpose."
"1. The condition or fact of not achieving the desired end or ends.
2. Nonperformance of what is requested or expected." (AHD)

Mistake – "1. An error or fault resulting from defective judgment, deficient knowledge, or carelessness.
2. A misconception or misunderstanding." (AHD)

Error – "1. An act, assertion, or belief that unintentionally deviates from what is correct, right, or true.
2. The condition of having incorrect or false knowledge.
3. The act or an instance of deviating from an accepted code of behavior.
4. A mistake.
5. *Mathematics* The difference between a computed or measured value and a true or theoretically correct value." (AHD)

Fault – "Something that impairs or detracts from physical perfection; a defect." (AHD)

Defect – "A serious functional or structural shortcoming." (AHD)

*Deficien*cy– "The quality or condition of being deficient; incompleteness or inadequacy." (AHD)

Flaw – "An often small but always fundamental weakness." (AHD)

Shortcoming – "A deficiency; a flaw." (AHD)

Sophism – "A deliberately invalid argument displaying ingenuity in reasoning in the hope of deceiving someone."

Paralogism – "Mistakenly invalid argument: in logic, an invalid argument that is unintentional or that has gone unnoticed" (Ören and Yilmaz, 2009).

There are three paradigms to reduce errors in simulation studies. They are: (1) V&V (validation and verification, (2) QA (quality assurance), and (3) FA (failure avoidance).

V&V (validation and verification) and QA paradigms

It is out of the scope of the article to present on overview of V&V and QA paradigms; however the most important references are provided below. V&V paradigm consists of a large number of techniques (Balci and Sargent, 1984; Balci, 1987, 1998). The focus is to develop a correct and appropriate model of the system of interest and computerize it correctly. Some early references on QA of simulation studies are developed by Ören (1981, 1984). Later, Ören (1986, 1987) developed quality assurance paradigms for Artificial Intelligence in modeling and simulation. Quality assurance paradigm is more comprehensive than verification and validation paradigm. (Balci 2004, Balci et al. 2009).

FA (failure avoidance) paradigm

"Two relationships exist between failure avoidance and simulation. Simulation can be used successfully for failure avoidance in several fields and failure should be avoided in simulation" (Ören and Yilmaz 2009). Many examples of failures in simulation studies are referred to in Ören and Yilmaz (2009). Failure avoidance paradigm benefits from systems approach and systems engineering paradigms and considers all aspects of failure. Table 1 lists categories of sources of errors that can occur.

Table 1. Categories of sources of errors
(adopted from Ören and Yilmaz, 2009)

In M&S, sources of failures can be:
Project management
Goal of the study
Scope of the study
Instrumentation
Data collection
Assumptions (explicit and/or implicit) in specifications of problem, models, experiments
- (scenarios, experimental frames) and
- (model, experimental frame) pairs
Modeling (conceptual models)
Scenarios (experimental conditions)
- realism and applicability of scenarios
- consistency of joint scenarios in federations and federations of federations
Design of experiments
Experimentation (behavior generation)
Computerization (of models, experiments, run-time libraries, and infrastructure)
Computation
- numerical computation
- soft computing
Logic and fallacies in logic (paralogism, sophism)
Artificial intelligence
- rule-based –expert– systems
- software agents (trustworthy agents, moral agents)
M&S infrastructure (including run-time facilities)
Documentation (inconsistent, erroneous, non-existent)
Communication (between stakeholders)
Recommendation of the simulation study
Implementation of the recommendations
- not implementing (ignoring the study)
- late implementing
- improper implementation

A successful M&S study can benefit from a multi-paradigm approach; i.e., from application of V&V, QA, as well as FA approach.

Some concerns to enhance the supply chain nodes simulation studies

Each simulation study has a goal and associated scope of applicability. However, most simulation studies can be enhanced either (1) by failure avoidance or (2) by extending its scope. To *enhance* the operations of the supply chain nodes operation, the study can be extended by systematically asking "what can go wrong?" type of questions. For example, the supply chain nodes operation study can be enhanced in the following dimensions:

- *Role of terrorist activities*. Impact of two types of activities can be studied; to eliminate them or to alleviate their impact: (1) Using containers to smuggle material to be later used in terrorist activities within a country. (2) Impact of terrorist activities on the equipment of a supply chain node.

- *Global supply chain risk management simulations.* In effect, the authors already used simulation for supply chain risk and resilience enhancement (see Longo and Ören, 2008).

- *Container scanning risk management simulation.* As in the previous case the authors are well aware of the importance of simulation in container scanning/inspection operations (Longo, 2010).
- *Role of maintenance of several types of equipment*. Similar to the simulation studies of a job shop, several types of equipment in a supply chain node would require maintenance. The existing study can be extended for this purpose. Otherwise, the existing study may not be sufficient to analyze the need and allocation of resources for maintenance purposes.
- *Trend analyses of the usage of the capacity of supply chain node*. Under different past conditions the capacity utilizations and associated usage trends can be established. This information can be used in marketing the unused capacity; or coupled with simulation studies with anticipated demands can be used to perform investment analyses.

CONCLUSION

An example for supply chain node simulation studies is developed (the simulation model of a container terminal is presented). Highlights of failure avoidance (FA) – as a paradigm to enhance simulation studies – is given. And some cases of the application of FA to enhance supply chain node simulation studies are enumerated. In is worth exploring the potential of FA as explained in detail by Ören and Yilmaz (2009) to extend ways to avoid failures in simulation studies and to enhance their usefulness.

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BIOGRAPHIES

FRANCESCO LONGO took the degree in Mechanical Engineering from University of Calabria (2002) and the PhD in Industrial Engineering (2005). He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard modeling & simulation of manufacturing systems and supply chain management, vulnerability and resilience, DOE, ANOVA. He is Responsible of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES), member organization of the MS&Net (McLeod Modeling & Simulation Network) He is also member of the Society for Computer Simulation International and Liophant Simulation.

TUNCER ÖREN is a professor emeritus of Computer Science at the University of Ottawa. His current research activities include (1) advanced M&S methodologies such as: multimodels (to encapsulate several aspects of models), multisimulation (to allow simultaneous simulation of several aspects of systems), and emergence; (2) agent-directed simulation; (3) cognitive and emotive simulations (including simulation of human behavior by fuzzy agents, agents with dynamic personality and emotions, agents with perception, anticipation, and understanding abilities); and (4) failure avoidance in M&S and user/system interfaces. He has also contributed in Ethics in simulation as the lead author of the Code of Professional Ethics for Simulationists, M&S Body of Knowledge, and multilingual M&S dictionaries. He has over 430 publications (some translated in Chinese, German and Turkish) and has been active in over 370 conferences and seminars held in 30 countries. He received "Information Age Award" from the Turkish Ministry of Culture (1991), Distinguished Service Award from SCS (2006) and plaques and certificates of appreciation from organizations including ACM, AECL, AFCEA, and NATO; and is recognized by IBM Canada as a Pioneer of Computing in Canada (2005). His home page is: http://www.site.uottawa.ca/~oren/ .

Appendix A. A List of 175 Types of Errors (adapted from Ören and Yilmaz, 2009)

absolute error	decision error	latent error	requirement error
acceptance error	deductive error	linearization error	residual error
accidental error	definition error	loading error	resolution error
accumulation error	description error	local error	rounding error
acknowledged error	design error	local integration error	round-off error
activation error	detected error	logical error	sampling error
active error	detection error	loss-of-activation error	scientific error
adjustment error	diagnostic error	machine error	semantic error
algorithm error	digitization error	measurement error	sensitivity error
algorithmic error	discretization error	measuring instrument error	sensor error
ambiguity error	disk error	mechanical error	sequence error
analysis error	dumping error	method error	simplification error
angular error	dynamic error	mode error	simulation error
approximation error	environment error	model error	single error
ascertainment error	error of rejecting valid model	modeling error	software design error
assumption error	estimation error	moral error	software error
attribution error	ethical error	non-sampling error	solution error
balance error	experimental error	observation error	specification error
balanced error	experimentation error	observational error	stable error
bearing error	extrapolation error	offset error	standard error
bias error	fatal error	omission error	static error
biased error	fixed error	overestimation error	substitution error
bit error	fractional error	parameter error	syntactic error
calculation error	frequency error	parameterization error	syntactical error
calibration error	gain error	parity error	syntax error
capture error	global error	perception error	system error
chaotic error	global integration error	persistent error	systematic error
classification error	global relative error	phenomenological error	transcription error
clerical error	hardware error	prediction error	transmission error
computational error	heuristic error	process error	truncation error
computer error	human error	processing error	type I error
computerization error	hypothesis error	program error	type II error
conceptual error	identification error	program-sensitive error	type III error
consistency error	inadvertent error	programming error	typical error
constraint error	inherited error	projection error	unacknowledged error
convergence error	input quantization error	propagated error	unbiased error
copying error	inscription error	proportional error	uncorrelated error
correlated error	instrument error	quadratic error	undetected error
cultural bias error	instrumentation error	random error	unification error
cultural perception error	integration error	read error	unstable
cumulative error	interpolation error	reasoning error	usage error
damping error	irrecoverable error	rejection error	user error
data error	judgment error	relative error	willful error
data-driven error	language error	representation error	