HLA-based real time distributed simulation of a marine port for training purposes

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Abstract: The research proposes critical issues related to cooperative training in a synthetic environment based on a federation of simulators operating in the same virtual world. The authors propose a real-time distributed simulation called ST-VP (simulation team virtual port simulator), for training purposes that is able to take safety and operative efficiency also into account. The simulators, installed on low-cost training workstations, cooperate and share the same virtual environment based on the high level architecture standard for distributed simulation (HLA). With this approach, it is possible to apply distributed simulation to a relevant number of entities and proceed with low-cost training sessions in cooperative operations in intermodal terminals.

Keywords: marine ports; advanced simulation; HLA; training; virtual environment

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Alberto Tremori has acquired experience on the development of Simulators to support process re-engineering, logistics, transportation systems and warehouse automation being involved in joint Simulation Researches Projects among National Simulation Center, Istitute for Simulation and Training and Kennedy Space Center and McLeod Institute of Simulation Science. Moreover he has worked as freelance consulting in Quality Management applied to Port Services, obtaining the first ISO9000 certificate for Mooring Nautical Service in Europe and completing the certification process of all 67 Italian Commercial Ports. Along the years he participated to several International Conferences as speakers in Europe, Asia and North America. He worked as responsible in several IT Companies, Logistics and Consulting Firms (think3, Solid Works, DIP Consortium, CFLI, MAST) in Technology Transfer, Innovative HiTech Projects and Business Development. He is currently active in Simulation Team, McLeod Institute of Simulation Science and DIME University of Genoa.

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1 Introduction

Recently, interoperable simulation has become even more popular as a training support in those sectors where different entities/components interact dynamically. In general, this technique was derived from experiences in the military sector and is spreading to other different application domains. In logistical infrastructures (i.e., seaports), for instance, there are many entities that interact dynamically and the synergies that can be established during such interaction processes affect the overall efficiency as well as the safety and security of the operators (Ottjes et al., 2006). In this framework, distributed simulation creates new opportunities to activate innovative research and development initiatives, as well as new product development.

As a matter of fact, the authors were involved in developing a new research project, founded by COSMOLAB Consortium (Italy), for the development of a distributed federation able to reproduce port operations with special emphasis on those involving quay cranes. In addition, it is worth mentioning that the authors of this paper have acquired extensive experience in developing advanced modelling and simulation tools for supporting operator training (Bruzzone et al., 2007a) and decision-making processes pertaining to different areas such as defence (Bruzzone et al., 2011), industry (Bruzzone et al., 2007b) and logistics (Bruzzone et al., 2010).

Taking advantage of the authors' experience, this research work introduces an innovative training tool based on distributed simulation. The proposed tool is devoted to supporting mobile training and is able to provide tailored solutions based on specific emerging needs. Other advantages are cost reduction in hardware and software, as well as improved effectiveness in cooperative training. In other words, the proposed simulation framework, which is based on the integration of advanced simulation architectures with low cost devices, tries to answer the need for cost-effective technologies and methodologies for delivering effective training services (i.e., mobile training laboratories, mobile training programmes, ad hoc equipment and trainers). The proposed tool is intended for training in marine ports with special attention to container terminals. In fact, such systems are quite complex in terms of management and operational processes and for this reason, all the actors need to have deep knowledge and special experience (Merkuryev et al., 1998). Therefore, it is evident that training is important not only at the strategic level, but also at the operational level. In this framework, modelling and simulation (M&S) has proved to be an effective approach both for decision support and training. In fact, the advantages of simulation-based training are not negligible. Among others, some notable advantages are: the possibility to train operators in a safe environment and in any desired working condition without disrupting ongoing operations; show in a visual manner the consequences of the actions undertaken by trainees; collect a large amount of data about training sessions. All these advantages, along with the possibility of cooperative training sessions and sharing of the computational workload among different resources, are the starting point of the proposed approach.

2 Distributed simulation for training

The use of synthetic training environments (STEs) for training in complex systems allows the overcoming of real-world limitations in terms of safety, costs, training conditions and the number of operators trained simultaneously (Bate and Carver, 1994; Bruzzone and Longo, 2013). One of the most effective techniques for developing STE is based on the integration of different components into a distributed system that is made up of simulators, virtual environments and live participants (Calvin and Van Hook, 1994; Hayuth et al., 1994). Furthermore, to develop realistic STE, several aspects have to be taken into account, namely, complex interactions among simulation models, integration with real-time man-in-the-loop solutions and the presence of both real and virtual components interacting with each other. Some of the most relevant applications in this field pertain to the military sector, e.g., ModSAF (Modular Semi-Automated Forces), developed by Loral Advanced Distributed Simulation, is a simulation-based training tool based on distributed interactive simulation (DIS) for military training and combat doctrine development (LADS, 1995).

Moreover, distributed simulation has been widely applied for military aircrew collective training. As a matter of facts, advanced simulation approaches have proved to be very effective in allowing the main drawbacks of live training (i.e., lack of airspace availability, environmental and security constraints, aircraft availability, airframe life reduction, exercises costs and limited opportunities to experience co-ordination of critical multi-national air missions) to be overcome.

The advantages of simulation-based training have become even more evident as information and communication technologies have been integrated into both management and operational systems (Bruzzone and Longo, 2010). Thenceforth, simulation has been widely applied in many areas, not only as a decision support tool, but also for training purposes. A literature review in this field reveals that there have been many efforts to develop M&S applications for industry and logistics, to cite a few instances (Jiing-Yih et al., 1997; Carraro et al., 1998; Ferrazzin et al., 1999; Cramer et al., 2000; Kwon et al., 2001; De Sensi et al., 2008; Longo and Mirabelli, 2008; Longo and Mirabelli, 2009; Cimino et al., 2009; Curcio and Longo, 2009; Longo, 2012a; Longo et al., 2012; and many others).

Moreover, special attention has been paid to marine ports and several training applications based on interactive simulation have been developed (Wilson et al., 1998; Nevins et al., 1998; Seron et al., 1999; Mosca et al., 2000; Huang, 2003; Daqaq, 2003; Rouvinen, 2005; Longo, 2012b).

In this field, the authors have gained experience of simulation and virtual reality applications intended for port operators' training and safety procedures design. In this research work, ST_VP (virtual port developed by simulation team), an evolution of the DIME Engine (Cocodris) developed within the Cybersar Project framework, has been presented. The project has been carried out in cooperation with national and international institutions and its focus was on the development process of a Portainer Simulator devoted to support training and virtual prototyping by integrating simulation and biometrics devices.

ST_VP is advanced training equipment that combines simulation and virtual reality. It offers the possibility of simulating different kinds of cranes and provides an immersive cave (270° horizontal and 150° vertical), which is able to reproduce sounds, vibrations, motions and all weather conditions; as a result, the users can experience very realistic sensations. Moreover, it has a great operational flexibility that makes it applicable to each port, crane and procedure easily. Technically, ST_VP is an HLA-based real time distributed simulation application developed through a modular approach that guarantees extensibility and reusability and facilitates the ST_VP adoption as a mobile training tool. More specifically, it allows both single user and cooperative training sessions where different kinds of vehicles, which can be computer or human controlled entities, enables users to recreate the seaport operational processes (i.e., containers being loaded and unloaded from ships up to the final destination on the yard) (Koh et al., 1994). Therefore, the main procedures can be simulated as a whole and multiple training objectives can be monitored simultaneously.

The single user mode allows practicing for gaining psychomotor capabilities, while the interoperable mode with multiple users is very useful for cognitive training on procedures and for team building.

3 ST_VP a distributed federation for port operations simulation

As mentioned before, the authors have developed a virtual port where the dynamic behaviour of intermodal equipment (cranes, stackers, trucks, etc.) has been simulated. The entities that act in the virtual scenario are distinct simulation models (federates) that can work standing alone or, as an alternative, can be integrated into an HLA federation. Therefore, the virtual port includes several simulation models that can run independently or concurrently. In particular, when the simulation models are able to interoperate as part of a federation, different trainees are able to work cooperatively in the same scenario.

An example could be the joint training of a crane operator, a truck driver and a reach stacker operator. The crane operator has to move a container from a ship onto a truck, which in turn has to convey the container from the dock to the yard and lastly, the reach stacker operator is expected to carry the container to the specific assigned location in the yard.

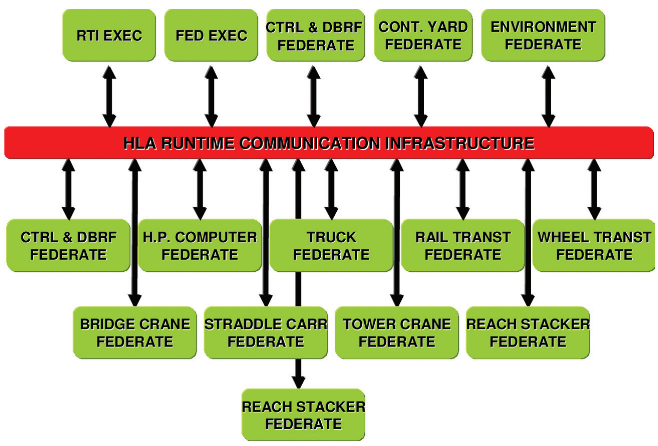
In addition, it is worth mentioning that previous research works carried out by the simulation team (a pool of hi-tech institutions active in modelling and simulation) have dealt with interoperable simulation-based training tools for managers/planners (i.e., dock managers, yard planners, control rooms, etc.). Therefore, the integration of such entities into the ST_VP framework makes its scope even wider, thanks to the additional capability of testing policies and procedures.

It is a remarkable feature considering that interactions among vehicles are the main cause of accidents and injuries during port operations, while handling policies and procedures are the key factors for improving productivity and safety (Fleming, 1997).

Going into the details of the proposed research work, it is worth saying that even if special attention has been paid to Portainers or dock gantry cranes (big equipment devoted to loading/unloading container ships), ST_VP integrates different kinds of equipment (i.e., trucks, forklifts, reach stackers, etc.), allowing the cooperative training of different operators.

The simulation models that are part of ST_VP have been integrated according to the HLA (high level architecture) standard working on DMSO RTI 1.3 v7 (IEEE Standard and regulation for US DoD Simulators) (Figure 1).

Figure 1 HLA Federation (see online version for colours)



The reason behind this technical choice is twofold: on the one hand, the simulators are enabled to interact and exchange data and on the other hand, interoperability supports trainees' capabilities in terms of cooperation, communication and information sharing.

Within the proposed simulation framework, each workstation is a federate that is entitled to get the ownership of a chosen vehicle. Furthermore the federates have been developed by applying OODA (object oriented design and analysis) and are both time constrained and time regulating. The simulation models have been integrated over a LAN/WAN (local area network/wide area network) set up with the purpose of allowing interactive real time simulation across the network.

As a result, a wide range of configurations and operative scenarios can be dealt with and two modes are available; the stand alone mode on a single PC and the cooperative mode, where there is a federation of cranes interacting over a network (Figure 2).

Figure 2 Run time infrastructure (see online version for colours)

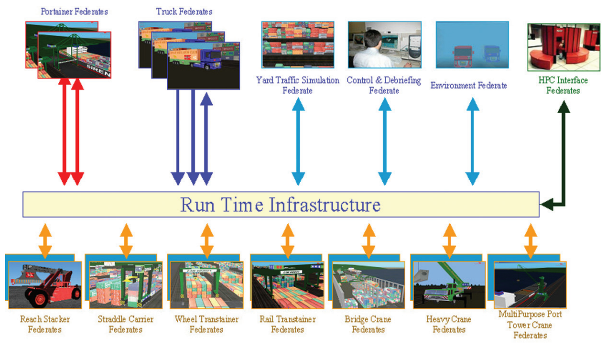
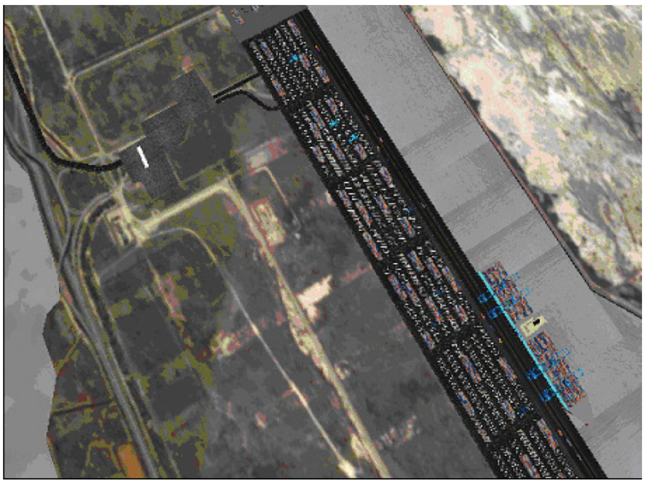


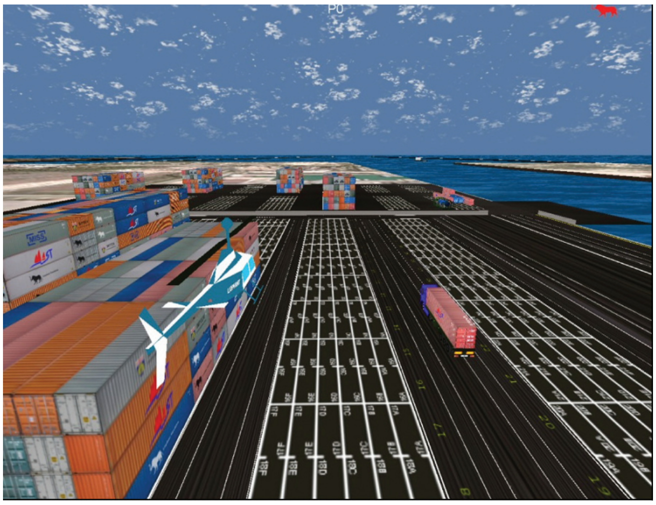
Figure 3 The whole virtual world with channels, terminal and roads (see online version for colours)



Thus, it is possible to define competitive operations where different teams/squads are working concurrently. To go into more detail, the ST_VP simulation environment includes:

1. Portainer: allows the operator to practice handling a gantry crane in different scenarios. The operator can load/unload containers to/from a ship in a virtual environment where different portainers work simultaneously
2. Control & Debriefing: the trainer is provided with the capability to navigate the virtual environment and to control the scenario configuration (i.e., set the number of containers and straddle carriers, the number and type of ships in the port area and the number of trains) and to set weather conditions (i.e., time, wind and sea conditions). In addition, the trainer is enabled to activate simultaneous debriefing sessions for immediate review of results
3. Truck, reach stacker, straddle carrier, wheel transtainer, rail transtainer, bridge crane and heavy crane federates: they dramatically improve the quality of the training session, enabling each trainee to practice on different vehicles/cranes in multipurpose operations
4. High performance computer (HPC) Interface
5. Yard traffic simulation, which controls traffic in the intermodal area
6. Environmental Simulation: based on such a federate, it is possible to set simulation starting time and weather conditions, including wind and sea conditions.

Figure 4 Virtual yard, virtual trucks and virtual copter (see online version for colours)



All the interactions between the trainees and the simulation are managed by the simulation engine that has been implemented in C++ and is based on combined simulation (continuous integration among specific events corresponding to actions).

The virtual world hosts the container terminal area and is based on the graphical environment Multigen Vega Prime. Therefore, an ad hoc virtual world reproducing a reference port has been developed and in this framework, real time distributed HLA-based simulation has been applied for recreating vehicle and crane operations. To this end, several issues have been considered, namely, definitions of operative procedures, operators' training and education, improvements in handling safety and improvements in operational efficiency. The virtual port includes the surrounding areas, roads, container yard, different types of yard cranes, ship cranes, ships, etc. (Figures 3, 4, 5, 6 and 7).

Figure 5 Virtual portainers operating on virtual ships (see online version for colours)

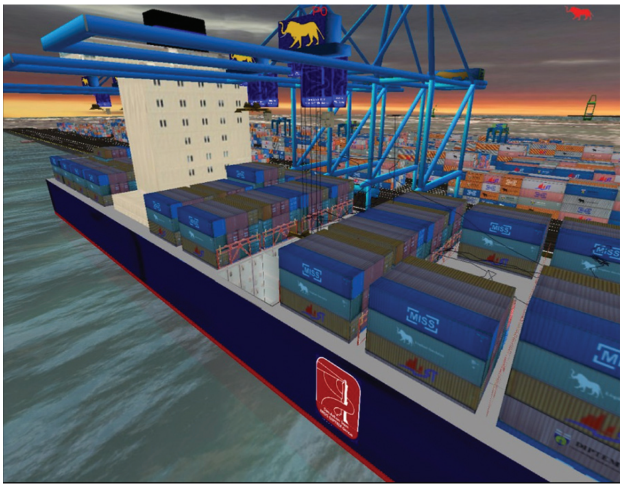


Figure 6 Virtual ships with four portainers (see online version for colours)

Figure 7 Virtual transtainer operating on the yard (see online version for colours)

As a graphical environment, the physics elements are developed by the authors by coding all the environment aspects and vehicle features, even including weather conditions; as an implementation tool, it used Visual StudioTM.

During the development phase, scalability was one of the most important driving requirements and therefore, different federates can be combined with each other in complex and distributed systems (with the possibility of distributing heavy computational workloads among federates).

Figure 8 Mock-ups motion platform (see online version for colours)

Moreover, the proposed simulation tool has been integrated with multiple hardware interfaces for external devices (i.e., joysticks, steering wheels, pedals, etc.). In particular, ST_VP is equipped with a 6-degrees-of-freedom (6DOF) motion platform so as to provide the trainees with very realistic experiences (Figure 8). Indeed, the motion platform, which is interfaced with the simulation models via sockets, allows reproducing roll, pitch and yaw and recreating the impact of shocks and speed changes as well as real accelerations and vibrations that can be perceived, for instance, in the Portainer cabin or inside a truck.

To this end, a preliminary phase of data collection and analysis has been carried out. The measures have been taken at different points and directions by accelerometers and each measure is related to a specific set of data defining the current boundary conditions (i.e., crane parameters such as current load, wind speed and crane configuration in terms of cabin position have been considered). Particular attention has been paid to cranes operations owing to the multiplicity and the complexity of the factors that affect their dynamical behaviour. As a result, data have been categorised and stored in tables. During the simulation, an ad-hoc interpolation algorithm calculates the current vibration spectrum based on the boundary conditions in the database that are closer to runtime parameters. Consequently, when additional data are stored in the database, the motion accuracy can be improved.

The actual configuration of the architecture is based on:

1. one full scope simulator
2. the 6DOF motion platform
3. advanced visualisation solutions integrated with eye tracking systems (crane operator)

4. interactive pilot stations
5. instructor station
6. workstations
7. large screens (truck drivers).

The whole architecture is installed within a shelter that can be easily moved from one location to another; thus, it is not constrained in a fixed position and can be relocated if necessary. In addition, this arrangement allows system reconfiguration according to specific needs thanks to the possibility of integration with other shelters.

An innovative feature embedded within ST_VP is the possibility of reproducing the motion of docking ships with detailed elastic models of the mooring cables. As is well known, ship motion, cables stress/strain and critical conditions/events are quite complex phenomena in a real-time environment and require high performance computing technologies; therefore, special federates running remotely (WAN) on high performance computers have been developed. However, when HPC technologies are no longer available, simplified models, running on local workstations (LAN) may be used (i.e., for regular training). In addition, the integration of traditional training techniques with simulation has been studied. Consequently, blended solutions combining different kinds of training equipment for cooperative/competitive training have been tested (Figure 9).

Figure 9 ST_VP training solution (see online version for colours)

4 Operational model

When a new training session starts, the simulator generates the mission automatically: the user defines, for each operator, which container has to be moved and the new position/destination to be reached (Figure 10).

The mission can include "multiple destinations", in other words, the trainee could be asked to move the container from a yard location to a truck trailer and back again. In addition, different levels of complexity such as, for instance, extra-move or disturbance (i.e., means and persons in the working area), which the user can choose from, are available.

Figure 10 Virtual yard operations (see online version for colours)

Moreover, containers and trailers properties are shared among different federates, whereas trucks, cranes and people properties are functions of each platform user. Therefore, specific C++ routines have been developed to carry out a continuous reassignment of the different attributes while containers handling processes take place. Furthermore, each federate has its own dynamics implemented and intelligent algorithms allow federates tracking. In this way, ST_VP is able to support not only operators' training, but also management policies, procedures design and infrastructure reengineering.

Considering that the overall efficiency depends upon the synergy and the coordination among actors and resources, the possibility to have many vehicles/equipments and actors involved in the same scenario has been a key requirement in the development phases of ST_VP. Indeed, this tool has also been used for policies redesign and analysis. During early testing, the virtual cockpit of a crane has been changed and the benefits in terms of overall logistics performances and safety levels were studied through an experimental campaign carried out by ST_VP.

5 VV&A process

Verification, validation and accreditation (VV&A) activities have been carried out throughout the development phase of ST_VP to check the logical consistency of the conceptual models and the accuracy of the interoperability factors that have been identified, as well as the validation of each federate and of the whole federation.

The validation of the federation in terms of implementation and factor tuning has been a critical step before the ST_VP's release.

On this subject, the IEEE 1516.3 high level architecture federation development and execution process as well as the fundamentals of the 5000.61 directive related to VV&A have been followed.

ST_VP has been verified and validated by a network of excellence involving well-recognised subject matter experts in the field of simulation applied to logistics and seaport management. In addition, the review and test of the ST_VP redesign capabilities have benefited from continuous feedbacks provided by logistic operators. The involvement of such actors has allowed the full validation of the proposed tool, taking into account both the real-time dynamic integration with external devices (hardware-in-the-loop, HIL) and the position change of the observer when switching between different points of view (man-in-the-loop, MIL).

6 Analysis about the virtual port benefits as mobile training tool

The main advantages of the proposed solution are related to the innovative concept of mobile training and to the low costs of the interactive distributed HLA-based environment. As a matter of fact, it runs on PCs equipped with simple devices (basic configuration) or, as an alternative, it can become a mobile classroom in its full configuration (i.e., containerised and integrated with the motion platform and an immersive video system). The "mobile" approach allows export of the concept/product of simulation-based training at low costs in new areas.

Moreover, ST_VP has multiple configurations and therefore, can be tailored for ports with different size and training needs.

As mentioned before, ST_VP is an innovative mobile training tool based on simulation, whose benefits have been carefully evaluated. To this end, the mobile training approach has been compared to traditional solutions in the application field of crane operators' training. In this context, the following options have been considered:

1. innovative mobile training based on simulation
2. traditional mobile pack with crane simulator
3. traditional containerised crane simulator
4. fixed solution for crane simulator
5. traditional training on a real crane.

The comparison has been based on quantitative factors, namely:

1. total training time required for a site (1)
2. the number of served ports over the period available for training (2)
3. the time of direct training (operator interacting with the equipment) vs. the frontal lectures and observation of other people operating (3)
4. training costs (4).

$$T_{tot} = \begin{cases} \alpha < 1; n_s[T_{tr} + n_p(T_{tvi} + T_{tri})] + T_{st} + T_{ta} + T_{sh} \\ \alpha = 1; n_s[T_{tr} + n_p T_{tri}] \end{cases} \quad (1)$$

$$N_{ports} = \frac{uc \cdot P}{T_{tot}} \quad (2)$$

$$Ex = T_{tr} \cdot \left(\frac{\alpha \cdot rcr + (1-\alpha) \cdot vcr \cdot p_u}{n_p} \right) \quad (3)$$

$$C_{tot} = \begin{cases} \alpha < 1; T_{tot}(Is + (\alpha \cdot Arcr + c)) + (1-\alpha) \cdot Avcr) \\ \quad + C_{st} + C_{ta} + C_{sh} \\ \alpha = 1; T_{tot}(Is + Arcr + lc) \end{cases} \quad (4)$$

where:

T_{tot} = total training time for a site
n_s = number of sessions on a site
α = percentage of time on real crane respect simulation
T_{tr} = training time
uc = use of the time frame for training (i.e., eight hours per day, five days/week)
p_u = number of users concurrently training on the simulator
lc = production losses due to unavailability of the real crane
rcr = number of real cranes
vcr = number of virtual simulators
T_{tvi} = student transition time on simulator
T_{tri} = student transition time on real crane
T_{st} = setup time for the mobile solution
T_{ta} = time for tailoring scenario for the mobile solution
T_{sh} = time of shipping for the mobile solution
P = period available for training
N_{ports} = number of serviced ports over P timeframe
Ex = trainee time operating directly
n_p = number of people in a training session
C_{tot} = total costs on a site including all sessions
Is = instructor cost
Arcr = time cost for using real crane
Avcr = time cost for using virtual crane
C_{st} = setup cost for the mobile solution
C_{ta} = cost for tailoring scenario for the mobile solution
C_{sh} = cost of shipping for the mobile solution

The parameters required for calculating the factors that have been introduced above are reported in Figure 11, while the comparison factors values for each option are reported on Figure 12.

The analysis of such numerical data demonstrates that mobile training has great advantages compared to traditional solutions. Indeed, it allows reduction of the total time for training in each site and as a consequence, the serving of a greater number of ports. Moreover, the time taken when trainees operate directly is higher compared to the other solutions; it means that trainees are actively involved in the learning process and therefore, the training actions are potentially more effective. In addition, all these advantages are available with a substantial reduction of costs. It is worth saying that tailoring is a critical factor for training effectiveness. The tailoring of traditional simulators is usually very limited; such simulators are based on predefined scenarios (set up with mean values and estimates from subject matter experts), with no possibility of recreating on-going procedures for each terminal being served. The effects of tailoring on each option (Mobile training,

Figure 11 Comparison scenario with tailoring

		Mobile Training	Containerized Simulato	Pack Simulator	Fixed Simulation	Real Crane	
ns	Number of sessions on a Site	3	3	3	3	3	[sessions]
alfa	percentuage on real crane	0.5	0.5	0.5	0.5	1	
Pu	parallel trainees on simulator	4	1	1	1	1	[people]
Ttr	training time	40	40	40	40	40	[hours]
Ttvi	student transition time on simulator	2	2	2	2	0	[minutes]
Ttri	student transition time on real crane	0	0	0	0	2	[minutes]
Tst	setup time for the mobile solution	0.5	1	0.2	0	0	[days]
Tta	time for tailoring scenario for the mobile solution	1	20	20	20	0	[days]
Tsh	time of shipping for the mobile solution	3	3	3	3	0	[days]
rcr	number of real cranes	0	0	0	0	1	
vcr	number of simulated cranes	4	1	1	1	0	
P	Period available for training	6	6	6	6	6	[months]
np	number of people in a training session	4	4	4	4	4	
Is	Instructor Cost	50	50	50	50	50	[Euro/h]
Arcr	Time Cost for using real crane	171	171	171	171	171	[Euro/h]
Avcr	Time Cost for using virtual crane	175	263	44	219	175	[Euro/h]
Cst	setup cost for the mobile solution	1000	1000	1000	1000	0	[Euro/movement]
Cta	cost for tailoring scenario for the mobile solution	1000	20000	20000	20000	0	[Euro/scenario]
Csh	cost of shipping for the mobile solution	1000	2500	1000	64000	0	[Euro/movement]
lc	loss of productivity	0	0	0	0	2325	[Euro/hour]

Figure 12 Results on scenario with tailoring

		Mobile Training	Containerized Simulato	Pack Simulator	Fixed Simulation	Real Crane	
Ttot	Total Training Time for a Site	228.8	696.8	677.6	672.8	120.4	[hours]
Nports	Number of serviced Ports over P timeframe	4.62	1.52	1.56	1.57	8.77	[ports]
Ex	Trainee time operating directly	25	10	10	10	10	[hours]
Ctot	Total Costs on a Site including all sessions	54,099	209,682	128,753	250,015	306,566	[euro/site]

Figure 13 Comparison scenario without any tailoring

		Mobile Training	Containerized Simulato	Pack Simulator	Fixed Simulation	Real Crane	
ns	Number of sessions on a Site	3	3	3	3	3	[sessions]
alfa	percentuage on real crane	0.5	0.5	0.5	0.5	1	
Pu	parallel trainees on simulator	4	1	1	1	1	[people]
Ttr	training time	40	40	40	40	40	[hours]
Ttvi	student transition time on simulator	2	2	2	2	0	[minutes]
Ttri	student transition time on real crane	0	0	0	0	2	[minutes]
Tst	setup time for the mobile solution	0.5	1	0.2	0	0	[days]
Tta	time for tailoring scenario for the mobile solution	0	0	0	0	0	[days]
Tsh	time of shipping for the mobile solution	3	3	3	3	0	[days]
rcr	number of real cranes	0	0	0	0	1	
vcr	number of simulated cranes	4	1	1	1	0	
P	Period available for training	6	6	6	6	6	[months]
np	number of people in a training session	4	4	4	4	4	
Is	Instructor Cost	50	50	50	50	50	[Euro/h]
Arcr	Time Cost for using real crane	171	171	171	171	171	[Euro/h]
Avcr	Time Cost for using virtual crane	175	263	44	219	175	[Euro/h]
Cst	setup cost for the mobile solution	1000	1000	1000	1000	0	[Euro/movement]
Cta	cost for tailoring scenario for the mobile solution	0	0	0	0	0	[Euro/scenario]
Csh	cost of shipping for the mobile solution	1000	2500	1000	64000	0	[Euro/movement]
lc	loss of productivity	0	0	0	0	2325	[Euro/hour]

Figure 14 Results on scenario without any tailoring

		Mobile Training	Containerized Simulato	Pack Simulator	Fixed Simulation	Real Crane	
Ttot	Total Training Time for a Site	204.8	216.8	197.6	192.8	120.4	[hours]
Nports	Number of serviced Ports over P timeframe	5.16	4.87	5.34	5.48	8.77	[ports]
Ex	Trainee time operating directly	25	10	10	10	10	[hours]
Ctot	Total Costs on a Site including all sessions	47,739	61,428	33,131	112,287	306,566	[euro/site]

Containerised Simulation, Pack simulator, Fixed Simulator and Real Crane) have been evaluated and the results are reported in Figures 13 and 14.

This data allow us to point out that traditional solutions become more competitive when no customisation activities are performed while the mobile training performances change slightly. It suggests that traditional solutions are not as flexible as mobile training. This becomes a crucial factor when training effectiveness is subject to the capability to satisfy specific training needs.

The ST_VP training solution provides great benefits when compared to traditional training on real crane and even to old style simulators, as summarised in Figures 15 and 16.

Figure 15 Benefits of ST_VP training in effectiveness and costs with scenario tailoring (see online version for colours)

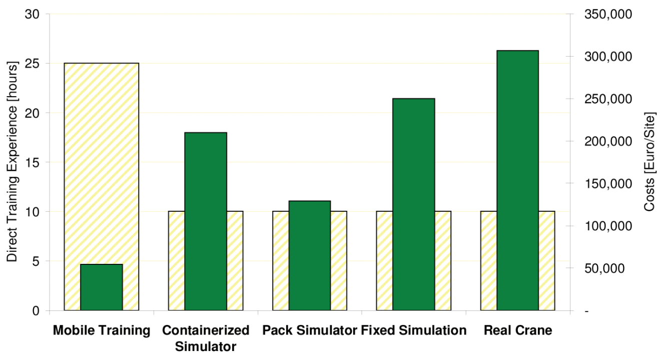
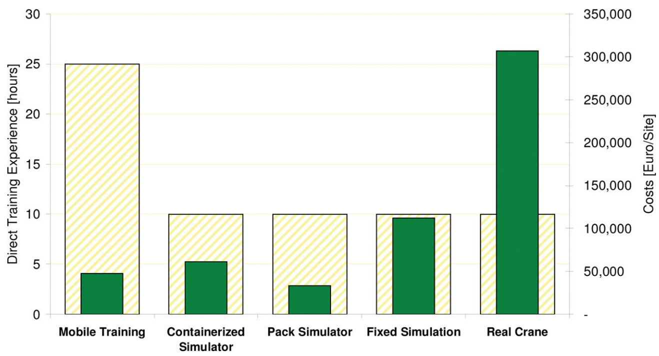


Figure 16 Benefits of ST_VP in effectiveness and costs without any scenario tailoring (see online version for colours)



7 Conclusions

The authors propose an innovative tool (ST_VP) to support mobile training and operational procedures definition in ports. From a technical point of view, ST_VP is based on virtual environments, distributed simulation and HIL and MIL solutions. Therefore, the development phase has required a great research effort to ingrate all these elements in a simulation-based training tool that can be tailored according to specific needs or user requirements. In addition, ST_VP allows trainees to experience scenarios involving interaction, cooperation and competition. These features, along with the capability of supporting mobile training, make ST_VP quite different from traditional simulators. As a matter of fact, a comparative study has shown that the proposed solution is more competitive in terms of cost savings and training effectiveness. The logical consistency of ST_VP has been extensively validated.

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