THE ROLE OF INFORMATION TECHNOLOGY IN MARITIME EDUCATION FOR HAZARD AVOIDANCE

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Abstract

Maritime transport is an important aspect of the economy of every maritime state and this needs safety and efficiency. It is well known that one of the major factors of accident prevention is the perfect theoretical and practical knowledge which can help to reduce risk of accidents at sea and at port terminals, collisions and loss of ships, cargo, human lives and protects the environment. There are numbers of different tools and systems, which are used to satisfy these demands. Our forefathers have sailed using paper charts and sextant, today we use radar, ARPA, GPS, nautical charts and publications.

In this paper, a review of how information techniques have been applied to help and improve the education of marine engineers presented. We report about a teaching experience for a group of graduate students and how new technology of modeling and decision making (Petri nets, genetic algorithms) bas been applied. All these are very effective for improving the engineers and officers' management experiences and operation skills in emergency situation. But for cadets who were lack of practical experiences, they had to spend most part of terms to learn theoretical courses and got course's marks on land.

In order to meet the challenge of modern maritime development, the responsibility education is to produce a great many talents with ideas and work abilities. This paper's conclusion is that the use of computer simulation - interactive programs in maritime education results in increased emergency preparedness and in consequence, leads to hazard mitigation and reduces the risk of human error in the operation and maintenance of marine equipment.

Introduction

In this paper, we present a teaching experience of marine engineers. In the centre of our observation are students of third year – Bologna process and use of modeling and simulation tools for emergency response related applications. During the previous years they learned the basics of computer programming and operating system and they had the knowledge based on the STCW (which includes IMO 7.01, 7.02). In order to give our students high-level emergency ability, our education process is optional and composed of several topics: Petri nets, techniques from optimization, like job-shop scheduling, genetic algorithms or mixed-integer linear programming, genetic algorithms, tools for specification and verification

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(Simulink), real-time systems. The students choose among these tools. All these are very effective for improving the engineers and officers' management experiences and operation skills in emergency situation. The paper does not provide a detailed list of references and of existing software packages, since it would be very hard for such a list to be complete and exhaustive.

Goals of project

Sea ports and maritime transportation play a vital role in the development and progress of any maritime state. It is well known that sea transportation is one of the most critical components in global and European freight transport logistic operations [IMO, 1995]. The risk of an accident is defined as the product of the probability of occurrence of the accident and the consequences of that accident. Accidents which occur in waterways are events such as collision, grounding, leakage, fire on board, mechanical failures, bad weather, conflict on board or epidemics. These emergency situations may have adverse consequences (e.g., injury, loss of life, financial losses, pollution of the environment, in unrepeatable damage to cultural heritage). Accidents are very infrequent events and it is obvious that the risk of accident can be reduced but never altogether removed. Statistics prove that up to 90% of total marine accidents at see have been attributed to human error.

There are three main factors in the occurrence of marine accidents; ship design, environment and traffic regulations.

The important ship design parameters relating to the vessel control are the engine and rudder performances and the hydrodynamic and aerodynamic behaviour of the vessel. Simulation modeling in this respect is used for studying ship manoeuvring characteristics as affected by geographical and hydrographical conditions and for the investigations in the development of accident risks under different navigation scenarios.

The master's judgment in controlling his ship is influenced by the data he has about his environment (geography, bathymetry, meteorological conditions and locations of other vessels in the waterway). Some of these data may be obtained by means of the vessel's own sensors but the ones that cannot be obtained must be transmitted to the vessel from shore facilities. Since measured data can only be available at a few suitably selected sensor sites modeling and simulation of the key environmental processes is needed in order to provide advice to the masters on the predicted spatial and temporal variability of the environment.

The third factor affecting accident risks relates to traffic regulations in force in the waterway which stipulate priorities for entering the waterway and navigational advice for safe passage taking into account the size, weight and cargo (hazardous, non-hazardous) characteristics of the vessels which are to use the waterway. Simulator is possible to estimate the traffic capacity of the waterway and to determine navigational rules which would assure safe and efficient passage of vessels through the waterway.

It is well known that crews who serve on board modern ships must have perfect technical and practical knowledge of highest standards to enable them to operate complicated machinery correctly. Marine engineers must be able to operate safety and properly a merchant vessel equipped with advanced automation system. To address this problem the educational process should become more available and progressive to ensure the necessary knowledge level of both cadets and existing officers. The responsibility of education is to produce a great many talents with ideas and work abilities.

The objective of this article is to provide a vision of how technological developments have been applied to improve the education of marine engineers. It focuses on the developments in the field of computing and information technology and their potential application in determination the optimal system composition for the formulation of rules and procedures necessary to reduce risk of accidents in waterways. Interactive simulators in comparison with educational facilities equipped with only a real on-board hardware, are obviously becoming a powerful tool to achieve this goal.

These techniques can be used for:

- Design of a layout and the associated traffic control,

– Simulation of a designed model to verify the layout and to measure the performance,
– Simulate the dynamical issues regarding the constructed model by reflecting the Activity diagram model (the pre-simulation model) into a Petri net model, which serves as a comprehensive input data for simulation,
– Implementation of the control of the actual transport system.

What is asked from students

This student's project was not only designed as an approach to simulation-optimization techniques, but also to emphasize the benefits of specification and validation these techniques. The ability to represent the system under study (and its dynamic behaviour) correctly and adequately is a key issue in simulation. Consequently, recognition of the necessary and sufficient constituents of the system is of crucial importance. For example, the students were asked to produce a graphical model, having the same aspect as the physical container terminal. So far, the Petri nets have been chosen as a model, due to their support of hierarchies, simulation, occurrence graph requirements. The students are asked to design a container terminal where automated guided vehicles (AGVs) are used to internally transport containers and automated stacking cranes (ASCs) to store and retrieve containers. A key issue in automated container terminals is the assignment of transportation orders to AGVs. They must prove that some security requirements are satisfied (no collision, no more than one AGV per job) as well as efficiency (no deadlock, improve the productivity of a system and reduce delay). Once the model has been proved correct, the students have to deduce the program for control transport chain. Namely, the decreasing of the duration of all delays leads to minimization of the total transportation time along the whole chain. Interruption of the chain in the terminal is possible in the following cases:

- Case 1: One AGV breaks down. The other vehicles have to take its jobs.
- Case 2: New ship is alongside the quay. How AGVs have to been dispatched?
- Case 3: The two mutually interacting types of transport are available in the port area but the hydro meteorological conditions in the region of the port do not allow the transport vehicle processing.
- Case 4: The two transport types occupy their places at the quay simultaneously and their processing is started – this is the optimal variant since the time of stay (delay) in the transport chain coincides with the time for realizing the cargo transhipment activities at the port.

The students must design a routing policy so that the same security and efficiency requirements as before are fulfilled.

Simulation and a formal method

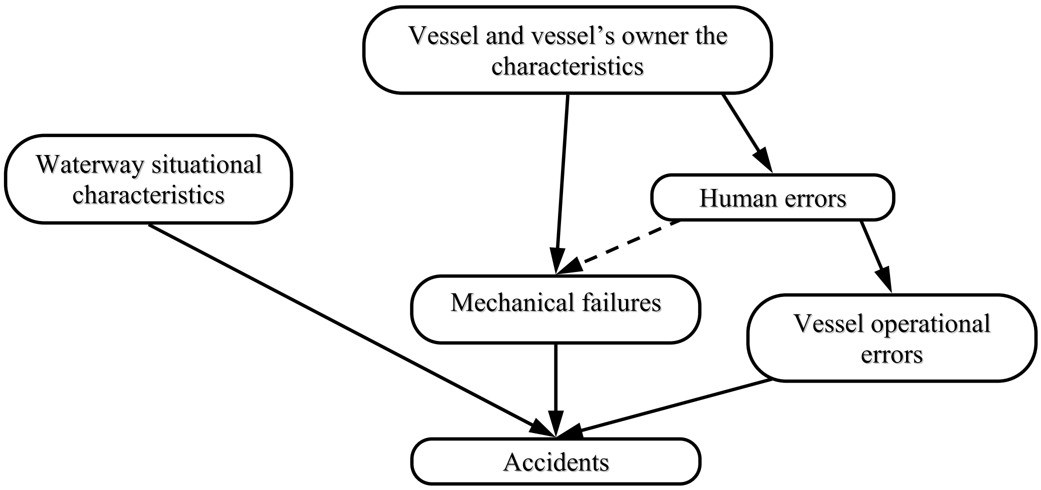
Worldwide maritime education and training is inconceivable without the use of simulation based training and assessment. The dynamic simulation approach to maritime risk was developed to compensate for two real-world constraints on the current state of the art of risk assessment:

(1) A comprehensive causal analysis of a busy port or waterway would require the creation of a complete logical construct representing all possible causal chains in the system. Existing research and data do not provide a basis for this complex construct.

(2) Data describing human error and other basic failures are not available.

The simulation methodology is based on two assumptions: (1) risk is a dynamic property of the maritime system, and (2) the judgment of the experts that have a deep understanding of the system provide a more accurate basis for the calculation of risk than do the sparse data. In this view, illustrated in Figure 1, the attributes of a vessel and the characteristics of the vessel's owner and operator are predictors of the likelihood that the vessel will experience a mechanical failure or human error. The situational attributes of the waterway (waterway configuration, location, traffic density, weather, current, etc.) will determine if that incident will become an accident.

Figure 1: Diagram illustrating conditional relationships used in simulation scheme



Almost every discipline for nautical and engineering training can be supported by simulators at various levels. These tools may range from interactive simulations using a monitor to totally immersive environments. Sophisticated simulators are tools that allow training daily operations, trouble shooting and handling emergency events. These may include interactive simulations where the tools create an imaginary scenario and the trainees input their response actions. The tools will help evaluate the response actions and thus help the trainee learn what works best under a given situation.

Experiences have shown that anti-accident and emergency training should not be limited to typical training in the sense to acquire the knowledge and skills necessary to perform correctly, but it has to be embedded within a long time education. Nowadays, huge changes are taking place in computing, information technology and simulation. Maritime education is not isolated from these tendencies. For these reasons maritime simulators in combination with some formal methods are increasingly used in our faculty for educational processes. Also, in this project the software packages Matlab, Simulink, and Stateflow developed by MathWorks, Inc., are used to generate a simulation model [KRCUM, 2005]. All these are very effective for improving the engineers and officers' management experiences and operation skills in emergency situation.

The ultimate goal of this program is to meet the need for high-level professionals capable of handling increasingly complex and important issues within maritime safety and marine environment protection. It prepares students for further career enhancement through constant up-dating and self-development. The specific objectives are: motivation, initiative, evaluation and feedback are important factors in making the maritime education successful. The teachers should motivate the students when they participate in drills. Evaluation, feedback and follow-up are essential during and after lessen and exercises.

The use of the simulator

In addition to the training and retraining of the marine engineering cadets and officers, the simulator has been and is being used extensively for research and development. These activities are mainly related to plant operational reliability, functional validation of critical systems, and reliability of man-machine interaction during emergency situations, training methods, human decision making and safety assessment studies. More details about the program are included in [KRCUM, 2005].

Simulators offer the best method of developing practical skills and assessing practical abilities with minimum danger to live and property. Engine Room Simulator is an important tool as part of the revalidation and refresher course for ships' officers and ratings.
Full-scope simulators are being used widely, not only in training marine engineer and deck officers, but also in training operators of different industries. These are widely accepted in the marine industry since they are proven to be an excellent high technology machines for training and assessing the ships personnel. They are also becoming very common in many countries to use the simulator as a testing tool in granting certificates. For those who have experience in simulator training know that it is economical and safe way to gain years of sea time skills in one to two weeks of intensive simulator training. It is widely known that one can reduce human errors, prevent catastrophic accidents, loss of life and or property through use of simulator-based training. Simulations are exercises that trainees participate in to demonstrate the real thing, probably present the greatest diversity and variety for evaluating training. Simulators are also used to teach, evaluate and simulate the skills that need to be acquired in training. In this paragraph we will give a short review how simulator training can help prevent casualties and increase efficiency of traffic flow.

The role of simulators in preventing casualties

Simulators are being used as excellent training equipment in order to simulate various operational procedures and unique scenarios together, so that effective training can be imparted to the marine professionals to a great extent of realism. The use of Engine room simulators for the effective training purpose and to achieve the dimensioning of electrical safety equipment in high voltage electro energetic systems that will ensure tolerance of breakdowns during operation, the authors of this paper were presented in [KRCUM, 2007].
Marin Navigational Simulators (MNS) are founded to be useful, even essential, tools for general training of seamen in order to prepare them to cope with unusual situation during sailing, transportation or maritime activity of all kind. Within the context of this paper the role of the MNS is to predict ship's behaviour in sea regions with critical navigation conditions and hence, they must take into account numerous and instantly changing external conditions, which influence the ship's motion.
These simulators provide modules for ship control, external effects and navigational aids. The elements for ship control are: options for the engine selection change of rudder angle and selection of thrusters (if they exist). The controllable external effects are direction and speed of wind and current. A three dimensional view of the environment and radar video images are used as the navigational aids.
The hydrodynamic characteristics of a vessel can be specified using analytic and empirical methods and are tabulated as parameters of a system of equations. A table prepared in this way contains all the basic information needed for the determination of the accelerated translational and the rotational movements of the vessel. The second aspect to be modeled would be the propeller or propellers. There are tables available which give the performance characteristics of the various types of propellers used (with 3, 4 or more blades and fixed or variable pitch). When rotational speed and power characteristics of the propeller were selected it is necessary to know the characteristics of the engine used in the vessel or alternatively to model the engine separately or together with the propeller. The third important aspect to be modeled is the rudder. Modeling of the rudder is accomplished by determining the hydrodynamic forces as defined by the rudder hydrodynamic parameters as a function of the rudder profile characteristics and rudder angle.

Modelling and simulation of vessel traffic flow

The objective of the traffic flow simulation is to study the traffic system in a narrow congested waterway, formed by the transiting vessels interacting with each other, with traffic regulations and with the environmental factors (geographic, meteorological, hydrologic). Simulation helps the following questions to be answered:

- What is the quality of service provided?
- How many vessels have to wait in the queue and for how many hours?

The simulator also provides a test bed environment, which allows the development of optimum navigational rules before they are formalized for the waterway, and the estimation of additional system improvements which may be brought about by technological developments.
A simulation tool is often required for the design of new VTS systems and/or improving the safety and efficiency of navigation in existing VTS areas including ports, harbour approaches, straits and channels.
The following factors bear on these problems:

- Geographical restrictions imposed by the waterways: width, turns and bathymetry,
- Environmental factors: winds and currents, visibility, precipitation and waves,
- Vessel traffic characteristics: density and variance, composition, arrival statistics,
- Vessel characteristics: length, weight, speed, manoeuvring capabilities, cargo and associated risks,
- Priority rules: used to determine the order in which the vessels waiting in the queue enter the waterway; FIFO (first in first out), smaller before large, hazardous before non-hazardous, etc.

The flow of maritime traffic, as the flow of any traffic, is determined primarily by the arrival statistics and the characteristics of the waterway. We shall assume that the following are known:

- Statistical data on ship arrival times,
- Statistical data on ship parameters, including:
  - dimensions (length, width, height),
  - speed (maximum, cruising),
  - manoeuvring capabilities (thrusters, one or two propellers),
  - cargo (type, hazard class).

Genetic algorithm

For a precise judgement and operation, theoretical criteria are not useful and a plenty of experience is required, but the captain or officer who has this ability are decreasing and necessity of automatic collision avoidance system is increasing.
Artificial Intelligence is thought to be an adequate method, but it needs a lot of knowledge data base and difficult to make effective system. In those days, the Genetic Algorithm (GA) is used in many fields as one of an intelligent control method. It shows some effective results in robotics fields to solve the problem of path design to avoid a collision to stopping or moving obstacles. For more details about genetic algorithm see [FANG, 1994].
The authors thought to adopt it to this subject and studied the possibility with computer simulation [KRCUM, 2005], [KRCUM, 2007].
The algorithm of GA starts with the definition of (a) Priorities, (b) Requirements, and (c) Constraints. The primary requirements can be rated by considering its effectiveness in reducing the risk of accidents in regard to the state-of-the-art techniques and technologies, their conformity with the international and national rules and regulations, and their cost-effectiveness. System constraints involve monetary, legal and technological factors imposed by the national and international authorities, as well as system implementation time constraints.

Collision Avoidance Control System with GA
Collision avoidance is one of the most important problems for ship navigation, because this subject is so dangerous not only in the open sea but in the complex situation such as harbour zone or narrow waterway.
When the ship is manoeuvred manually the operator should watch the situation, make judgment and control the ship. In those process, the criteria of judgment is so complex that miss judgment or miss operation would be able to occur. For a precise judgment and operation, GA is thought to be an adequate method.
The collision avoidance control system is constructed with following functions:

1) Get the information of another ship with ARPA system;
2) Decide the navigating condition with GA.

The subject of this problem is how to avoid one or several ships which are oncoming, crossing or passing her own route safely. The difficulty of this subject is that the head direction to have the optimum course changes every time depending on a ship position or condition. To decide the optimum avoiding course, we applied Genetic Algorithm.

As the evaluating function, we considered following conditions: *a* - the level of danger is better as it is lower; *b* - the length of avoiding path is better as it is shorter; *c* - the avoiding course is better as it is more straight; *d* - the loss of energy is better as it is smaller.

From those conditions, we evaluate the avoiding course with following equation:

$$f = w_1 \cdot a + w_2 \cdot b + w_3 \cdot c + w_4 \cdot d \quad , \qquad (1)$$

here w_1, w_2, w_3, w_4 are weighting factors.

The step of decision of optimum course with GA is as follows:

- Set the random passing points from present position to finish position as the initial condition
- Evaluate the course with (1)
- Select the course which has higher value and change the passing point with roulette method
- Change the course with new optimum course which has lower value of evaluation
- Repeat this operation 100 times.

The results were shown good in some case but not good in another case. Although some of them might be solved with small improvement, there is an essential problem that it should meet a transportation rules.

Discrete event simulation approach

The discrete event simulation approach adopted enables modelling of the system as it evolves over time by representing the changes as separate events. There are numerous ways of describing the mechanism of the logic within discrete event simulation. Event scheduling is the first way simulations were developed. An event is anything that changes the system statistics (also known as the state of the system) other than the mere passage of time. The essential idea of event scheduling is to move along the time scale until an event occurs and then, depending on the event, modify the state of the system and possibly schedule new events.

The arrival and departure of vessels at a port occur at distinct points of time. This is referred to as events. The number of events occurring in a port is finite; thus the discrete event simulation approach offers the best fit.

One of the possible methods for transport stream modelling is by using Petri's nets [GUDELJ, 2006]0, [GUDELJ, 2007]0. This approach turns out to be very convenient for achieving the desired tasks because of the following reasons: the Petri's nets [MURATA, 1989] are based on causal-consequence connections found in abundance in transport problems and the graphical representation by means of the net elements is easily perceived by man, i.e. there an easy way of visualization of the transport problem under consideration. Discrete-event dynamic systems can be used to easily represent all the activities performed by the complex terminal system. In particular, Petri Nets give an immediate and powerful graphical representation of all the necessary operations. Examples will be given of how information flows are modelled.

Information flows and their modeling

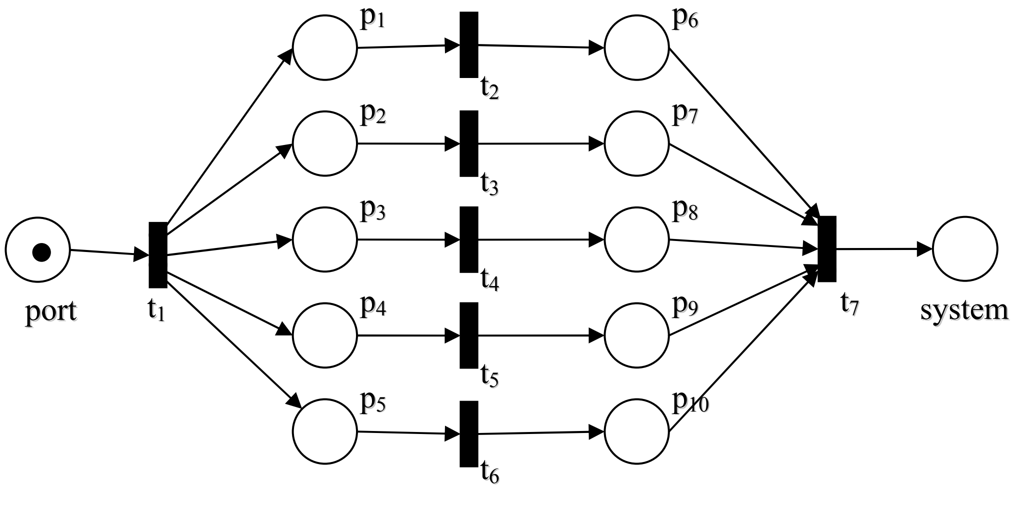
The term "information flow" should imply the whole set of data used by the system which facilitates passenger and cargo transfer. In order to reduce congestion and increase safety and efficiency on ports, it is necessary to dispose of exact and timely information about the

movement of the transport vehicles, the total volume of the transferred cargo, the duration of coordinated activities at the port for transferring the cargo and the conditions in the port. Except for their independent importance for the operative management, these flows exert also substantial impact on the choice of the strategic solution for optimizing the control of transport activities.
There are three types of information:

1. Static data – the input of data proceeds once and updating is made after a very long period of time. Such data concern information about the ship (vehicle) – name, identification number, load capacity, engine power, fuel, velocity, etc.; data for the hydro-meteorological regime of the water (transport) route – dimensions, depth, flow velocity, lock clearance, time for lifting/letting down the ship or time for passing through the lock, height of gates under the bridges, situation of the border check-points, etc.; port characteristics, for the ships; storehouses, internal port transport, norms for reloading of cargoes from storehouse → quay place →ship and vice versa, supply of spare parts, etc.
2. Dynamic data with longer duration of updating – these are data for the load type, time for loading the ship and hour of departure, rate stakes, freight cost, time and date of ship arrival at the different points, etc.
3. Dynamic data with short duration of existence – coordinates of ship location, hydro-meteorological forecast and temporary changes in the water route. The updating of dynamic data is made automatically or manually by the servicing personnel.

The users of information might be: Ship; Navigation company; Ship owner; Load senders; Shipping agency; Load recipient; Port; Inspection on navigation; Marine police; Customs office; Ecological organization; Rescue-coordination centre; Border checkpoint; Railroad centre; Motor transport centre; Others.
All types of data can be presented by Petri's nets, in which the transitions represent the transfer action itself and the places indicate which data have already been transmitted.
Figure 2 below shows Petri net corresponding to data transmitted from the port to the control system. The port transmits information about: Quay places – situation, dimensions, depth; Port equipment for carrying out the reloading operations at each quay – stationary and mobile; Access roads to the quays for the motor and railway transport; Specialization of the quays for reloading certain cargoes, especially hazardous cargoes; Possibilities for supply of water, fuel-grease materials, food, electric supply, etc.; Weighing (measuring) the cargo.
The port receives information about: Arriving loads – type, quantity, allocation, packing; Type of transport delivering the loads; Possibilities for storage and special requirements; Certificate of the load from the customs office; Time of ship arrival; Specific conditions during the stay of the ship; Freight cost; State of the loading rooms; Type of the loading rooms.

Figure 2: Petri net modelling information flows



Conclusion

In order to meet the challenge of modern maritime development, greater skills and knowledge are required and education is becoming even more important. The future should not be taken for granted. Our generations have the responsibility to convince future generations of the need for technical skill and education. The responsibility of education is to produce a great many talents with ideas and work abilities.

Integration of modeling, simulation and optimization tools will allow looking at the overall picture and help guide better decision-making. It will allow bringing together tools from various modeling domains such as traffic movement, communication processes, hospital operations for rapidly building a virtual representation of an emergency response scenario. The requirements for such a framework include the capabilities for integrating non-homogenous software and a user base that includes non-computing professionals. We proposed the Petri net model and the genetic algorithm to obtain the good solutions. This approach turns out to be very convenient for achieving the desired tasks because the Petri's nets are based on the graphical representation by means of the net elements is easily perceived by man, i.e. there an easy way of visualization of the transport problem under consideration. If an intuitive and easy-to-read graphical model is the main concern rather than an exact description of the underlying system. It is shown the potential of genetic algorithm to improve the solutions. All these techniques are very effective for improving the engineers and officers' management experiences and operation skills in emergency situation. But for cadets who were lack of practical experiences, they had to spend most part of terms to learn theoretical courses and got course's marks on land.

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Author biography

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Maja Krčum was born in Split, Croatia (1958). She was graduated from the Faculty of Electrical, Mechanical Engineering and Naval Architecture, University of Split on March 1981. She received a graduate degree (M.Sc.) at the Faculty of Electrical Engineering, University of Zagreb in 1996. Her master's thesis was entitled “Simulation on Model of Shipboard Electrical System”. In 1997, she was appointed Head of Department, also working as a tutor and counsellor. Now, she is quality manager at the Faculty. She was participated in a number of both national and international conferences where her papers and lectures were generally acknowledged as an active and valuable contribution towards the development of her profession. Her primary interest lies in the field of shipboard propulsion systems, with a special emphasis on electrical propulsion and its numerous applications (simulation methods). She is also a member of several national and international societies (e.g. IEEE, TIEMS, KOREMA…)

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