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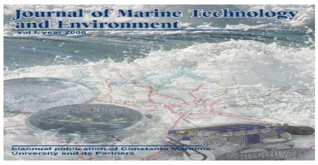

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STUDY OF A FREQUENCY CONVERTER POWERED BY SINGLE PHASE VOLTAGE DESIGNED TO CONTROL THREE-PHASE INDUCTION MOTOR

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Abstract. The paper presents the design and the experimental study of a prototype of frequency converter powered by single phase voltage designed to control three-phase induction motor for the needs of the Laboratory of electric drives of the Technical University - Varna. A number of tasks related to the design of the basic elements of the frequency converter as a bridge rectifier, bridge inverter and driver board are determinate and solved. A special programming of the converter is realized concerning different operating regimes of the three-phase induction motor. In addition, numerous experiments are conducted with the real-made prototype.

Key words: frequency converter, induction motor, inverter, microcontroller, PWM.

1. INTRODUCTION

Variable-frequency AC drives are now available from fractional kilowatts to very large sizes, e.g. to 15 000 kW and transistor based pulse-width modulated (PWM) voltage source converters driving induction motors are almost exclusively used [1]. These motors are currently widely used in ship electric drives. Figure 1 illustrates the basic power circuit topology of the voltage source inverter.

Today constant U/f (volt per hertz) drives are built using PWM IGBT-based inverters and the speed range includes very low speeds although operation very near to zero speed (less than 1 Hz). Ideally, by keeping a constant the U/f ratio for all frequencies the nominal torque-speed curve of the induction motor can be reproduced at any frequency. If the U/f ratio is kept constant the stator flux, stator current, and torque will be constant at any frequency. This means that to control the torque it needs to simply apply the correct amount of U/f (V/Hz) to stator windings [1].

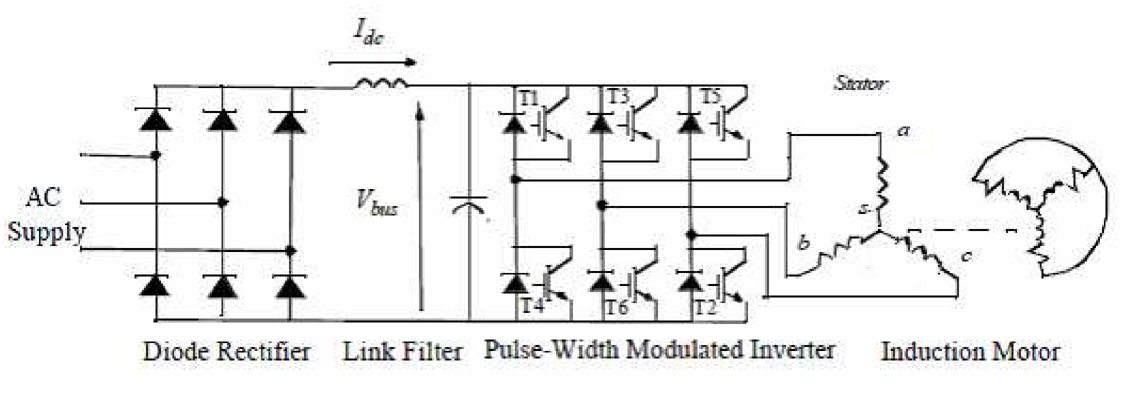

Figure 1 Basic circuit topology of pulse-width modulated inverter drive [1]

2. STEPS OF THE CONVERTER DESIGN AND BUILDING

The task is to design and realize a modern energy efficient system of frequency control of three-phase induction motors.

The performance and the reliability of the designed device is significantly increased if it is used for control of the inverter a microcontroller, which combines many functions in one. Thanks to the advanced capabilities of the microcontroller greater accuracy and speed of the regulatory process is achieved, which has a beneficial effect on the mechanisms driven by the motor. A digital implementation of the system is selected, based on a specialized microcontroller and integrated voltage inverter as each of them is characterized by its specific function setting the operation of the device[5], [7]. Since the microcontroller is capable to operate in communication regime via UART (Universal Asynchronous Receiver / Transmitter) [6] a serial protocol for data exchange is necessary for conversion to universal serial bus (USB), which facilitates the connection to PC. The main elements of the realized frequency converter are:

- Specialized microcontroller for frequency control of 3-phase induction motors by sinusoidal PWM - Freescale MC3PHAC [2], [4];
- Specialized integrated inverter for frequency control of the 3-phase induction motors by PWM - Fairchild FNB41560 [3].

There are highly intelligent modules, embedded discrete components constituting an inverter system, designed to work with electric motors with rated power ranging from a few tens of watts to tens of kilowatts. One such module is the typical monolithic integrated inverter FNB41560 of Fairchild company. Thanks to this newly developed module inverters with very small dimensions can be constructed, used in professional applications such as air-conditioning and refrigeration equipment, the field of automation and other custom applications. The inverter unit combines low losses, IGBT transistors with short circuit protection and optimized driver boards. The system reliability is further increased thanks to the built-in thermistor for temperature control, additional function to control the voltage of the power transistors and current protection input. Three independent terminals of of the power transistors emitters make possible the track of the current of each phase of the motor.

The recommended schematic diagram of the integrated inverter module is shown in Figure 2. The main element in the scheme of the power inverter module is the specialized integrated circuit FNB41560.

The main requirements to the inverter are sufficiently high response – at least 20 kHz and presence of inverse ultrafast diodes to conduct the reverse currents and voltage pikes caused by switching processes and connecting the inverter to inductive loads.

The inverter module FNB41560 of the company Fairchild meets those requirements. The inverting module consists of a three-phase inverter bridge circuit composed of six ultrafast N-channel IGBT transistors with reverse ultrafast diodes as well as two logical drive schemes to control the upper HVIC and lower LVIC transistors of the inverter bridge.

The used microcontroller MC3PHAC is monolithic specialized microcontroller intended to control AC motors and featuring high performance. It is designed specifically for the needs of inexpensive and relatively simple to implement systems for frequency control of 3-phase electric drives. The device is self-adaptive and configurable, depending on the environment in which it is located. It contains all active functions, laws and algorithms essential for ensuring the control part of the frequency converting system of 3-phase induction motor in open loop without feedback.

The MC3PHAC microcontroller unit (MCU) can operate in two regimes:

- Independent regime – in it MC3PHAC is controlled by hardware configuration consisting of discrete components.
- Communication regime – when MC3PHAC is operated by software from an external device such as a PC or another microcontroller via an interface for serial communication.

Our scheme is realized by using the second regime - Figure 3.

The MCU is operating through the specialized software FreeMASTER. It is easy to use tool for diagnosis, monitoring and visualization of data in real time. The program provides a fully independent monitoring of the performance variables in the operating system. A multiple variables in function of the time can be visualized shown in a window type "oscilloscope" or to be displayed as a text. FreeMASTER also supports additional features such as buffer for data transmission from the device to the host computer.

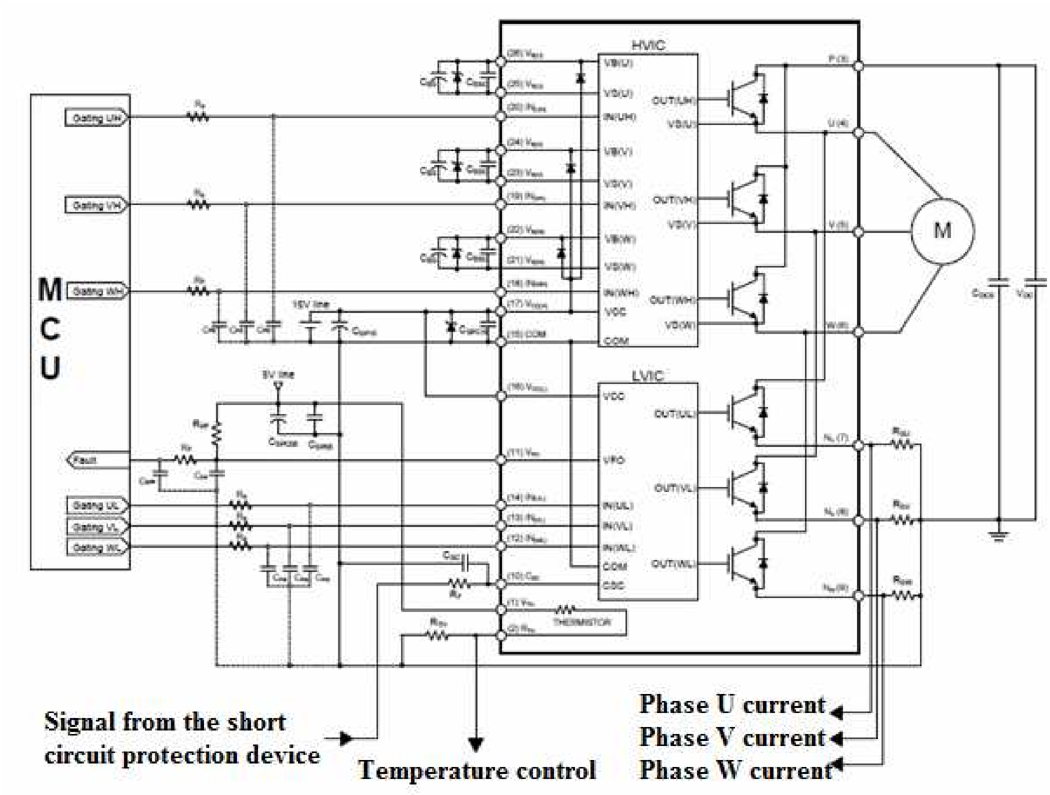

Figure 2 General schematic diagram of the inverter module

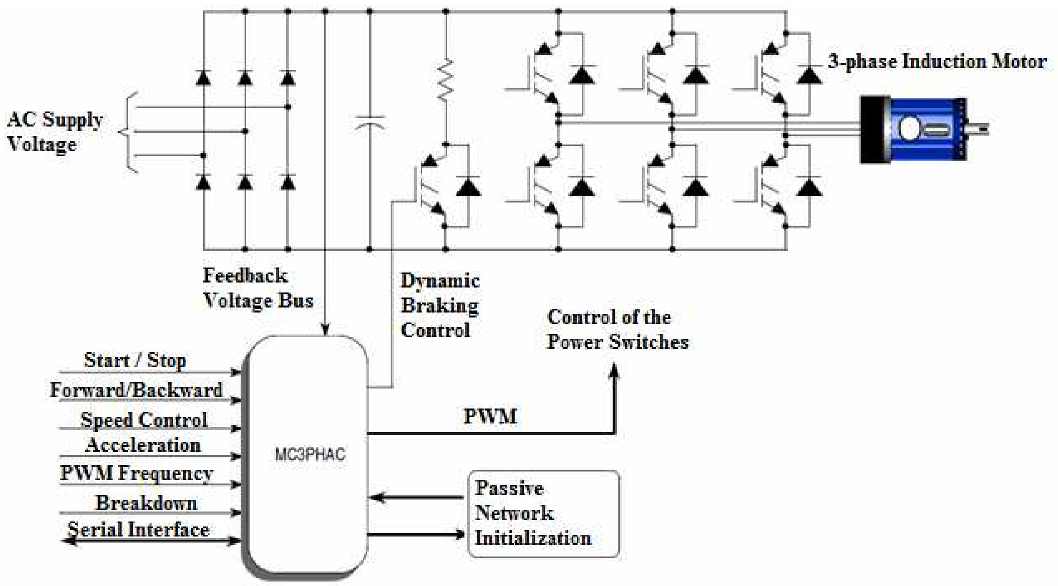

Figure 3 Steerable electric drive, based on microcontroller MC3PHAC

3. EXPERIMENTAL INVESTIGATION OF THE DEVELOPED PROTOTYPE OF FREQUENCY CONVERTER

Actually is realized a laboratory prototype of the above-described converter and a number of experiments are conducted with it – Figure 4.

The scheme of the experimental set is presented in Figure 5. The results are set out as oscillograms.

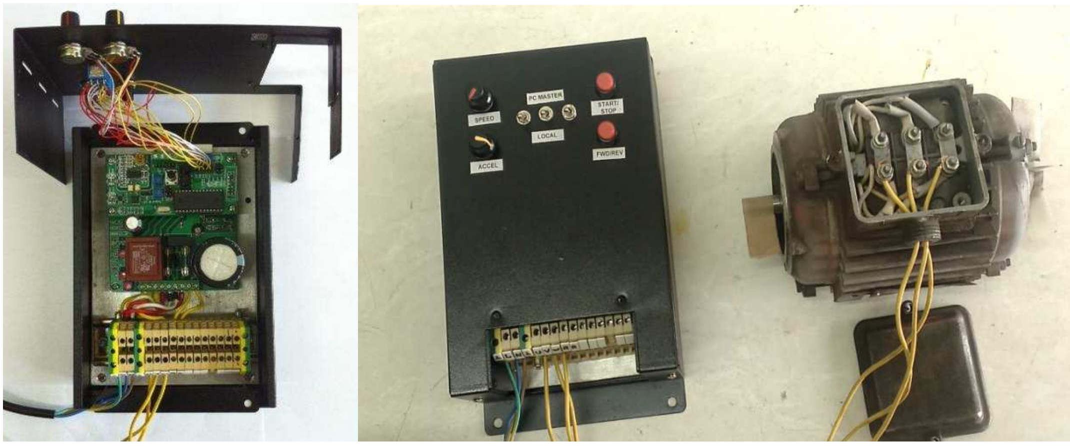

Figure 4 General view of the developed prototype of frequency converter

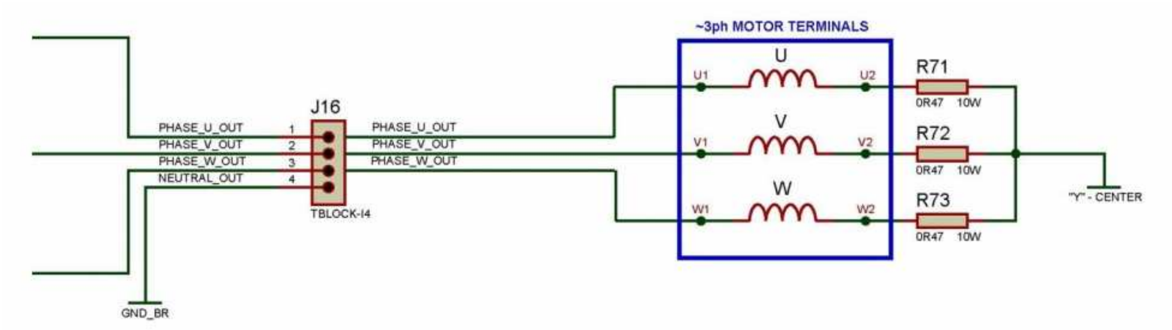

Figure 5 Schematic diagram of the experimental set

Originally are recorded the switching pulses at the output of the specialized microcontroller MC3PHAC generating the three-phase PWM voltage-Figure 6.

The following results represent the three-phase voltages (line and phase) applied to the three-phase induction motor set at different values of the parameters of the inverter-Figures 7 and 8.

The special feature of the scheme is that it is possible to split the supply voltage of the circuit of the supply voltage of the motor. This can be done if a DC supply voltage from external independent source is required.

The AC voltage supplied to the control system needs to be with a rated value of 220 V ±10%, 50 Hz and in case of DC power supply the later needs to be at value of 0÷330 V.

Besides the phase and line voltages are also recorded the phase currents obtained during the operation of the frequency inverter with three-phase squirrel cage induction motor in open circuit regime. The objective is to show the amplitude, frequency and phase shifts between voltages and currents-Figures 9 and 10.

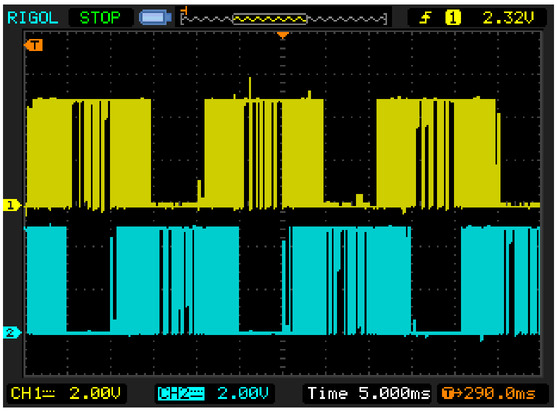

Figure 6 Oscillogram of the switching pulses in phase W. Yellow signal – upper transistor; blue signal – lower transistor. Set frequency of the output voltage – 50 Hz, set PWM frequency – 10 kHz

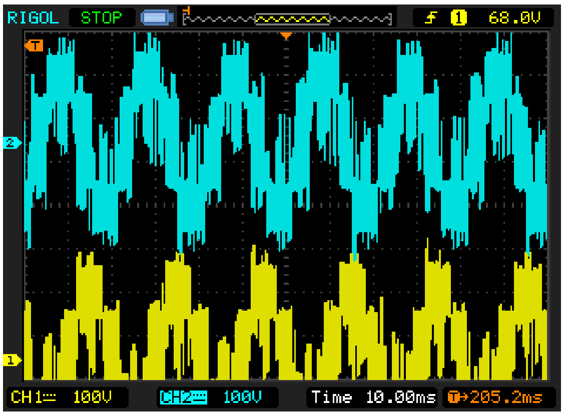

Figure 7 Oscillogram of the phase voltages in phase V and phase U. Yellow signal - U_{UN}; blue signal - U_{VN}. Set frequency of the output voltage – 50 Hz, set PWM frequency – 10 kHz

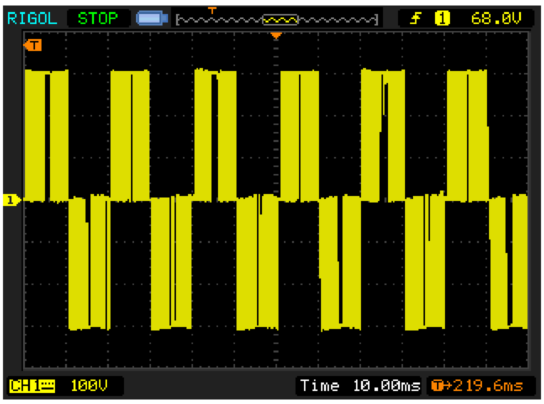

Figure 8 Oscillogram of the voltage between phases V and U - U_{UV}. Set frequency of the output voltage – 50 Hz, set PWM frequency – 10 kHz

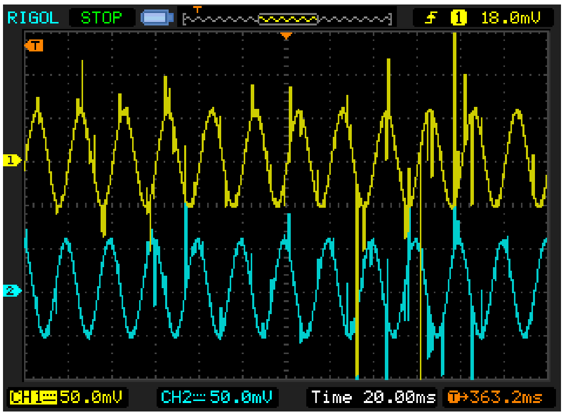

Figure 9 Oscillogram of phase currents in phase V and phase U. Yellow signal - I_{UN} ; blue signal - I_{VN}. Set frequency of the output voltage – 50 Hz, set PWM frequency – 10 kHz

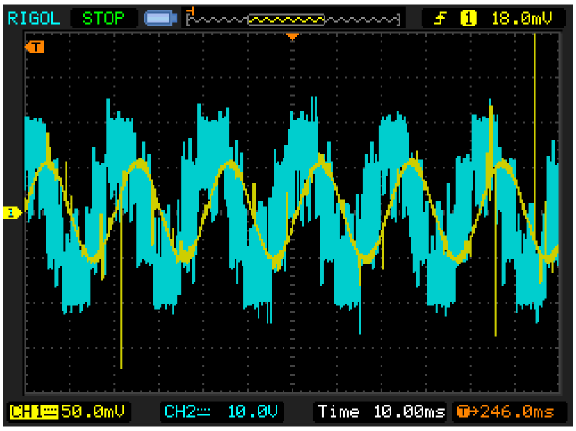

Figure 10 Oscillogram of the phase shift between the phase current – I_{WN} and voltage U_{WN} of phase W at open circuit operation of the induction motor. Yellow signal - I_{WN}; blue signal - U_{WN}. Set frequency of the output voltage – 50 Hz, set PWM frequency – 10 kHz.

4. CONCLUSIONS

In the Laboratory of electric drives of the Technical University-Varna is designed, constructed and experimentally tested a prototype of frequency converter based on microcontroller MC3PHAC designed to control three-phase induction motors.

The experimental studies of the prototype lead to the following conclusions:

- The frequency converter is without feedback and allows smoothly change of the speed of the motor above and below the nominal speed applying the condition U/f = const.;
- The inverter allows a three-phase induction motor with a rated voltage of 3x220 V, with delta connected windings to be powered from single-phase AC network with a voltage of 220 V. The scheme also allows the motor to work autonomously without external involving and system control from PC in communication regime;

In speed increasing regime the acceleration to the set speed can be smoothly set in the range of 1 Hz/s to 127Hz/s. This condition is satisfied and in speed decreasing regime.

- A system of dynamic braking is included and during the process of stopping the energy accumulated in the motor windings is dispersed in braking resistor.

The power supply voltage is divided from the control voltage as it allows the use of an independent power source, such as autonomous DC or AC network.

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GIS TECHNOLOGY IN MARITIME: A MET INNOVATION AT MAAP

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Abstract: This paper introduces MAAP, its curriculum and research and extension initiatives including but not limited to one of MAAP latest best practices in introducing GIS to its community (internal and external) who share similar passion for MET innovation. The various GIS–based accomplishments led and shared by MAAP as part of its Research and Extension Services (RES) initiatives are presented namely: several GIS-based papers presented and published both local and international; GIS-based project proposals for campus management enhancement prepared for MAAP, Bataan Peninsula State University (BPSU), Lyceum University of the Philippines (LPU) and Catanduanes State University (CSU); capability Training on GIS for MAAP community and other interested institutions; and Commission on Higher Education (CHED) and Department of Science and Technology (DOST)- endorsed National 3-day GIS Conference are also discussed. There are 78 proposed GIS-based research project workshop outputs currently being implemented by 20 higher educational institutions (HEIs) in the Philippines, 17 of which are applicable to any maritime education and training institutions (METIs). MAAP has six on–going GIS- based special academic research and development projects which this paper intends to share to co-AMFUF members.

Key words: GIS, managemenyt, location, software, industry, people, event, methodology, implementation, service

1. ABOUT MAAP

The Maritime Academy of Asia and the Pacific (MAAP), is situated on a 103 hectare campus in the Bataan Peninsula about 50 km. west-southwest of the Philippine capital city, Manila, at 14°26'42.04"N and 120°32'58.79"E.

Figure 1 MAPP@Google Earth, 12 August 2012

Figure 2 Map courtesy of Google Earth MAAP Imagery on 19 April 2005

Founded in January 1998, MAAP is a non-stock, non-profit academic institution established by the Associated Marine Officers' and Seamen's Union of the Philippines (AMOSUP), to ensure continues supply of competent marine deck and engine officers thru quality and full scholarship education (www.maap.edu.ph). As full scholars, MAAP students enjoy state of the art facilities, free board and lodging and sure employment from their sponsoring company that has collective bargaining agreement with the AMOSUP.

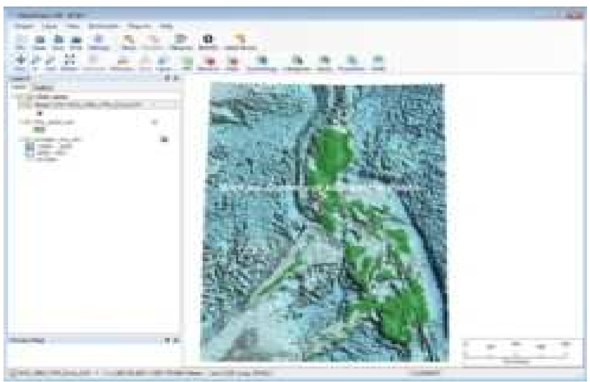

Figure 3 MAPP geographic location (red square) and Philippine map using Mapwindows software

MAAP being at the forefront of innovative MET through outcome-based program enhancement, is positively affected by the rapid rise in global demand for maritime manpower.

Since its establishment on January 14, 1998, with an initial intake of only 150 scholars in June 1999, and with currently 500 fresh men scholars admitted annually, MAAP has continued to grow with 2,015 scholars this year. To date MAAP has produced a total of 1, 498 competent maritime graduates (646 BSMT, 7021 BSMarE and 131 Dual course who are all officers. For the past 15 years, MAAP graduates have registered an average passing rate of more than 98 % in their PRC licensure examination as operational level deck and engine officers.

2. MAAP MET CURRICULUM

The Commission on Higher Education (CHED) is the government entity responsible in regulating and supervising higher educational institutions (HEIs), offering formal education programs like Bachelor degrees in Marine Transportation (BSMT) and Marine Engineering (BSMARE). To date, there are 95 maritime HEIs offering BSMT and BSMarE, 67 of which are offering both courses, while 28 offer only either one of the courses The BSMT and BSMarE curricula of MAAP consist of 155 and 158 units of professional and general education courses, respectively; plus 40 units which is equivalent to one-year shipboard training during the third year.

Similar to other Philippine maritime schools, MAAP students' curriculum consists of three -year classroom and one-year on board ship. It also conducts various post-graduate maritime courses and continuing education training.

The education core courses for BSMT and BSMarE cover a diverse array of topics including: information and communication technology; ships and ship routines; meteorology and oceanography; world geography; maritime pollution and prevention; and merchant ships search and rescue.

These courses can potentially be enhanced with the integration of GIS topics relevant for future deck officers, faculty, and researchers. Starting 2011, MAAP is the only school in the country authorized by CHED to offer vertically articulated Master degree programs in Marine Transportation (MSMT) and Marine Engineering (MSMarE). GST topics can be integrated more in-depth in its graduate curriculum.

MAAP addresses the global demand for highly qualified maritime officers due to its various innovative value- added MET programs, and one of which is the introduction of GIS as one of an innovative tool for MET programs enhancement.

3. MAAP RESEARCH AND EXTENSION SERVICES INITIATIVES

As part of MAAP Research & Extension Program, the Department of Research & Extension Services (DRES), with more than one year coordination (2011-2012) with GIS specialist Dr Alejandro Tongco from Oklahoma State University, has accomplished a number of training activities (whole month of March 2012) and presented and published papers on GIS. DRES has been fascinated with the wide application of GIS in any discipline which may be applicable in MET, research, extension and campus management. It has been surmised that the real power of GIS is in analyzing the relationships of people, places, things, and events using several spatially referenced data layers representing the earth.

The maritime or shipping industry is certainly spatial in nature, since it possesses many of these components: people (e.g., mariners of all kinds, maritime and shipping industry personnel, and MET students and faculty); places (e.g., ship destination and departure points, docks, ports, approaches, harbors, shipping lanes, mariner's and student's addresses, and MET schools); things (e.g. ships and watercraft, marine infrastructures and installations, protected marine sanctuaries, and artificial reefs); and events (e.g. transport routes and networks, hazards and incidents including fire, shipwrecks, groundings, oil and chemical spills, and piracy). It is opined, that the maritime industry including MET schools can leverage the power of GIS through analysis and finding innovative ways, means and solutions to the shipping industry's multifaceted and interlinked global challenges. The increasingly widespread application of GIS in the maritime and related industries necessitates the integration of GIS techniques in METIs.

3.1 Effects of GIS Integrated in METIs

GIS may be used to improve teaching methodologies and curriculum content.

Maritime graduates equipped with GIS skills shall be honed with spatial analytical competence and be at eased with equipment and activities in the workplace that uses GIS. It behooves MET schools to not limit itself to producing maritime graduates to simply man vessels but to give graduates the opportunity and encouragement to be analytical thinkers and to train them to be future researchers in the wide ocean of maritime research.

GIS may be used as an aid to teaching and as a skill to be taught to students.

Instructors can integrate GIS techniques in field laboratory exercises, e.g. to plan for, perform, and analyze results of fieldwork. At the same time, GIS software skills can be taught to students to enhance the student's analytical thinking abilities. These would require instructors with required GIS skills that maybe developed through training and experience. A potent method to build GIS knowledge capability in MET schools is for instructors and students to engage in GIS-based research and development activities.

GIS techniques may be integrated in the MET curriculum.

The enclosure of GIS topics can enrich the curricular content of several courses. Existing courses may include: information and communication technology (ICT); ships and ship routines; meteorology and oceanography; world geography; maritime pollution and prevention; and merchant ships search and rescue. Ideally, GIS may be offered as a distinct course or subject within the BSMT degree program, e.g., Geospatial Technology in Maritime. This would be an in-depth treatment of the subject matter, taking into account the various GIS applications in the maritime industry. A similar course or subject could also be offered in the graduate school within the Master of Science in Marine Transportation (MSMT) or Shipping Management (MSSM) program being offered by the newly established MAAP Center for Advanced Maritime Studies (CAMS) accredited by the Commission on Higher Education (CHED) in 2011.

Some examples of GIS curriculum content are those of the GST competency model developed by the GeoTech Center (2012). Further, in establishing curriculum guidelines on GIS, the following URLs from the internal pages of the company IPTC or Integrated Power Technology Corporation founded by Engr. Andrew Gizara, would be good references:

1. Geographical Information System Development (http://www.intpowertechcorp.com/gis.htm);
2. Supervisory Control & Data Acquisition Development (http://www.intpowertechcorp.com/scada.htm);
3. Velocity Performance Prediction Development (http://www.intpowertechcorp.com/vpp.htm);
4. Unmanned Marine Vehicles Development (http://www.intpowertechcorp.com/umv.htm)

3.2 Various MAAP GIS papers presented and published

The first MAAP GIS paper and power point presentation thru its DRES Director was entitled "Human Security and GIS: An Introduction" during the CHED-endorsed 20th General Conference by the International Federation of Social Science Organizations (IFFSO) with theme "Social Science Perspectives on Human Security", hosted by Lyceum of the Philippines University in Batangas City on November 18-20, 2011.

The second 12-page paper was entitled "Introducing GIS as Catalyst for Research, Extension Services and Development of Catanduanes Island" in support to the 2012 National Conference on Water and Biodiversity (BIOME3) with thematic Scope "Water plus Diversity Equals Food plus Life" at Virac Catanduanes Island on October 21-23, 2012.

The third 10-page paper was entitled "GIS as an Innovative Tool for MET Research, Extension and Campus Management Enhancement: MAAP Initiatives (2013), AM Baylon and EMR Santos" in support to the 10th Anniversary Celebration of TRANSNAV.

This was presented at the Gydnia Maritime University on June 19-20, 2013 wherein the DRES Director serves as one of the members of the International Programming Council, Scientific Programme Committee (Rewriters) since June 2007. The said paper is published in refereed book by GMU and Nautical Institute Book (ISBN 978 -1-138-00104-6), Weintrit A; Neumann T (eds): STCW, MET, HR and Crew Manning, Marine Navigation and Safety of Sea Transportation: A Ballema Book on Marine Navigation and Safety of Sea Transportation on Transportation, CRC Press, Taylor & Francis Group Boca Raton, London-New York- Leiden 2013 pages 13-22.

3.3 Various MAAP prepared GIS-based project proposals

MAAP thru DRES has embarked on GIS-based project proposals within MAAP and with other institutions who share the same passion for innovation.

As early as November 7, 2011, a 46-page GIS-based project proposal entitled "University–wide Integration of geographic information systems (GIS): enhancing campus management & academic capability building of Bataan Peninsula State University (BPSU)" has been prepared which was also shared with Lyceum International Maritime Academy (LIMA) of the Lyceum of the Philippines University (LPU) (41-page GIS-based proposal) & the Catanduanes State University (CSU) (39-page GIS-based proposal) for their respective institution-wide GIS implementation.

A proposed institution-wide implementation of GIS for a MET school may be illustrated in the diagram below.

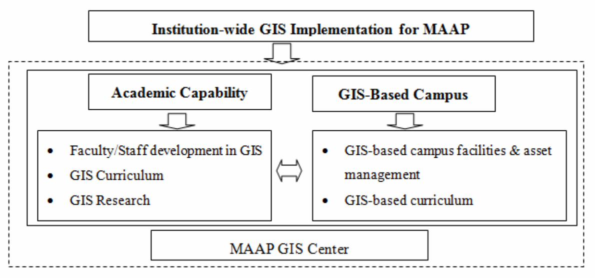

Figure 4 Institution-wide GIS Implementation System

As illustrated in the diagram, the two major target areas for GIS engagements are: academic capacity building through GIS techniques and technologies, &

enhancing campus management through GIS. Academic capacity building includes faculty and staff development in GIS, GIS curriculum and instruction, and GIS-based research. GIS-based campus management includes GIS-based campus physical facilities, assets, and resource management and GIS-based student admissions and alumni management. Academic capacity building and campus management can mutually benefit and grow from each other through GIS. For example, faculty and staff can enhance their GIS skills through involvement in GIS-engaged campus facilities and asset management as well as in GIS-based student admissions and alumni management studies. On the other hand, the campus management can benefit from the involvement of faculty and staff. Involving both students and campus managers in campus wide projects can likewise mutually enrich GIS-engaged curriculum and instruction and campus management. GIS-based research in the maritime is a new wide-open field. GIS-skilled graduates are expected to be more prepared to face the new challenge, whether the research is sea or land based. Within the campus, these activities could well be facilitated by a physical entity such as a GIS center or a Research and Extension Services center with GIS-skill technical staff, to act as the central coordinating body and knowledge base, as well as to set the direction and sustainability of GIS-engaged activities in MET schools. Furthermore, in order to institutionalize GIS, this may need to be integrated in the MET's strategic vision, mission, and goals, specifically in departments and offices where GIS activities are to be conducted.

GIS is an information system that takes advantage and produces valuable information about the unique geographic locations and inter-relationships among people, places, things, and events in the campus. The application of GIS to manage campus facilities and assets is applicable to any school campus or facility as well.

Campus GIS involves the development and management of a central spatial database of all buildings and assets within. The spatial database allows for a fast and easy query of the campus' physical resources relative to each other. GIS provides for the visualization, query, and reporting of specific information. Additionally, a GIS data portal can provide data access for faculty, staff, researchers, and students in campus.

A central spatial database provides an enhanced communication and cooperation between departments, offices, faculty, staff, students, and administration. As a result, workflows become more efficient and resources are efficiently allocated. Planning, monitoring, and assessment of campus resources are better informed through GIS. Information is more accurate as a result of GIS analysis.

GIS data can be visualized and thus minimizes guesswork on factors involved in campus processes. The overall result is increased campus productivity and economic efficiency.

3.4 Capability GIS Training at MAAP and other institutions

MAAP has already embarked on integrating GIS in the campus in March 2012. MAAP believes that human resources are the key to institutional enhancement made possible thru capability building. An initial introduction of GIS for its faculty, staff, and students was conducted. Two separate four-day GIS hands-on workshops were held, one group for faculty and staff (20-23 March 2012 and 26-29 March 2012) at MAAP campus, For upper-class students, GIS hands-on workshops were conducted every Saturdays (March 12, 17 and 24, 2012). Student-participants had presented their GIS-Based research project entitled "Piracy Attack Analysis and Monitoring through GIS "by 1/Cl Sun, Patrick John Austine and "Integration of GIS to Automatic Integration System (AIS)" by 1/Cl Espago, Marville Cullen. Dr Alejandro F Tongco, GIS Specialist from Oklahoma State University, had served as technical adviser, facilitator and trainer on GIS, organized and shared by MAAP at various venues: Philippine Navy Education and Training Compound (March 7-10, 2012), Bataan Provincial Hall (March 13-16, 2012), MAAP and BPSU community (March 12, 17, 21-24, 2012) and other HEIs (March 26-29, 2012). MAAP-DRES on the other hand thru power point presentation had trained the participants on how to write a GIS-based research project proposal (includes title, summary of your project, background and significance, beneficiaries and implications, objective, data, procedure, results and analysis, conclusion, future work).

One of the training includes learning to Apply GIS in Institutional and Marine Transportation Research with Alejandro F. Tongco, PhD, the Research Specialist – Geographic Information Systems (GIS) as the trainer from the Oklahoma State University U.S.A (al.tongco@okstate.edu). The target 20 participants were Administrators, Office Heads, Faculty Members, and Researchers with minimal qualifications as being average computer-literate; and enthusiastic to learn GIS. The free downloadable software used were: MapWindow GIS, Quantum GIS, OpenOffice, Google Earth, ArcGIS Explorer Desktop, 7-Zip, and other software as may be necessary. The workshop taught participants with the basics of GIS and to how use GIS software. These skills included: fundamentals of GIS; Basic hands-on skills how to use a common GIS and visualization software (install/ download, file management and to process and display data); and how to plan, implement, and report a GIS project. With fast internet connection at the training venue, all participants brought their individual Laptop (newer version with at least 2-gig memory; installed with Windows XP, Vista,

or 7), Maps and datasets from MAAP/AMOSUP, government agencies (e.g. CHED, TESDA, NAMRIA, MARINA, NOAA, POEA, etc.), and other sources (including digital maps, GIS datasets if any, paper maps, and tabulated data) and Thumb/flash drive.

Each participants had accomplished all workshop exercises (Exercise 1: Creating a Simple Map; Exercise 2: Creating Complex Maps with Several Layers; Labeling and Using the Coloring Scheme; Exercise 3: Digitizing Features (Creating Points, Lines, and Polygons) in MapWindow, Google Earth, and ArcGIS Explorer, including conversion between KML or KMZ and GIS files; Exercise 4: Editing Attribute Tables, including using Open Office Calc (or Excel) to Populate Tables ;Exercise 5: Geoprocessing and Exercise 6: Projections, Geographic Referencing, and GPS); individual simple GIS project ,power point presentation of GIS project and packaged project digital output (includes project report, power point presentation, datasets used and produced, and related files - all in single folder). All packaged output (in single digital forlder) were submitted to the DRES Director.

4. CHED AND DOST ENDORSED NATIONAL 3- DAY GIS CONFERENCE

Organized by MAAP's empowered Department of Research and Extension Services, the very first CHED and DOST -endorsed national 3-day PAEPI-PAIR-PhilARM-NAUCP-AERA National Conference on Geographic Information Systems (GIS) with theme "Enhancing Research, Extension Services and Institutional Capacity of HEIS through GIS" was successfully hosted and accomplished by MAAP at its campus in Mariveles Bataan Philippines on March 29-31 2012.

The activity was conducted in cooperation with partner agencies as shown on National GIS Conference photo souvenir. Photo from left to right: Bataan Provincial Government (PMO Engineer Ric Yuzon); CHED Zonal Research Regional Center/ Angeles University Foundation (Director Dr. Roberto Pagulayan); Commission on Higher Education (ARMM CHED Dr. Carmencita Aquino); Philippine Association of Extension Program Implementers with SEC CN-10059 (PAEPI President/MAAP Director/Dr. Angelica Baylon); Association of Universities of Asia and the Pacific (AUCP Secretary General Dr Ruben Umaly); Department of Science and Technology (DOST Regional Director Dr. Victor Mariano as GOH and Speaker); Maritime Academy of Asia and the Pacific (MAAP President Vadm Eduardo Ma. R. Santos, AFP (Ret.)); National Research Council of the Philippines / Philippine Normal University (NRCP VP/Chair Division/PNU President Dr. Ester Ogena), Oklahoma State University, USA (represented by the OSU GIS Specialist Dr. Alejandro Tongco as trainer and resource speaker); Provincial DOST (Director Ms. Rosalina Ona); Asian Educational Research Association (AERA Chair Dr. Gismo Agulan).

Other GIS partners not on photo are Philippine Navy (PN Education and Training Head (N8) Capt. Anthony Sean Villa), Commission on Higher Education (CHED Regional Director Dr Virginia Akiate); Philippine Association of Research Managers (PhilARM President Dr. Ricardo Castro) and Philippine Association of Institutional Researchers (PAIR President Dr. Genaro Japos).

With target audience such as higher educational institutions, local government units, academicians, researchers, and extensionists Cum PAEPI Annual General Assembly and Election of Officers 2012 on March 29-31, 2012, the following objectives have been accomplished: introduced GIS and its wide uses in enhancing institutional capability in research and extension services, as well as to present samples of various proposed GIS projects for PN, LGUs, BPSU and MAAP; presented a pilot project for a university-wide GIS integration at BPSU for possible implementation in 2013-2015; produced proposed GIS project outlines from participants for their respective institutions; came up with a joint resolution among partner organizations in endorsing a number of GIS projects for the support of government agencies; and provided a venue for networking among professional organizations with the same thrusts of enhancing research, extension services and institutional capabilities of the member individuals for the betterment of the institution or organization that the participants served.

Likewise the PAEPI General Assembly and Election of Officers with theme "Solidarity and Transparency Towards a Consolidated PAEPI" had been accomplished that assembled all members of the association for the presentation of accomplishments and future plans and programs beneficial for its members; reinforced and supported development partnership among extension stakeholders and members; and consolidated the association towards a stronger and sustainable Philippine Association of Extension Program Implementers (PAEPI with SEC 10059), led by its

DRES Director of MAAP as PAEPI President and MAAP President as PAEPI adviser.

This first GIS national activity was participated in by 20 Higher Education Institutions (HEIs) and has come up with a list of proposed GIS-based research projects to be implemented in their respective institutions. There are 78 GIS-based projects proposed by 20 participating institutions nationwide (MAAP; Philippine Merchant Marine Academy; Holy Cross College of Davao; SPAMAST; Asian Institute of Maritime Studies; University of the Cordilleras; San Beda College; New Era University; Baliuag University; Bataan Peninsula State University; Philippine Normal University; Philippine Navy; University of Luzon; CPU Outreach Center Central Philippines University; Central Luzon State University; University of Northern Philippines; Cebu Normal University; Mindanao Sanitarium Hospital; some local government units participated by Balanga City and Bataan Province) with total of 115 seminar-workshop active participants. There were 18 GIS-based research projects that have been successfully presented: three GIS-based presentations by the Philippine Navy (6-9 March 2012); four GIS-based presentations from the Province of Bataan by local government units (13-16 March 2012); four GIS-based presentations by Bataan Peninsula State University (20-23 March 2012); three GIS-based presentations by the Maritime Academy of Asia and the Pacific (12,17,24 March 2012); and four GIS-based presentations by other MET/HEIs (20-26 March 2012). Some of the 17 GIS-based proposed projects applicable to METIs are as follows:

1. GIS-based Campus-wide Management of Physical Facilities & Assets;
2. GIS Applications in Ship Management: Database Query & Visualization of Ship's Facilities & Assets;
3. Development and Production of IMO Compliant Philippine Electronic Navigational Charts(ENCs) Using Geospatial Technologies;
4. Development of a National Maritime Geospatial System & Data Portal: A Research & Extension Initiative;
5. Students, Faculty and Staff Profiling Using GIS;
6. Enhancing Alumni Data Base Using GIS;
7. A Graduate Level Subject Offering "GIS with Maritime Applications " at the MAAP Center for Advanced Maritime Studies;
8. Identifying Vulnerability of Different Barangays to Different Types of Risks Using GIS;
9. Tracer Study of MET Graduates;
10. Research on the Employability of MET Graduates in the Various Programs Offered;
11. Community Baseline Data on Outreach Areas;
12. Monitoring of Outreach Projects Using GIS;
13. Enhancing Outreach Community Planning Using GIS;
14. Resource Mapping of Outreach Areas Using GIS;
15. Integrating GIS in Outreach Program Implementation;
16. Geo-Hazard Mapping & Risk Reduction Management by GIS;
17. Impact Evaluation of Outreach Projects Using GIS.

MAAP is always on the search for innovative means to enhance its various MET programs. Out of these 17 GIS-based proposed projects applicable to METIs, the first 7 project titles are currently being implemented at MAAP.

4.1 On-going MAAP GIS – Based Special Academic Research Projects

1. GIS Visualization and Spatial Analysis of MAAP Midshipmen, Faculty, Staff, and Alumni (Profiling of MAAP Midshipman, Faculty, Staff and Alumni Using GIS)

Project Lead: VADM Eduardo MA R Santos, AFP (Ret) and Dr A M Baylon

Associate Project Lead: Capt. R F Raz MM

Assistants (2): Ms Janice W Vergara and MIS/CS graduate [GIS proficiency desired]

Duration: 1 year initial development and continuously maintained thereafter

Project Output: GIS data visualization, trends, and patterns profiling cadets, faculty, staff, and alumni of MAAP. Also (Optional): Mapping of nationwide cadet applicants and passers based on residences and high schools graduated.

Significance: Past and present human resource distribution trends are viewed and analyzed. Data is valuable for intelligent expansion planning, recruitment, retention, policy making, and sustainability of students and human resource at MAAP. This will be a "first" for a MET school in the country.

Implementation Processes include:

- Collection of digital basemaps, e.g. administrative boundaries down to barangay level;
- Collection of national census and demographic data;
- Collection of MAAP human resource data of cadets, faculty, staff, and alumni from Registrar or Records Office or Human Resource Dept;
- Mapping and profiling cadets based on information such as residence, course, and year;
- Also, profiling of faculty and staff including the alumni.

Hardware/Software Requirements: Laptop; GIS Software (Gratis).

2. GIS-Based Campus-wide Management of MAAP Physical Facilities and Assets

Project Lead: VADm Eduardo MA R Santos, AFP (Ret) and Dr A M Baylon

Associate Project Lead: Capt R Raz MM

Assistants (2): Civil Engineer or Architect and CS/MIS graduate [GIS and web mapping proficiencies desired].

Duration: 2 years initial development and continuously maintained thereafter.

Project Output: A computerized GIS visualization and database of campus infrastructure, physical facilities, and assets within, including engineering utilities, campus natural resources, and landscape. It will allow users to access and perform complex queries of information about MAAP's varied resources.

Significance: The President, MAAP Governing Board, Stakeholders, Sponsors, and ACAT/EXECOM of MAAP are provided with a single, centralized data source to aid them in decision-making related to planning, expansion, management, monitoring, and assessment of MAAP's resources toward sustainability of its vision, mission, and goals. This will be a "first" among the country's MET schools and HEIs.

Implementation Processes include:

- Training of project team in specific GIS project skills;
- Collection of GIS basemaps of the area, e.g. administrative boundary, landcover, and natural resources;
- Collection of campus infrastructure layout, boundary, landscape, and topography drawings;
- Acquisition of high-resolution aerial and/or satellite imagery;
- Analog-to-raster-to-vector data conversion and geo-referencing;
- Designing the GIS database;
- GPS data collection, digital conversion, and attribution of vector footprints of campus infrastructure and natural resources;
- Asset inventory and classification;
- Creation of the various thematic map data layers;
- System design and implementation of project output for Intranet-ready accessibility;
- CD/DVD data packaging.

Hardware/Software Requirements: Desktop; Laptop; Sub-meter GPS Receiver; Range Finder; Digital Camera with Geo-tagging Capability; Large-format Color Scanner (36-in wide); Digitizing Tablet; GIS Software (Gratis); Measuring Tape (2), 5 and 100 meters length.

3. Development and Production of Electronic Navigational Charts (ENCs) at MAAP Using Geospatial Technologies

Project Lead: Capt Alfonso MM

Associate Project Lead: Capt R Raz MM and Dr. A M Baylon

Assistants (2): MIS/CS and BSMT/MTE graduate [GIS, hydrography, and maritime cartography proficiencies desired].

Duration: 2 years initial development and continuously maintained thereafter.

Project Output: ENCs for the Philippines that meet the minimum requirements of IHO S-57 and compatible with the IMO-mandated Electronic Chart Display Information Systems (ECDIS). ENCs shall include information such as coastal topography, bathymetry, landmarks, geographic place names, and marine protected areas. Integration of emergent datasets such as currents, tides, meteorology, and other oceanographic variables shall be explored.

Significance: Presently the production of ENCs in the Philippines is planned or done by NAMRIA as the sole government hydrographic body authorized by IHO for each country. However, development and production can be hastened if a third party such as MAAP is also given authorization to do so by IHO. ENCs that depict Philippine waters are mainly manufactured and purchased abroad. Having this capability, MAAP will be able to quickly develop and produce its own digital and paper navigation maps to serve the teaching and training needs of its cadets and seafarers on continuing education.

GIS technologies will be used to produce data layers to update and upgrade existing navigation maps for the Philippine archipelago. This will be a "first" in the country's MET schools.

Implementation Processes include:

- Training of project team in specific GIS project skills;
- Collection of basemaps, both paper and digital;
- Collection of paper and digital (if available) such as navigation charts, bathymetric maps, country administrative maps, and coastal maps
- Analog-to-raster-to-vector conversion as necessary;
- Geo-referencing;
- Re-projection to a uniform spatial referencing system;
- Upgrading and integration of necessary features and oceanographic variables such as currents and tides;
- Production of desired thematic data layers;
- Conversion to IHO S-57 format or most recent version;
- Establishment of the "MAAP Navigation Mapping Center";

Hardware/Software Requirements: 2 Dual-monitor Desktops; Large-format Color Scanner (36-in wide); Large-format Color Printer (36-in wide); Digitizing Tablet (8.5 x 11-in); ENC Production Software (Existing free software, such as that of NOAA's, will be utilized as applicable.)

Possible Collaboration: NAMRIA

4. Development of an Archipelago-wide Maritime Geospatial Information System and Data Portal: A Research and Extension Initiative of MAAP

Project Lead: Capt P Alfonso and Dr. A. M. Baylon

Associate Project Lead: Capt. R F Raz MM

Assistants (2): MIS/CS/MT graduates [GIS, hydrography, maritime cartography, and web mapping proficiencies desired]

Duration: 2 years initial development and continuously maintained thereafter

Project Output: A comprehensive web-based maritime geospatial information system and data portal for the maritime and shipping industry as well as for other ships plying or entering Philippine waters.

Significance: Presently, no national maritime information system exists in the country. This will be first of its kind, and to be spearheaded by MAAP DRES. It shall develop and produce GIS data layers and a system for easy data access by users in the industry.

Implementation Processes include:

- Training of project team in specific GIS project skills;
- Collection of paper and digital (if available) such as navigation charts, bathymetric maps, country administrative maps, incidence maps, and coastal maps;
- Analog-to-raster-to-vector conversion as necessary;
- Geo-referencing;
- Re-projection to a uniform spatial referencing system;
- Upgrading and integration of necessary features and oceanographic variables such as currents and tides; Production of desired thematic data layers;
- System design, data distribution, and web mapping;
- Establishment of the “National Maritime Geospatial Information Center”.

Hardware/Software Requirements: Desktop; Laptop; GIS and web map server software.

Collaborations Desired: Philippine Navy, Coast Guard, MARINA, and/or NAMRIA.

5. A Graduate-Level Subject Offering: GIS with Maritime Applications at the Center for Advanced Maritime Studies

Project Lead: VAdm Eduardo MA R Santos, AFP (Ret) and Dr. A. M. Baylon.

Associate Project Lead: DRES Staff Ms Janice Vergara, Visiting MAAP Lecturers/Faculty

Duration: 1.5 years

Project Output: Syllabus and detailed lesson plan for a graduate-level and continuing-education subject offering in “GIS with Maritime Applications”. Subject content shall focus on the fundamental principles of GIS and its increasingly wide applications in maritime transportation, ports management, and marine and coastal environment.

Significance: GIS is now part of the emergent technology skills needed in maritime information technologies. Knowledge of GIS is becoming highly desired, for example, in marine transportation traffic and fleet management as well as in ports planning, operations, and administration. This will be a “first” in the country.

Implementation Processes include: The theory and principles behind GIS shall be discussed and applications in the maritime shall be given more emphasis. Since GIS technology applications in the maritime is a fairly new field, the subject offering shall be continuously developed and open always to new developments and inputs especially from visiting lecturers who have experienced actual exposure to the technology. State-of-the-art applications of the technology shall also be examined closely, such as those in the Netherlands and Singapore.

Hardware/Software Requirements: Student-supplied.

6. GIS Application in Ship Management: Database Query and Visualization of the Ship’s Facilities and Assets

Project Lead: Capt Raz and Dr. A. M. Baylon

Associate Project Lead: Visiting MAAP Lecturers and Faculty [Desired]

Assistants (2): MIS/CS/MT graduates [GIS and web mapping proficiencies desired]

Duration: 2 years

Project Output: A computerized GIS-based database and query system of the physical and spatial aspects of a ship. Data shall include ship’s floor spaces, facilities, assets, and manning assignments, including passenger and/or cargo hull capacities.

Significance: Ship captains, master mariners, and ship managers will be able to visualize the various floors of a ship; facilities, equipment, and assets therein; manning assignments; cargo hulls and allocations; and their conditions, through a single, centralized source on a computer system. Having access to this data quickly allows effective and efficient management and monitoring of the ship’s facilities and assets.

Implementation Processes include:

- Gathering of the ship’s blueprints;
- Analog-to-digital conversion;
- Referencing and vectorization;
- GIS database design and attribution;
- GIS database query and display system;

Hardware/Software Requirements: Desktop computer; large-format scanner.

5. CONCLUDING REMARKS

Most of the sharing on scientific and technological studies and researches that includes GIS as a software technology are mostly found in seaborne trade and none in an educational setting for campus, research and MET enhancement.

This makes the paper unique and original. It may be first time in MET that downloadable free GIS software may be used in an educational setting. This is feasible because GIS can be used in whatever discipline as long as four (4) components exist: People, place (location), things and events. It only takes imagination and creativity to utilize technology such as GIS with significant outputs. GIS as a tool can be applied in any discipline. GIS can be introduced initially as one of the topics within existing maritime-related courses and can be used as a tool in field research work.

Then, it can grow into a distinct GIS course within the undergraduate and graduate programs. With GIS-skilled faculty and staff researchers, GIS-based maritime researches can be developed.

A GIS-based campus management system can grow hand in hand with that of GIS in teaching, research and extension services, constantly nourishing and building each other's knowledge base toward an institution-wide integration of GIS technologies.

VAdm Eduardo Ma R. Santos, AFP (Ret) – MAAP President. He is a man with class of his own, with strong expertise and proven innovative leadership in the areas of human resource development and management, organizational development, public administration/governance, military intelligence and strategic leadership, built on previous experiences, education and prestigious and sensitive positions he held. VAdm Santos is a graduate of the Philippine Maritime Academy.

He finished his MS Computer Systems Management at the US Naval Postgraduate School Monterey, California, USA.

He is an alumnus of Ateneo De Manila, having finished both his secondary education and graduated with his Master of Business Administration. With regard to his continuing military education, Vadm Santos had his Naval Command Course at the US Naval War College, Newport Rhode Isle, USA.

Worth mentioning are some of his prominent and top positions he held: Manager, Port of Manila,

Commander, 5th Coast Guard District, Chief of Staff, Philippine Fleet, Chief, Naval Intelligence, Philippine Navy, Flag Officer in Command, Philippine Navy and Acting Vice Chief of Staff, AFP. He has with him a string of awards and decorations as a proof of being a military man of substance.

He also received a number of recognitions in research and MET leadership because of the accomplishments of MAAP under his admirable leadership.

He continues to innovate a lot of MET new academic projects being implemented by MAAP which is recognized by government agencies in the Philippines. He is the pioneer President of the Maritime Academy of Asia and the Pacific (MAAP) and the Executive Vice – President of the Association of Marine Officers and Seamen's Union of the Philippines (AMOSUP-PTGWO-ITF).

Prof Angelica M. Baylon, PhD-MAAP Director for Research and Extension Services.

She holds a Master in Shipping Business Management (MSBM), PhD in Educational Administration, MBA major in Management, MS Chemistry and BS Chemistry, all earned with honors and scholarships/grants. She was also trained on Research and SPSS Short Course at Cardiff University, UK for the accomplished collaborative research led by the Seafarers International Research Centre (SIRC), which was funded by the European Commission (2004-2006).

She also completed the IMO model courses and the free fall lifeboat familiarization and has a seaman's book. With more than 20 years teaching experience, she taught Math Chemistry and Physics in Far Eastern University (FEU Manila), University of the Philippines (UP Manila), PMMA and MAAP.

She earned the highest rank of Prof IV at PWU Graduate School in 1996 prior to her Directorship position at Philippine Merchant Marine Academy (PMMA in 1997-1998) and Executive Dean Position in MAAP in 1999. She is a commissioned reserved officer of the Philippine Navy with the rank of Lieutenant Commander (LCDR from May 5, 2005 to date).

She currently serves as President of the Philippine Association of Extension Program Implementers (PAEPI), pioneer Director for Research and Extension Services at the Maritime Academy of Asia and the Pacific (MAAP), 2011 pioneer International Exchange Professor at the Bataan Peninsula State University (BPSU) & 2012 pioneer Honorary Professor of the Australian Asian Foundation.

She is a member of the National Research Council of the Philippines (NRCP) and other prestigious research associations both local and international. She is recipients of the 2011 ASIAN Research Leadership

Award and other national prestigious awards on research and extension services.

Professional details can be read at http://ph.linkedin.com/pub/prof-angelica-baylon-phd-msbm-mba-ms-bschemistry/31/b03/140 and www.maap.edu.ph.

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THE SATELLITE NAVIGATION SYSTEMS – STATUS, PROBLEMS, FUTURE

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Abstract: The satellite navigation systems are very important for the contemporary navigation, including and maritime navigation. Currently, there are several satellite navigation systems, used actively for navigation. There are several systems, which are currently being constructed. To provide the necessary coordinates and other navigation dates, they use geodetic reference systems (GRS). GRS are systems of parameters, describing the Earth as a complex geometric and physical figure. These parameters are defined based on the large amount of geodetic, astronomical, gravimetric, Doppler, geomagnetic and others measurements, related to the determination of the figure of the Earth. In world practice, including and satellite navigation systems, are used parameters of several GRS systems - of US, Russia, China, India and others. Can be mentioned that during 1979 was developed by the International Association of Geodesy and Geophysics (IUGG) international GRS system, which is recommended for application in various geodetic activities. This system is known as GRS 1980. There are some differences in the values of some of the corresponding parameters of the various GRS due to different Earth measurement databases, which are used for their determination. These parameters are continuously specified during the performing of every subsequent Earth measurement and adjusted so that GRS systems to be modified without changing of their abbreviations. There is an irreversible trend regarding getting near of values on corresponding parameters in the different GRS to the internationally accepted, moreover these differences are negligible.

Key words: ellipsoids, geodesic reference systems, global and regional navigation satellite system.

1. ACTUAL SATELLITE NAVIGATION SYSTEMS

Nowadays for determining of position have been used two global and one regional navigation satellite systems, which have high accuracy by defining of position, velocity and time at any point on the Earth's surface and in Earth space in real time.

1.1 NAVSTAR GPS - Global satellite navigation system of the United State

The american idea for building a satellite navigation system came in the end of 50s, after launching of first artificial Earth satellite "Sputnik 1" on 4 October 1957 from USSR. Till realization of this idea passed about 20 years. The first test satellite was launched into orbit on 14 July 1974 and on 22 February 1978 was launched the first operational satellite of the current system.

Between 1978 and 1980 the number of satellites reaches 6 and the system is in operation from 6 January 1980. The last of these 24 satellites, needed for complete Earth observation, is launched into orbit at the end of year 1993. The system is passed into fully operational on 17 January 1994. [1] The maximum number of satellites can be reached 32, which is the capacity of the transmission channel of the navigation data. At any time of the day over 15º above the horizon can be observed 8 satellites, over 10º - 10 satellites and more than 5º - 12 satellites.

Generally NAVSTAR GPS (NAVigation Signal Timing And Ranging Global Positioning System) was developed as a military project. In order to avoid tragedies like the fallen from Russia South Korean civilian airliner in 1983, US put into commission the system for civil use. In 1999 the US announced a plan for enhancement of system accuracy for civil purposes. The method of selective availability was canceled in 2000 and the use of additional frequencies was part of system innovation.

Figure 1 Logo, orbits and satellites of Global satellite navigation system NAVSTAR GPS [1], [2]

NAVSTAR GPS consists of three segments: space, control and user. Space segment consists of 24 operational satellites in six geocentric orbital planes containing four satellites with orbit inclination to Equator at an angle of 55º. They cross the Equator line uniformly less than 60º. (Fig. 1) The orbital altitude of satellites is 20,200 km. The satellites are arranged so that at any time and in any Earth point to receive the signal of at least four of these satellites. Each satellite completes a full orbit round for 11 hours and 58 minutes. The satellites have a guaranteed 10 year period of exploitation.

The system has 7 additional satellites for complete configuration in case of failure of one of these 24 operational satellites. [1], [2] The control segment consists of earth control center, located in Colorado Springs and monitoring stations, situated in different earth areas that manage the whole system. The user segment consists of GPS-receivers, which utilized for military and civilian purposes.

1.2 GLONASS - Global satellite navigation system of Russia

Development of Russian global satellite navigation system starts in the 60s, and on 27 November 1967 was launched the first navigation satellite "Cosmos-192" into orbit. In 1979 was put into operation the navigation system of the first generation "Cicada". Testing processes connected with getting in exploitation of system GLONASS began in October 1982 with launching into orbit of the satellite "Cosmos-1413". In 1995 finished the launching of all satellites into the orbit.

The system GLONASS (GLObalynaya NAvigatsionnaya Sputnikovaya Sistema) consists of 24 active satellites located in three orbits at altitude 19,100 km. Each orbit is inclined to the Equation in 64,8° and contains eight satellites. Each satellite makes a full orbital round for 11 hours and 15 minutes. [2], (Fig. 2)

Insufficient project funding makes a system out of usage for almost a decade. Full coverage of Earth's surface from GLONASS was restored again in year 2010. In order to avoid future similar scenarios, NAVSTAR GPS and GLONASS are currently using 31 satellites, 24 of which are operational and 7 additional.

Civil application of GLONASS system is less active than the NAVSTAR GPS, due to low supply and demand of receivers on the market. From several years the companies manufacturers offer combined receivers GLONASS/GPS. (Fig. 2) Major advantage of GLONASS is that the system can be used successfully in regions with latitudes greater than 75°, where it has a much better coverage from NAVSTAR GPS. The accuracy of GLONASS is as the same as NAVSTAR GPS.

Figure 2 Orbits, satellites and receiver of Global satellite navigation system GLONASS [10]

1.3 BeiDou - Regional satellite navigation system of China

Implementation of BeiDou (BeiDou Navigation Satellite System) started in year 2000, when was launched into orbit the first satellite from the system. Then China declared that began building an independent, open and compatible satellite navigation system that will be performed in three stages. BeiDou is the Chinese term for the constellation "Big Bear". Abbreviated system displays abbreviated BDS. In year 2007 the name has been changed to COMPASS.

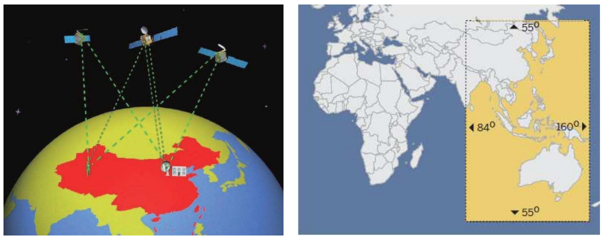
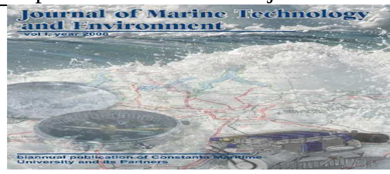


Figure 3 First stage BeiDou-1 and BeiDou-2 coverage [5]

The first stage of the program - BeiDou-1, was completed in 2003 by launching into orbit of three geostationary satellites. [5], (Fig. 3) They ensure navigation system of China region. This stage was announced as experimental. The second stage of the program - COMPASS (BeiDou-2), was completed in year 2012 when was launched 14 satellites, provided great coverage in the Asia-Pacific region (Fig. 3). From December 2012 the system was officially used in Asia region. [5] The third stage, which will be coming into force in year 2020, ensure arising to orbiting satellites till 30. Thus the system COMPASS will provide global coverage. The negotiations lead between China and Russia will ensure the compatibility of COMPASS with GLONASS.



2. SATELLITE NAVIGATION SYSTEMS UNDER CONSTRUCTION

Currently one global and two regional satellite navigation systems are under process of construction. Some countries as Taivan, consider the possible construction of regional satellite navigation system.

2.1 GALILEO - Global satellite navigation system of the European Union

GALILEO is the European project of global satellite navigation system, designed as an alternative to systems NAVSTAR GPS and GLONASS. It must ensure the independence of the European Union of american and russian systems and to serve the EU needs in the field of economy and security. The signed agreement between the European Union and the United States ensure the compatibility of GALILEO with the NAVSTAR GPS.

The GALILEO system will comprise 30 satellites, placed in three orbits at altitude of 23,222 km. Each of the three orbits will have operational 9 and 1 additional satellites. The orbits have inclination to the Equator and to each other of 56°, which will allow very precise determination of location at latitudes above 75°. Each satellite will make one orbit round for 14 hours. It is planned that till 2019 all satellites to be launched staged into the orbit. [3], [4], (Fig. 4)

Figure 4 Logo, orbits and satellites of Global satellite navigation system GALILEO

The project started during year 2003 as a joint project of European Union and the European Space Agency. Besides the EU countries in project taking place also following countries: Israel, Morocco, Saudi Arabia, South Korea, India, Switzerland, Ukraine. The negotiations are held with the participation of representatives of Argentina, Australia, Brazil, Chile, Malaysia and Mexico. [3], [4].

The first two satellites of the system were launched in October 2011. They have names of children in the European Union that won on national competitions in aeronautics - Taste (Belgium) and Natalia (Bulgaria). Other satellites will also have names of children from other countries of the European Union. Till the end of 2014 are launched 6 satellites in orbit.

The GALILEO system expects to provide greater accuracy for all users compared to the current satellite navigation systems, better coverage at north latitude above 75° and guarantees system using even during the global conflict and war. Very important for maritime search and rescue operation (SAR) cooperative work of systems GALILEO and COSPAS-SARSAT, which is part of the Global Maritime Distress and Safety System (GMDSS). Now the accuracy in determination of position of emergency position indicating radio beacon (EPIRB), using COSPAS-SARSAT, is in range of about 5 km, which is insufficient. Creating of the GALILEO system will significantly improve this accuracy. [3], [4]

2.2 IRNSS - Regional satellite navigation system of India

In 2006 the Government of India has approved a project for building of regional satellite navigation system IRNSS (Indian Regional Navigational Satellite System). According to this project, the space system will include seven satellites. Three of them will be on the geostationary orbit and the other four - in geosynchronous orbits at an altitude of about 24,000 kilometers. (Fig. 5)

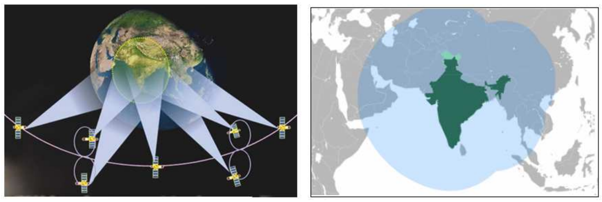


Figure 5 Satellite configuration and coverage of Regional satellite navigation system IRNSS [6]

According to the project plan, India will launch into orbit one satellite every 6 months. The system will be fully configured in year 2016. The first satellite from the system was launched in July 2013, the second - in April 2014 and the third - in October 2014. [6] IRNSS is designed to provide civic services in India and up to 1500 km beyond the borders. Signals intended for military purposes will be encrypted (Fig. 5).

2.3 QZSS - Regional satellite navigation system of Japan

The project for establishing a regional satellite navigation system QZSS (Quasi-Zenith Satellite System) is approved by the Government of Japan in year 2002. The system is designed to solve several important for Japan and Japan area tasks: improvement of characteristics and assessment to GPS signals in the Japan territory and provide useful services and functions from new generation, as warnings for earthquakes, weather forecasts, indoor-navigation and etc. In Japan QZSS system is known as Jun-Ten-Cho.

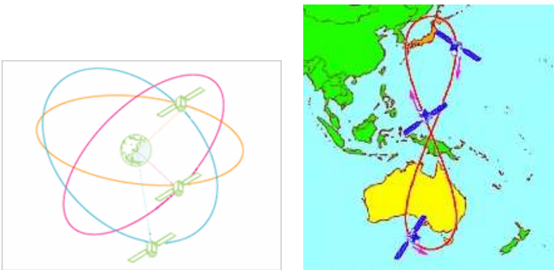


Figure 6 Orbits, satellites and coverage of Regional satellite navigation system QZSS [13]

According to the project the space system segment will include three satellites that will be on three high elliptical geosynchronous orbits, describing a complex trajectory over the region between Japan and Australia. (Fig. 6) Every satellite can be observed at an angle of 70º above the horizon during the whole day from the territory of Japan and Korea. This will clarify one big Japan problem - receiving of GPS signals in huge cities is almost impossible due to high buildings. This feature is giving the system name - Quasi-Zenith. The signals, which will be emitted from QZSS satellites, will be fully compatible with the NAVSTAR GPS signals. [13]

The first satellite of the system is launched in September 2010. It is intended to be deployed and ready for exploitation at the end of year 2017. It is assumed that after this year the number of satellites in the system will be increased to seven.

2.4 TRNSS - Regional satellite navigation system of Taiwan

Currently The Bureau of national space programs of Taiwan (National Space Program Office, NSPO) make assessment regarding potentialities of a future regional satellite navigation system TRNSS (Taiwanese Regional Navigational Satellite System). The program includes research and determination of satellites number required for full coverage of Taiwan area. It has be discussed several options for the space segment - 3, 4 or 7 satellite and their optimal configuration. [9]

3. GEODETIC REFERENCE SYSTEMS USED IN GLOBAL AND REGIONAL SATELLITE NAVIGATION SYSTEMS

Global coordinate system, together with the relevant ellipsoid and geodetic data source for its earth orientation are the main components of every geodetic reference system. When the orientation is in connection with geocentric, geodetic reference system is global. Such systems are satellite geodetic reference systems. They define three-dimensional coordinate systems that can single-valued identify all point objects on the Earth surface and in near-Earth space. The differences in geodetic reference systems used by global and regional satellite navigation systems are very small and lead to small distinction in the coordinate determinations - from few hundredths to one or two tenths of arc second. [8]

3.1 International Geodetic Reference System GRS 1980

GRS 1980 is an internationally accepted geodetic reference system with ellipsoid GRS 1980, which is adopted as an Earth geometric model and model of her gravitational field. The system is developed by the International Association of Geodesy and Geophysics. On the General Assembly of the association in 1979 in Canberra, Australia, the system is recommended for using in whole geodetic activities. The system GRS 1980 was introduced by almost all countries in the world and is the base of satellite geodetic reference systems. It is planned GRS 1980 to be used in GALILEO.

The most important basic parameters of GRS 1980, presented in a usable form in geodetic coordinate transformations are: [7], [8], [14]

- *Geometric constants*:

- semi-major axis (equatorial radius) a = 6 378 137.0 m;
- semi-minor axis b = 6 356 752.3141 m;
- polar radius of curvature c = 6 399 593.6259 m;
- flattening f = 0.003 352 810 681 18;
- reciprocal flattening 1:f = 1:298.257 222 101;
- first excentricity squared e^2 = 0.006 694 380 022 90;
- mean radius of semi-axes R_1 = 6 371 008.7714 m.

- *Physical constants*:

- gravitational constant GM = 3 986 005 x 10^8 m^3 s^{-2};
- angular velocity ω = 7 292 115 x 10^{-11} rad s^{-1};
- dynamic form factor J_2 = 108 263 x 10^{-8};
- normal gravity at equator γ_e = 9.780 326 7715 m s^{-2};
- normal gravity at pole γ_p = 9.832 186 3685 m s^{-2}.

3.2 World Geodetic Reference System WGS 1984

WGS 1984 is a global geodetic reference system of USA, which used ellipsoid WGS 1984 adopted Earth geometric model and the model of its gravitational field. The most important basic parameters of WGS 1984 are: [1], [2]

- *Geometric constants*:

- semi-major axis (equatorial radius) a = 6 378 137.0 m;
- semi-minor axis b = 6 356 752.3142 m;
- reciprocal flattening 1:f = 1:298.257 223 563;
- first excentricity squared e^2 = 0.006 694 379 990 14;
- mean radius of semi-axes R_1 = 6 371 008.7714 m.

- *Physical constants*:

- gravitational constant GM = 3 986 004.418 x 10^8 m^3 s^{-2};
- angular velocity ω = 7 292 115 x 10^{-11} rad s^{-1};

- normal gravity at equator γ_e = 9.7803253359 m s^{-2};
- normal gravity at pole γ_p = 9.8321849378 m s^{-2}.

When comparing the basic parameters of WGS 1984 and GRS 1980 can be found negligible differences between some of them.

Basis on the global geodetic reference system WGS 1984 has been created a global geocentric coordinate system WGS 1984, which is used by the global satellite navigation system NAVSTAR GPS.

In the coordinate system WGS 1984 the prime meridian passes of 5,31" east from the Greenwich meridian. In maritime navigation GPS receivers are commonly used for determination of vessel position in a coordinate system WGS 1984. Therefore all modern navigational charts are in a coordinate system WGS 1984 (Fig. 7).

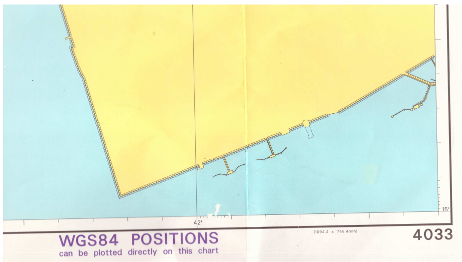


Figure 7 Navigational chart in coordinate system WGS 1984

3.3 *System with the Earth parameters PZ 90*

PZ 90 (Parametry Zemlya 1990) is the geodetic reference system of Russia, which used ellipsoid PZ 90, adopted for Earth geometric model and her gravitational model field. Basis on the geodetic reference system PZ 90 was established a state geocentric coordinate system PZ 90, which is an alternative to the global geocentric coordinate system WGS 1984. The coordinate system PZ 90 ensures working of global satellite navigation system GLONASS [2].

There are specified versions PZ 90.02 (2007) and PZ 90.11 (2012) of geodetic reference system PZ 90. At the end of 2012, Russia introduced new national geodetic reference system GRS-2011, which appears to be an alternative of system PZ 90.

The most important basic parameters of GRS-2011 are: [10].

- *Geometric constants*:

- semi-major axis (equatorial radius) a = 6 378 136.5 m;
- reciprocal flattening 1:f = 1:298.256 4151;

- *Physical constants*:

- gravitational constant GM = 3 986 004.415 x 10^8 m^3 s^{-2};
- angular velocity ω = 7 292 115 x 10^{-11} rad s^{-1};

3.4 *China Terrestrial Reference Frame CTRF 2000*

CTRF 2000 (China Terrestrial Reference Frame 2000) is the geodetic reference system of China. Based on CTRF 2000 was created geocentric coordinate system CGCS 2000 (China Geodetic Coordinate System 2000). It serves the workability of the satellite navigation system COMPASS (BeiDou-2).

The most important basic parameters of earth ellipsoid CGCS 2000 are: [11].

- *Geometric constants*:

- semi-major axis (equatorial radius) a = 6 378 137.0 m;
- reciprocal flattening 1:f = 1:298. 257 222 101;

- *Physical constants*:

- gravitational constant GM = 3 986 004.418 x 10^8 m^3 s^{-2};
- angular velocity ω = 7 292 115 x 10^{-11} rad s^{-1}.

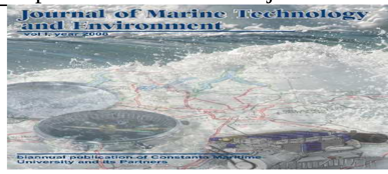
3.5 *Japanese Geodetic Datum JGD 2000*

JGD 2000 (Japanese Geodetic Datum 2000) is the geodetic reference system of Japan, created on the basic parameters of the international geodetic reference system GRS 1980. On the basis of GRS 1980 has been created geocentric coordinate system JGS 2000 (Japanese Geodetic System 2000). [12] [13] It will serve satellite navigation system QZSS.

4. CONCLUSIONS

In the near future for navigation will be used in total 4 global and 2 regional satellite navigation systems. This will lead to a significant increase in the accuracy of the navigation dates, which they provide. This will happen and due to GRS, which they use. Geodetic reference system GRS 1980 is a aggregation of internationally accepted parameters, defining the shape of the Earth and its dynamics. It was adopted for utilization by almost all countries. On its basis were created many national geodetic reference and coordinate systems, including and those that serve satellite navigation systems.

The parameters of GRS 1980 are determined on the basis of a huge volume of measurements of the Earth and thanks to the efforts of many scientists worldwide. For defined period of time these will be the main Earth parameters. When it was considered that they have become unusual and outdated, will be adopted new ones. This is coming from a fact that the Earth is not a frozen planet. The Earth is a dynamic system. Her speed of rotation and gravitational field is changing slowly, the flats inside are rearranging and hence she amends her form. In case that the competent international institutions consider that these basic parameters are no longer relevant, they will recommend and adopt for using new ones. Countries will also change their national geodetic reference systems.



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COMPARATIVE APPROXIMATE STUDIES ON THE SHIP'S ROLLING MOTION

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Abstract: The new geometrical and analytical techniques of nonlinear dynamics offer to the naval engineer ideal tools for studying the ship dynamics and stability. Between them, the bifurcation diagram, the Poincare map, the phase plane, and the time histories are considered in the paper in an attempt to demonstrate the low period solutions of the asymmetric roll equation derived by Kan and Taguchi. The model assume a linear damping, a restoring moment represented by a third-order polynomial and a single frequency harmonic excitation. For moderate forcing amplitudes, the system exhibits a period 1 motion, characterized by a period doubling bifurcation to a period 2 motion that warns about the beginning of a period doubling cascade to chaos. Two different approaches, the Fast Fourier Transform and the Harmonic Balance Technique are used to obtain approximate solutions for the period 1 and 2 motions and to predict the period doubling bifurcation by a stability analysis. The two sets of solutions match reasonably well with the numerical solution, especially for the first mentioned approach.

Key words: Fast Fourier Transform, Harmonic balance, Nonlinear Roll, Stability Analysis.

1. INTRODUCTION

A full dynamic's analysis of a ship's motion is an extremely difficult task involving the solution of a ship regarded as a rigid solid experiencing three types of displacement motions (heave, sway and surge) and three angular motions (yaw, pitch and roll). Accurate calculation of ship-wave hydrodynamic interactions leads to strongly non-linear models, whose analysis is almost very cumbersome and has a computational cost remarkably high.

Between the six motions of the ship, the roll motion is the most critical one, because it can lead to the ship capsizing. If we assume small motions in all modes of motion excepting roll and the existence of a coordinate system origin (i.e. the roll centre), then these assumptions lead to a single equation of motion in which roll is uncoupled from the other five degrees of freedom [1, 2]. This equation is linear for small angles of roll motions. As the amplitude of oscillation increases, non-linear effects come into play. They are due to the nature of restoring moment, which depends on the shape of the righting arm diagram, and of the damping.

Various models of roll motion containing such non-linear terms have been studied by many researchers. Thus, Dalzell [3] and Cardo et all [4] introduced in the equation of motion a damping moment containing linear-quadratic or linear-cubic terms in the angular roll velocity. Ikeda [5] proposed empirical methods for estimating various damping components such as wave, lift friction and bilge keel. Experimental investigation concerning damping has been carried out by Haddara , Umeda and Hamamoto, and others [6, 7].

On the other hand, the nonlinear restoring moment can be approximated reasonably well by quadratic and cubic polynomial of roll angle. Realistic restoring representations, like fifth or higher-order polynomial lead to tremendously problems when the analytical route is followed [8, 9].

Clearly, it is of great interest to be able to introduce in the equation of roll motion as many as possible of the parameters involved in a real sea, but analytical solutions are impossible in all but the simplest cases. Some useful information can, however, be obtained by considering particular cases, for example those in which damping is assumed linear, the restoring moment is represented by a third-order polynomial and the regular waves are described by a single frequency harmonic excitation. For these simplified models, steady state responses to the amplitudes of external forcing can be approximated analytically, by means of harmonic balance method, or numerically, using fast Fourier transform. In our paper, we explore the low period solutions of the asymmetric roll equation studied by Kan and Taguchi, and perform a stability analysis for finding the flip to a sub-harmonic motion of order two, that signals in fact the start of a period doubling cascade to chaos [10].

2. ROLL EQUATION

In the paper, the following equation, derived by Kan and Taguchi, is further investigated with a view to explain the roll instability:

$$I\frac{d^2\varphi}{dt^2}+\xi\frac{d\varphi}{dt}+W\cdot GM\cdot\varphi\left[1-\left(\frac{\varphi}{\varphi_V}\right)^2\right]=M \qquad (1)$$

where φ is the roll angle, t is the time, φ_V represents the vanishing angle of stability, I is the moment of inertia for roll, ξ the damping coefficient, W the displacement weight, $M=M_0+M_1\cos\Omega t$ the exiting moment, GM the metacentric height, and Ω the encounter angular frequency.

Equation (1) could be transformed into the non-dimensional form

$$\ddot{x}+\beta\dot{x}+x-x^3=f_0+f_1\cos\omega\tau \qquad (2)$$

by means of non-dimensional quantities:

$$x=\frac{\varphi}{\varphi_V},\omega_0=\sqrt{\frac{W\cdot GM}{I}},\tau=\omega_0 t,\beta=\frac{\xi}{I\omega_0},$$
$$f_0=\frac{M_0}{I\omega_0^2\varphi_V},f_1=\frac{M_1}{I\omega_0^2\varphi_V},\omega=\frac{\Omega}{\omega_0} \qquad (3)$$

The dots denotes the order of differentiation with respect to the non-dimensional time τ. Despite of its relative simplicity, equation (2) shows a wide spectrum of qualitatively distinct types of behaviours, including steady-state solutions, jumps to resonance or period doubling cascades leading to chaos [11, 12, 13].

It is difficult, within the scope of this article, to give a complete and detailed discussion of equation (2), so we restrict our attention here on the approximate solutions for the periodic orbits of period 1 and 2. This will be done in the next sections by means of two different approaches, namely the *fast Fourier transform* (hereafter denoted by FFT) and the *harmonic balance method*.

3. APPROXIMATE SOLUTIONS WITH FAST FOURIER TRANSFORM

Equation (2) has been numerically integrated with zero initial conditions by use of a Runge-Kutta-Gill procedure implemented under MalLab environment for the parameters values $\beta=0.15,\omega=1.8, f_0=0.1$, and different forcing amplitudes f_1. As forcing amplitude is gradually increased starting with 0, different types of periodic motions are obtained. The bifurcation diagram for x and $\dot{x}$, restricted to period 1-orbit and period 2-orbit, is presented in Figure 1.

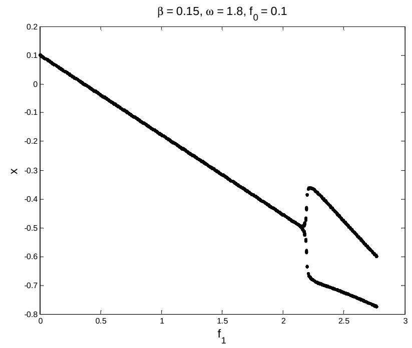
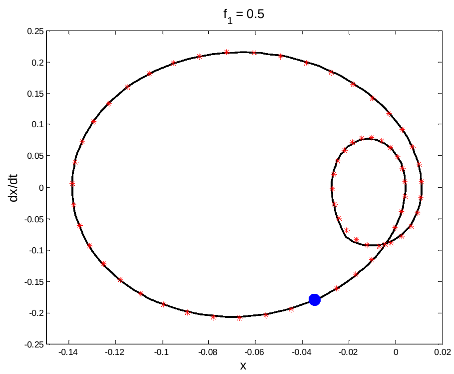
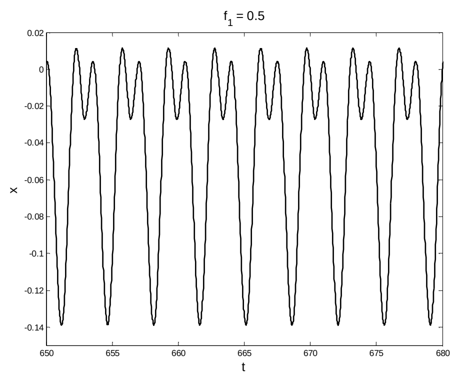


Figure 1 Bifurcation diagram

The phase plane plots, the time histories, and the Fourier spectra for the cosine and sine components when $f_1\in\{0.5, 2.1, 2.4\}$ are shown in Figures 2 to 4. The points of the Poincare maps corresponding to one period of harmonic excitation, $T=2\pi/\omega$, are also plotted in the phase plane and are indicated by blue dots. The integration time was taken as $200T$, and the first 100 periods were discarded to avoid transients. From these figures, it is clear that for relatively small forcing amplitudes f_1 the system executes oscillations with period 1.



(a)



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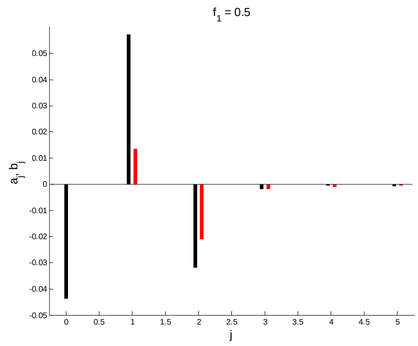


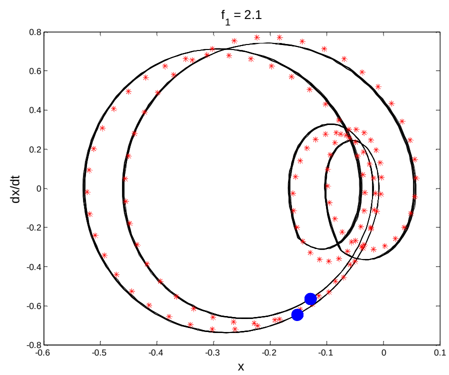
(c)

Figure 2 (a) the phase plane plots; (b) the time histories; (c) the Fourier spectra for roll equation (2) with $f_1 = 0.5$

The motion is well approximated by a finite series of the form

$$x(t) = A_0 + A_1 \cos\omega\tau + B_1 \sin\omega\tau + A_2 \cos 2\omega\tau + B_2 \sin 2\omega\tau \qquad (4)$$

As f_1 increases further and reaches 2.07, the period 1-orbit bifurcates into a period 2-orbit and build up of 1/2 sub-harmonics occurs.



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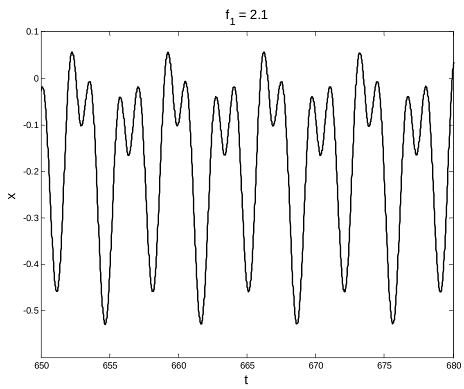

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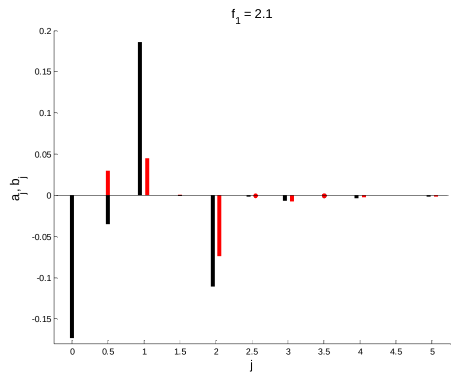


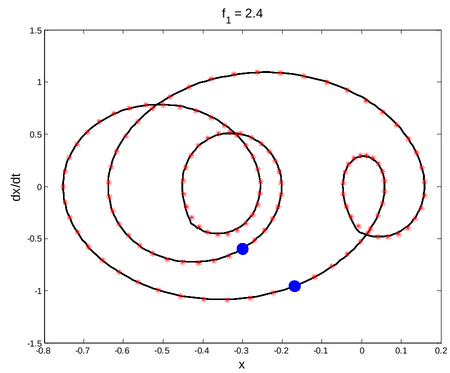
(c)

Figure 3 (a) the phase plane plots; (b) the time histories; (c) the Fourier spectra for roll equation (2) with $f_1 = 2.1$

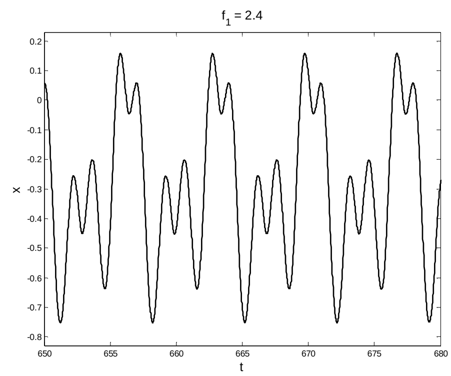
Now, the motion could be approximated by

$$x(t) = A_0 + A_{1/2} \cos\omega\tau/2 + B_{1/2} \sin\omega\tau/2 + A_1 \cos\omega\tau + B_1 \sin\omega\tau + A_2 \cos 2\omega\tau + B_2 \sin 2\omega\tau \qquad (5)$$

The coefficients A_i, B_i for the cosine and sine terms are given by FFT method.



(a)



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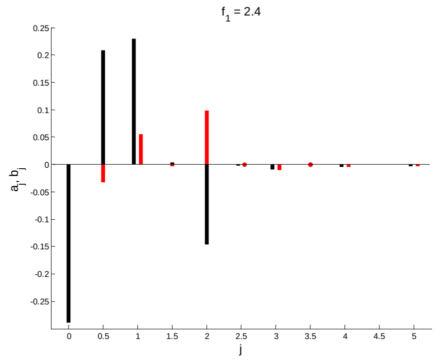
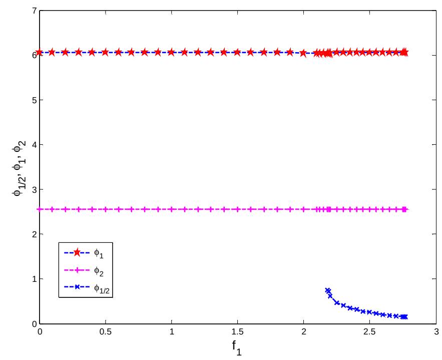


(c)

Figure 4 (a) the phase plane plots; (b) the time histories; (c) the Fourier spectra for roll equation (2) with $f_1 = 2.4$



(b)

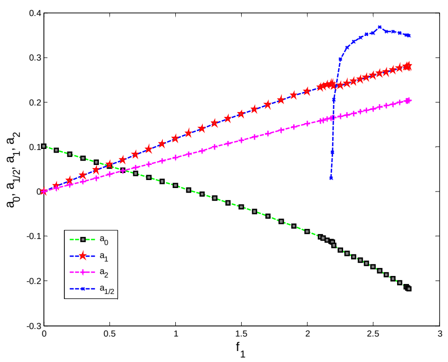
Figure 5 Dependence of (a) amplitudes and (b) phase angles involved in solution (6) on forcing amplitude f_1

From Figures 2 to 4 it seems obvious that only first two harmonics are important for period 1-orbit, while for the period 2-orbit on must to retain the first three harmonics. The next harmonics are two or three order of magnitude smaller than the first harmonics. The results obtained by FFT method, which include the first five harmonics, are also presented in the phase planes and are indicated by red asterisks. The agreement between the solution obtained by the FFT method and the numerical integration is excellent, in what when one is superimposed over the other they are practically indistinguishable.

Note that the solution (5) could be rewritten as

$$x(t) = a_0 + a_{1/2}\cos(\omega\tau/2+\phi_{1/2}) + \\ + a_1\cos(\omega\tau+\phi_1) + a_2\cos(2\omega\tau+\phi_2) \qquad (6)$$

The dependence of amplitudes $a_0, a_{1/2}, a_1$, and a_2 and phase angles $\phi_{1/2}, \phi_1$, and ϕ_2 on the forcing term f_1 is shown in Figure 5. It is interesting to observe that the huge difference between the orbits' shapes for $f_1 = 0.5$ and $f_1 = 2.4$ appears because of the term $a_{1/2}\cos(\omega\tau/2+\phi_{1/2})$, which becomes dominant with respect to the other terms.



(a)

4. APPROXIMATE SOLUTIONS WITH HARMONIC BALANCE METHOD

To justify the bifurcation from period 1-orbit to period 2-orbit a harmonic balance analysis has been carried out. Based on our previous experience concerning the solution of (2), a function of the form (5), consistent with the Fourier components, was assumed.

Replacing solution (5) into equation (2), equating free terms and the coefficients of $\cos\omega\tau, \sin\omega\tau$, $\cos 2\omega\tau, \sin 2\omega\tau$ on both sides the following non-linear algebraic equations for the amplitudes a_0, a_1, a_2 and the phase angles ϕ_1 and ϕ_2 are obtained:

$$a_0\left(1-a_0^2-1.5a_1^2-1.5a_2^2\right) = f_0 + 0.75a_1^2 a_2\cos(2\phi_1-\phi_2)$$

$$\left[a_1\left(1-\omega^2\right)-0.75a_1^3-3a_0^2a_1-1.5a_1a_2^2\right]\cos\phi_1- \\ -a_1\omega\beta\sin\phi_1 = f_1 \qquad (7)$$

$$-a_1\omega\beta\cos\phi_1-\left[a_1\left(1-\omega^2\right)-0.75a_1^3-3a_0^2a_1\right]\sin\phi_1 = 0$$

$$\left[a_2\left(1-4\omega^2\right)-0.75a_2^3-3a_0^2a_2-1.5a_2a_1^2\right]\cos\phi_2- \\ -2a_2\omega\beta\sin\phi_2 = 1.5a_0a_1^2\cos 2\phi_1$$

$$-\left[a_2\left(1-4\omega^2\right)-0.75a_2^3-3a_0^2a_2-1.5a_1^2a_2\right]\sin\phi_2- \\ -2a_2\omega\beta\cos\phi_2 = 1.5a_0a_1^2\sin 2\phi_1$$

By eliminating phase angles ϕ_1 and ϕ_2 from above equations a set of three non-linear equations for amplitudes a_0, a_1, a_2 are obtained. They are as follows:

$$F = f_0,\ A^2+B^2 = f_1^2,\ C^2+D^2 = E^2 \qquad (8)$$

The quantities *A*, *B*, *C*, *D*, *E* and *F*, which are functions of a_0, a_1, a_2, are given as follows:

$$A = a_1\left(1-\omega^2\right) - 0.75a_1^3 - 3a_0^2\,a_1 - 1.5\,a_1 a_2^2$$

$$B = -\omega\beta\, a_1$$

$$C = a_2\left(1-4\omega^2\right) - 0.75\,a_2^3 - 3a_0^2\,a_2 - 1.5\,a_1^2 a_2$$

$$D = -2\,\omega\beta\, a_2 \qquad (9)$$

$$E = 1.5\,a_0\,a_1^2$$

$$F = a_0\left(1 - a_0^2 - 1.5a_1^2 - 1.5a_2^2\right) - \frac{a_2}{2\,a_0}C$$

To solve the system (8) we have used the Newton-Raphson procedure. The obtained results for different values of forcing amplitude f_1, chosen between 0 and 2.07, are plotted in Figure 6.

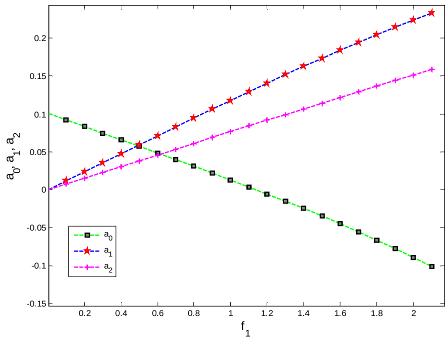


Figure 6 Dependence of amplitudes on forcing amplitude for the period 1- orbit

The values for the amplitudes a_0, a_1, a_2 have been considered then for finding the phase angles ϕ_1 and ϕ_2 from:

$$\cos\phi_1 = \frac{A}{f_1},\ \sin\phi_1 = \frac{B}{f_1},\ \cos\phi_2 = \frac{C}{E}\cos 2\phi_1 - \frac{D}{E}\sin 2\phi_1$$

$$\sin\phi_2 = \frac{C}{E}\sin 2\phi_1 + \frac{D}{E}\cos 2\phi_1 \qquad (10)$$

Like for numerical integration case, the phase angles remain almost constant, $\phi_1 \cong 6.04\ rad$ and $\phi_2 \cong 2.54\ rad$ Thus, we have had the data for plotting the time histories and phase planes for period 1-orbit. The results for $f_1 = 0.5$ are shown in Figure 7, together with the numerical solution.

We have noted in the previous section that period 1-orbit has bifurcated into a period 2-orbit around $f_1 = 2.07$. To investigate this bifurcation we have performed a study of the stability for the period 1-solution by considering a perturbed solution of the form

$$\bar{x}(\tau) = x(\tau) + \delta x(\tau) \qquad (11)$$

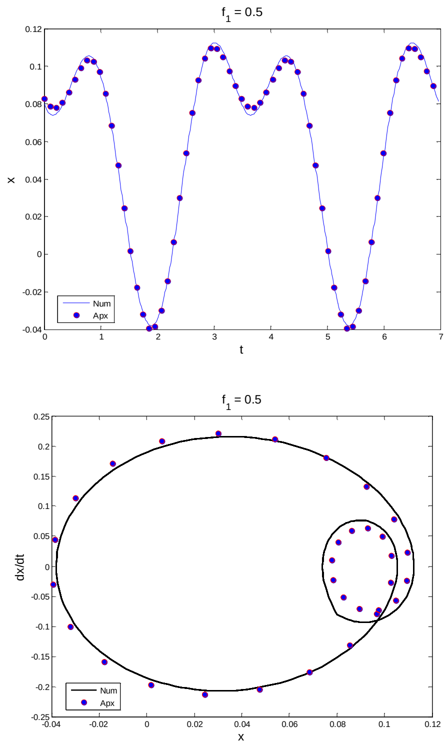


Figure 7 Time histories and phase plane for roll equation (2) with $f_1 = 0.5$

Replacing solution (11) into (2) and observing that x satisfies the same equation, one obtains the following variational equation

$$\delta\ddot{x} + \beta\,\delta\dot{x} + \left(1 - 3x^2\right)\delta x = 0 \qquad (12)$$

Considering

$$\delta x = a_{1/2}\cos\left(\omega t/2 + \phi_{1/2}\right) \qquad (13)$$

using (5) for x, and equating the harmonic terms in both sides of equation (12), the next homogeneous algebraic system with unknowns $a_{1/2}\cos\phi_{1/2}$ and $a_{1/2}\sin\phi_{1/2}$ is obtained:

$$\begin{aligned} m_{11}\cdot a_{1/2}\cos\phi_{1/2} + m_{12}\cdot a_{1/2}\sin\phi_{1/2} = 0 \\ m_{21}\cdot a_{1/2}\cos\phi_{1/2} + m_{22}\cdot a_{1/2}\sin\phi_{1/2} = 0 \end{aligned} \qquad (14)$$

where

$$m_{11} = 1 - 0.25\,\omega^2 - 3a_0^2 - 1.5a_1^2 - 1.5a_2^2 - 3a_0\,a_1\cos\phi_1 -$$

$$-1.5a_1 a_2\cos\left(\phi_2 - \phi_1\right),\ m_{22} = 0.25\,\omega^2 - 1 + 3a_0^2 + 1.5a_1^2 +$$

$$+1.5a_2^2 - 3a_0 a_1\cos\phi_1 - 1.5a_1 a_2\cos\left(\phi_1 - \phi_2\right) \qquad (15)$$

$m_{12} = m_{21} = -0.5\,\omega\,\beta + 3a_0\,a_1 \sin\phi_1 + 1.5a_1\,a_2 \sin(\phi_2 - \phi_1)$

and a_0, a_1, a_2, ϕ_1 and ϕ_2 are the solutions of (8) and (10). The period 1-orbit becomes unstable and bifurcates into period 2-orbit when the determinant of the homogeneous system (14) changes its sign from negative to positive [14, 15].

In the analysed case, this change of sign appears for $f_1 = 2.05$, which is a good estimate of the bifurcation value $f_1 = 2.07$ (see Figure 8).

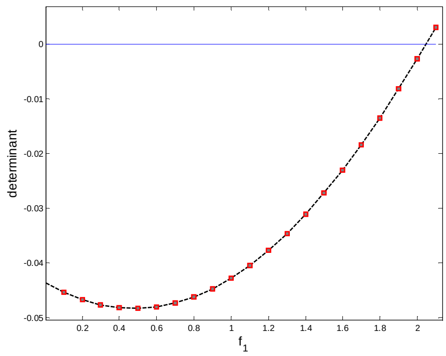


Figure 8 The dependence of the system (14) determinant on the forcing amplitude

Starting with this value for f_1, the system oscillates according to solution (6). Proceeding like in the period 1-orbit's case, the following seven strong non-linear equations in $a_0, a_{1/2}, a_1, a_2, \phi_{1/2}, \phi_1$, and ϕ_2 are obtained:

$$a_0\left(1 - a_0^2 - 1.5\,a_{1/2}^2 - 1.5a_1^2 - 1.5a_2^2\right) - 0.75a_{1/2}^2\,a_1 \cdot$$

$$\cdot\cos(2\phi_{1/2} - \phi_1) - 0.75a_1^2\,a_2\cos(2\phi_1 - \phi_2) = f_0$$

$$a_{1/2}\cos\phi_{1/2}\left(1 - 0.25\,\omega^2 - 0.75a_{1/2}^2 - 3a_0^2 - 1.5a_2^2 - 1.5a_1^2\right)$$

$$-0.5\,\omega\,\beta\,a_{1/2}\sin\phi_{1/2} = 0$$

$$-a_{1/2}\sin\phi_{1/2}\left(1 - 0.25\,\omega^2 - 0.75a_{1/2}^2 - 3a_0^2 - 1.5a_2^2 - 1.5a_1^2\right)$$

$$-0.5\,\omega\,\beta\,a_{1/2}\cos\phi_{1/2} = 0$$

$$a_1\cos\phi_1\left(1 - \omega^2 - 0.75a_1^2 - 3a_0^2 - 1.5a_2^2 - 1.5a_{1/2}^2\right) -$$

$$-0.75a_{1/2}^2\,a_2\cos(\phi_2 - 2\phi_{1/2}) - 1.5a_0\,a_{1/2}^2\cos 2\phi_{1/2} -$$

$$-\omega\,\beta\,a_1\sin\phi_1 = f_1 \qquad (16)$$

$$-a_1\sin\phi_1\left(1 - \omega^2 - 0.75a_1^2 - 3a_0^2 - 1.5a_2^2 - 1.5a_{1/2}^2\right) +$$

$$+0.75a_{1/2}^2\,a_2\sin(\phi_2 - 2\phi_{1/2}) + 1.5a_0\,a_{1/2}^2\sin 2\phi_{1/2} -$$

$$-\omega\,\beta\,a_1\cos\phi_1 = 0$$

$$a_2\cos\phi_2\left(1 - 4\omega^2 - 0.75a_2^2 - 3a_0^2 - 1.5a_1^2 - 1.5a_{1/2}^2\right) -$$

$$-0.75a_{1/2}^2\,a_1\cos(\phi_1 + 2\phi_{1/2}) - 1.5a_0\,a_1^2\cos 2\phi_1 -$$

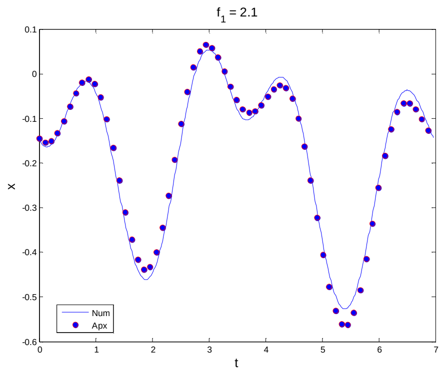
$$-2\,\omega\,\beta\,a_2\sin\phi_2 = 0$$

$$-a_2\sin\phi_2\left(1 - 4\,\omega^2 - 0.75a_2^2 - 3a_0^2 - 1.5a_1^2 - 1.5a_{1/2}^2\right) +$$

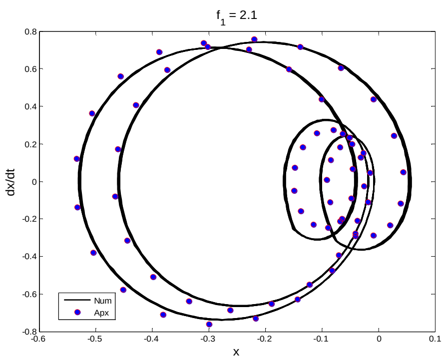
$$+0.75a_{1/2}^2\,a_1\sin(\phi_1 + 2\phi_{1/2}) + 1.5a_0\,a_1^2\sin 2\phi_1 -$$

$$-2\,\omega\,\beta\,a_2\cos\phi_2 = 0$$

Solution of (16) was approximated with Newton-Raphson method, having as initial conditions the values suggested by FFT, just for $f_1 \in \{2.1, 2.4\}$. The obtained solutions are reported in Table 1 and are used in equation (6) to draw the time histories and the phase planes in Figures 9 and 10. It could be seen that the agreement between the harmonic balance solution and the numerical one is pretty good, with some notable differences at peaks and troughs of the time histories plots.

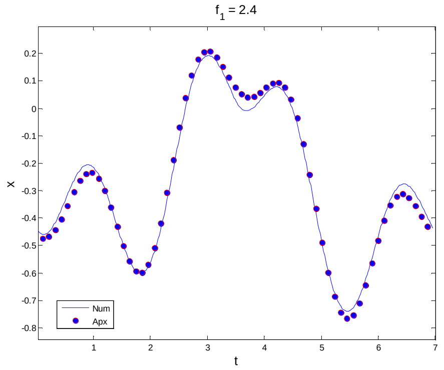


(a)

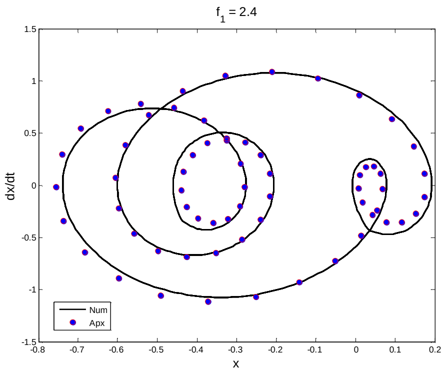


(b)

Figure 9 Time histories and phase plane for roll equation (2) with $f_1 = 2.1$



(a)



(b)

Figure 10 Time histories and phase plane for roll equation (2) with f_1= 2.4

Tabel 1. Amplitudes and phase angles for selected forcing amplitudes

f_1	0.5	2.1	2.4
a_0	0.0572	0.1135	0.1529
$a_{1/2}$	-	0.0887	0.3448
a_1	0.0590	0.2395	0.2501
a_2	0.0383	0.1650	0.1784
$\phi_{1/2}$ (rad)	-	0.7261	0.3146
ϕ_1 (rad)	6.0504	6.0459	6.0511
ϕ_2 (rad)	2.5532	2.5522	2.5597

5. CONCLUSIONS

In the paper, the rolling motion of a ship was modelled by a second order differential equation with the forcing amplitude as a parameter. The model included a linear damping, a restoring moment represented by a third-order polynomial and a single harmonic excitation term.

Harmonic balance technique with appropriate harmonic terms in the assumed solution, suggested by the Fourier spectra, permitted us to find approximate solutions for the period 1 and 2 orbits, which matched resonably well with the numerical solutions given by Runge – Kutta – Gill method. The bifurcation between the two types of periodic motions was estimated with a fair degree of approximation by a stability analysis. Because of the complictions involved in approximating the higher-order periods, the harmonic balance method becomes inappropriate to study the next period-doubling bifurcations leading to chaos.

On the other hand, the Fast Fourier Transform, implemented under MatLab environment, has given excellent results when compared with the numerical ones, in what one solution is superimposed over the other they are practically indistinguishable. To obtain this very good agreement, just the first five harmonics were retained in the approximate solution.

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APPLICATION OF SOME NEW POWER QUALITY INDICES IN ANALYSIS OF THE SHIPBOARD ELECTRICAL SYSTEM EFFICIENCY

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Abstract: Improving the quality of electricity and electromagnetic compatibility is a topical issue in shipboard electrical power systems as these concern two main technical aspects. First is to improve the electromagnetic compatibility, which leads to improvement of the operating modes of the equipment and thus increase of the overall reliability of the system. Second aspect is related to the quality of electricity leading both to increase in overall reliability and refinement of measures to reduce the power and energy losses. The latter is particularly relevant, since it is directly related to saving primary energy sources - liquid fuels, and this in turn leads to reduction of greenhouse gas emissions. This paper focuses on the possibilities of using some new quality indicators of electricity and electromagnetic compatibility, which are not regulated by normative documents. Practical software application has been developed in MathCAD Prime 3.0 environment and its use is shown in experimental studies of cruise ship class 1A1.

Key words: energy efficiency, power quality, shipboard electrical power systems

1. INTRODUCTION

Traditional approaches to quality assessment of electricity and electromagnetic compatibility, which are regulated by a number of standards IEC, EN, and IEEE groups, address the issue separately [4], [5]. Power quality is understood primarily as voltage mode regulating a number of parameters, for which the relevant indicators are defined and specified limits are stipulated. The main ones include voltage deviation ΔU, voltage fluctuations δU, voltage unbalance defined by a voltage unbalance factor, harmonic distortion coefficient identified as THDU. With electromagnetic compatibility, the shipboard energy systems use assessment by the harmonic distortion coefficient of current THDI, for which permissible limits are defined. There are some studies [1], [2], [3] suggesting the use of new aggregated indicators to generally assess the quality. The methodology suggested includes traditional assessment methods in combination with practical and applied methodologies for assessing unbalance and new quality indicators.

2. METHODOLOGY

The methodology suggested is designed to provide quick analysis of data bases recorded by stationary or portable digital analyzers, using software application in MathCAD Prime 3.0 environment. Matrix calculation has been adopted as main instrument. Measurement file is assigned by an operator such as matrix of automatic dimensionality - it depends on the quantities selected for recording (number of matrix columns) and duration of measurement (number of matrix rows - n).

$$data := filename.xlsx \quad n := rows(data) \qquad (1)$$

Then each electrical quantity is derived from the general matrix as a matrix column. For example, using the output file of medium and high grade Fluke analyzers, setting voltage (as rms) occurs in the following way:

$$U_{12} := data^{\langle 2 \rangle} \quad U_{23} := data^{\langle 3 \rangle} \quad U_{31} := data^{\langle 4 \rangle} \qquad (2)$$

In an analogous manner currents, active and reactive power, full power, PF, THDU, THDI are defined. Variable j is introduced – row counter, which is minus 1, because the first row of the Fluke's file is of "character" format.

$$j := 1..n-1 \qquad (3)$$

3. CALCULATION OF SOME NEW INDICES IN PRESENCE OF UNBALANCE AND HARMONIC DISTORTION

3.1. Calculation of equivalent voltage and current

$$Ue_j := \sqrt{\frac{U_{12_j}{}^2 + U_{23_j}{}^2 + U_{31_j}{}^2}{3}} \qquad Ie_j := \sqrt{\frac{I_{12_j}{}^2 + I_{23_j}{}^2 + I_{31_j}{}^2}{3}} \quad .(4)$$

3.2. Calculation of rms for fundamental harmonics out of rms readings of voltages and THDU

$$U_{12\_F_j} := \frac{U_{12_j}}{\sqrt{\left(\frac{THDU_{12_j}}{100}\right)+1}} \qquad U_{23\_F_j} := \frac{U_{23_j}}{\sqrt{\left(\frac{THDU_{23_j}}{100}\right)+1}} \quad (5)$$

$$U_{31\_F_j} := \frac{U_{31_j}}{\sqrt{\left(\frac{THDU_{31_j}}{100}\right)+1}} .$$

Analogously the rms of the fundamental harmonics of currents is also calculated. The equivalent fundamental harmonics are calculated in a manner similar to (4).

3.3. Calculation of TDD of voltage (VTDD) – total demand distortion to IEEE 555

$$VTDD_{12_j} = \sqrt{\frac{U_{12_j}{}^2 - U_{12\_F_j}{}^2}{U_{12_j}{}^2}} \quad VTDD_{23_j} = \sqrt{\frac{U_{23_j}{}^2 - U_{23\_F_j}{}^2}{U_{23_j}{}^2}} \quad (6)$$

$$VTDD_{23_j} = \sqrt{\frac{U_{23_j}{}^2 - U_{23\_F_j}{}^2}{U_{23_j}{}^2}} .$$

In a similar manner TDD of currents – ITDD, is calculated.

3.4. Calculation of generalized three-phase factors VTDD3P and ITDD3P

$$VTDD_{3P_j} = \frac{1}{\sqrt{3}}\sqrt{\sum_{i=1}^{3} THDU_{ij}{}^2 \cdot \frac{U_{i\_Fj}{}^2}{Ue_{ij}{}^2}} \quad (7)$$

$$ITDD_{3P_j} = \frac{1}{\sqrt{3}}\sqrt{\sum_{i=1}^{3} THDI_{ij}{}^2 \cdot \frac{I_{i\_Fj}{}^2}{Ue_{ij}{}^2}}$$

3.5. Calculation of DI – deviation index for voltage (VDI)

$$VDI_{12_j} := \sqrt{\frac{\left|U_{12\,j} - Ue_j\right|^2}{Ue_j{}^2}} \cdot 100 \quad VDI_{23_j} := \sqrt{\frac{\left|U_{23\,j} - Ue_j\right|^2}{Ue_j{}^2}} \cdot 100 \quad (8)$$

$$VDI_{31_j} := \sqrt{\frac{\left|U_{31\,j} - Ue_j\right|^2}{Ue_j{}^2}} \cdot 100$$

Calculation of DI of currents (IDI) is carried out in a manner similar to (8).

3.6. Calculation of coefficient of total unbalance TU of voltages and currents (VTU and ITU)

$$VTU_j := \frac{1}{\sqrt{3}}\sqrt{VDI_{12\,j}{}^2 + VDI_{23\,j}{}^2 + VDI_{31\,j}{}^2} \quad (9)$$

$$ITU_j := \frac{1}{\sqrt{3}}\sqrt{IDI_{12\,j}{}^2 + IDI_{23\,j}{}^2 + IDI_{31\,j}{}^2} .$$

3.7. Calculation of ITDDW (Total Demand Distortion Weighted of Current) – total weighted factor of harmonic distortion for each phase and THDW – weighted THD for each phase

$$ITDDW_{12\,j} := \frac{ITDD_{12\,j} \cdot S_{12\,j}}{S_{3P\,j}} \quad ITHDW_{12\,j} := \frac{ITHDW_{12\,j} \cdot S_{12\,j}}{S_{3P\,j}}$$

in a similar manner for currents „23" and „31" (10)

3.8. Calculation of three-phase ITHDW (Total Harmonic Distortion Weighted of Current) – total weighted factor of harmonic distortion

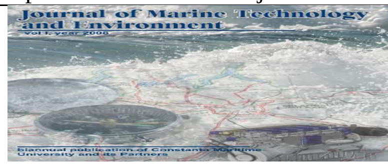
$$ITHDW_j := \frac{1}{\sqrt{3}}\sqrt{\begin{array}{l} ITHDW_{12\,j}{}^2 \cdot \frac{I_{12\,j}{}^2}{Ie_j{}^2} + \\ + ITHDW_{23\,j}{}^2 \cdot \frac{I_{23\,j}{}^2}{Ie_j{}^2} + ITHDW_{31\,j}{}^2 \cdot \frac{I_{31\,j}{}^2}{Ie_j{}^2} \end{array}} . \quad (11)$$

3.9. Calculation of three-phase total weighted unbalance factor ITUW (Total Unbalance Weighted of Current)

$$ITUW_j := \frac{1}{\sqrt{3}}\sqrt{\begin{array}{l} IDIW_{12\,j}{}^2 \cdot \frac{S_{12\,j}{}^2}{S_{3P\,j}{}^2} + \\ + IDIW_{23\,j}{}^2 \cdot \frac{S_{12\,j}{}^2}{S_{3P\,j}{}^2} + IDIW_{31\,j}{}^2 \cdot \frac{S_{12\,j}{}^2}{S_{3P\,j}{}^2} \end{array}} . \quad (12)$$

4. OBJECT OF THE STUDY

Suggested methodology is used in the study carried out of a class 1A1 cruise ship Sovereign. The ship belongs to the class of the largest passenger ships



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(Figure 1), characterized by the predominant energy load of the hotel part, which includes a wide variety of technological facilities (kitchen, cold rooms, elevators, etc.); lighting installations of common areas, electrical equipment for utility facilities (restaurants, casinos, SPA, etc.) as well as users in the cabins.

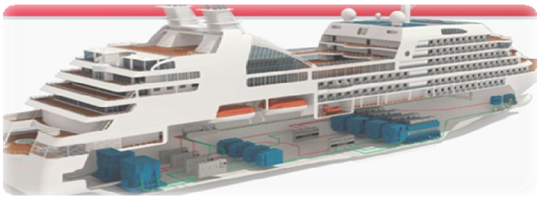


Figure 1 General layout of electrical power equipment and substations of cruise ship

This implies different single-phase and three-phase loads of various characteristics and operation modes their turning-on being both by technological regimes and of random nature. Separate units of the energy system are studied using Fluke 434 series portable quality power analyzer, the measurements are recorded in the database as averages for each 5 minute interval. The resulting databases are treated to the methods suggested. Below the characteristic curves are presented of the variation of energy consumption and the various indicators of electric power quality and electromagnetic compatibility.

Ship power system uses three standard voltage levels - 6.6; 0.44 and 0.22 kV 60Hz.

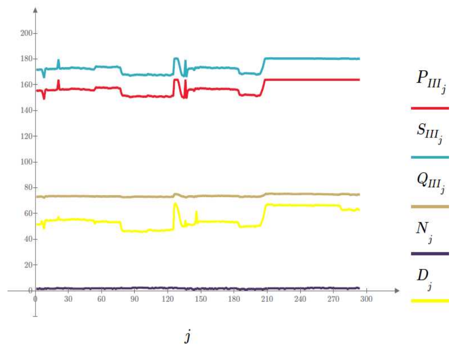


Figure 2a Active and Non-Active Power variation for 24-hour interval

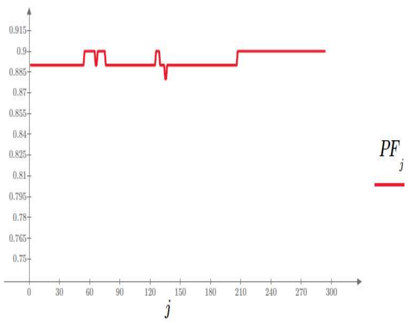


Figure 2b Power Factor variation for 24-hour interval

The application of the methodology is presented for one of the substations, powering technological consumers for ventilation and air conditioning of the hotel part - Substation # 3 440V. For a typical 24-hour load profile variations of active P [kW], reactive Q [kVAr], full S [kVA], pulsating N [kVA] and deformation D [kVA] powers are shown in Figure 2a and Figure 2b.

The voltage variation is within +2 and +3.6%, current load schedule is close to constant – Figure 3a and Figure 3b.

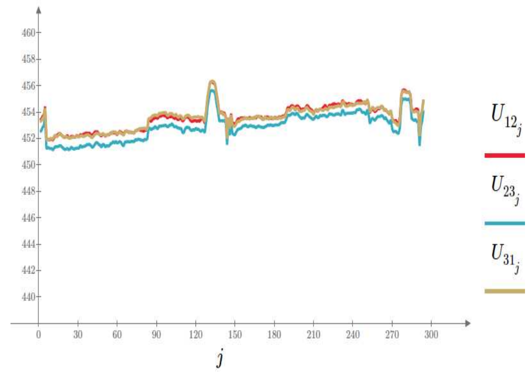


Figure 3a Voltage variation for a 24-hour interval

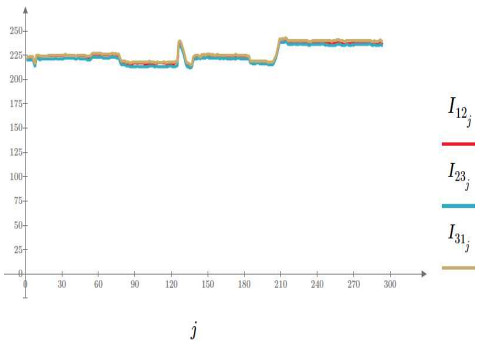
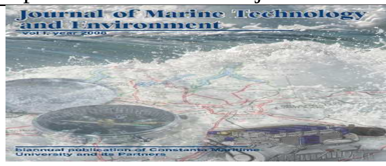


Figure 3b Current variation for a 24-hour interval

Traditional indicators of quality assessment - THDU [%] and THDI [%] are shown in Figure 4a and Figure 4b. varying within the range from 3.2 to 4% and from 8 to 10.5% respectively. Levels are permissible according to standards IEC60092-101, EN50160 and IEC 61000, but imply an increased level of losses caused by the presence of high-order harmonics. Factors of voltage total unbalance (VTU - voltage total unbalance) and current total unbalance (ITU - current total unbalance), which essentially incorporate the impact of high-order harmonics using the calculated equivalent voltage and current (8.9) are shown in Figure 5a and Figure 5b.

The values of VTU and ITU are percentages and show negligible influence of unbalance and pulsating power respectively (Figure 2a). This is expected because



of the significantly predominant share of three-phase power consumers, particularly for Substation # 3.

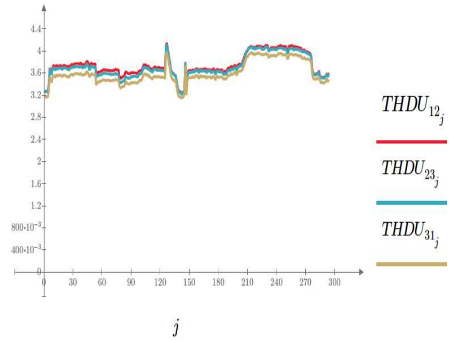


Figure. 4a Variation of THDU – 24-hour period

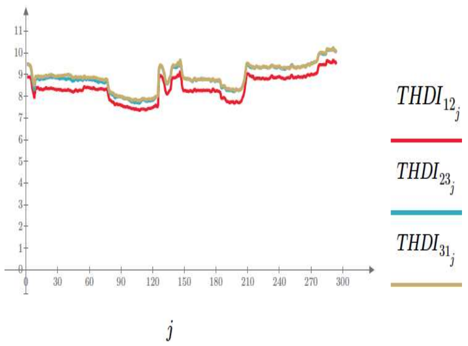


Figure. 4a Variation of THDI – 24-hour period

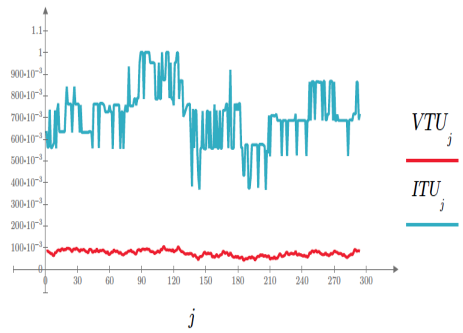


Figure 5a Variation of VTU and ITU

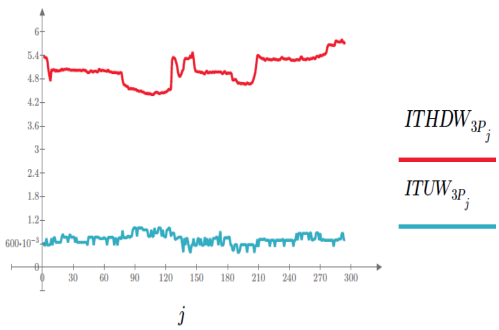


Figure 5b Variation of ITHDW and ITUW

Dynamics of the new indicators - ITHDW and ITUW in [%] is shown in Figure 5a and Figure 5b . The ITHDW curve shape coincides with the THDI curve for the individual phases. Quantitative assessment is different, because ITHDW is weighted to load by the equivalent current (11), which in turn includes the current loading in different phases. Using THDW is appropriate, because unlike THD (which is calculated from the first harmonic) it indicates the real energy influence of harmonics at various loads.

Weighted unbalance factor has insignificant values and little difference compared to ITU due to lack of significant unbalance.

6. RESULTS AND CONCLUSIONS

Using some new indicators to assess the quality of electric power and electromagnetic compatibility in shipboard power systems is possible and appropriate, since it better illustrates the energy influence of unbalanced and non-linear consumers. The methodology developed in an MatCAD Prime 3.0. environment is compatible with a number of digital analyzers and is a convenient tool for analysis of the nature of electricity consumption and electrical power quality in shipboard energy systems. The indicators suggested give a better visual assessment of the energy influence of the harmonic composition. In this case, it amounts to 4.8 to 6% of the total current load and power respectively in levels of THDI reported within 8-10%. Practical measures of compensation and filtration are technical-economic optimization problem, which is not the subject of this study.

7. ACKNOWLEDGMENTS

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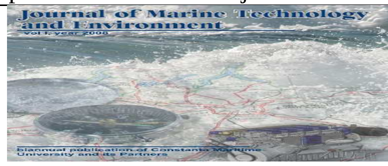

MODELLING THE HEAT TRANSFER PROCESS DURING THE COMBUSTION IN MARINE HIGH SPEED DIESEL ENGINES

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Abstract: The heat transfer in marine diesel engines is a complex phenomenon that occurs by two main components, the connective and radiative components under varying conditions such as temperature, pressure, and composition of in-cylinder gases. Hence, modeling the heat transfer phenomenon during the combustion process in high speed marine diesel engine imposes many difficulties in determining the heat flux through the combustion chamber walls. Many researches have been carried out many studies to understand and to model this phenomenon. Since modeling this phenomenon is an important step for modeling the whole combustion process which takes place inside the combustion chamber, many models and correlations of these models have developed for modeling this it in satisfied results and in a relative short time. This work concentrates on the two main methods for modeling the heat transfer in diesel engines which they are Hohenberg, Woschni and their correlations, with the use of MATLAB program for numerical modeling.

Key words: diesel engines, heat transfer, heat transfer coefficient, combustion modeling.

1. INTRODUCTION

The peak temperature of the burned gases inside the combustion chamber reaches high values over than 2400 K; on the other side for many considerations the temperature of engine components that form the combustion chamber space should not exceed a certain range. Hence, the engine should be equipped with a cooling system, which will lead to a heat flux through the components of the combustion chamber.

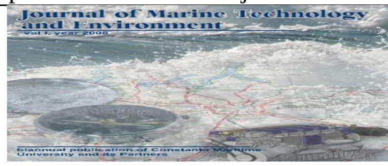
Heat flux varies during the engine working cycles, it reaches high values during the combustion period, However essentially heat flux is so much lower in the other engine working cycles. As well as the heat flux varies according to the variation of the temperature inside the combustion chamber, so the heat flux is higher at the locations where the higher burned gases temperature exists.

Each of cylinder wall, cylinder head, piston, and valves that form the combustion chamber boundaries are made of different materials, so the heat flux is different and it is not the same for all surfaces. However for simplicity the combustion chamber area is not subdivided and the heat transfer coefficient is considered the same for piston, valves, cylinder head and liner areas. Also for simplicity the wall temperature is considered a constant value.

2. HEAT TRANSFER COMPONENTS

Heat transfer in Diesel engines as mentioned before consisted of two main components radiation, and convection components. The convection component in the cylinder chamber is called forced convection because the motion between the in cylinder gases and the cylinder surfaces is produced by a force not by the gravity. Hence, the heat transferred during induction, compression, expansion, and exhaust strokes is transferred by the forced convection through the cylinder walls and head to the coolant water, and through the piston to the lubricant, the main portion of forced connective heat is from exhaust valve and exhaust manifold to the coolant water and surrounding air. On the other hand the heat transfer in the inlet system from the components of inlet system components to the charge (inducted air), the final type of heat convection is the heat transfer between the engine and environment.

The second component of heat transfer is the radiation component, In Diesel engines the radiation component occurs from the high temperature of combustion gases, and from the soot in the diffusion flame, through electromagnetic waves, these waves are the infrared waves with length range between ($0.4\mu m$ to $40\mu m$), and the visible waves with length range between ($0.4\mu m$ to $0.7\mu m$) [10]. The method of heat



transfer through radiation depends on a black body concept, which has the ability to emit and absorb the radiation of all wavelengths equally through its surface and does not reflect the radiation.

In the combustion chamber the proportion of exchanged heat by radiation depends so much on the soot that formed inside the combustion chamber during the combustion process. Soot is considered the only solid body in the combustion chamber that emits radiation, whereas the characteristics of soot radiation done not only depend on the soot temperature and mass but also on the connective heat transfer. The gas radiation may be neglected because of the selective radiation nature of the gases, i.e. the gases on the contrary of the solid bodies only radiate and emit in narrow wavelength. Carbon dioxide, water vapour, and carbon monoxide are considered to be the essential participating gases in radiation component. On the other hand the gases with simpler molecules such as oxygen, nitrogen, and hydrogen are considered transparent gases to radiation.

In addition to the two main component of heat transfer there is a third component of heat transfer is the thermal conduction component, Heat transferred by conduction occurs by molecular motion between solids and between fluids at rest, due to a temperature gradient. Hence, in direct vicinity to the wall the heat exchange is caused by thermal conduction because the flow in the direct vicinity to the wall must be laminar. However, the heat transfer by forced convection dominates outside this boundary layer in diesel engines heat is transferred by conduction through the piston, cylinder liner, cylinder head, and through piston rings to cylinder liner.

3. MODELING THE HEAT TRANSFER PHENOMENON

In order to simulate the combustion, heat loss in combustion chamber through the walls is calculated by Newtonian heat transfer as an integral which is described in the next equation [10]:

$$Q_w = \frac{1}{w}\int h \cdot A \cdot \left(T_w - T_g\right) \cdot d\varphi \quad (1)$$

From the previous equation it can be noticed that the value of the heat loss during the combustion is negative value, because the values of the heat transfer coefficient, angular velocity, and combustion chamber surface area are positive values, whereas the value of the difference between in cylinder gases and wall temperature is negative.

In order to analyse the heat transfer phenomenon in internal combustion engines, the forced connective heat transfer conditions are applied in the vicinity area to the combustion chamber walls. Hence, the dimensionless coefficients that used to describe the heat transfer phenomenon are the Nusselt number ($Nu = \frac{aD}{\lambda}$) is used to describe the temperature, the Reynolds number ($\mathrm{Re} = \frac{\rho \cdot w \cdot D}{\eta}$) for describing the flow boundary layer, and Prandtl number ($\mathrm{Pr} = \frac{\eta}{\rho} a$) for describing the interaction between the two boundary layers [10].

The heat transfer coefficient can be calculated by the following relation:

$$Nu = C \cdot \mathrm{Re}^n \cdot \mathrm{Pr}^m \quad (2)$$

In order to simulate the combustion process, the instantaneous heat transfer should be determined and calculated by the use of the next equation which describes the heat transfer:

$$\frac{dQ_w}{dt} = \frac{dQ_a}{dt} + \frac{dQ_\varepsilon}{dt} \quad (3)$$

Where: $\frac{dQ_a}{dt}$ is the radiation component and $\frac{dQ_\varepsilon}{dt}$ is the conviction component. The description of the wall heat flow is given as:

$$\frac{dQ_w}{dt} = \sum \alpha A\left(T_w - T_{gas}\right) \quad (4)$$

For simplicity the combustion chamber area is not subdivided as mentioned before. Hence, the heat transfer coefficient is considered the same for piston, cylinder head and liner areas. There are different models which used for modelling the heat transfer, (Woodchip 1970) Heat transfer model is used for this study.

The calculation of heat transfer through the combustion chamber walls with using heat transfer coefficients and Newtonian approach requires the calculation of the mean gas temperature and pressure which can be calculated from the ideal gas equation, as well as the calculation of the piston speed which can be determined from the engine specification and the measurements of engine speed.

So many semi-empirical equations were developed over the last century for calculation of heat transfer, the use of semi-empirical term because many factors which used to calculate the heat transfer can only be determined by experiments. In this work two method for calculating the heat transfer will be introduced the first method is the Woschni method which was developed for diesel engine which has been verified in so many studies and tests, many improvements and additions were adapted for special cases, the second method is Hohenberg’s method and correlation (1979) which considers the truly conditions inside the combustion chamber of diesel engine

3.1 Woschni model:

Woschni method calculated the heat transfer coefficient based on the assumption of stationary fully turbulent pipe flow, by using the Reynold, Nusslet, and Pradentl numbers. The heat transfer coefficient is given as [7]:

$$\alpha = 127.93 D^{-0.2} p^{0.8} w^{0.8} T^{-0.53} \left[\frac{W}{m^2 K} \right]. \tag{5}$$

Where: the characteristic of speed is given after the modification as

$$w = C_1 c_m + C_2 \frac{V_{swept} T_1}{p_1 V_1} (p - p_0) \tag{6}$$

Where: $(p - p_0)$ the difference between the pressure during combustion and the motored pressure which can be calculated by the use of polytrophic relation from the cylinder volume, the constants C_1, C_2 in the previous equation are given as follows $C_1 = 2.28 + 0.308 \frac{c_c}{c_m}$, $0 \le \frac{c_c}{c_m} \le 3$, where c_m the piston mean speed, and c_c the circumferences speed $C_2 = 3.24 \cdot 10^{-3} \left[\frac{m}{sK} \right]$.

3.2 Hohenberg model:

The method of Hohenberg and its correlations was developed based on many experiments and researches which carried on Diesel engine with employing the radius of sphere with a volume corresponding to the instantaneous volume of the combustion chamber as the characteristics length [10], the heat transfer coefficient is given as:

$$h_c = \frac{130 \cdot P^{0.8} \cdot (c_m + 1.4)^{0.8}}{V^{0.06} \cdot T^{0.4}} \tag{7}$$

And the heat transfer according to Hohenberg as follows:

$$\frac{dQ_w}{d\theta} = h_c A (T_{gas} - T_w) \cdot \left(\frac{1}{6N} \right). \tag{8}$$

There are other methods for calculating the heat transfer in Diesel engines such as Bargende method, but it will not be used in this work, since Woschni and Hohenberg models are simpler to be modelled than Bargebde model

4. ENGINE SPECIFICATIONS

The modelling process has been carried out by the use of technical data for Hino W04D high speed diesel engine. This type of engines can be used for different kinds of applications; one of these applications is a marine engine in order to power small boats.

Table 1. Hino marine high speed Diesel engine specifications

Model	**Hino W04D**
Displacement	4.009
Number of cylinders	4
Stroke	118mm
Bore	104mm
Compression Ratio	17.9:1
Needle opening pressure	215 bar
RPM Range	1500-2800
Peak Power	56 kw at 2550 rpm
Peak Torque	245Nm at1600rpm
Aspiration	Naturally Aspiration
Combustion	Direct injection

5. RESULTS AND DISCUSSION

The numerical modelling carried out by the use of MATLAB.

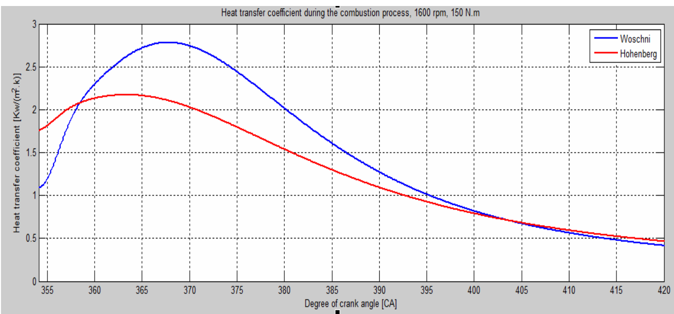


Figure 1 Heat transfer coefficient during the combustion process

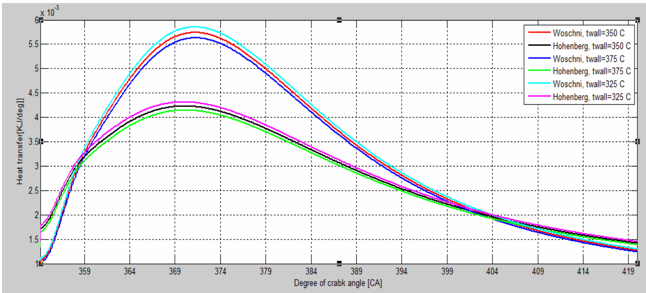


Figure 2 Heat transfer according to Woschni and Hohenberg during the combustion process for varying cylinder wall temperature

From Figure 1 we can observe that heat transfer coefficient value by using Woschni method for modelling it reaches a higher peak than the result from using Hohenberg method, this peak is correspondent to crank angle where the peak result from using Hohenberg method occurs at crank angle, as well as we can observe that at the last phase of combustion, the result from Woschni method getting lower than the result from Hohenberg method. The peak result of heat coefficient by using Woschni method is higher than the result of using Hohenberg method by 23%.

The effect of heat transfer coefficient results is apparent on the result of heat transfer in figure 2 , the heat transfer results from Woschni method reaches higher peak than the result from Hohenberg method. The difference between the results of using Woschni and Hohenberg methods are similar to the result from other research about heat transfer coefficients which carried out by other researcher on similar engines, as well as the results show the effect of heat release on the heat transfer. Also the figure 2 illustrates the effect of cylinder wall temperature on the heat transfer.

Finally it should be mentioned that the results were taken as an absolute values of the equations results

6. CONCLUSIONS

The results from numerical modelling of heat transfer phenomenon during the combustion in high speed marine diesel engine by using MATLAB program are completely satisfactory, and obtained in a short relative time. despite of the complex heat transfer phenomenon because it occurs by radiative and conective components in a transient conditions the Woschni and Hohenberg methods which used in this work for modelling the heat transfer give a practical feasible solution for understanding and modelling the heat transfer through the combustion chamber walls. The result revealed that the peak heat transfer coefficient by using Woschni model is higher than the result of using Hohenberg model.

Choosing the accurate value for cylinder wall temperature is very important to obtain an accurate heat transfer results.

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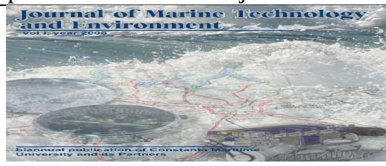

TWO ZONES THERMODYNAMIC MODEL FOR HIGH SPEED MARINE DIESEL ENGINES

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Abstract: In this paper two-zone thermodynamic model has been used for modeling the combustion process in direct injection diesel engine based on the results of modeling the combustion process by using single zone thermodynamic method. Single zone thermodynamic method depends on the average value of in-cylinder temperature and pressure, which considered one of the main defects of using one-zone thermodynamic model. Hence, developing a new model is very necessary especially for better description of the in-cylinder peak temperature during the combustion process. The concept of two-zones thermodynamic model is based on dividing in-cylinder gases in two zones the first zone is unburned zone which contains fresh air and the injected fuel, and the second zone is burned zone which is formed from combustion products with high temperature. The importance of the two-zone thermodynamic model is using it to calculate and to model Nox emissions. The formation of Nox emissions highly depends on the in-cylinder peak temperature. Hence, the more accurate results in modeling the temperature of in-cylinder gases lead to obtain more accurate results in modeling Nox emissions

Key words: combustion, diesel engine, thermodynamic models, two zones.

1. INTRODUCTION

The combustion process in diesel engines is a complex process and many researches have been carried out in order to model this process in simple and accurate way. Thermodynamic models are considered the simplest way for modeling the combustion process and many models have been developed during the last century for this purpose. One of these models is single-zone thermodynamic model which is considered a useful choice for calculating some parameters of diesel engine such as the fuel consumption and the engine performance, but this type of models cannot be a reliable choice for predicting the emissions, so the development of single zone model to thermodynamic two-zone model is very necessary to get accurate and satisfied results.

2. THERMODYNAMIC COMBUSTION MODELS

2.1 One zone thermodynamic model:

The single-zone thermodynamic model or it is called one-zone thermodynamic model is considered the fastest easiest and the most simple method to model the combustion characterization and emission formation in the combustion chamber of diesel engine. The main assumptions for single-zone thermodynamic models are:

- The working fluid inside the combustion chamber obeys the perfect gas laws.
- The working fluid inside the combustion chamber forms a close thermodynamic system.
- The engine rotational speed is uniform.
- Pressure and temperature inside the combustion chamber are uniform and change with crankshaft angle.
- There is no change in the mass of in-cylinder gases during the period between the close of intake valves and the open of exhaust valves.
- The in-cylinder gases are in equilibrium state.

Only the laws and the equations of the conservation of mass and energy are used as we stated before, so after the close of intake valves there is no mass transfer out of the combustion chamber, which means the mass exchange into and out the combustion chamber occurs only at intake and exhaust strokes. Hence, the mass that forms the cylinder charge “fresh air” can be calculated by the equations of engine air flow. Regarding the energy conservation, the heat transfer between the in-cylinder gases and the walls of combustion chamber; and the rate of heat release from the burned fuel during the combustion process all can be calculated by the use of certain equations which model the actual heat release and transfer characteristics in a satisfied way, the equations of mass and energy conservation give us the instantaneous pressure and temperature during the combustion process which allows us to determine the in-cylinder gases state at every crank angle. Temperature, pressure, and composition of in-cylinder gasses are used for gas emissions calculations, and this is the one of the principle of thermodynamic modeling of the combustion process.

The mass balance for the cylinder is written as

$$\frac{dm_s}{dt} = \frac{dm_{in}}{dt} + \frac{dm_f}{dt} + \frac{dm_{exh}}{dt} + \frac{dm_{ev}}{dt} + \frac{dm_{bb}}{dt} \quad (1)$$

Where m_s the mass of the system, m_{in} the mass of the fresh air which entered from inlet valves, m_{exh} the mass of exhaust gases, m_f the mass of evaporated fuel, and m_{bb} the mass of blow by gases which escaped from cylinder to the crankcase. The first law of the thermodynamics describes the conservation of energy. It states that only the enthalpy supplying and removal through the thermodynamic system boundaries changes the combustion chamber gases energy. Hence the energy conversation for the system according to the 1^{st} law of thermodynamics is written as:

$$\frac{dE_{sys}}{dt} = \frac{dU}{dt} = \frac{dQ_w}{dt} + \frac{dQ_f}{dt} - P\frac{dV}{dt} + \frac{dm_{in}}{dt}h_{in} + \frac{dm_{exh}}{dt}h_{exh} + \frac{dm_{bb}}{dt}h_{bb} + \frac{dm_f}{dt}h_f + \frac{dQ_{ev}}{dt} \quad (2)$$

Where: E_s System energy, U the total internal energy, Q_w the heat transfer in the cylinder, h_{in} the enthalpy of the fresh air, h_{exh} exhaust gas enthalpy, h_{bb} the enthalpy of blow by gases, h_f evaporation enthalpy of the fuel, Q_f the heat release rate, Q_{ev} the amount of heat which taken from gas to heat up the fuel before the evaporation.

As explained before single-zone thermodynamic model can be modeled by the assumption that the combustion chamber is a closed system. According to these assumptions, the mass balance equation for in-cylinder gases can be written as follows

$$\frac{dm_s}{dt} = 0 \quad (3)$$

Also for simplicity heat losses due to the friction between the piston and the cylinder walls can be neglected, and the fuel evaporation enthalpy is relatively small compared with the others and can be neglected, as well as due to the negligence of blow by gases, the energy conservation equation can be written as.

$$\frac{dE_s}{dt} = \frac{dU}{dt} = \frac{dQ_w}{dt} + \frac{dQ_f}{dt} - P\frac{dV}{dt} \quad (4)$$

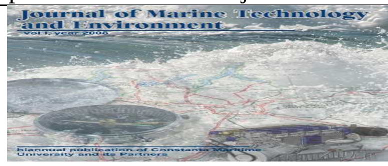
The equation (4) determines the change in internal energy of our thermodynamic system, the terms of the equation are the mechanical work, the heat from chemical energy released by combustion, and the heat transfer through the cylinder, all should be calculated Hence, From solving the equation(4) and by the use of a polynomial equation that describe the internal energy of in-cylinder gases, we can get the value of in-cylinder gases temperature during the combustion and expansion period, this temperature can be used in emissions calculating and modeling.

2.2 Two zones thermodynamic model:

One of the main shortcomings of single-zone thermodynamic model is the assumption that the in-cylinder gases temperature is the same, but on the contrary the in-cylinder gases temperature varies on the entire combustion chamber, this shortcoming of the single-zone thermodynamic model can be reduced by using empirical two-zone model during the combustion of the engine's working process.

In the case of the two-zone thermodynamic model the cylinder charges is divided into two zones. One zone contains the unburned components of fresh air fuel and residual gases, the residual gases component is can be neglected and only is taken into consideration in the case of using exhaust gas recirculation system, the temperature in this zone is relatively low, the other zone contains burned products, or more precisely incompletely oxidized fuel which called the reaction zone, and the temperature in the reaction zone is high. There is a third zone which considered with no mass an infinitely thin, so it will not be taken into our calculation, this zone assumed to separate between burned and unburned zones.

There are many models which used for modeling the thermodynamic process inside the cylinder, one of these models is Hohlbaun model, the approach which is used in this model is before the start of the combustion the content inside the whole cylinder is the content of the zone1 which is unburned zone, after the combustion starting, the zone two is formed by adding and subtracting the content of zone 1 via combustion through the turbulent mixing inside the cylinder and the flame front propagation. The other method to model the combustion process is Heider model, the model approach is described by (Heider 1996) [3], [4] has been selected for the two-zone thermodynamic model calculation in our study due to the simple formulation, good computation and low calculation time. The Hieder model



is based on empirical model for temperature difference between the two zones. Heider model uses the cylinder pressure difference between the cylinder pressure when combustion takes place and the theoretical pressure of the motored engine which called motored pressure.

The first step for building the two-zone model will be determination the mass of each zone depending on the rate of heat release of one zone thermodynamic model, the second step will be the determination of each zone temperature basing on empirical equation, the third step will be after calculating the burned zone temperature where the equilibrium concentration will be determined, after that all the data which needed especially to calculate Nox emissions will be available. All these steps will be explained in details.

The calculation of the state within the two-zones is based on the solution of the Single-zone model and the following condition and assumptions:

- Cylinder content is considered as ideal gas
- The pressure value is the same in both zones
- The conservation of mass and volume for both zones
- The heat that released by the combustion occurs only in the reaction zone
- No Nox emissions are formed in the unburned zone
- The equivalence ratio in the reaction zone is constant with time

The temperature difference between zones 1 and 2 has a maximum at the start of combustion and decreases to zero when the exhaust valves open due to the energy transfer between the zones.

According to the previous conditions and assumption:

$$m_1 + m_2 = m_s \; ; \tag{5}$$

$$V_1 + V_2 = V_S \; ; \tag{6}$$

$$p_1 = p_2 = p_s \, . \tag{7}$$

Where: numbers 1 and 2 denote the burned and unburned zones respectively. The mass of zone 1 is calculated as follows:

$$m_1(\varphi) = m_{air,1}(\varphi) + m_{fuel}(\phi) = m_{fuel}(\varphi)\cdot\left[\frac{af_{stoic}}{\phi_1} + 1\right] = \frac{Q_{chem}(\varphi)}{LHV}\left[\frac{af_{stoic}}{\phi_1} + 1\right] . \tag{8}$$

Where: LHV is the lower heating value usually $42000 \, {}^{kj}\!/_{kg}$, $m_{fuel}(\varphi)$ is the injected fuel until the crank angle φ, af_{stoic} is the stoichiometric air-fuel ratio, $Q_{chem}(\varphi)$ the heat released until the crank angle φ, ϕ_1 fuel/air equivalence ratio.

The ideal state equation is valid for the both zones, and each zone volume is related to the respective masses, temperatures and the cylinder pressure:

$$V_1 = \frac{m_1 R_1 T_1}{P_S} \, , \tag{9}$$

$$V_2 = \frac{m_2 R_2 T_2}{p_s} \, . \tag{10}$$

For the more conditions for the mean cylinder temperature it is satisfied to write

$$m_1 T_1 + m_2 T_2 = m_s T_s \, . \tag{11}$$

The difference between the temperature of burned zone and the temperature of unburned zone reduced with the progress of combustion process, due to the transfer of energy between the two zones, so the difference in temperature decrease till reaching zero at the moment when the exhaust valves open, turbulent mixing is considered responsible for the heat transfer between the two zones, as well as the radiation and convection of heat but in minor effect.

The rate of the heat transfer is empirically described by the use of pressure difference between fired and motored engine operation $p_s - p_{mot}$

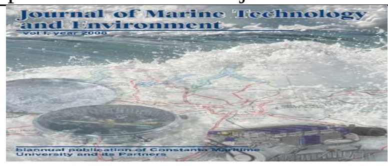
$$T_1(\varphi) - T_2(\varphi) = B(\varphi)\cdot A^* \, . \tag{12}$$

Where:

$$B(\varphi) = \frac{\int_{\varphi_{SOC}}^{\varphi_{EVO}} [p_s(\varphi) - p_{mot}(\varphi)] m_1(\varphi) d\varphi - \int_{\varphi_{SOC}}^{\varphi_{EVO}} [p_s(\varphi) - p_{mot}(\varphi)] m_1(\varphi) d\varphi}{\int_{\varphi SOC}^{\varphi_{EVO}} [p_s(\varphi) - p_{mot}(\varphi)] m_1(\varphi) d\varphi} \, . \tag{13}$$

The value of B decreases from 1 to 0 when the exhaust valves open

A^* Is given by the following equation:



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$$A^{*} = A \cdot \frac{\phi_s}{2.2\phi_1} \cdot \left[1.2 \left(\frac{1}{\phi_s} - 1.2 \right)^{0.15} \right]. \quad (14)$$

Where $\phi_1 = 1$ for small to medium size diesel engines, and ϕ_s is global air fuel ratio

More details about these equations can be found in reference [3], [4]

In spite of the empirical nature of the Heider method to determine the temperature of burned and unburned zones, it gives satisfied results regarding the calculations of Nox emissions from diesel engines, adding to satisfied results, its simplicity and short computational time which makes from Heider method a preferable way for thermodynamic calculation of Nox emissions.

3. RESULTS AND THE DISCUSSION

The results are obtained by the use of MATLAB program for the sake of modelling in-cylinder gases temperature and pressure for Hino W04D high speed marine diesel engine at 1600 rpm, and torque150N.m.,

As Figure 1 shows the difference between the pressure during motored operation and the pressure during combustion this difference as mentioned before will be used to divide the temperature between the two zones inside the combustion chamber.

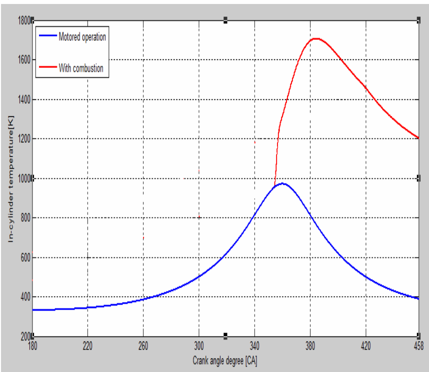


Figure 2 In-cylinder temperatures

The Figure 2 shows the difference between temperature during the combustion and the temperature during the motored operation the peak temperature occurs shortly after the top dead centre by 3.5 $^{\circ}$CA. the importance of accurate determination of peak pressure because its effect on emissions formation specially Nox emissions.

this engine is naturally aspirated with direct injection, the number of cylinders 4, the peak power is 56 kw at 2550 rpm, the peak of torque is 245N.m at 1600 rpm, and the displacement is 4.009 liter, the range of the degree of crank angle is from the beginning of compression stroke till the open of exhaust valves.

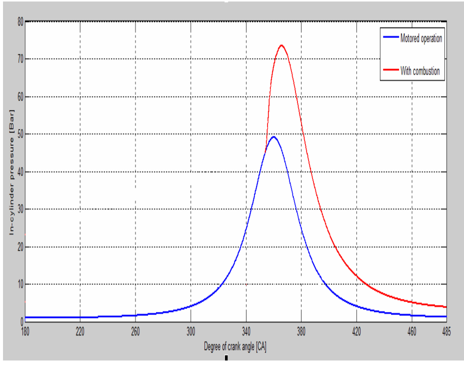


Figure 1 In-cylinder pressure

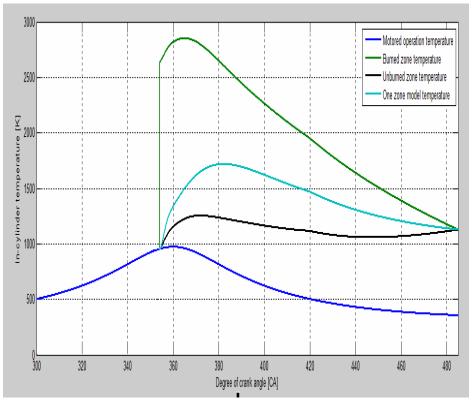
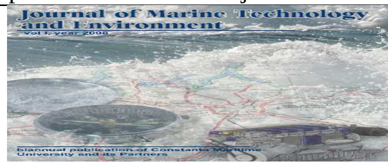


Figure 3 The temperature of two zones model

Figure 3 shows the difference between the burned, unburned, in-cylinder temperature comparing with the in-cylinder temperature during the motored operation and combustion, the peak temperature of burned zone reaches a high values about 2784 C, whereas the temperature of unburned zone hardly reaches 1254.

5. CONCLUSIONS

Two-zones thermodynamic model gives more accurate conception for the temperature iside the combustion chamber by dividing it to two zones relatively in a short time, and also in a small additional computing efforts. The two zones thermodynamic model helps to calculate the peak temperature of in-cylinder burned gases in more accurate way than one cylinder



model. The main defect of this method is its incapapility for calculating the real distributing of the temperature inside the comustion chamber, this defect can be reduced by extend the two zones thermodynamic model to multi-zones thermodynamic model.

Inspite of this defect the two-zones thermodynamic model is considered one of the practical model for modeling and prediction the diesel engine performance and the gas emissions, this model which presented in this paper it can be used for calculating and predecting the Nox emissions from diesel engines.

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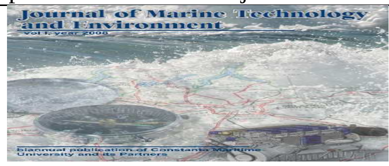

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VELOCITY OVER THE TARGET SURFACE AND PRESSURE FOR A NUMERIC GEOMETRY OPTIMIZATION OF AN WED

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Abstract: The pressure on ships designers to achieve both reduced fuel costs and reduced emissions by optimizing the hull and propeller has never been higher. Being one of the key strategic business goals for ship owners and operators, the reduction of fuel cost becomes essential; and furthermore a variety of recent legislations require owners and operators to move towards the reduction of emissions from ships of SOx, NOx and CO. There has been great interest in the potential to enhance the performance of existing vessels through retrofit of devices to the hull, in parallel to the performance improvement of new built vessels. The Wake Equalizing Duct (WED) device must be customized to fit to the afterbody of the ship in terms of performing its supposed function as Velocity over the Target Surface and Pressure. The Designer is therefore placed in the front of multiple geometric solutions from between he has to make a choice. A given geometry of a WED device is taken and via Design Optimization the geometry of the duct was refined so that better results are achieved with a smaller and more compact WED. A rational choosing approach by involving the numeric optimization of the geometry of the WED in order to select the best fitted WED to perform the best in order to achieve some predefined parameters is targeted in this papers.

Key words: Design Explorer, Finite Volume Analysis, Geometry Optimization, Maritime Ships, Wake Equalizing Duct.

1. INTRODUCTION

The reduction of fuel cost has always been one of the key strategic business goals for ship owners and operators. In the current climate of high oil prices, the reduction of fuel costs becomes essential; and furthermore a variety of recent legislations require owners and operators to move towards the reduction of emissions from ships of SOx, NOx and CO.

Hence the pressure on designers to achieve both reduced fuel costs and reduced emissions by optimising the hull and propeller has never been higher. In parallel to the performance improvement of new built vessels, there has been great interest in the potential to enhance the performance of existing vessels through retrofit of devices to the hull. A wide range of concepts has been proposed, many of which involve modification or control of the flow in the vicinity of the propeller. The interest in these devices arises with increasing oil price. These devices are commonly called “energy saving devices (ESD)” and sometimes “retrofitting technologies” although many can be considered for new designs as well[1].

In any case for instance the WED device must be customized to fit to the afterbody of the ship in terms of performing its supposed function. The Designer is therefore placed in the front of multiple geometric solutions from between he has to make a choice. This paper is intended to help the Designers to have a rational choosing approach by involving the numeric optimization of the geometry of the WED in order to select the best fitted WED to perform the best in order to achieve some predefined parameters.

The claims may not give details as to the conditions under which the savings have been achieved and/or how the savings have been calculated and/or measured. Furthermore, the magnitude of the savings may well be within the range of uncertainties and measurement errors on the full-scale vessel. Consequently, cautious operators may well be skeptical about the validity of the figures being presented to the market, and it is absolutely reasonable and necessary for a buyer to verify independently the amount of savings before any investment on an ESD or ESDs [2].

The savings look very attractive to ship operators, for instance a saving of 7-9% from installation of a wake equalising duct (Schneekluth, 1986, Schneekluth (WED) and Bertram, 1998) or 8-9% from a combination of wake equalising duct and pre-swirl fins (Mewis, 2008, Mewis, 2009). In general, the negative aspects of the devices include the considerable cost of installation, and also the reported reluctance of manufacturers to guarantee the claimed savings[3].

2. CAD AND FINITE VOLUME ANALISYS (FVA) MODEL OF THE SHIP

The goal of this paper is to calculate via software Ansys 13^{TM} the best geometric solution for a WED device. It is known that a poor design of the WED is not only improving the overall efficiency of the vessel but may have an adverse impact failing to achieve its purpose.

The model has as departure point a real portcontainer as seen below, with the following parameters:

- Length *L*- [m]- 173
- Breadth *B*- [m]- 25
- Draught *T*- [m] -9.50
- Diameter *D*- [m]- 5
- Number of blades *Z* - 6
- Propeller RPM-120
- Average Speed-16 knots (7 m/s)

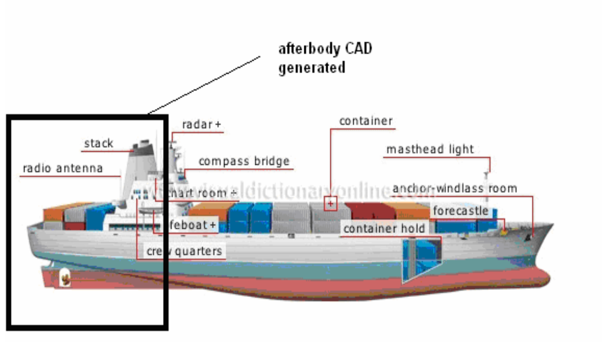


Figure 1 Port-Container

In order to have a starting point for the simulation, first of all the afterbody was firstly CAD generated with the WED device attached, and all the parameters for fluid flow were calculated accordingly. From that point on the Ansys Design Explorer was involved in order to optimize the geometry[4][5].

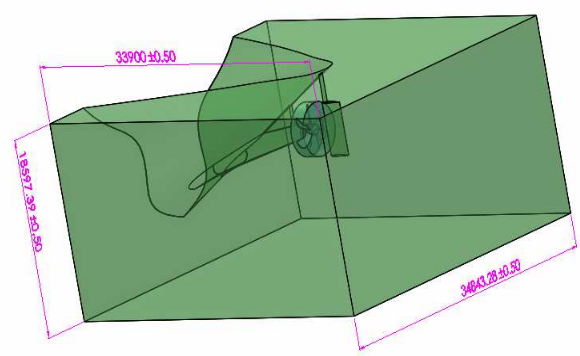


Figure 2 CAD geometry with WED

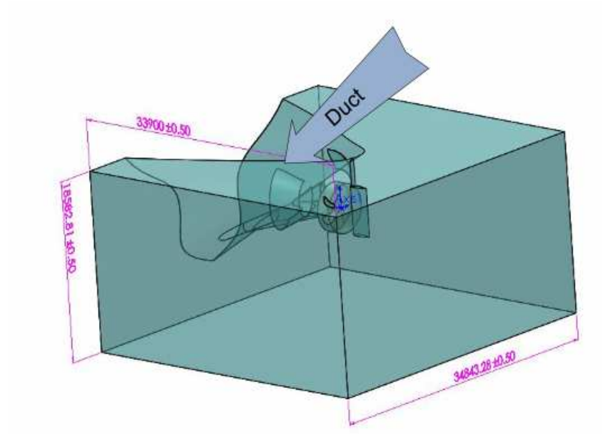


Figura 3 CAD geometry with WED

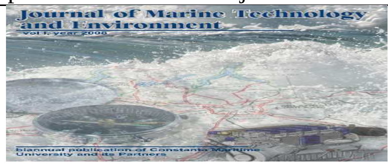
In order to provide more details on the geometry of starting model of the WED device and the optimization input parameters, the below figure is shown, with dimensions in [mm].

5 input geometric parameters were defined as follows:

Table 1. Input geometric parameters

	Name	Type	Lower limit	Upper limit
P1	Angle Minimize	Continuos	14 [degree]	22 [degree]
P2	Duct Length Minimize	Continuos	1980 [mm]	2420 [mm]
P3	Small radius Minimize	Continuos	1600 [mm]	2250 [mm]
P4	Bigger cone radius Minimize	Continuos	2250 [mm]	2750 [mm]
P5	Distance from the propeller Minimize	Continuos	1800 [mm]	2200 [mm]

The fluid domain was divided in two: the fluid domain which is surrounding the afterbody having the relative velocity on Oz axis of 7 m/s and the Propeller



fluid domain with CFX option of “frozen Rotor” where the fluid is moving circularly around OZ axis with 120 RPM. In between these two domains interfaces were established. The other boundary conditions were inlet, outlet and openings as decided earlier[6][7]

In order to make clear some important surfaces, three control planes were defined as follows:

- Control plane number 1 (P1) placed at 1200 mm above the propeller axis and coplanar with the two WED devices axis;
- Control plane number 2 (P2) which is including the propeller axis;
- Control plane number 3 (P3) placed at 1500 mm away from the propeller domain;
- Target Plane which is in fact one of the propeller domain interfaces as below:

Taking into account the above defined control planes as output parameters[8] needing to be optimized were defined as being the Average fluid velocity passing through the Target Plane (suspected to improve the propeller efficiency-the bigger the better) and the average pressure on the inside of the WED device (suspected to increase the drag-the smaller the better)[9]:

Table 2. Output parameters

ID	Parameter Name	Starting Value	Unit
P6	VelocityTarget (maximize)	14.769	m s^-1
P7	PressureDuct (minimize)	89874	Pa

3. CFA SIMULATION AND OPTIMIZATION RESULTS

After reaching the convergence of the given starting models, and going through Design Explorer Module, 27 design points were calculated in order to define the response surfaces of the project:

Table 3. Design Points

Name	P1 - Angle (deg)	P2 – Duct Length (mm)	P3 – Small Radius (mm)	P4 – Bigger cone radius (mm)	P5 – Distance from the propeller (mm)
1	18	2200	1925	2500	2000
2	14	2200	1925	2500	2000
3	22	2200	1925	2500	2000
4	18	1980	1925	2500	2000
5	18	2420	1925	2500	2000
6	18	2200	1600	2500	2000
7	18	2200	2250	2500	2000
8	18	2200	1925	2250	2000
9	18	2200	1925	2750	2000
10	18	2200	1925	2500	1800
11	18	2200	1925	2500	2200
12	16.867	2137.7	1832.9	2429.2	2056.7
13	19.133	2137.7	1832.9	2429.2	1943.3
14	16.867	2262.3	1832.9	2429.2	1943.3
15	19.133	2262.3	1832.9	2429.2	2056.7

16	16.867	2137.7	2017.1	2429.2	1943.3
17	19.133	2137.7	2017.1	2429.2	2056.7
18	16.867	2262.3	2017.1	2429.2	2056.7
19	19.133	2262.3	2017.1	2429.2	1943.3
20	16.867	2137.7	1832.9	2570.8	1943.3
21	19.133	2137.7	1832.9	2570.8	2056.7
22	16.867	2262.3	1832.9	2570.8	2056.7
23	19.133	2262.3	1832.9	2570.8	1943.3
24	16.867	2137.7	2017.1	2570.8	2056.7
25	19.133	2137.7	2017.1	2570.8	1943.3
26	16.867	2262.3	2017.1	2570.8	1943.3
27	19.133	2262.3	2017.1	2570.8	2056.7

Taking each and every design points to be calculated via CFA, the output parameters to be optimized are shown below:

Table 4. Output calculated parameters for each design points

Name	P6 – Velocity Target (m s^-1)	P7 – Pressure Duct (Pa)
1	14.518	1.0123E+05
2	14.75	99999
3	14.514	1.0294E+05
4	14.553	1.02E+05
5	14.482	1.0077E+05
6	14.527	1.033E+05
7	14.541	97174
8	14.561	97907
9	14.581	1.0307E+05
10	14.556	1.0094E+05
11	14.571	1.0135E+05
12	14.65	1.015E+05
13	14.596	1.0155E+05
14	14.574	1.008E+05
15	14.543	1.0136E+05
16	14.6	98976
17	14.539	99788
18	14.563	98563
19	14.576	99455
20	14.595	1.0255E+05
21	14.553	1.0314E+05
22	14.547	1.0218E+05
23	14.514	1.0297E+05
24	14.588	98469
25	14.577	1.0143E+05
26	14.57	1.0046E+05
27	14.558	1.0152E+05

The software is automatically selecting the maximum and minimum calculated values of output parameters as below:

Table 5. Minimum and maximum output parameters

	Minimum value	Maximum value
P6 - VelocityTarget (m s^-1)	14.478	14.784
P7 - PressureDuct (Pa)	67648	1.4648E+05

By judging the above minimum and maximum value of the pressure inside the duct, the difference is 20 folds which is clearly making a difference between a good and a poor design.

By setting the goals of maximization or minimization defined above for all the parameters, at the end of the optimization process three best candidates will be generated:

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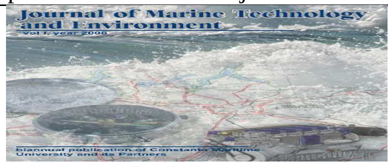


Table 6.The three best candidates

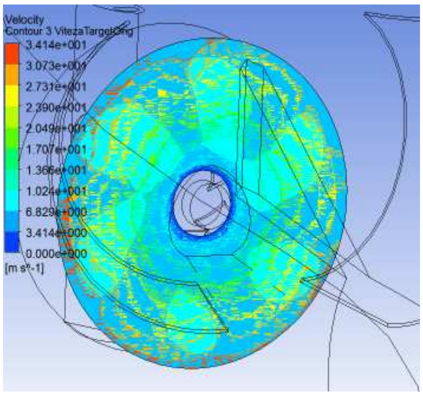
	P1 - Angle (degree)	**P2 – Duct Lenght (mm)**	**P3 – Small Radius (mm)**	**P4 – Bigger cone Radius (mm)**	**P5 – Distance from the propeller (mm)**	**P6 – Velocity Target (m s^-1)**	**P7 – Pressure Duct (Pa)**
Candidate Point 1	★★★ 14.164≈ 14 degree	★★ 2049≈ 2050	★ 2081.8≈ 2080	★★ 2330.3≈ 2330	★★ 2159.4≈ 2160	★★★ 14.78	★ 98351
Candidate Point 2	★★★ 14.644	★★★ 1997.4	★★★ 2242.3	★★★ 2282.3	– 2005.4	★★ 14.756	★ 94591
Candidate Point 3	★★ 15.284	★★★ 1988.8	★ 2028.3	★★ 2295.1	★★ 2154.7	★ 14.702	– 1.0633E+05

Here once again the Designer is called to make a decision, we choose the first candidate having three stars to the most of the parameters.

In order to have an overall idea on the influence of each and any input parameter has on the output parameter, the sensitivity charts and response surfaces are the best aids for judgment. Since the possible combinations are many, only few response surfaces are given below.

- The influence of optimized parameters on the velocity through the target surface

By analyzing the figures below, one may see that the shape of the velocity fields on the upper zone of the propeller is more extended, so that the optimized version is “pushing” more fluid on this zone.



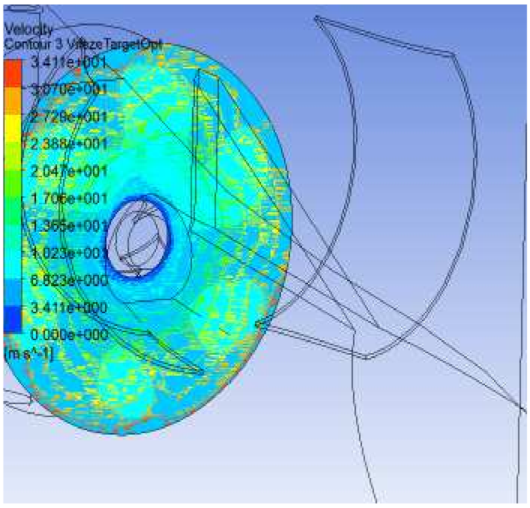
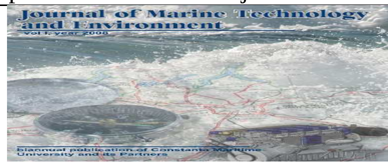


Figure 4 The starting model and the optimized model velocities

- The influence of optimized parameters on the pressure inside the duct



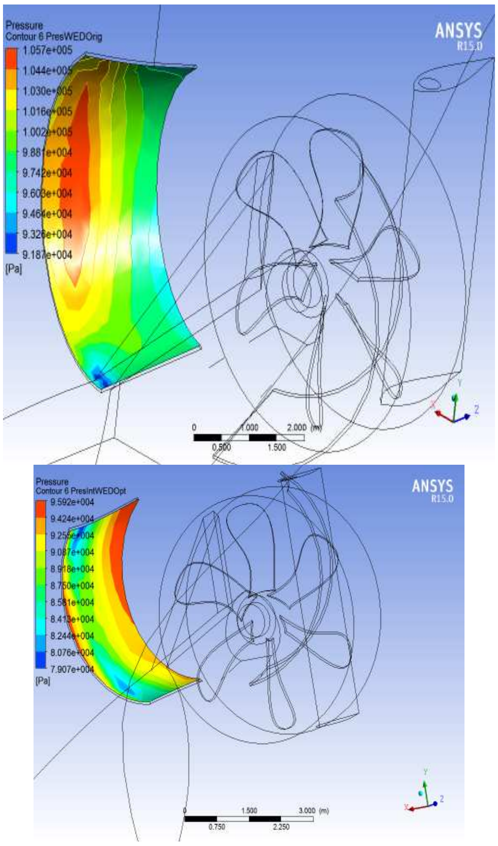


Figure 5 The starting model and the optimized model duct pressures

The starting model has a bigger (red colored) pressure fields on the inside the duct whereas the optimized version has smaller and placed at the outlet zone of the duct pressure fields, which is an indication that the inside pressure and the drag is then diminished for the optimized version.

In order to place all the influences on a single chart, the sensitivity chart is used as below:

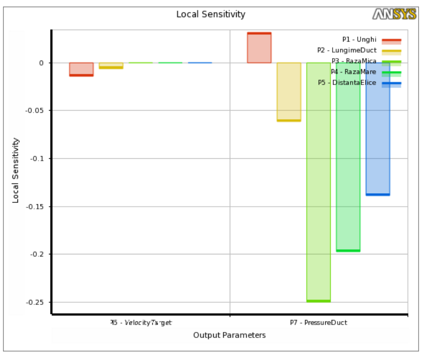


Figura 6 Sensitivity chart

Finally if one wants to visualize the effect of the optimized input parameters, we can recalculate the model with these new optimized parameters for geometry.

4. CONCLUSIONS

In this paperwork a given geometry of a WED device is taken and via Design Optimization the geometry of the duct was refined so that better results are achieved with a smaller and more compact WED regarding Velocity over the Target Surface and Pressure. In doing so, the Designer is assisted by numeric optimization methods to choose from only three final candidates instead of several thousands in order to provide the best fitted WED geometry for a given ship afterbody.

The wake equalizing duct (WED) is one of the most commonly used energy saving devices for improving the propulsion performance of a ship; and reducing the propeller-excited vibrations and viscous resistance forces.

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A POINT OF VIEW ON THE THEORY OF OPEN CYCLE GAS TURBINES

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Abstract: In the context of the high interest on the concept of energy, engineering education has to adapt to the modern technical requirements. In this respect, marine engineering, as a part of engineering education is facing curricula changes.

This paper deals with an attempt related with the improving of the teaching syllabus of the discipline called Thermodynamics / Part 1, included in the curricula of future marine engineers, enrolled in Constanta Maritime University (CMU). More exactly, it is about the theory of open cycles of gas turbines. The need of improving this theory came from the fact that in the last decades, this technology became more and more attractive for different industries. Maritime industry is one of these, where it is registered a high interest for thermal performance improving.

Thus, if the classic theory of open cycles gas turbines was based on considering the working fluid to be a perfect gas, having constant specific heats, the new approach is discussing the case of irreversible cycle and specific heats of air and flue gas depending on temperatures. Results the need of a new hour allocation.

This theoretical basis is allowing a more detailed thermal efficiency evaluation and assessment of specific fuel combustion.

Key words: gas turbines, thermodynamics, specific heats

1. INTRODUCTION

In present, gas turbines are recognized to be among the most used power generating systems, these technologies being similar to internal combustion engines in which after the combustion of air and fuel mixture result hot gases that spin a turbine in order to produce power; if in reciprocating internal combustion engines the fuel burning takes place intermittently, in gas turbines it occurs continuously [1].

Regarding land based sector, gas turbines can be met both in direct drive and mechanical drive application, the weight being an important motivation for the offshore platform use; usually on board the ships, and a gas turbine is driving the propellers through a gear box [2].

The maritime industry relies on the academic education when it is about involving high quality staff. All over the world, higher maritime education is included in engineering education and in Romania it is governed by international standard – formulated by the International Maritime Organization and also by national standards – found in the national engineering curricula.

In Constanta Maritime University efforts are constantly done in order to upgrade curricula and thus to be able to assure an easier penetration of our graduates in the world’s fleet.

In this paper it is discussed the manner in which the course of thermodynamics is enriched related to the topic of gas turbines.

In the following section will be presented details regarding the syllabus of this discipline, delivered to the future marine engineers, in the context of the analysis for the working fluid as a perfect gas with constant specific heats and specific heats of air and gas as a function of temperatures.

2. METHODS AND MATERIALS

In Constanta Maritime University, students are first introduced in the topic of gas turbines within the course of Thermodynamics / part 1, delivered for the future marine engineers, in their second year of academic preparation.

Thermodynamics / part 1 is a discipline with a total of 70 hours for Electromechanics Specialization, which are distributed as: 42 hours for courses, 14 hours for seminars and 14 hours for laboratories.

Compulsory prerequisites are physics and advanced mathematics and recommended it is chemistry.

Course objectives are stated as having theoretical knowledge for the application of thermodynamics laws in order to study processes developed in marine thermal plants, while applications objectives are defined as knowledge and calculus understanding and application gained during courses, through specific problems.

Related STCW objectives are found in Appendix 3: the capacity of translating in practice theory gained during theoretical courses, obtaining solutions to specific engineering problems and the ability of communicating these results.

Course outlines are as follows, with the specification of duration and relationship with IMO regulations:

- Thermodynamic properties: pressure, volume, temperature (7.04 Appendix 3-1.1, 4 h)
- Thermodynamic energy: internal energy and enthalpy, kinetic energy, heat and work (7.04 Appendix 3-1.2, 6 h)
- Thermodynamic systems: closed, open, adiabatic, isolated systems (7.04 Appendix 3-1.3, 1 h)
- Energy exchange: first law, sign of heat and work exchange, practical utility of the first law, second law (7.04 Appendix 3-1.4, 8 h)
- Ideal gases: simple transformations, characteristic state equation (7.04 Appendix 3-1.7, 6 h)
- Theoretical cycles of thermal machines: internal combustion engines, gas turbines, reciprocating compressors (7.02.1.2.1.1, 10 h)
- Vapours: characteristic equations, types of vapours, thermodynamic tables, simple transformations, Clausius-Rankine cycle (7.04 Appendix 3-1.6, 3 h, 7.02.1.2.1.2, 4 h).

Seminars deal with: thermodynamic parameters of a thermal system, mixtures of ideal gases, simple transformations of ideal gases, cycles of thermal machines, combustion of liquid fuel, vapours.

The classic approach of the theory of gas turbines with isobaric fuel combustion presented during course delivery, consists in discussing the case of the air standard cycle, for which the thermodynamic system is an ideal gas, with the specific heat at constant pressure given by:

$$c_p = \frac{k - R}{k - 1} \qquad (1)$$

where:
R – specific gas constant
k – adiabatic exponent.

In this type of analysis, the heat capacities present in formulas are those for air.

A simple gas turbine cycle with isobaric combustion of fuel is the Brayton cycle, known also as Joule cycle.

This cycle is given in Figure 1 and it consists by the processes: adiabatic compression in the compressor, isobaric fuel combustion with heat addition, adiabatic expansion and isobaric air cooling till its initial condition, with heat rejection.

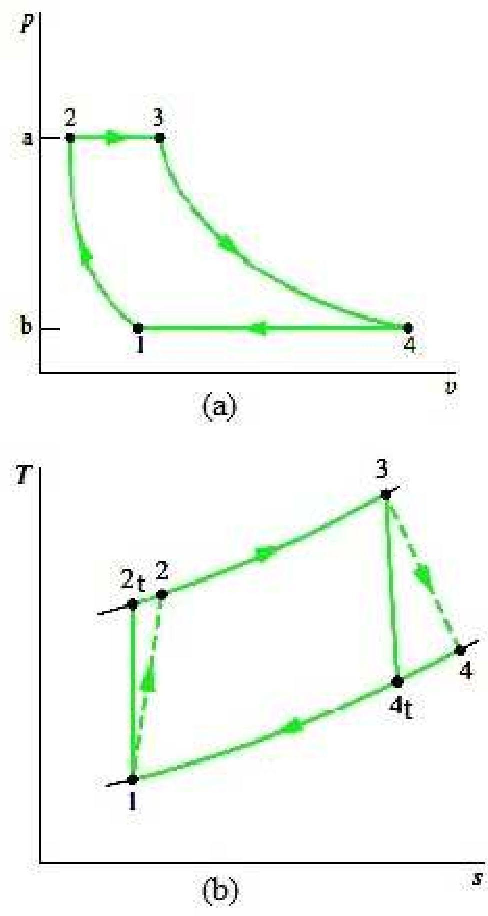

Figure 1 Brayton cycle (gas turbine) a: p-v diagram; b: T-s diagram

Above, 12_t and 34_t represent the reversible adiabatic processes (theoretical).

Despite the fact that we are discussing about the open gas turbine cycle, Figure 1b is specific to the closed cycle, which implies a heat exchanger after the turbine, in order to be isobaricaly cooled the working fluid till state 1 and the cycle repeats [3].

The new approach deals with the perspective for which are exposed formulas for the assessment of the specific heats of air and gas depending on temperatures.

3. RESULTS AND DISCUSSION

The new approach related with the theory of gas turbines, to be included in the syllabus of Thermodynamics / part 1, is given by the equations written bellow [4].

The thermal cycle efficiency is calculated with the formula:

$$\eta_t = \frac{W_n}{Q_i} \tag{2}$$

where:
W_n – net work of the gas turbine
Q_i – heat added to the working fluid.

$$W_n = c_{pg} T_3 \eta_{ae} \left(1 - \frac{1}{\beta^{\frac{k_g - 1}{k_g}}} \right) - c_{pa} T_1 \left(\frac{\beta^{\frac{k_a - 1}{k_a}}}{\eta_{ac}} \right) \tag{3}$$

where:
c_{pg} – specific heat of flue gas
T_3 – temperature at the end of isobaric combustion
η_{ae}, η_{ac} – efficiencies of isentropic expansion and compression
β – compression ratio (ratio between pressures at compressor exit and inlet)
c_{pa} – specific heat of air
k – ratio of specific heats (adiabatic exponent)
T_1 – temperature of air at compressor inlet

$$Q_i = c_{pga} \left[T_3 - T_1 \left(1 + \frac{\beta^{\frac{k_a - 1}{k_a}}}{\eta_{ac}} \right) \right] \tag{4}$$

where:
c_{pga} – average value of the specific heat of the flue gas

The specific heats are found with the equations:

$$\begin{aligned} c_{pa} &= 1.0189 \cdot 10^3 - 0.1378 \cdot T_{air} + \\ &+ 1.9843 \cdot 10^{-4} T_{air}^2 + \\ &+ 4{,}2399 \cdot 10^{-7} T_{air}^3 - 3{,}7632 \cdot 10^{-10} T_{air}^4 \end{aligned} \tag{5}$$

available for the air temperature in the range (200-800) K.

$$\begin{aligned} c_{pg} &= 1.8083 - 2.3127 \cdot 10^{-3} T_g + \\ &+ 4.045 \cdot 10^{-6} T_g^2 - 1.7363 \cdot 10^{-9} T_g^3 \end{aligned} \tag{6}$$

The effect of irreversibilities is introduced together with the isentropic efficiencies, assessed with:

$$\eta_{ac} = \frac{T_{2t} - T_1}{T_2 - T_1} \tag{7}$$

$$\eta_{ae} = \frac{T_3 - T_4}{T_3 - T_{4t}} \tag{8}$$

The air temperature at compressor exit is found with:

$$T_2 = T_1 \left(1 + \frac{\beta^{\frac{k_a - 1}{k_a}} - 1}{\eta_{ac}} \right) \tag{9}$$

The specific fuel consumption is evaluated with:

$$c_{sp} = \frac{3600 f}{W_n} \tag{10}$$

where:
f – ratio of mass flow rate.

According also to [5], "f" is the rate between the fuel mass rate and air mass rate, so:

$$f = \frac{c_{pg} T_3 - c_{pa} T_2}{LHV - c_{pg} T_3} \tag{11}$$

In the burning chamber, the energy balance equation is as:

$$\begin{aligned} &\dot{m}_{air}\, c_{pa} T_2 + \dot{m}_f\, LHV + \dot{m}_f\, c_{pf} T_f = \\ &= \left(\dot{m}_{air} + \dot{m}_f \right) c_{pg}\, T_3 \end{aligned} \tag{12}$$

By the help of the above theoretical assessment it is possible to be evaluated the effect of air temperature on the thermal efficiency of the gas turbine, for different values of the compression ratio and temperature of working fluid at the end of combustion, the influence of air temperature on the specific consumption of fuel for different values of the temperature at the end of burning, the influence of the compression ratios on thermal efficiency and specific fuel consumption for different values of the temperature at the end of combustion.

In order to add to the classical approach of the gas turbine theory the above mentioned analysis methodology should be reconsidered the hour allocation for the chapter called "Theoretical cycles of thermal machines", as proposed bellow (see Table 1).

Having in view that the topic of reciprocating compressor will be discussed in detail during the course named Marine Refrigeration Plants, included in the curricula of future marine engineers, the theory presented during Thermodynamics / Part 1 course can be structured for 1.5 h course presentation, from 2 h.

Table 1. Hour allocation for theoretical cycles of thermal machines

Topic	Classic hour allocation	New hour allocation
internal combustion engines	5 h	5 h
gas turbines	3 h	3.5 h
reciprocating compressors	2 h	1.5 h

4. CONCLUSIONS

Because in the last years gas turbines became more interesting in different industries such as transport, engineers should be ready for the growth of this technology.

This paper focused on the interest in improving of syllabus of the discipline called Thermodynamics / Part 1, specific to the academic training of future marine engineers, enrolled in CMU.

In order to enrich the part of theory dedicated to gas turbines with a new approach, was proposed a new hour allocation within the chapter dealing with thermal cycles. This new allocation will not negatively affect the general knowledge of future graduates.

The new approach deals with specific heats of air and flue gas depending on temperatures. The analysis methodology will allow to future marine engineers to assess different effects:

- variation of thermal efficiency with air temperature
- variation of thermal efficiency with compression ratio
- variation of specific fuel consumption with air temperature
- variation of specific fuel consumption with compression ratio.

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DEVELOPMENT OF MATHEMATICAL MODEL FOR HUMAN RELIABILITY ASSESSMENT

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Abstract: The assessment of the human reliability is an attempt to predict the behavior and the attitude of the man, which could lead to the realization of a critical situation. This is a complex process, mainly due to the fact that unlike machines which failures are predictable and easy to be identified because of the exact parameters that the process must have at any point in its development, when dealing with people, we cannot speak of "failures” in the purely technological sense of the word. Some of the most important reasons for that are: that the people’s work is often described qualitatively, but not quantitatively; in most of the cases the action carried out by a human is part of a process shaped by the actions of other people involved in it; and in the complex of factors, physical and psychological, personality-related, qualifications, experience and knowledge, as well as the environment and the nature of work, which affect the human in the performance of his duties.

Key words: human reliability assessment, risk, integral risk index, quantitative risk assessment

1. INTRODUCTION

The complicated production environment nowadays defines specific risk areas, which require special attention to each of the risk factors, which provoke them, in order to determine their impact on the overall processes - both technological and managerial. The working environment leads additional risk factors due to the presence and the intervention of the human factor and the possibility of its influence on the process in a different then the planned direction. Human action cannot be ignored, despite the high automation of the processes and the seemingly less and less involvement of a direct human involvement. The man is a part of the working environment and of the process of its planning, engineering design, operational implementation and of any direct activities, done by managers, designers and operators, but also by external (sometimes accidental) participants, users and others.

Statistics show as a major cause of up to 90% of all accidents occurring in the workplace in the last few decades the human error [1]. This means that the human error occupy a key place among the reasons for realization of critical situation because it has a potential to result in a accident of different scale, causing a disaster or a catastrophe.

The risk analysts usually pay a lot of attention to the assessment of the technogenic risk and quite less to the assessment of human reliability in the production environment. The reasons for this are the complex relations in “man-production” environment in which are difficult to identify the hazards and the risks, emerging by the human actions. On other hand, constituting a major part of the technological risk, in the process of implementation of specific critical situation, the human errors can be attributed to many factors - incompetence, poor motivation, negligence, poor organization, and this requires a high degree of analyze and segmentation of any of the above listed factors. The results from the implementation of the complex working situation is a combination of these factors, but in our opinion the most important in the process are the professional and personal characteristics of a human, which determine the human reliability.

The human reliability assessment in this study is interpreted as a way to predict what is the potential of a person, in the context of a particular job, to take actions, which could lead to the realization of a critical situation, or with other words how can be relied on a man for the sustainable functioning of the system. In this sense, were selected five, most important basic factors which influence the expression of this potential. This assessment is related with clarification of the reasons, most of which-personal characteristics - attitude, character, or "background" of the human response to a particular action or operation. The most important result of this multi-criteria analysis in this study is the quantification of the integral risk index, which is also an objective possibility for comparing of the human reliability of the people, in different situations and with different job duties.

2. MATERIALS AND METHODS

The human reliability (*HR*) is defined on the base of the integral risk index - R_{int} ($R_{int} \in [0, 1]$) on the following formula:

$$HR = 1 - R_{int} \tag{1}$$

From the formula is obvious that the lower risk indicator is the higher human reliability is.

For the calculation of the integral risk index R_{int}, is created a mathematical model. This model is based on the method - Linear combination of private criteria (LCPC) and on hierarchical model of basic and their constituent factors. The creation of this model for calculation of R_{int} is done through the following algorithm:

2.1 Determining the basic risk factors

Through an expert opinion amongst the full range of risk factors had been defined a set of five basic risk factors r_i (i=1,..,M), (M=5), which are most important for obtaining of a complex assessment of risk associated with human reliability. In this case we selected five of them, but the model allows the additionally adding of other factors, taking into account the specifics of the activity.

2.2 Determining the relative importance (weight) of the factors

For every basic factor r_i had been determined the level of its relative importance (weight) w_i

$$(\sum_{i=1}^{M} w_i = 1) \tag{2}$$

Table 1. Weights of the basic factors

Basic factors r_i	**Weight**
r_1 – Professional characteristics (ProfC)	w_1
r_2 – Personal characteristics (PC)	w_2
r_3 – Working environment (E)	w_3
r_4 –Physical State (PS)	w_4
r_5 – Behavior (B)	w_5

For the determination of the weights of the factors could be used different methods of expertise (immediate evaluation, ranking, pair wise comparison), as well as the method of analysis of the hierarchy (AHP). When the factors are ranked according their decreasing importance, the worth (weight) of the i-th factor w_i can be defined by the rule of Fishbern.

$$w_i = \frac{2(M - i + 1)}{(M + 1)M} \tag{3}$$

We chose the rule of Fishbern to determine the weights of the basic factors because of its easy application and at the same time the possibility of inclusion of expert opinion of a risk expert, who can rank the factors, by listing them, in accordance with their importance. In the present study this order is obtained as a result of a research done in four commercial sites in Bulgaria, offering different types of job duties, environment, physico-chemical parameters - oil refining and sale of fuels and services, glass manufacture and maintenance and sale of agricultural machinery.

2.3 Determining the subset of component factors

Trough an expert way for the basic factors r_i, which contain subordinate factors had been defined a subset of component factors (S-factors). In our case S-factors are quality attributes.

For each S-factor is determined its weight p_i compared to the base factor (the sum of the weights of all S-factors of a basic factor is equal to one). The current values of the S-factors are results of measurements, expert assessment for their expected value or are determined on the basis of the results obtained by the usage of relevant models.

Table 2. Values and weights of *S*-factors

***S*-factors of the basic factor r_i**	***Current values of S*-factors**	**Weight**
s_1	x_1	p_1
s_2	x_2	p_2
...	...	...
s_N	x_N	p_N

2.4 Normalization of the current values of the S-factors

The method *Linear combination of private criteria*, which we use, requires normalization of the current values before its implementation. The problem of normalization arises due to the fact that as a rule the meanings of the risk factors are set in different units and different scales of measurement. This makes their immediate generalization impossible. The operation for bringing the immediately asked meanings of factors to a single scale and dimensionless form is called normalization. Normalization can be performed in various ways. In our mathematical model, is applied the method of replacing the absolute values of the factors with relative values in the interval [0, 1] by the following formula:

$$x_{i01} = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}. \qquad (4)$$

In those cases where the factors are quality attributes, which have no quantitative assessment, are set numerical values corresponding to quality levels (*very low, low, medium, high, very high*), which are also converted to the interval [0, 1]. The transformation of qualitative levels or their quantitative assessments in their normalized form can be accomplished by the following rule.

Table 3. Normalized values of the quality levels of the factors

Quality levels of the factor	**Normalized values**
Very low	[0-0,20)
Low	[0,20-0,37)
Medium	[0,37-0,63)
High	[0,63-0,80)
Very high	[0,80-1,00]

The normalized values are set through expert assessments.

2.5 Calculating of the aggregate value of each basic factor

We calculate the aggregate value A_i^N of every basic factor r_i , consisting component factors (*S*-factors) on the following formula:

$$A_i^N = \sum_{k=1}^{N} p_k x_{k01} \qquad (5)$$

whereas:

N – number of the *S*-factors (k=1,..,N) for the relevant basic factor r_i,

p_k – weight of the k-th *S*-factor in the generalization,

x_{k01} – normalized value of the k-th *S*-factor.

The results are listed in a table with the values and weights of the basic factors -Table 4.

Table 4. Values and weights of the basic factors

Basic factors r_i	**Aggregated or current values of the basic factors**	**Weight**
r_1 – Professional characteristics (ProfC)	A_1^N	w_1
r_2 – Personal characteristics (PC)	A_2^N	w_2
r_3 – Working environment (E)	A_3^N	w_3
r_4 –Physical State (PS)	A_4^N	w_4
r_5 – Behavior (B)	A_5^N	w_5

2.6. Calculation of the integral risk index R_{int} on the following formula:

$$R_{int} = \sum_{i=1}^{M} \left(w_i \cdot A_i^N \right) \qquad (6)$$

whereas:

w_i – relative importance (weight) of the base factor (indicator) r_i; $\sum w_i = 1$;

A_i^N - aggregated (current) value of the i-th basic factor r_i;

M – number of the basic factors in the studied problematic situation.

The model can be built out from arbitory number of levels of hierarchy, *and for each S-factor could also be used a variety of component factors with their current values and weights.* The obtaining of the aggregated values of the S-factors on the basis of the values of the respective meanings of the component factors is carried out in a similar manner.

It is important to point out that the requirement of the model is that all risk factors and their component factors should vary in the *same direction* - the higher value means a higher level of risk, and there should be no correlation between the factors from the relevant level.

2.7. Performing a procedure for recognition of linguistic level R_{int}

Table 5. Quality levels of R_{int}

Values of R_{int}	Quality level of R_{int}
[0-0,20)	Very low
[0,20-0,37)	Low
[0,37-0,63)	Medium
[0,63-0,8)	High
[0,80-1,00]	Very high

2.8. Human reliability, estimated by R_{int}

Table 6. Human reliability, estimated by R_{int}

Value of R_{int}	Value of Human reliability	Human reliability assessment
[0-0,20)	(0,8-1,00]	Very high
[0,20-0,37)	(0,63-0,80]	High
[0,37-0,63)	(0,37-0,63]	Medium
[0,63-0,80)	(0,20-0,37]	Low
[0,80-1,00]	[0-0,20]	Very low

The human reliability assessment can be presented in the range [0-10] for the sake of its easy interpretation and use. This requires the resulting assessment to be multiplied by ten-table 7.

Table 7. Human reliability assessment through the integral risk index

Value of R_{int}	Value of Human reliability	Human reliability assessment
[0-0,20)	(8,00-10]	Very high
[0,21-0,37)	(6,3-8,00]	High
[0,37-0,63)	(3,70-6,30]	Medium
[0,63-0,81)	(2,00-3,70]	Low
[0,81-1,00]	[0-2,00]	Very low

3. THEORY

3.1 The human reliability assessment (HRA), as part of the risk assessment

The human reliability assessment (HRA) is the comon name for a range of methods and models which are used to predict the occurrence of human error and as a way of reducing the vulnerability of the system as a whole [1]. In all the methods and approaches of human reliability assessment is used the term "human error" and is aiming to develop an assessment of the probability of its occurrence. On other hand the use of this term raises negative views of some scholars who state that "human error" is not well defined and is very fuzzy concept because it can not be specific category of human performance. Attribution of error actions to certain individuals, team or organization is essentially a social and psychological process, not an aim of a technical nature. [3].

In the developed by us mathematical model the human reliability is determined by the value of the integral risk index on the basis of five basic factors. They are outlined through our study of fifty employees, working in four different commercial entities. These are the factors which we consider as most influencing on human reliability.

The assessment of these factors in the created mathematical model includes an analysis of five key according to us characteristics of human reliability, these are:

3.1.1 Factor 1 (r_1), Professional characteristics, or how the operator

Is trained to develop his duties and how his professional competence and experience, influences the performance of his direct tasks. This factor has three component factors, which are: experience; qualification; education and skills. This factor is quality presented, and for the minimal and the maximal values, which it can have are used quality levels corresponding to numerical values as shown in table 5 (very low, low, medium, high, very high), which are also converted to the interval [0, 1] - table 8.

Table 8. Quality levels of Professional characteristics (r_1)

Quality level of r_1	**Interpretation**	**Values of r_1**
Very low risk	Five or more years of qualification, Five years of education, Five or more years of experience, Courses taken	[0-0,20)
Low risk	Five or more years of qualification, Five years of education, Five or more years of experience	[0,20-0,37)
Medium risk	Education-at least three years, Experience -three years; No courses taken	[0,37-0,63)
High risk	Course, related with the work duties, No education, No experience	[0,63-0,80)
Very high risk	No qualification, No education, No experience, No skills	[0,8-1,00]

3.1.2 Factor 2 (r_2), Personal characteristics

Is the ability of each employee to be part of a working team [3]. To determine the component factors of this factor we used five factor's model of personality [4, 5], created by Oliver John, through which are defined these personalities' features which make the operator a part of a team making its individuality a working part of common working mechanism. Personal characteristics are a very important part of the human reliability, because although the working environment in any technology unit is very specific and highly standardized, the personal characteristics of the people employed in the process affect the way they behave and perform their duties in this limited environment.

The factor has five component factors (known as Big Five), in relevance with the model of Oliver John [6]:

- Neuroticism (N): the degree to which a person is anxious, irritable, aggressive, temperamental and moody;

- Extraversion (E): the degree to which a person is nice, tolerant, kind, open and warm to others around;

- Openness (O): the degree to which a person is curious, original, intellectual, creative and open to new ideas;

- Agreeableness (A): the degree to which a person is nice, tolerant;sensitive, trusting, kind and warm;

- Conscientiousness (C): the degree to which a person is organized, systematic, punctual, achievement oriented and dependable [6]

For the purposes of the study we used the percentage and graphical representation of personality, according the five factor analysis of personality test (Big Five), which can be found at www.outofservice.com/bigfive/.

The component factors values are chosen from the interval [0-100], but because of the specific features of the component factors they are interpreted in a way explained in table 9. Except the first component factor – Neuroticism, each of the component factors has better meaning with bigger values. Since for delegating the right value, we followed the rule, that as closest to 0 means less risk and on the contrary- the closest it is to 100- bigger risk, we turned the tendency of growing by adding the words "risk of". At this way while interpreting extraversion, which is better, assessed closer it is to 100, with the addition "risk of", we add the opposite meaning, or closer it is to 0, better it is (with less risk).

Table 9. Personal characteristics' values interpretation

Personal characteristics (r2) component factors	Minimum value (less risk)	Maximum value (more risk)	Explanation [6]
Neuroticism	0	100	Neurotic people have a tendency to have emotional adjustment problems and habitually experience stress and depression. People very high in Neuroticism experience a number of problems at work. For example, they have trouble forming and maintaining relationships and are less likely to be someone people go to for advice .[7]
Risk of Extraversion	0	100	At its maximum level these people are effective managers, salesman and they demonstrate inspirational leadership behaviors [8]
Risk of Openness	0	100	People high in openness seem to thrive in situations that require flexibility and learning new things. They are highly motivated to learn new skills, and they do well in training settings.[9]
Risk of Agreeableness	0	100	People who are high in agreeableness are likeable people who get along with others. Not surprisingly, agreeable people help others at work consistently; this helping behavior does not depend on their good mood [10].
Risk of Conscientiousness	0	100	Conscientious people not only tend to perform well, but they also have higher levels of motivation to perform, lower levels of turnover, lower levels of absenteeism, and higher levels of safety performance at work [11].

Factors r_1 and r_2 develop the ability of each worker to respond to emergency situations and to take decisions that can prevent or induce disaster.

3.1.3 Factor 3 (r_3), Environment

This is a factor describing the components of the environment which most affect the performance of work duties of each worker, the realization or prevention of emergencies. This factor has four component factors that aim to describe the influence of all external factors depending on workplace organization and management of the work duties, which affect the execution of works and the implementation of crisis situation. These are:

- Ergonomics - an indicator of the suitability of the working place to the job duties;

- Organization of work-how to manage the workflow, what is the hierarchy of decision-making, which can lead to or prevent a critical situation

- Climate - physicochemical indicators of the environment, which describe the degree of aggressiveness with which it affects to the performance of the employee- salinity, temperature, noise, odor, vibration;

- Control - how the worker reports his activities, is he obliged to report to someone directly, is there a person to verify his decisions or actions, is he allowed to take decisions?

This factor is quality presented, and for the minimal and the maximal values, which it can have are used quality levels corresponding to numerical values as shown in table 5 (very low, low, medium, high, very high), which are also converted to the interval [0, 1]- table 10.

Table 10. Quality levels of Environment (r_3)

Quality level of r_3	Interpretation	Values of r_1
Very low risk	High level of ergonomic of the working position; Effective work organization; Not aggressive climate; High control;	[0-0,20)
Low risk	High level of ergonomic of the working position; Effective work organization; Medium/High Aggressive climate; High control;	[0,20-0,37)
Medium risk	Good level of ergonomic of the working position; Good work organization; Medium/High Aggressive climate; Average control;	[0,37-0,63)
High risk	Low level of ergonomic of the working position; Some work organization; Medium/High Aggressive climate; Low control;	[0,63-0,80)
Very high risk	Low level of ergonomic of the working position, Bad work organization Aggressive climate; Low control;	[0,80-1,00]

3.1.4 Factor 4 (r_4), Physical State

This is a factor, describing the physical and the psychological health of the employee. The values are moving in the interval [0-1], as shown in table 11.

Table 11. Physical State (r_4) interpretation

Values of component factors	Quality level of r_4	Explanation
[0-0,20)	Very low risk	Excellent physica health; Excellent psychological health;
[0,20-0,37)	Low risk	Vey good physica health; Very good psychological health;
[0,37-0,63)	Medium risk	Average physica health; Average/good psychological health;
[0,63-0,80)	High risk	Not good physica health; Average/good psychological health;
[0,80-1,00]	Very high risk	Poor physical health; Average/bad psychological health;

The maximal and minimal values of this factor are facing the.

3.1.5 Factor 5 (r_5), Behavior

This factor consists of two component factors-alcohol abuse and stimulant's usage.

The values of the component factors are moving in the interval [0-100]. The interpretation is related with the percentage of the presence of this factor in the person. For example in there is a person, who rarely use alcohol, he will receive value-5 (5 % of presence of this factor in this person's physical profile), on the contrary if we have someone, who drinks every weekend, he will receive value - 70 (70 % of presence of this factor in this person's physical profile).

The graphical representation of the model (Fig.1) gives visibility and clarity of the connection between basic and component factors:

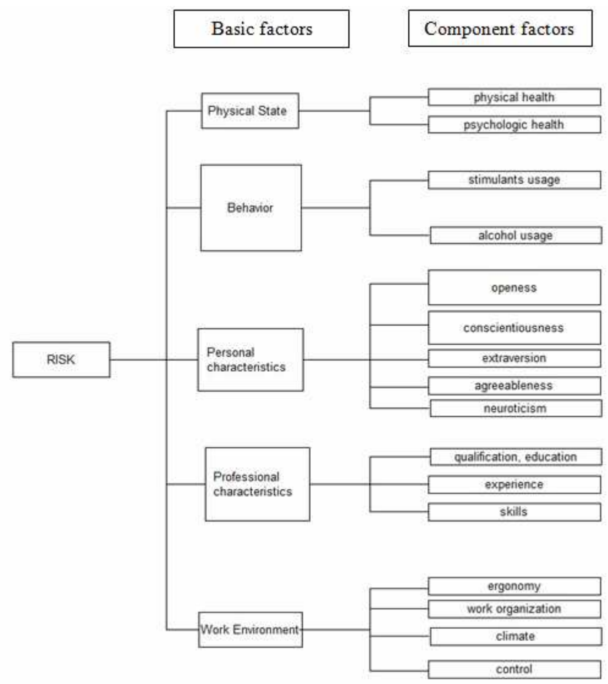

Figure 1 Graphic presentation of the model for integrated risk assessment

4. RESULTS AND DISCUSSION

The mathematical model is applied to employees in four business and production areas, suggesting different types of job responsibilities, environment and physicochemical parameters, in the field of oil refining, glass manufacturing and maintenance, sale and service of agricultural machinery, gas station. The basic factors are five. The component factors have almost equal weights.

The obtained results will be converted to a numeric scale at the range from 0 to 1, where the lower values indicate low risk and high human reliability and high values - high risk and low human reliability.

We have studied more than 50 employees in Bulgaria. Here we present the results of two of them working in same production area. Our task is to illustrate how their personal and professional profile can be assessed by the created mathematical model and after receiving a quantify assessment of the integral risk index and then of the human reliability to compare the employees and to make the relevant conclusions.

Background Installation for processing of oil products, launched in 2010 for the production of fuels in accordance with the European environmental standards. Low levels of odor and vibrations. Average noise level. Not aggressive environment. The work requires physical strength, because it includes climbing at a height of 5 meters. The surveyed jobs positions have the same level of control because people, working at them are equal in terms of responsibilities and duties operators and the performance of their duties shall be verified by a list of people - a senior operator, a head of installation, a head of production, chief engineer.

4.1 Case 1

Background: 54 years old operator in a refinery. He has 31 years of experience in the refinery, he graduated from a college of chemistry, he has no additional qualifications or courses taken, but he has vast skills because of his long working experience in the refinery as an operator, responsible for three different installations. He is very serious smoker, he smokes for 30 years now.

Table 12. Basic and component factors values for Case 1

Basic Factors	Component factors		Quantitative assessment of the factor				
	Title	Weight	Current value	Minimal value of the factor	Maximum value of the factor	Explanation	Normalized value
Working environment							
	Ergonomy	0,3	0,2	0	1	Low risk, new instalation	0,2
	Work organization	0,25	0,2	0	1	Four levels of control after the operator	0,2
	Climate	0,25	0,3	0	1	Low risk from the surrounding environment	0,3
	Control	0,2	0,4	0	1	Need for serious control because of the raw mat	0,4
		1				Aggregate value of the basic factor	0,27
Physical state							
	Psychological health	0,5	0,2	0	1	In excellent psychological health	0,2
	Physical health	0,5	0,4	0	1	Not excellent shape because of the age	0,4
		1				Aggregate value of the basic factor	0,3
Behavior							
	Alcohol abuse	0,5	10	0	100	Used alcohol rarely	0,1
	Stimulant's usage	0,5	50	0	100	Serious smoker	0,5
		1				Aggregate value of the basic factor	0,3
Personal characteristics							
	Risk of Openess	0,2	10	0	100	Open to others person	0,1
	Risk of Conscientiousness	0,2	20	0	100	Very Conscientiousness	0,2
	Risk of extraversion	0,2	20	0	100	Extrovert	0,2
	Neurotism	0,2	10	0	100	Relaxed and calm	0,1
	Risk of agreeableness	0,2	80	0	100	Doesn't agree with other's opinion	0,8
		1				Aggregate value of the basic factor	0,28
Professional characteristics							
	Qualification	0,4	0,4	0	1	College education (not university education(	0,4
	Experience	0,3	0,1	0	1	Vast practical experience	0,1
	Skills	0,3	0,1	0	1	Vast practical skills	0,1
		1				Aggregate value of the basic factor	0,22

Table 13. Integral risk index for Case 1

Input:

First level titles		Integral risk index		Results	Integrated assessment
Number of the basic factors		5			0,26
№	Title of the basic factors	Weight of the basic factor	Number of factors from second level	Aggregate (current) value	Weighted value
1	Professional characteristics	0,33	3	0,22	0,07
2	Personal characteristics	0,27	5	0,28	0,07
3	Working environment	0,20	4	0,27	0,05
4	Physical state	0,13	2	0,30	0,04
5	Behavior	0,07	2	0,30	0,02
		1			

Figure 2 Graphic presentation of the factors

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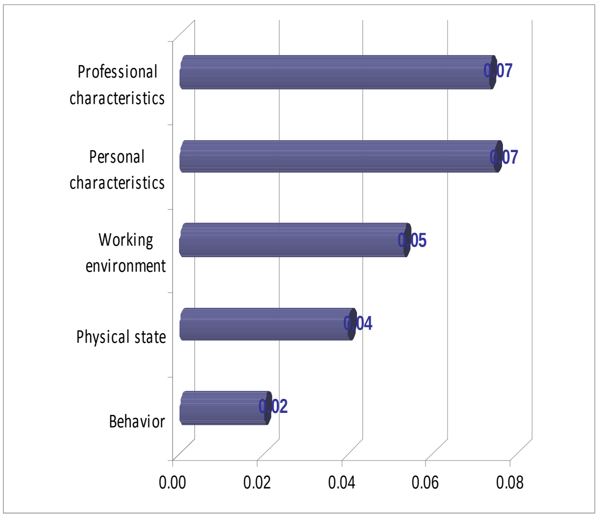

Figure 3 Graphic presentation of the factors

The graphical representation of the factors allows us to identify the factors with the highest risk for a particular worker which should currently be monitored and evaluated. For the sake of developing of the right conditions for an employee to develop and to evolve we recommend this assessment every six months and the results would show how the factors are developing-increasing or decreasing in time.

Recognition of the level of the integral risk index (Case 1)

Recognition of the level of the integral risk index					
Level	Very low	Low	Medium	High	Very high
		0,26			

Human reliability assessment:

HR = 1 - R_{int}

HR = 1 - 0,26

HR = 0,74

The received result of the assessment of the human reliability of the operator 0.74 means high-human reliability and the obtained value of the integral risk index 0.26 places this person at the low-risk zone. These results mean that this operator is evaluated as a person with a low risk of errors and very reliable in his direct actions.

4.2 Case 2

Background: Operator at the same working position as Case 1, at the age of 28 years. He has three years of experience in the refinery, but he graduated from a Technical University in specialty "Oil and Gas" with honors, and also completed postgraduate training in this specialty for the acquisition of practical skills. He is nonsmoker and he goes to the gym every evening.

Table 14. Basic and component factors values for Case 2

Basic Factors	Component factors		Quantitative assessment of the factor				
	Title	Weight	Current value	Minimal value of the factor	Maximum value of the factor	Explanation	Normalized value
Working environment							
	Ergonomy	0,3	0,2	0	1	Low risk, new instalation	0,2
	Work organization	0,25	0,2	0	1	Four levels of control after the operator	0,2
	Climate	0,25	0,3	0	1	Low risk from the surrounding environment	0,3
	Control	0,2	0,4	0	1	Need for serious control because of the raw mat	0,4
		1				Aggregate value of the basic factor	0,27
Physical state							
	Psychological health	0,5	0,2	0	1	In excellent psychological health	0,2
	Physical health	0,5	0,2	0	1	Excellent shape	0,2
		1				Aggregate value of the basic factor	0,2
Behavior							
	Alcohol abuse	0,5	5	0	100	Does not use alcohol often	0,05
	Stimulant's usage	0,5	25	0	100	Non smoker, but uses a lot of energized liquids	0,25
		1				Aggregate value of the basic factor	0,15
Personal characteristics							
	Risk of Openess	0,2	68	0	100	Not very open	0,68
	Risk of Conscientiousness	0,2	58	0	100	Average Conscientiousness	0,58
	Risk of extraversion	0,2	82	0	100	Introvert	0,82
	Neurotism	0,2	28	0	100	Relaxed and calm	0,28
	Risk of agreeableness	0,2	63	0	100	Doesn't agree with other's opinion	0,63
		1				Aggregate value of the basic factor	0,598
Professional characteristics							
	Qualification	0,4	0,1	0	1	University education with honours	0,1
	Experience	0,3	0,8	0	1	Minimum practical experience	0,8
	Skills	0,3	0,7	0	1	Courses taken, not practical skills	0,7
		1				Aggregate value of the basic factor	0,49

Table 15. Integral risk index for Case 2

Input:					
First level titles		Integral risk index		Results	Integrated assessment
Number of the basic factors		5			0,41
№	Title of the basic factors	Weight of the basic factor	Number of factors from second level	Aggregate (current) value	Weighted value
1	Professional characteristics	0,33	3	0,49	0,16
2	Personal characteristics	0,27	5	0,60	0,16
3	Working environment	0,20	4	0,27	0,05
4	Physical state	0,13	2	0,20	0,03
5	Behavior	0,07	2	0,15	0,01
		1			

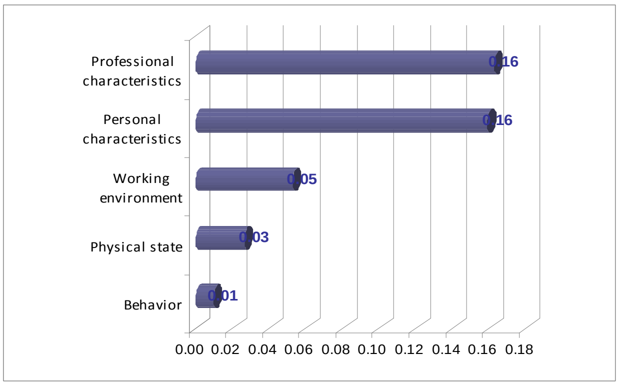

Figure 4 Graphic presentation of the factors

Recognition of the level of the integral risk index (Case 2)

Recognition of the level of the integral risk index					
Level	Very low	Low	Medium	High	Very high
			0,41		

Human reliability assessment:

HR=1 - R_{int}

HR=1 - *0,41*

HR = 0,59

The received result of the assessment of the human reliability of the operator 0.588 means medium level of

human reliability and the obtained value of the integral risk index- 0.412 places this person at the medium zone of risk. These results means that this operator is evaluated as a person who is more likely then the first evaluated (Case 1) to admit mistakes mostly because the lack of practical experience and because of the critical potential of the examined production this can lead to the realization of an accident of different scale.

4.3 General conclusion

The research we done, based on the developed mathematical model of two operators show different values of human reliability. In Case 1 there is positive influence of the long, practical experience and the appropriate for this operator's duties and responsibilities personal characteristics, while in Case 2 the positive influence comes from the theoretical basis, honors and course of qualification. The overall result, however, shows a lower value of the integral risk index for Case 1 and accordingly a higher assessment of human reliability.

5. CONCLUSIONS

The developed mathematical model for the determination of integral risk index based on the method Linear combination of private criteria (LCPC) and the hierarchical model of five basic and their component risk factors enables a risk expert, while assessing the overall risk to include in it human reliability assessment by focusing on specific criteria (basic factors), namely: Professional characteristic, Personal characteristics, Working environment, Physical state and Behavior.

For high risk productions, these are the factors, that influence the implementation of duties and obligations, which could lead to the realization of mistakes of varying severity. For each factor was determined the degree of its relative importance (weight) w_i, depending on its ranking and the rule of Fishbern.

This allows factors to be arranged on the expertise of the evaluator and in relevance with the nature of the studied work duties.

The method Linear combination of private criteria, that we used allows to normalize the current values of the risk factors that despite of their setting in different units and different scales of measurement are brought to a uniform scale and dimensionless form.

Thus, the absolute values of the factors are replaced by relative values in the interval [0, 1]. Factors that are quality signs and have no quantitative assessment obtained numerical values corresponding to quality levels (*very low, low, medium, high, very high*), which are also converted to the interval [0, 1]. This is one of the most valuable qualities of the created mathematical model for the integral risk index and human reliability assessment, which are obtained in quantitative meaning - as a number. This allows including of quantifiable factors if needed.

Due to its numeric expression the developed mathematical model allows simple comparison, which make it objective and easily applicable.

6. VERIFICATION

The mathematical model was verified as useful and correct by the feedback we have from some of the evaluated people. The aim was to connect the result, received by the model with the real profesional profile of the person.

The problem here was the fact that in many of the cases, where there was a human error, related with low level of human reliability, which subsequently led to an accident, no one of the people involved felt free to share this with us.

Nevertheless, by the information we gathered after the study we can make a strong paralel between the high level of human reliability anf the low number of accidents in the production. If the model is implemented in the production's plant activities and the employees are examined on every six months, this would make quite clear feedback on the relevance of the assessment and the real situation, which can cause risk of different scale.

This would undoubtfully point the weak points in every one's performance of the work duties and give possibility for their overcoming with less effords and less investments.

7. ACKNOWLEDGEMENTS

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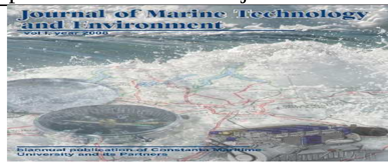

¶MODEL OF PROCESS OF PORT INFRASTRUCTURE SAFETY MANAGEMENT

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Abstract: The article presents a model of process of port infrastructure safety management, based on proactive approach, which is defined as an activity, directed on maintenance and improvement of the future state of port infrastructure safety. Model is directly related to the adoption of project decisions, because provides the concordance of the put aims and chosen strategies through their realization. Proactive management is one of the basic principles of port infrastructure safety management, laid down in the proposed model. Proactive approach to port infrastructure safety management involves planning strategy of this activity by formation of a portfolio of projects that achieve strategic objectives of port safety improvement program. Proposed model of port infrastructure safety management allows effectively manage the current state of port infrastructure safety through measures aimed primarily at reducing the probability of an emergency, as well as to forecast and evaluate the future state of port infrastructure safety with regard to its development.

Key words: acceptable risk, port infrastructure, risk assessment, safety, proactive approach.

1. INTRODUCTION

Lately in most countries of the world community for risk management, and consequently, eventually for safety management adopted the concept of ALARA - as low as risk acceptable, allowing to use the principle "to foresee and prevent" [1].

Therefore one of the basic principles of port infrastructure safety management, laid down in the proposed model, is the principle of proactive management. It is known that the difference between classic (reactive) principle of management and proactive management consists in the following [2]. The purpose of the first is to react on incidents and prevent their recurrence. The purpose of the second is to foresee and prevent their origin. In relation to port infrastructure safety management this principle means:

1. «Proactive» management of current state of port infrastructure safety through measures directed, above all things, at reducing the probability of an emergency situation.
2. Prediction and assessment of the future state port infrastructure safety taking into account its development.

The second base principle, laid down in the offered model, is the use of program-oriented approach. According to the generally accepted definition, the program – is an organic combination of a group of related projects and processes aimed at achieving the overall mission of the program. Thus, the program will include the processes of monitoring and control of the level of safety seaport water area and territory on its infrastructure, as well as on ships handled at the port. In addition, the program contains the groups of technical and organizational projects, aimed at improving safety. Technical projects include work on the maintenance and repair of the port facilities, implementation of progressive processing echnology of ships, etc. Organizational projects include retraining and advanced training of specialists in the field of safety or reorganization some management structures.

It is necessary to consider a condition, on which the budget of project appears less, than decreasing of risk of an accident as a result of realization of this project [3-6].

The general mission of such program can be formulated as follows: «Providing of the use of such level of specialists on safety use of such organizational and technological schemes on seaport water area and territory such level of port infrastructure safety, at which the risk of an accident as a result of any process does not exceed an acceptable level».

2. THE BASIC MATERIAL

The proposed model of process of port infrastructure management safety includes 6 stages and is presented in Figure 1.

Stage 1. Estimation of technical state of port infrastructure objects.

Safety of seaport infrastructure defines a property of infrastructure to be safe or have an acceptable level of safety for port production processes, environment and population.

All port infrastructure objects on the level of risk, technical complexity, potential danger and functional significance can be divided into the following categories:

- objects of technical regulation;
- dangerous production objects;
- critically important objects.

The function of the strategic planning in a proactive management is defined as activity, directed on maintenance and improvement of the future state of safety of port infrastructure objects. It has direct attitude toward acceptance of project decisions, because provides the concordance of the put aims and chosen strategies through their realization [3]. It should be kept in mind that as a result of port production processes planning is predicted not only change the safety settings of infrastructure, but also planned financial income from port charges, which should be the economic basis of implementation of projects for improving safety at the port.

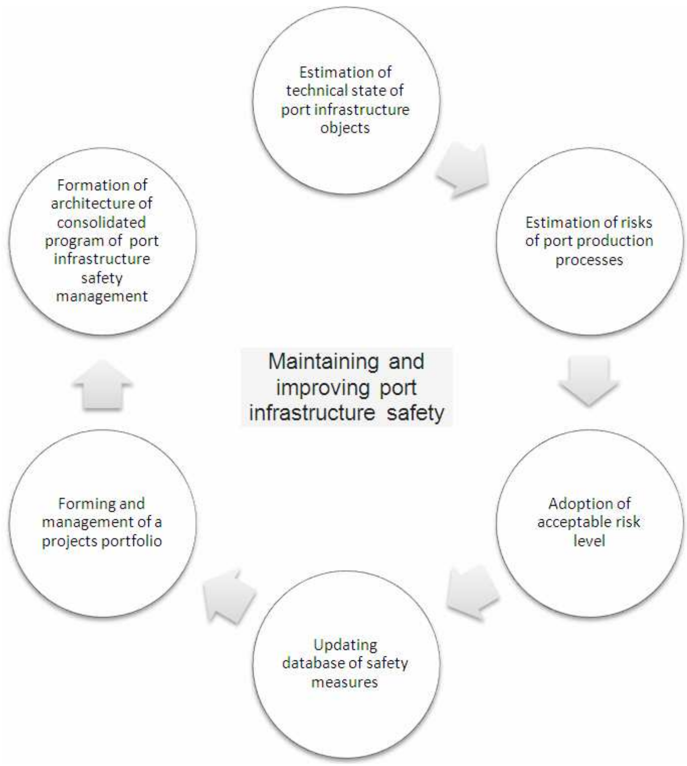


Figure 1 Model of process of port infrastructure safety management

The planned increase of port infrastructure safety must be oriented to the long-term, medium-term and short-term prospects. It identifies the main directions connected with a reduction in accidents of port operations in the production of port perspective development. By means of the strategic planning are made decisions about what primary purposes are, using what strategy and what term they must be realized in.

Stage 2. Estimation of risks of port production processes.

The base stage that allows to form strategy of port infrastructure safety management is the stage of production processes risk estimation. At this stage hazards are identified, risk amount analysis is carried out, which is compared (when estimating) to the set threshold values, determined by risk criteria.

Risk analysis during realization of measures, their estimation and comparing to the possible levels will enable grounded, with the use of quantitative indexes, to make decision about admission or, vice versa, impermissibility of realization of one or another projects, about direction of their improvements and adjustments, leading to risk reduction.

It is known that risk assessment is a process that includes identification, analysis and comparative risk assessment [1]. The risk of port production processes can be estimated, using different methods of risk assessment [1,6].

The objectives of risk assessment are:

- receiving reliable baseline information;
- carrying out the necessary analysis;
- making reasonable decisions in risk estimation;
- forming of basic data for the further choice of optimal solutions for risk treatment.

The stage of risk assessment includes the following procedures:

- risk analysis;
- risk evaluation.

Risk analysis, in same queue, consists of the following steps:

- determination of application domain;
- risk identification;
- risk amount estimation.

The main component of risk assessment stage is the procedure of risk analysis, which occupies a special place in the risk management process and determines the efficiency of risk decreasing.

On the different stages of life cycle of port infrastructure specific objectives of risk analysis may vary. At the stage of pre-project works or planning the purpose of risk analysis can be:

- hazards identification and risk amount estimation in view of influencing factors on personnel, population, material objects, the environment;
- consideration results when analyzing the acceptability of proposed solutions and making wise choices for equipment or facility placement, taking into account the local environment;
- providing information for development instructions, technological regulations and plans of liquidation of near-accidents;
- assessment of various engineering design proposals.

At the stage of operation and reconstruction of port infrastructure objects the purpose of risk analysis can be:

- comparison of the conditions of facility operation with the respective safety requirements;
- clarification of information about the basic hazards;
- development of recommendations on the justification or modify regulatory requirements, on questions of licensing, determining the frequency of audits, safety, etc.;
- improvement of operation and maintenance manuals and plans for localization of hazards;
- assessment of the effect of changes in organizational structure, methods of practical work and technical service in relation to safety performance.

At the stage of decommissioning (or commissioning) the purpose of risk analysis can be:

- hazards identification and assessment of their impact;
- providing information for development or clarification of instructions for
- decommissioning (or commissioning).

After the risk assessment is made a decision about acceptance or rejection of risk. If a risk is not accepted, its treatment is carried out in order to decrease it.

In assessing the effectiveness of planned activities to ensure port infrastructure safety it is necessary to take into account the following:

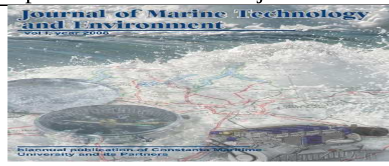
- prediction of unfavorable events, scientific substantiation of risk assessment during implementation of the planned activities, both each of them separately and integrally;
- estimates of critical (unacceptable) risks scientific substantiation;
- setting of levels of possible (acceptable) risks which are accepted by management expertly or directively, based on the assigned task;
- management of technical and technological development taking into account safety requirements by risk criteria.

Risk analysis during implementation of measures, their evaluation and comparison with the permissible levels will enable reasonably, using quantitative indicators to decide on the admissibility or, vice versa, the inadmissibility of the realization of these projects, about the direction of their improvements and adjustments, leading to risk decreasing.

To improve the safety and efficiency of port infrastructure should be formed a portfolio of projects or program to reduce risk with certain expenses, depending on the risk value.

During the analysis of functional safety of port infrastructure facilities should be considered both the generally accepted scenarios (optimistic, inertial and pessimistic) and followings scenarios:

- object functioning under normal conditions (ordinary situations);
- object functioning with maximum deviations from normal conditions with return to the initial state;
- object functioning with deviations from normal conditions, caused by "beyond design basis situations" when made decisions need to be revised, stopping realization of measures or processes, with transition to a new state with the set level



of vulnerability (resistance to unfavorable events);

object functioning in hypothetical conditions with unfavorable events, developing the most worst (heavy) embodiments with unforeseen factors of initiation, which do not allow to implement measures or activities related to the functioning of the object.

Risk value evaluation includes analysis of frequency (or probability) of an emergency at port infrastructure object. In literature represented a large number of methods of analysis and evaluation of risks. Choice of a particular method is performed on the basis of the features of technological processes and equipment, implemented at the facility.

Stage 3. Adoption of acceptable risk level.

Activities of marine administration on providing safety on the territory and seaport water area should be directed at making potential risks of production processes in the port below the level of acceptable risks, which are normalized in advance, on the basis of a common strategy for port development, taking into account the expected final economic effect.

Acceptable risks levels are determined and assigned by seaport administration according to a balance of scientific and technical capabilities and economic feasibility.

Stage 4. Updating database of safety measures.

Actualization of base of measures on safety is carried out in the branches of administration of marine ports of Ukraine. In general case, structure of data about a model measure, directed on the increase of safety of objects of port infrastructure described the following cortege:

Updating database of safety measures is carried out in the branches of seaport administration. In general, the data structure of typical measure aimed at improving port infrastructure safety described by the following cortege:

$$MP = <B, P, A, E>,$$

where B – the set of factors, indicating the necessity of measure implementation;

P – the set of parameters describing the problem, which include a reference to the requirements of rules, regulations and standards for the safety, a reference to the international recommendations and detailed description of the problem;

A – the set of characteristics that describe conducted measure, conceptual description of measure;

E – the set of factors describing the existing experience and the available solutions on this problem.

Thus, measure aimed at improving the safety of transport process, characterized by the following properties:

- presence of purpose - despite the fact that any measure aimed at reducing the risks of loss in case of accidents, each of them has a certain technical or organizational purpose;
- uniqueness - every measure is developed for a specific transport process in a particular port;
- limitation in time - efficiency and effectiveness of measures directly related to the timing of their implementation, so it is important to solve tasks of safety providing in the shortest time.

Consequently, to the measures aimed at improving port infrastructure safety, are inherent basic properties that are typical for concept of project [6]. These measures regulated by the port authority and aimed at improving of port infrastructure safety in their very essence are projects. Thus, it is necessary to apply methods and models of effective management developed in project management, in the implementation of measures aimed at improving port infrastructure safety [7]. Use of the best project management practices will allow:

- to increase the effectiveness of measures aimed at improving of port infrastructure safety;
- to provide more rapid realization of measures;
- to reduce costs and improve a commercial component of works in the plan of measures for providing port safety .

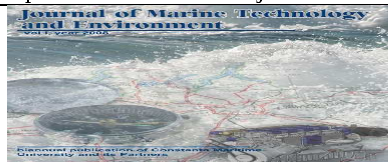
Under the project of increase of port infrastructure safety will understand such project which includes a set of measures of organizational and technical character directed at reducing quantitative estimations of risk of occurrence of accidents at the facility and reducing the negative impact of their consequences. This concept satisfies the basic rules of logic definitions [8].

A project of increase of safety has the following similar with any other project signs [9]:

- objective should be achieved with simultaneous implementation of all technical and environmental standards;
- certain deadlines (start and finish);
- set financial, material, information and human resources (the allocated resources);
- measures and actions needed to achieve the objective.

Differences of this type of project from others are expressed in the following:

- project objective function is not always associated with profit received from the project;



- clear orientation - all without exception safety improve projects are directed on improving the environment and protecting port personnel;
- specificity of control of projects results by government and public, which necessitates organization of information support of complex projects with lighting project progress in the press and on television.

Reasons for initiation of projects of port infrastructure safety improvement can be [10]:

- requirements of norms, regulations and standards for safe operation of production facilities;
- international recommendations (IMO, etc);
- safety analysis results;
- demands / requirements of national supervisory authorities;
- accumulated experience.

Stage 5. Forming and management of a projects portfolio.

Proposed in the concept proactive approach to port infrastructure safety management involves planning strategy of this activity by formation of a portfolio of projects that achieve strategic objectives of port safety improvement program. For each port production operation taking place using port infrastructure, based on the work of an expert committee forms a set of projects - a portfolio that allows reduce the rate of an emergency state for each factor of risk.

At each port simultaneously is realized a set of projects to ensure the safety of that infrastructure facilities, which is advisable to manage using methods and models of portfolio management [11-14].

Define this portfolio as a set of projects and other works joined together with the purpose of efficient management these work for achieving the objectives and implementation of safety requirements.

Analysis of specificity of project portfolio management and the possibility of using known management mechanisms allow to conclude that actual is solving the following tasks of theoretical project portfolio management:

- evaluation of projects in terms of achieving the strategic objectives;
- formation of an effective project portfolio;
- planning of the implementation of a portfolio of projects, taking into account the possibilities of optimization of financial flows;
- allocation of organization resources between the projects of a portfolio;
- operative management of a projects portfolio taking into account changing of external conditions and objectives.

Stage 6. Formation of architecture of consolidated program of port infrastructure safety management.

Architecture of consolidated program of port infrastructure safety management is formed as a set of portfolios for individual ports, integrated in a program having the required functionality and appropriate flexibility that is arranged to changes in surroundings. Architecture Management includes structuring of developed program, monitoring implementation of activities under the program, implementation of its functionality, creation for the subsystems of the program vision of the future desired state in order to obtain the values of the program.

Consolidated program design when constructing of its architecture should not only involve an effective response to the program changes in surroundings, but also be characterized by a certain innovation and make it to the missions of the program. At a program design the followings five steps will be realized:

1) binding of program scenarios with the processes outlined in the strategy of its implementation;

2) development of models applied for use in projects;

3) forming of necessary administrative structures;

4) identify functions for each structure element;

5) providing of program capacity.

These steps determine the sequence of consolidated program architecture designing, the implementation of its creative mission, program development functions and interactions of projects components from the software life cycle position. The need for long-term management of program worth and worth of its life cycle determines the main reason why the program design and management of its architecture are appropriate.

The structure of the consolidated public safety management program includes all approved port infrastructure projects portfolios of individual ports, as well as major projects, which are centralized managed for all ports of Ukraine.

3. CONCLUSION

Developed a model of port infrastructure safety management based on a proactive approach that allows effectively manage the current state of port infrastructure safety through measures aimed primarily at reducing the probability of an emergency, as well as to forecast and evaluate the future state of port infrastructure safety with regard to its development.

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UTILIZATION OF RESOURCES ON TECHNO-NAUTICAL SERVICES BY DEVELOPING A DYNAMIC SIMULATION MODEL: AN APPLICATION ON THE PILOTAGE SERVICE IN ISTANBUL STRAIT

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Abstract: In Turkey, techno-nautical services' principles are determined in Port Regulations prepared by Turkish Transportation, Maritime Affairs and Communication Ministry. But the principles are set mostly empirically or experience based. This study helps decision-makers and stakeholders for the correct utilization of resources on techno-nautical services by developing a dynamic simulation model. For this purpose, the pilotage service algorithm has been developed according to structured interviews with pilots, with statistical data of Traffic in Bosporus and all rules and regulations in effect on the waterway. It is found out that by the designed algorithm, it is possible to make correct decision about the required human resource as pilots even in a complex system as in Istanbul Strait. And due to dynamic nature of algorithm with application of simulation software different scenarios can be evaluated easily.
Key words: techno-nautical services, marine pilot, algorithm

1. INTRODUCTION

Techno-Nautical services are key factors for safety of maritime transportation. Due to their expensive and critical nature such a complex resource must be utilized optimally under in any situation. Optimum utilization of resources is always a challenge for decision makers and it is also a well-accepted fact that the authority normally makes its decision on utilization of resources empirically or when such a decision has to be given due to apparent faults in systems which is feed backed by stake holders.

But in this information age nearly all complex systems can be formatted such that a scientific decision might be predicted before the circumstances requires so. One way of accomplishing such a task is creating a simulation model of said system [2]. To create a reliable simulation model a good algorithm must have been written. To create a good algorithm all inputs to system must be evaluated and the problem should be well-specified. Also an algorithm must be correct and efficient and if possible easy to implement [3].

2. OBJECTIVE

2.1 Objective, cost or safety

This study is born by the authors' amazement when they have found that the utilization of techno-nautical resources especially the pilots' utilization is conducted by empirical decisions.

It is clear that an algorithm might be designed to mirror the traffic in Strait and thus that algorithm might be used in a dynamic simulation model for optimization. Even then normally such optimizations are mainly based on the cost of the operations [1]. However, in this study the major aim of the application was the safety of traffic in Bosporus Strait. To this end, the fatigue element of the maritime pilots is taken into consideration [5]. But because the study is based on fatigue of the pilots it shall be the most cost efficient way for the relevant organizations nonetheless.

2.2 Importance of Istanbul Strait

Istanbul Strait is also called Bosporus. It is a well-known and highly busy waterway which connects Black Sea and Marmara Sea which leads to Aegean and farther into Oceans. It is 17 nm long strait and one of the most dangerous waterways to pass through as a ship needs to alter her course at least 12 times with the sharpest turn of 45^0-80^0 at Kandilli Peninsula while always struggling with ever changing surface currents which may go up to 6 knots because of the geographical shape and environmental conditions of the Bosporus [4].

The safety of Istanbul Strait is great concern for Turkey as Bosporus directly divides the country's biggest city in half but also all Black Sea countries care for it because it is the only open waterway for them to trade by seaway. Due to its utter importance regulations governing the Istanbul Strait always become an international issue. After the Ottoman Empire declines in power in World War I, three consecutive international treaties signed internationally about the Straits all over ruling the previous one, Treaty of Sevres (1920),

Lausanne (1923) and Convention of Montreux(1936). Even today Bosporus is governed by regulations in line with Convention of Montreux and not according to UNCLAS unlike other similar waterways.

2.3 Importance of pilotage service in Istanbul Strait

Due to Montreux Convention, it is not possible to force pilots to ships using Bosporus. Under Section I, Merchant Vessels, Article 2 of Convention, it is stated that in time of peace, merchant ships shall enjoy complete freedom of transit and navigation with any kind of cargo, without any formalities. Pilotage and towage remain optional. This article is in the convention for the safe and free passage through straits by merchant ships.

But after years passed and Bosporus traffic ever become more populated by transit vessels and inland traffic gets more and more busy due to the most populated city of Turkey enveloping the Strait, this article became a great problem for the safety of the Bosporus itself. Statistically 93 % of ships involved in accidents in Bosporus between 1982 and 2003 were without pilots [5]. And normally nearly all accidents in Bosporus resulted in delays in transit traffic due to a closed Strait while rescue operations taking place. One of the most infamous accident of such kind was the Independenta Tanker burning (1979) in the Bosporus resulting crew loss and huge environmental pollution and delay in transit.

2.4 Pilots in Istanbul Strait

Pilots in Istanbul Strait are employed by Republic of Turkey, Ministry of Transport, Maritime Affairs and Communications, Directorate General of Coastal Safety (KEGM). Pilots are employed according to "Competence, training certification and working procedures regulations" published by the mentioned Ministry [6].

In this regulation in Article 5, Turkish Straits' Pilots are differentiated from harbour pilots and also classified as junior and senior pilots based on experience.

Requirements to be a Turkish Straits' Pilot are:

- Being a Turkish Citizen;
- Being legally clear to be a civil servant;
- Being a master mariner with at least 1 year of experience and graduated from a university;
- Being healthy according to seamen standards;
- Being a fluent speaker;
- Being successfully completed the basic pilot training.

Even then the pilot becomes a cadet pilot and shall work in a pilotage organization with a senior pilot and records his achievements in a cadet book to represent to harbour master at the end of its training. For the Strait pilots this training means cadet pilot should attend to transit manoeuvres of at least 160 vessels above the 5000 GRT for more than 4 months period if possible evenly distributed from both ways of passage. This training also includes some attendance to tugs and VTS stations.

After that if training found satisfactory cadet pilot should take a written and oral exam prepared by authority. If all goes well, cadet pilot can be accepted as a junior pilot for 4 years duration where he is limited to handle the ships below 20000 GRT [6].

As can be seen from above regulations, Bosporus Pilots are highly trained individuals with great experience. But also due to this factor, utilization of this resource is extremely important as it is not possible to employ any mariner as a pilot in a whim.

2.5 Fatigue and marine pilots

It is a well known fact that fatigue interferes with concentration of marine pilots. Especially sleep deprivation is found a major factor of fatigue. Though most pilots claim that fatigue is not a major concern in their job due to fatigue management procedures, it is also apparent that due to commercial pressure of the business and maybe, due to lack of sufficient number of pilots, pilots might find themselves in fatigue condition more than they want to admit. Even though there are control procedures to prevent these kinds of situations again commercial pressure might be too hard to avoid [7].

3. METHODOLOGY

3.1 Designing an Algorithm

To design an algorithm the question must be known well. This study's question is "If ship traffic is predicted correctly, how many pilots will be sufficient for safe transit in Istanbul Strait in any given time according to pilots' rest periods?"

Then inputs must be known. Here inputs might be summarized as below:

- Ships' arriving rate to Bosporus;
- Probability of a ship to request the optional pilotage service;
- Any regulations forcing ships to behave particular way;
- Bosporus traffic regime at the moment;
- Pilot stations;
- Pilot rest hours;
- Pilot on duty times.
- Duration of a voyage through strait

Then the output of this algorithm must be evaluated. The output will be the resting times of the pilots in this study. But lots of other statistical data can be analysed like waiting time of ships for pilots, average passing times, if requesting pilot shortens the transit time etc. Anyway those data is out of scope of the study. The algorithm designed here can be used in any simulation software and optimizations can be calculated accordingly. Due to changing nature of inputs of the Bosporus, created simulation model will be also a discrete and dynamic simulation.

In this paper a pseudocode is created as an algorithm so it will be easy to understand by humans and it may be replicated with success with any number of programming languages [8].

Also algorithm is optimized to calculate the resting periods of pilots according to on duty pilot numbers. Even though other factors can change rest periods of the pilots, according to interviews with stakeholders other methods will be hard to implement and unpractical.

3.2 Gathering Data

The data for the algorithm is gathered from various resources. For example the arrival spread of the ships to Bosporus is gathered from KEGM's statistical data of 2010 and 2011. Samples are used to analyse the arrival spread of the ships from North to South and vice versa. Even though a regular spread could not be achieved according to chi square tests, the least square error is achieved by using exponential spread, this analyse is computed by Rockwell, Arena Input Analyser V10. Low chi square test results means might be interpreted that there are far too many variables affecting the first contact report times of ships to be accepted as exponential spread. But as shown in figure 1 spread is closely resembles an exponential curve and exponential spreads commonly used for arrival intervals. Thus in this study exponential spread is used for arrival times of the ships.

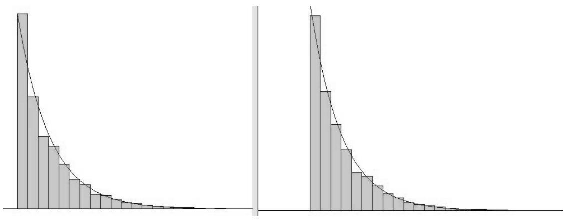

Figure 1 Visual familiarity between ships arrival times from N to S and S to N and exponential spread

According to these analyses from 100690 sample data, for arrival intervals from North to South exponential spread of 20.7 and for South to North exponential spread of 20.5 is computed. Type of ships also calculated from this data. But before that it should be considered what types of ships need to be evaluated for a scheduling algorithm.

There are studies about the scheduling problem of the Istanbul Strait [9]. Because, due to safety concerns, it is not practical to open the Strait to free passage of ships any time even though it is written in Montreux convention which is still in effect in Turkish Straits. Trafic should have been scheduled and safety measures taken can not be interpreted as restrictions on free passage [10]. It should be noted that Turkish Coastal Safety General Directorate classifies vessels in different groups to schedule the transit passage of vessels. These types can be described as follows:

- MPR : Passanger, Yachts, canli hayvan
- NAV : Military

Ships other than Tankers without IMDG Cargo

- G 12 : Ships shorter than 150 meters
- G 3 : Ships between 150 – 200 meters
- G 4 : Ships between 200 – 250 meters
- G 5 : Ships longer than 250 meters

Tankers and other ships carrying IMDG Cargo

- T 12 : Ships shorter than 150 meters
- T 3 : Ships between 150 – 200 meters
- T 2, 5 : Ships longer than 200 meters

Towed Ships

- Ships larger than 300 meters.

According to KEGM's application procedures MPR and NAV have priority over other vessels. G5, T4, T5, Towed vessels, Ships larger than 300 meters can only pass Strait in day light conditions. Tankers and IMDG cargo carrying vessels have lower priority as safety conditions are re examined for passage. So a tentative scheduling can be determined as follows;

MPR=NAV>G12>G3>G4>G5>T12>T3>T2,5>Towed

Of course day time and night time passage will shift according to the requirements of only day light passage vessels and scheduling must be reorganized accordingly. It must be remembered that vessels larger than 300 meters requires special permission to transit the Strait.

In following table statistical data about the Istanbul Strait for years 2010 and 2011 has been analyzed to find out the frequency of these types of vessels for the creation of model. So it is noted that some types of vessels transit the Strait extremely rare and modelling of such vessels will not contribute to the model in the scope of analyze of pilot fatigue, because such vessels actually stops the Strait traffic causing a long rest period for other pilots not onboard the vessel. For example vessels over 300 meters long are in these category and G5 vessels are extremely rare.

Table 1. Frequency of Vessel Types Transiting Istanbul Strait at 2010&2011

	South to North		North to South	
	All	Freq.	All	Freq.
MPR	585	1,16	591	1,18
NAV	96	0,19	104	0,21
G12	32886	65,38	32728	65,07
G3	5874	11,68	5966	11,86
G4	554	1,10	588	1,17
G5	6	0,01	6	0,01

T12	5163	10,27	5345	10,63
T3	4463	8,87	4417	8,78
T4-5	670	1,33	648	1,29
TOTAL	50297	100	50393	100

Source: KEGM Statistical Data

After the scheduling algorithm, another important part of the model is the Strait pilot working conditions. To gather this data, structured interviews have been completed with Strait pilots.

The most important analyses of these interviews can be submitted as follows:

- There are two pilot stations in Istanbul Strait. One is located at South and other is at North entrance of Strait;
- One shift of pilot consists of 23 pilots;
- Pilots arrive their 48 hours shift at south pilot station. Rest 96 hours after each shift and start their shift "well rested" according to their perception;
- Strait traffic is one way due to safety precautions of KEGM and Turkish government;
- Due to one way traffic, there is a transportation problem between south and north pilot stations;
- This problem is generally solved by a dedicated service boat for pilot transfer and generally 8 pilots transferred with each service. (This number may greatly vary but 8 people is average);
- Pilot transfer generally completed between 45 minutes to 1 hour;
- There are other possible ways for transporting pilots when need is immediate or need requires a few of pilots, but they are uncommon and not convenient and usually takes more time due to land traffic congestion. (Mini-bus, taxi etc.);
- General scheduling frequency is 6 vessels in an hour, 7 when Strait is congested. (According to KEGM statistical data approximately 1 vessel per 8 minutes.);
- One way traffic changes direction in rough 12 hours periods but also subject to lots of other considerations as available pilots, ship number in queue, weather or other conditions;
- It takes approximately 15 minutes for a pilot to board a vessel from pilot station and nearly 15 minutes disembark from a ship and arrive to pilot station.

There are some special points analysed from above declarations. It is clear that 2 models must be simulated as one from south to north and other from north to south. But there is only 1 resource available and it is Istanbul Strait. Real limitation of Strait is follow distance between ships though in practice a time limit is used as rule of thumb. Due to pilot boarding and disembarkation times a 30 minute must added to transit times of vessels to calculate real working hours. A transportation system must be modelled and 1 hour should be taken as transit time and must be count as working hour.

And final transit times are important as it actually shows that pilot is on-board the vessel and working.

Vessel transit times are subject to great change due to lots of external factors and analyse of KEGM data points out there is not an optimum spread for passing times. Thus average time for ship type is taken as transit times of vessels.

As it can be seen from below table 2 average transit from South to North takes considerable more duration (apprx. 26 %) than the passage from North to South. The main reason of this phenomenon is the southerly surface currents affecting the Istanbul Strait under normal conditions.

Table 2. Average transit times for Vessels Transiting Istanbul Strait at 2010&2011

In Hours	South to North	North to South
MPR	1.657	1.555
NAV	1.736	1.6
G12	2.029	1.583
G3	1.634	1.414
G4	1.542	1.381
G5	2	2.002
T12	1.8	1.447
T3	1.517	1.376
T4-5	1.491	1.411
TOTAL	1.89	1.53

Another consideration about the model is frequency of pilot service usage for the vessel transiting the Strait. Again KEGM data is analysed for this purpose in Table 3. It shows that nearly half of the vessels transiting Istanbul Strait are using pilots. And there is a slight more pilot usage when vessels transiting from South to North.

Even though frequency is not very different between North and South bound vessels, probably same phenomenon of surface currents are also in affect in selection of the pilotage service. It is deducted that mariners sailing with the current have more confidence to navigate alone than sailing against it.

Table 3. Frequency of Pilot Service Usage for Vessels Transiting Istanbul Strait at 2010 & 2011.

	South To North			North To South		
	TTL	W/P	FREQ	TTL	W/P	FREQ
MPR	585	512	87.52	591	518	87.65

NAV	96	24	25	104	29	27.88
G12	32886	13134	39.94	32728	11731	35.84
G3	5874	4638	78.96	5966	4767	79.90
G4	554	554	100	588	588	100
G5	6	6	100	6	6	100
T12	5163	2906	56.29	5345	2652	49.62
T3	4463	4351	97.49	4417	4326	97.94
T4-5	670	670	100	648	648	100
TOTAL	50297	26795	53.27	50393	25265	50.14

4. ALGORITHM

There are different parts of this model. Firstly, some parts must be created to check the time in simulation software. Such an algorithm in pseudocode can be written as follows:

a) Time Creation

Even though different simulation software might have an internal clock, due to discrete event simulation specifications it is safer to create a time logic to specify important times.

First part is the checking of day light. 12 hour day light is taken as average for the purpose of this simulation.

1. Create 1 entity at experiment start (Experiment time 1000);
2. Assign entity that sun is up;
3. Delay entity for 480 minutes (8 hours);
4. Assign entity that sun is down. (Experiment time 1800);
5. Delay entity for 720 minutes (12 hours);
6. Assign entity that sun is up. (Experiment time 0600);
7. Delay entity for 240 minutes (4 hours);
8. Loop entity to line 3.

Time logic must be created to check the availability of Strait to north to south or south to north traffic. This is a rough guide to see which side of passage must be open for the strait in any given time in experiment. This logic will be evaluated with other considerations too.

1. Create 1 entity at experiment start (Experiment time 1000);
2. Assign entity that Strait is open from South to North;
3. Delay entity for 720 minutes (12 hours);
4. Assign entity that Strait is open from North to South. (Experiment time 2200);
5. Delay entity for 720 minutes (12 hours);
6. Loop entity to line 2.

Also different time logic must be created for pilot transfer times, as it will be unnecessary to send pilots to a pilot station when the traffic will shift its directions before the pilots arrive.

1. Create 1 entity at experiment start (Experiment time 1000);
2. Assign entity that transfer is allowed from North station to South station;
3. Delay entity for 660 minutes (11 hours);
4. Assign entity that transfer is not allowed.(Too late for transfer);
5. Delay entity for 60 minutes (1 hours);
6. Assign entity that transfer is allowed from South station to North station;
7. Delay entity for 660 minutes (11 hours);
8. Assign entity that transfer is not allowed.(Too late for transfer);
9. Loop entity to line 2.

b) Queues Creation

There are 4 queues in this model. 2 for pilot station and pilots and 2 for arriving ships from two side of the Straits.

For pilots:

1. Create number of pilots required in experiment start;
2. Assign each entity a name to distinguish them in model;
3. Mark each pilot’s time now in experiment;
4. Send each pilot to first queue;
5. Name the queue Pilot Station South;
6. Queue ranking First In First Out.

1. Create a Queue for North Pilot Station.
2. Queue ranking First In First Out.

Other 2 queues have more sophisticated models and will be explained in Istanbul Strait Models.

c) Istanbul Strait Model

1. Create ships according to exponential spread;
2. Assign created ships type;
3. Branch ships according to their type;
4. Assign ships a priority for the Entrance Queue according to their type;
5. Assign a random pilot request to ships based on their type and KEGM data;
6. For ships types that requires day light to pass through strait check if sun is up, if sun is up give them highest priority for strait. If sun is down delay them 60 minutes and send them to line 4;
7. Check if ship is requested pilot and update priority over pilotless ships;
8. Put ships in a queue (Istanbul Strait South Entrance);
9. Queue ranking rule is lowest priority first;
10. Seize entities from queue if Strait is open for transit for correct direction. If not do not accept ships to Strait;
11. If strait open seize the highest priority ship from queue first in first out between two same priorities;

12. If ship requested pilot check availability of pilot in pilot station, if there is no pilot delay ship for 10 minutes and send back to queue;
13. Use strait as a resource;
14. Release resource after 10 minutes for pilot requested ships and 8 minutes for other ships.
15. Check if ship requested pilot;
16. Take a pilot from South Pilot station;
17. Mark time for specific pilot. Substract time from the pilots arrive time to pilot station queue;
18. Record time as Rest period, record pilot name, record experiment time. (This data will be analysed to see pilot resting times);
19. Delay pilot in ship according to average time from KEGM statistics;
20. Drop off pilot from ship;
21. Mark dropped off pilot’s time now in experiment;
22. Send pilot to next station;
23. Dispose of ship that finish its transit of Strait.

Create same model for other direction of Istanbul Strait passage. Here most important part is marking times of each pilot before entering the pilot station queue and after exiting from the pilot station queue.

5. CONCLUSIONS

If above pseducode is created in any discrete simulation software and resting period data is analysed this created dynamic simulation model can be used to safely assess the required number of pilots in Istanbul Strait according to their recommended rest periods.

In this algorithm cost of pilots and ships delayed due to lack of pilots is not evaluated. But such additions can easily be modified to algorithm.

Also model can easily be altered for more or less arriving ships, different number of pilots, more frequent pilot requests, for faster pilot transfers etc.

In this paper KEGM data is analysed to give numerical examples and clearly demonstrate what the required data is to design an algorithm for Istanbul Strait pilotage service. Though with these key elements any such waterway can be modelled easily and analysed clearly.

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THE MATHEMATICAL DESCRIPTION OF THE PROCESS OF OIL SPREADING ON THE WATER SURFACE

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Abstract: The aim of this paper is to study and explain the spreading of oil on the water surface. Oil spills in sea waters are serious environmental disaster often leading to significant and long-term impacts on the sensitive aquatic systems. Having a detailed knowledge of oil slick behavior on water can be important in making operational decision and taking appropriate action against pollution. When crude or refined oil products are spilled on the sea, they are spread to form an oil slick. The slick spreads over the water surface due to a balance between several forces. A number of natural processes take place, which disperse the oil and change its chemical and physical properties.

Key words: gravity pressure force, inertia force, oil spreading, surface tension force, viscous friction force.

1. INTRODUCTION

The most effectiveness forces in oil spreading process can be categorized as surface flow, wind and turbulent forces due to wave breaking.

The spreading of oil is the horizontal movement of oil film due to gravity and inertia forces balanced by tension and viscosity forces. This process is considered completed when oil film thickness is very small and the original film is broken into several smaller films.

If the oil spill is near the shores, it reaches the shore shortly after the spill and this process can not be considered.

For the mathematical description of the process of oil product spreading on the water surface in the last 50 years several models have been proposed of which the most important are: Blokker's model (1964), Fay (1971), Hoult (1972), Mackay (1984), Johansen (1985), Elliot (1986), Shen Yapa (1988) Reed (1991).

Of all these models, Fay's model is considered as the most representative because it has been verified experimentally in the laboratory in 1971 [1].

Fay's assumed that the initial and final form of slick is circular. The model considers that the oil product spreading on the water surface is divided into three phases including inertial-gravity, gravity-viscous and viscous-surface tension phases, corresponding to the four dominant forces (gravitational pressure, inertia, viscous friction and tension).

For the mathematical description of the process of spreading oil on the water surface are necessary the following assumptions [2]:

- discharge of oil product on the water surface is instantaneous;
- the thickness of the oil film is small compared with the area so that the hydrostatic pressure distribution is uniform over the whole surface;
- during the spreading process, the movement of the oil product on the water surface is laminar;
- acceleration of particles centers of oil is low;
- effects of Coriolis forces are negligible;
- relative motion film of oil to current and wind is negligible;
- physico-chemical properties of oil product are time varying depending on atmospheric processes.

The fraction of oil floating above mean water, $\mathbf{\Delta}$, is calculated by the relation [2], [3], [4], [5]

$$\Delta = \frac{\rho_a - \rho_p}{\rho_a} << 1, \tag{1}$$

where ρ_a and ρ_p is the density of water and oil product.

From equation (1) it follows that the thickness of the oil film above the mean water level, Δh, is much less than that of water below.

For example, at a temperature of 20 °C for the studied oil product $\rho_p = 888{,}77$ kg/m^3 and $\rho_a = 1000$ kg/m^3 the fraction of oil that floats above the average water level is $\Delta = 0{,}11$.

2. THE FORCES THAT INFLUENCE THE SPREADING OF OIL PRODUCTS ON THE WATER SURFACE

2.1 The gravity pressure force

The gravity pressure force (F_p) is given by the level of average oil product above the water, in the horizontal direction, the film tends to spread on the water surface. The module is given by relationship [1], [2], [3], [4], [5]

$$F_p \approx \rho_p g \Delta h \cdot hl = \rho_p g \Delta h^2 l\,, \tag{2}$$

where ρ_p is the density of the oil product (kg/m^3), g is the gravitational acceleration (m/s^2), hl is the sectional area of the oil film (m^2), Δh is the thickness of the oil film above the average water level (m). It is denoted by l the horizontal dimension feature oil film (m).

2.2 The inertia force

The inertia force (F_i) tends to prevent spreading the oil film on the water surface and its modulus is given by [1], [2], [3], [4], [5]

$$F_i = ma = \rho_p Va \approx \rho_p hl^2 (lt^{-2})\,, \tag{3}$$

where V is the volume of spilled oil $V \approx hl^2$ (m^3) and a is the oil film acceleration $a \approx lt^{-2}$ (m/s^2).

2.3 The viscous friction force

The viscous friction forces (F_{fv}) at the interface between oil product and water slows down the spread of oil on the water surface and its mode is given by [1], [2], [3], [4], [5]

$$F_{fv} \approx \tau A_p = \eta_p \left(\frac{dv}{dz}\right) l^2\,, \tag{4}$$

where the oil film area is considered $A_p \approx l^2$ (m^2), the oil film speed $v \approx lt^{-1}$ (m/s) and the thickness of the boundary layer of the water, z,

$$z \approx \delta = \sqrt{\nu_p t} = \sqrt{\frac{\eta_p t}{\rho_p}}\,, \tag{5}$$

where ν_p is the kinematic viscosity of the oil film (m^2/s), η_p is the dynamic viscosity of the same oil product film (kg/m·s), and t is the time (s).
Therefore

$$F_{fv} \approx \eta_p \frac{lt^{-1}\rho_p^{1/2}}{\eta_p^{1/2} t^{1/2}} l^2 = \eta_p^{1/2} \rho_p^{1/2} l^3 t^{-3/2}\,, \tag{6}$$

is the final shape of viscous friction forces.

2.4 The surface tension force

Surface tension force (F_{ts}) is acting at the outer limit of the oil product film (interface water-oil product) and promotes spreading as long as is positive. The module is given by relationship [1], [2], [3], [4], [5]

$$F_{ts} \approx \sigma l = \left(\sigma_a - \sigma_{p-a} - \sigma_p\right) l, \tag{7}$$

where the net scattering coefficient $\sigma = \sigma_a - \sigma_{p-a} - \sigma_p$ (kg/s^2) is the algebraic sum of the surface tension of water σ_a (kg/s^2) and oil product σ_p (kg/s^2) and tension at the water-oil σ_{p-a} (kg/s^2).

3. THE SPREADING REGIMES OF THE OIL PRODUCT ON THE SEA WATER SURFACE

3.1 Inertial regime

Immediately after the discharge of oil product the film is thick and the area is small. Therefore, the gravity pressure force (F_p) is greater than the surface tension force (F_{ts}) so that the gravity pressure is the main cause of the expansion of the oil film, according to the equation [1], [2], [3], [4], [5]

$$\rho_p g \Delta h^2 l > \sigma l \qquad \Rightarrow \qquad h > \sqrt{\frac{\sigma}{\rho_p g \Delta}}\,. \tag{8}$$

At a temperature of 20 °C, for the fresh oil product with density $\rho_p = 888{,}77$ kg/m^3, $\Delta = 0{,}11$, the gravitational acceleration $g = 9{,}81$ m/s^2 and the net spreading coefficient $\sigma = 24{,}19 \cdot 10^{-3}$ N/m, results that the thickness of the oil film is $h > 5{,}02 \cdot 10^{-3}$ m.

During the first moments after the discharge, between the two forces, which slow down the spread, the force of inertia (F_i) is smaller than the viscous friction force (F_{fv}), first force is proportional to t^{-2} and the second force with $t^{-3/2}$.

In the case of the inertial regime the inertia force (F_i) have the same order of magnitude as the gravity pressure force (F_p), from which it follows the characteristic size of the oil film, *l*, according to the equation [1], [2], [3], [4], [5]

$$F_p \approx F_i \Rightarrow \rho_p g\Delta h^2 l \approx \rho_p h l^3 t^{-2}$$
$$\Rightarrow g\Delta V \approx l^4 t^{-2} \Rightarrow l \approx (g\Delta V)^{1/4} t^{1/2}, \quad (9)$$
$$hl^2 \approx V \Rightarrow h \approx \frac{V}{l^2}$$

to be proportional with $t^{1/2}$.

For large amounts of spilled oil, this regime occurs in the first hours of discharge when the oil film thickness is large enough, and the polluted area is small.

3.2 *Viscous regime*

As time passes, the viscous friction force (F_{fv}) becomes greater than the inertia force (F_i), it follows the relation [1], [2], [3], [4], [5]

$$\rho_p h l^3 t^{-2} < \eta_p^{1/2} \rho_p^{1/2} l^3 t^{-3/2} \Rightarrow$$
$$\Rightarrow \rho_p^{1/2} h t^{-1/2} < \eta_p^{1/2} \Rightarrow h < \sqrt{\nu_p t}, \quad (10)$$

where ν_p is the kinematic viscosity of the film $\nu_p = \frac{\eta_p}{\rho_p}$ (m^2/s) and η_p is the dynamic viscosity (kg/m·s), $\eta_p = 0{,}013$ kg/m·s, $\nu_p = 14{,}6 \cdot 10^{-6}$ m^2/s, then result that, for *t=2* s $h < 5{,}403 \cdot 10^{-3}$ m,

Therefore, for the thickness of the oil film $h \in \left[\sqrt{\frac{\sigma}{\rho_p g\Delta}}, \sqrt{\nu_p t}\right]$, the gravity pressure force (F_p) have the same order of magnitude as the viscous friction force (F_{fv}), and according to the previous relationships [1], [2], [3], [4], [5]

$$\rho_p g\Delta h^2 l \approx \eta_p^{1/2} \rho_p^{1/2} l^3 t^{-3/2} \Rightarrow$$
$$\Rightarrow \rho_p^{1/2} g\Delta \frac{V^2}{l^4} \approx \eta_p^{1/2} l^2 t^{-3/2}. \quad (11)$$

Therefore is resulting feature size of the oil film *l*, according to the equation [1], [2], [3], [4], [5]

$$l^6 \approx \frac{1}{\nu_p^{1/2}} g\Delta V^2 t^{3/2} \Rightarrow$$
$$\Rightarrow l \approx \nu_p^{-1/12} (g\Delta)^{1/6} V^{1/3} t^{1/4}, \quad (12)$$

to be proportional with $t^{1/4}$.

This regime occurs immediately after inertial regime and influence later development of oil film starting after the first hours of the spill and continuing for several days.

3.3 *Regime caused by the surface tension of the water-oil interface*

This regime occurs at high times of the spill, when the film thickness (*h*) gets very thin (*h* tends to zero). Accordingly the gravity pressure force (F_p) is equal to the inertia force (F_i) and both are equal to zero ($F_p = F_i = 0$), and the viscous friction force (F_{fv}) is approximately equal to the surface tension force (F_{ts}) [1], [2], [3], [4], [5]

$$\eta_p^{1/2} \rho_p^{1/2} l^3 t^{-3/2} \approx \sigma l \Rightarrow l^2 \approx \frac{\sigma t^{3/2}}{\rho_p^{1/4} \eta_p^{1/2}} \Rightarrow$$
$$\Rightarrow l \approx \sigma^{1/2} \frac{t^{3/4}}{\rho_p^{1/8} \eta_p^{1/4}}. \quad (13)$$

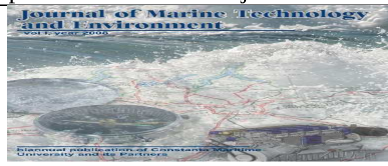
As a result, the characteristic dimension of the oil film *l* is proportional to $t^{3/4}$.

Note in this regime is that the size of the feature film of oil *l* does not depend on the volume of oil spilled *V*.

The spreading process of the oil product on the water surface begins immediately after his discharge, but the speed with which this is done depends to the viscosity and the volume of spilled oil product. Petroleum products having a low viscosity is spread more quickly than those which have a high viscosity [4].

At lower temperatures than the pour point, the product oil solidifies rapidly and the spreading is made difficult, it floating on the water surface in thick layers. The action of wind, current or wave, causes the formation of narrow bands of oil, or their direction parallel furrows. In this phase, the oil product properties become less important in determining the movement of the film [4].

This regime follows viscous regime and influence spreading oil film on the water surface when the oil film



is very thin (tends to zero). It starts after a few days of discharge and influence the development of oil film several weeks, and in some cases even a few months.

4. CONCLUSIONS

Major impact produced on the environment from accidental spillage of petroleum products on the surface of water has led to the need for better monitoring of pollution and reducing the time to intervention for the organization and conduct remediation operations. Therefore, modeling of the pollution is becoming a very important and useful operation required for all institutions involved in remediation operations.

Developed simulators are a powerful tools for forecasting the simple fact that enables the simulations of a large number of scenarios (emergency) are discharged various types of petroleum products in different environmental conditions.

Also it can deliver in a short time optimal solutions for using by teams formed to limit pollution and recovery of spilled oil on the water surface.

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