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Safety and reliability of complex industrial systems and process Poland-Singapore Joint Project

Keywords

safety, reliability, infrastructure systems, decision modelling, system and design optimisation, data mining, maritime transport

Abstract

The project aims mainly to propose new and to develop existing methods, tools and software capable of supporting intelligent modelling and decision support systems, in controlling and optimising the safety and reliability of complex real industrial systems and processes, with their primarily applications in the maritime transportation sectors. Its main focus is on the use of new safety and reliability analysis techniques to improve and optimise safety and reliability of complex real industrial systems related to their operation processes. It will look into the design of industrial systems and development of new methods and the employment of new theoretical results that are applicable to designing and safety and reliability evaluations as well as the improvements of real complex industrial systems and processes.

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1. Introduction

The project will involve the use of new developed methods of systems, sub-system and their operation processes safety and reliability evaluation and optimisation with the empirical safety and reliability data mining related tools for these systems and processes. With the adopted methods and tools, the proposed project will improve and link the conventional approaches within current methods and procedures of safety and reliability in maritime and coastal transportation sectors, by providing an integrated package of solutions consisting of various packages of practical tools. These methods and tools will be ready for direct use by safety and reliability practitioners in dealing with complex industrial systems and processes, and particularly with complex systems and processes of various maritime and coastal transportation sectors. This will enable current safety and reliability decision support systems for various maritime and coastal transportation sectors to be verified and validated.

The project is intended to last for 3 years and it consists of 1 workpackage for management, 9 thematic workpackages and 1 workpackage for dissemination and training. These workpackages, each composed of a number of tasks, will be implemented in 3 stages:

- Stage 1 (months 1-12) will deliver detailed results for safety and reliability models of complex industrial systems related to their operation processes, particularly for maritime and coastal transportation systems;
- Stage 2 (months 13-24) will integrate detailed results into the integrated package of solutions, delivering general methods to evaluate, design and optimise the safety and reliability of complex industrial systems and processes;

- Stage 3 (months 25-36) will provide the packages of practical tools (e.g., guidebooks, computer programs, procedures and regulations) and apply and test them in the maritime and coastal transportation industry in providing practically validated individual safety and reliability decision support systems for individual maritime transport sectors as well as an overall Integrated Safety and Reliability Decision Support System for Maritime and Coastal Transport.

2. Main objectives, scope & constraints, and deliverables

The objectives of the proposed project are as follows:

- To conduct a systematic safety and reliability study of complex industrial systems and processes;
- To develop new and innovative models for safety and reliability improvements for complex industrial infrastructure systems;
- To initiate long-term interdisciplinary research resulting in safer, more effective and more competitive people engaging in industrial activities;
- To develop an integrated package of practical tools (guidebooks, procedures. computer programs), inclusive of new safety and reliability methods in investigating, improving and optimising complex industrial systems and processes;
- To provide and implement techniques for the design of safety and reliability decision support systems for various maritime transportation sectors;
- To offer education and training courses, addressing knowledge and technology enhancement within current industry.

The main scope of the project is in the treatment of safety and reliability issues related to the integration of complex industrial systems and processes. The project main emphasis is on improving and optimising the industrial systems and processes from the point of safety and reliability. Methods for the assessment and improvement of real existing complex structures and operations will be considered, as well as approaches for the optimisation of lifetime of real systems and processes. The project will also aim to study and enhance existing modelling and optimisation methods. It also proposes to develop new methods in safety and reliability of complex systems and processes and integrate these issues into practically useful packages of tools.

The project aims to deliver the followings:

- A general model for complex industrial systems operations and processes relating to their environment and infrastructure;
- A systematic study of methods for safety and reliability that includes an evaluation of current complex industrial systems;
- A statistical study of current complex systems to evaluate unknown parameters of these general models using data mining techniques;
- A computer based Integrated Safety and Reliability Decision Support System for Maritime and Coastal Transport;
- A web-based program package and their description;
- User-friendly guidebooks for practitioners, which includes methods, procedures, descriptions, applications, etc.

3. Potential impact (applications) exploitation for commercialisation

The potential of the project is in its ability to mobilize a critical mass of research and development resources and competence in the field of safety and reliability of complex industrial systems and processes, which would improve current safety, effectiveness and competitiveness. It will have positive impact on the sustainable development of knowledge in safety and reliability of complex industrial systems and processes. The ability to develop new knowledge applications will result in safer, more reliable and more effective people engaging in current industrial activities.

The proposal also brings together theoretical and applied research, which also includes research in the natural social, economical sciences and industry practice with a strong inclination towards practical applications. Linking scientific activity with practical applications is particularly important for increasing complex industrial systems safety and operational procedures optimizations. Examples of potential impacts of the project are as follows:

- The adopted systematic approaches will be made available and accessible to practitioners, which would improve industrial systems safety and reliability, especially in maritime transportation sector;
- The project will contribute to increasing the international research potential with respect to the development of safety and reliability methods in investigating complex industrial systems through the dissemination activities such as conferences, workshops, schools and seminars organized within the project;
- In ports and shipyards transportation sector and in shipping at restricted and open water areas, the results of the project will have significant impact on improving the transportation processes infrastructure and operational decision-making resulting in making the whole sector safer, economically-efficient and user-friendly to the environment;
- In the long term, the project will contribute significantly towards increasing the safety level of maritime and coastal transportation systems, transportation processes and operations;

- The results of the project will form an important input to activities for national and international organizations, standardization and certification bodies as well as similar institutions that deals with the transportation industry.

The following are some potential exploitation that partners could embark upon project completion:

- Organisation of regular seminars and presentations of the methods, procedures and software tools to existing customers as well as to new potential customers operating in all kind of industrial sectors;
- Presentation of the project and publishing the developed works in reputable scientific journals and specialised magazines all over the world;
- Analogous presentation on special information reports will be made available for the MSHE and SERC with the possibility for presentations at the events organised by them;
- Presentation of the whole project and results published at the project website.

4. Background information

Many technical systems belong to the class of complex systems as a result of the large number of components they are built of and their complicated operating processes. This complexity very often causes evaluation of system reliability, availability and safety to become difficult. We meet large systems, for instance, in piping transportation of water, gas, oil and various chemical substances, in rope transportation and in port and shipyard transport using belt and rope conveyers and elevators. In the case of large systems, the determination of the exact reliability and availability functions of the systems and the system risk functions leads us to very complicated formulae that are often useless for reliability practitioners. Optimisation of the reliability structures of large systems with respect to their safety and costs is also complicated and often not possible to perform by practitioners because of the mathematical complexity of the exact methods. In addition, analysing these systems in their variable operation conditions and considering their changing in time reliability structures and their components reliability characteristics these problems become much more complicated. One of the important techniques in this situation proposed in the project is the asymptotic approach to system reliability evaluation and joining this approach with the semi-markov modelling of the system operation processes.

The aim of the proposed approach is to deliver a significant development and a complete elaboration of the state of art on the methods of reliability and availability evaluation improvement and optimisation for as wide as possible a range of complex industrial systems and processes. The analytical methods in systems' reliability and availability evaluation, improvement and optimisation proposed in the project will significantly extend the state of the art in this field by introducing new methods of investigation of complex systems related to their operation processes. The algorithms and the software will be based on the achievements given in latest publications of the project participants [1]-[22]. These approaches are innovative and very important aspects of the project as in the word science there are no integrated and general solutions concerned with the safety and reliability of complex industrial systems related to their operation processes. These methods extensive practical application in the operation processes of real complex maritime and coastal transportation systems is also an important reason for this project proposal.

5. Detailed research approach and methodologies

The project is organised into 1 workpackage for management (WP1), 9 thematic workpackages (WP2-WP10) and 1 horizontal workpackage for results dissemination and training (WP11). Essentially, it is organized as follows:

- WP1: Management Workpackage;
- WP2: Modelling Environment and Infrastructure of Industrial Systems;
- WP3: Modelling Safety and Reliability of Industrial Systems;
- WP4: Integrating Environment and Infrastructure Models and Safety and Reliability Models of Industrial Systems;
- WP5: Safety and Reliability Optimisation of Complex Industrial Systems and Processes;
- WP6: Data Mining for Identification and Prediction of Safety and Reliability Characteristics of Complex Industrial Systems and Processes;
- WP7: Integrated Package of Solutions for Complex Industrial Systems and Processes Safety and Reliability Optimisation;
- WP8: Packages of Tools for Complex Industrial Systems and Processes Safety and Reliability Optimisation;
- WP9: Applications and Testing of Packages of Tools in Complex Maritime Transportation Systems and Processes Safety and Reliability Optimisation;
- WP10: Safety and Reliability Decision Support Systems for Various Maritime and Coastal Transport Sectors;
- WP11: Education, Training, Results Dissemination and Implementation.

Figure 1 presented in Annex shows the relationship between the workpackages proposed in the project.

At stage 1 of the project, after reviewing the current state of the art, general models and methods of the

complex systems environment and infrastructure influence on their operation processes are developed. Namely, new general analytical models of complex systems' operation processes related to their environment and infrastructures are constructed. These models will form the basis for all further tasks. Also, originally new and universal tools for safety and reliability of complex systems evaluation are developed and after the validation and testing those in the selected maritime transport sectors accepted. Towards the end of stage 1, the final integration of the general analytical models of complex industrial systems reliability, availability and safety evaluation with the general models of their operation processes related to their environment and infrastructure is made (WP4). This integrating environment, infrastructure, safety and reliability models of complex industrial systems is the basis for building, at the project activity stage 1, such integrated particular models for complex transportation systems and processes for selected maritime and coastal transport sectors considered in the project and for all further tasks developed at the stages 2 and 3 of the project. Preliminary application and testing of these integrated particular models in port and shipyard transportation and in shipping at restricted and open water areas will be performed before the implementation of the next two stages of the project. The integration made at the stage 1 is the binder and the innovative and main core of the entire project in the sense that at each particular activity of the project the interactions among environment, infrastructure and safety and reliability of the industrial systems and processes are analysed and investigated.

At stage 2 of the project, models of safety and reliability improvement and optimisation of complex systems and processes are developed and considered together with organizational and management aspects. These topics of investigation is to be the starting point in the construction of the system ensuring safe and reliable people industrial activity and implementing it to maritime and coastal transport sectors. Data mining for identification and prediction of safety and reliability characteristics of complex systems and processes is performed at this stage as well. High performance computing methodologies are also intended to be employed for parallelisation of the different WPs, design and development of high performance data structures to speed up the extensive simulation processes in the software and for data mining (WP6) to allow the large datasets to be analysed within a reasonable time. All results at this stage of project activity are integrated into the Integrated Package of Solutions for Complex Industrial Systems and Processes Safety and Reliability Optimisation (WP7) at the end of this stage. The activity at this stage results in integrated methods and procedures addressed to reliability practitioners allowing them to identify reliability data, to evaluate and to optimise reliability structures of complex systems including their operation processes and safety aspects.

At stage 3 of the project, the integrated package composed of software tools developed using the methods and algorithms at the stages 1 and 2 for the optimisation of safety and reliability of complex industrial systems as whole and of specific processes occurring therein will be created. Also, the Package of Tools (PT) will be testified by its following applications:

- Applications of the PT in Gdynia Port and Gdynia Shipyard transport sectors and its quality and accuracy testing;
- Applications of the PT to analysis of selected shipping systems of the Baltic Sea region and a critical assessment of the usefulness of the package.

At the end of this stage detailed safety and reliability support decision systems for port, shipyard and ship at restricted and open water areas will be constructed and joined into an Integrated Safety and Reliability Decision Support System for Maritime and Coastal Transport (WP10).

From the point of view of safety and effectiveness of system operation, apart from the traditional two-state systems reliability models, the developed methods will consider a multi-state approach to system reliability and availability analysis. This will enable different critical system reliability states to be distinguished, such that it ensures a demanded level of the system operation effectiveness with consequences on the accidents dangerous for the environment, population, etc. In reliability and availability analysis of multi-state systems, the asymptotic approach to systems reliability evaluation and semi-markov models of the systems operation processes can be used to simplify and to accelerate the evaluations of their reliability, availability and risk characteristics. Linking the asymptotic approach to reliability and availability modelling of large two-state and multi-state systems with semi-markov modelling of their operation processes can be called an asymptotic approach to reliability and availability modelling of complex systems considered partly in the latest publications [1]-[22] of the project participants cited in References. This joining is a further and main innovative aspect of this proposal and the basis for the formulation and development of the new solutions concerned with the evaluation, improvement and optimisation of complex systems related to their operation processes.

Furthermore, generalizations, developments and software tools preparations based on the methods given in these publications will be conducted in the proposed project. In this aspect the project proposal is aimed on

the entire elaboration of the methods of asymptotic evaluation and improvement of reliability and availability of as wide as possible class of large two-state and multi-state systems related to their operation processes and on the pointing out of the possibility of these methods and based on them software practical applications to complex maritime and coastal transportation systems. The analytical methods proposed will be complemented with the fault tree analysis, network modelling and statistical methods. The statistical methods for reliability data processing include an innovative approach to the methods of reliability and safety evaluation and optimisation on the basis of the existing rough data and a rich assembly of computer methods for the processing of reliability data on the basis of the most important distribution functions of the classical statistics. Thus, these all approaches will fulfil a comprehensive solution of problems the project is concerned with. The activities suggested are research and technology development, innovation and demonstration, newly developed tools practical testing, education and training.

6. Competitive/comparative advantage of the research and benchmark with current international efforts

This project aims to bring 2 active research groups together. The GMU group has been conducting research in safety and reliability of large systems with the focus of maritime industry for many years. The NUS team has been active in reliability research concerning systems and software. In addition, the involvement of research staffs from the Institute of High-Performance Computing nicely complement the expertise of the other investigators. The formation of such a team for research collaboration is expected to lead to the development of high quality research with potential industry applications and impact.

The main activities are concerned with the issue of safety and reliability research, education and training. It will also look into the definition of strategies and concepts for transport research as well as its implementation into maritime transport policies which is convergent with the European Maritime Agency (EMA), Helsinki Committee (HELCOM) and International Maritime Organization (IMO) objectives given in their regulations, directives and declarations. With such a foundation, the project will undoubtedly contribute to the national and international organizations.

7. How the proposed research would leverage on capabilities in Singapore and Polish collaborating partners

As highlighted in 6, the formation of collaboration team complement each other very well and the Polish Project Manager (Prof. Krzysztof Kołowrocki) and the Singapore Project Investigator (Prof. Min Xie) are internationally recognised experts in their fields. This research is built upon the research strength of all the partners. Particularly, the collaborators from Gdynia Maritime University, which is an outstanding maritime university in Europe, with highly educated scientific and teaching personnel giving excellent qualified officers and specialists for international shipping and maritime industry. The project would help to create in future the International Maritime Education and Training Centre placed at Gdynia Maritime University. The Singapore side has been carrying out research in reliability and safety analysis with the focus on specific methodology such as fault-tree analysis, and statistical approaches. It has also been carrying out research in integrated software and hardware systems with the focus on reliability modelling and analysis. Thus, the project proposal ambitious objectives and research activity are strategically very important to collaborating partners from social, economical, environmental and technological dimensions and will have a significant impact on reinforcing their competitiveness and excellence in overall safety and reliability research activity in general and particularly in safety and reliability of maritime and coastal transport scientific and technological advances and knowledge.

8. Possibility to use in the applicant's country results of research and/or development conducted within the project

There is a great potential for future commercialisation of the developed methods and software and of its consequent application by end-users. The results from this project can be profitably applied to:

- improve, on the basis of reliability criteria, the maintenance planning applied on the industrial systems and processes;
- adequately define the maintenance planning to be applied on the industrial systems and processes in order to improve their competitiveness;
- support the application of a suitable quality assurance program;
- perform suitable reliability analyses and risk assessment studies, there included the improvement of existing industrial systems and processes;
- allow the adaptation of the industrial activity to the market request and improve it.

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The paper is a part of the Poland-Singapore Joint Research Project "Safety and Reliability of Complex Industrial Systems and Processes" granted by the Poland's Ministry of Science and Higher Education (MSHE) and by Singapore's Agency for Science, Technology and Research (A*STAR).

Project Website: http://p-sjp.am.gdynia.pl/index.php

Annex

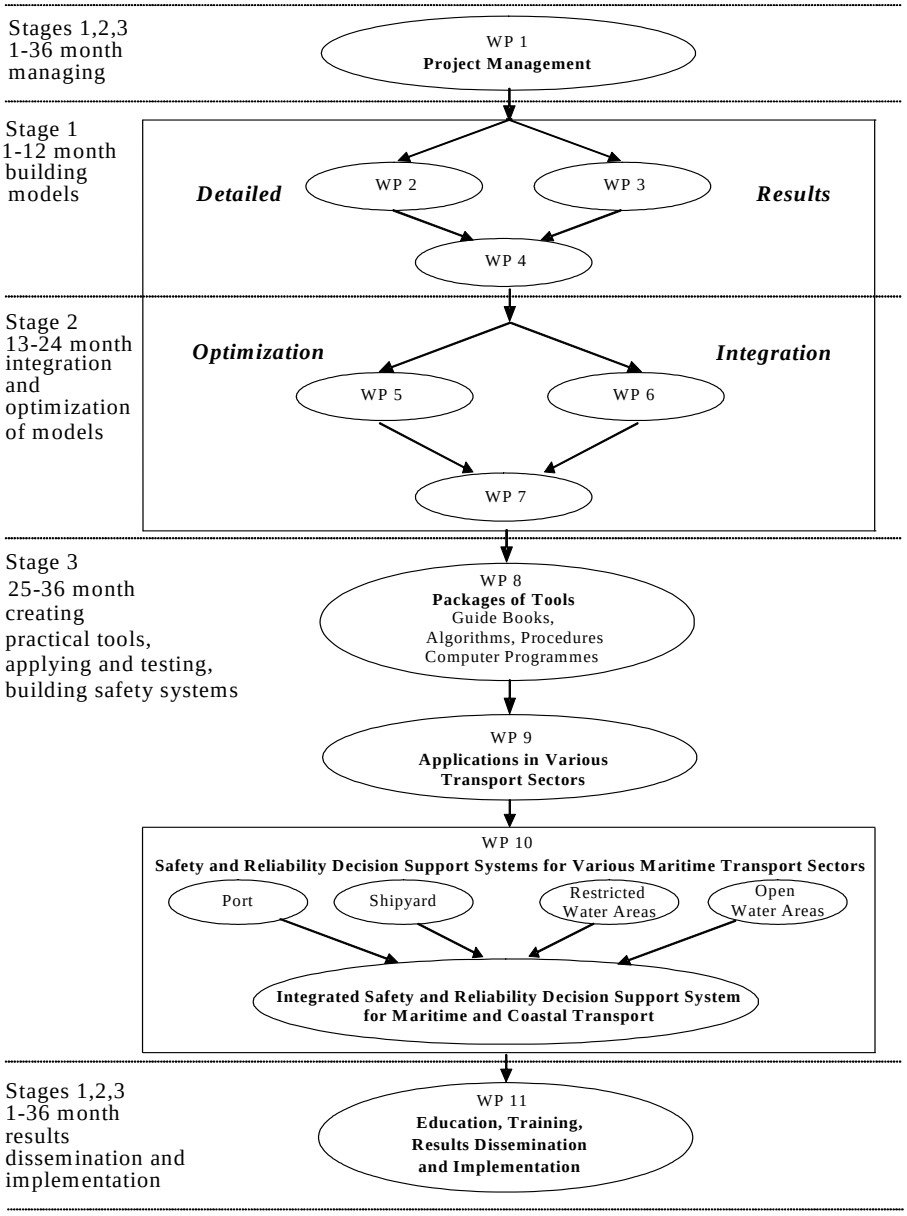

Figure 1. Relationship between the various workpackages