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Abstract

of a doctoral thesis

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Systemowa analiza bezpieczeństwa bezzałogowego statku handlowego w ujęciu jakościowym

System-theoretic analysis of unmanned merchant vessel's safety – qualitative approach

In the thesis, an issue of unmanned merchant vessels' safety has been analysed. The concept of unmanned shipping is currently in its early development phase, whereas some prototypes are to be launched within next few months, thanks to a joint effort of international enterprises of maritime industry as well as Research and Development centres. Its implementation may bring about a variety of consequences that are currently under-investigated. Therefore, there is no consensus pertaining to its both direct and indirect impact on the safety of navigation.

The goal of the thesis is to conduct an analysis of unmanned merchant vessel's operational safety and to complement it by an uncertainty analysis by applying a qualitative approach. It has been accomplished through achieving partial purposes, such as:

1. Elaboration of the model of unmanned merchant vessel's operational safety;
2. Elaboration of a method for assessing and depicting the uncertainties of system-theoretic safety analysis' results;
3. Conducting a complex, qualitative analysis of unmanned merchant vessel's operational safety, based on previously elaborated model and System-Theoretic Process Analysis (STPA);
4. Elaboration of suggestions for mitigation measures' implementation, aiming in ensuring the overall safety of unmanned merchant vessel's operations starting from its early development phases.

In order to achieve the above goals, a qualitative approach has been applied, including:

1. Human Factor Analysis and Classification System (HFACS) to identify potential causes of unmanned merchant vessels' accidents, based on an analysis of accident investigation reports from various countries;
2. System-Theoretic Process Analysis to elaborate and analyse a model of unmanned merchant vessel's operational safety;
3. Delphi method to obtain tacit knowledge in order to determine model's parameters and their interactions;
4. A novel method of assessment and classification of the uncertainties within STPA results.

Due to the issue of unmanned merchant vessels' safety being of an immediate interest to both industry and academia, four stages of its analysis have been conducted.

In the first stage, the potential impact an implementation of unmanned merchant vessels can have on both probability and consequences of a maritime accident has been determined. Herein, one hundred accident investigation reports following different types of events have been analysed to determine their causes and consequences. Certain categories of both have been assigned to either having a bigger or smaller potential of occurring should the vessel involved in the accident be unmanned. The results indicate that the implementation of unmanned merchant vessels can help reduce the number of accidents, but those that would occur despite that effect and would involve unmanned vessels might have some more serious consequences.

The second stage consisted in an expert study, aiming in determining the anticipated course of unmanned merchant vessel's accident. An initial model of potential causes and consequences of such accident as well as interactions between them have been elaborated.

The third stage was the most important from the cognitive point of view. Herein, the System-Theoretic Process Analysis has been applied to analyse safety aspects of unmanned merchant vessels. The STPA has been developed to assist with modelling the safety of complex sociotechnical systems and consists in analysing interactions between systems' components rather than on the very components' reliability (as is the case for numerous other methods). Improper interactions between system's components may lead to the emergence of hazards. Therefore, potentially improper interactions shall be identified through the analysis together with potential causes and consequences. When that is accomplished, mitigation measures against particular improper interactions' occurrence shall be elaborated. An important feature of STPA is that no risks are calculated since these always exist and numbers describing it can be misleading. This feature is of importance for unmanned merchant vessels' safety analysis. The technology is still on an early phase of the development and therefore it may change in time. By that, its reliability features may also change significantly depending on final organisational and technical arrangements.

This stage included a safety analysis of an unmanned merchant vessel operating on two autonomy levels: remote control and full autonomy. Their safety control structures have been elaborated through an expert elicitation, attended by experts participating in one of R&D projects in the field. These included employees of both industry and academia: design of on-board systems as well as operational factors. Despite the structures' models being created on a low-detail level, not only the unmanned vessel and her equipment has been included, but also her organisational environment. The results of this stage indicate that at the present stage of the unmanned shipping technology development, quantifying its safety is impossible and unreasonable. Despite that fact, the available information supported and enabled for elaboration of some general recommendations for the design of said systems so as to make them safe.

The final, fourth stage of the conducted research was focused on the issue of third stage's results' validity. Herein, an uncertainty analysis has been performed including the uncertainties that might affect the final results of the study. To this end, a method of categorizing uncertainties in risk analysis has been modified and applied so as to be used in a qualitative domain. It has been applied to assess the uncertainties in a key aspect of STPA: mitigation measures' generation. The results of this stage indicate that significant uncertainties are related to software-related mitigation measures. These are expected to be extremely sophisticated and innovative so as to enable unmanned vessels' operations.

The development and application of a novel method of uncertainties' assessment in STPA is the major contribution of the hereby thesis and the most valuable achievement of a candidate. The method can be applied to assess uncertainties in system-theoretic analysis of the safety of various systems as an extension of the safety analysis itself. This in turn can be an important input of a decision-making process.