UDC 629.5.064

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ReliBase – Database Model of the Integral System for the Determination of Marine Power Plant RAM Characteristics

Original scientific paper

Due to the complexity of modern marine power plants, the criteria of reliability, availability and maintainability became key features in ship design, exploitation and maintenance. The best results in application are obtained when the analysis of reliability is an integral part of the design process of new components and systems. One of the conditions for analysing and estimating a design solution or a maintenance function on the basis of reliability criterion is the existence and availability of data on RAM (Reliability, Availability, Maintainability) characteristics of a marine power plant. The paper presents a methodology of creating a database for collecting the operational characteristics of the system components. It also presents the created database structure. Using the database structure, an information system that enables the determination of RAM characteristics of a single marine power plant component has been designed. The minimal set of essential operative characteristics has been determined. The system is conceived in such a way that it can easily encompass some additional characteristics with the purpose to extend its potential applications.

Keywords: *marine power plant, reliability, availability, maintainability, database, operational characteristics*

Relibase - model baze podataka integralnoga sustava za određivanje operativnih značajki pouzdanosti brodskih energetskih postrojenja

Izvorni znanstveni rad

Zbog složenosti suvremenih brodskih energetskih sustava, kriteriji pouzdanosti, raspoloživosti i pogodnosti za održavanje postali su veoma bitni čimbenici u procesu projektiranja, korištenja i održavanja. Najbolji rezultati primjene postižu se kad je analiza pouzdanosti sastavni dio procesa projektiranja novih sastavnica i sustava. Jedan je od uvjeta za analiziranje i ocjenjivanje projektnog rješenja ili funkcije održavanja prema kriteriju pouzdanosti postojanje i raspoloživost podataka o RAM (Reliability, Availability, Maintainability) značajkama brodskog energetskog sustava.

U radu je prikazana metodologija izrade i izrađena je struktura baze podataka za prikupljanje operativnih značajki sastavnica sustava. Na temelju nje izrađen je informacijski sustav pomoću kojeg je moguće odrediti RAM značajke pojedine sastavnice brodskog energetskog sustava. Određen je minimalan skup nužnih operativnih značajki, a sustav je koncipiran tako da lako može obuhvatiti i neke dodatne značajke, s ciljem povećanja njegove primjene.

Ključne riječi: *brodsko energetsko postrojenje, pouzdanost, raspoloživost, pogodnost za održavanje, operativne značajke, baze podataka.*

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Received (Primljeno): 2005-04-05
Accepted (Prihvaćeno): 2005-07-30

1 Introduction

In marine and shipbuilding industry there is a growing number of those who support the idea that in the future, an approach based on the analysis of reliability and on the risk analysis will become a widely accepted common approach for determining new safety norms for marine power plant components. The analysis of the marine power plant failures and their impact on the system operation, as well as the frequency of their occurrence are the decisive factors in the development and application of new regulations for technical inspection and classification of ships. Advantages of regulations based on reliability are the increase of safety level and the increase of system application efficiency, which in turn can have a positive influence on the reduction of investment and maintenance costs of marine power plants.

The analysis of the reliability of a particular engineering system is useful at any particular time in the system operating life. However, conditions for application, methods and limitations of application, as well as the application results will differ from case to case. The best results in application are obtained when the analysis of reliability is an integral part of the design process of new components and systems. This process is called Reliability Based Design – RBD. In modern procedures of marine power plant design, the reliability based design has not yet become

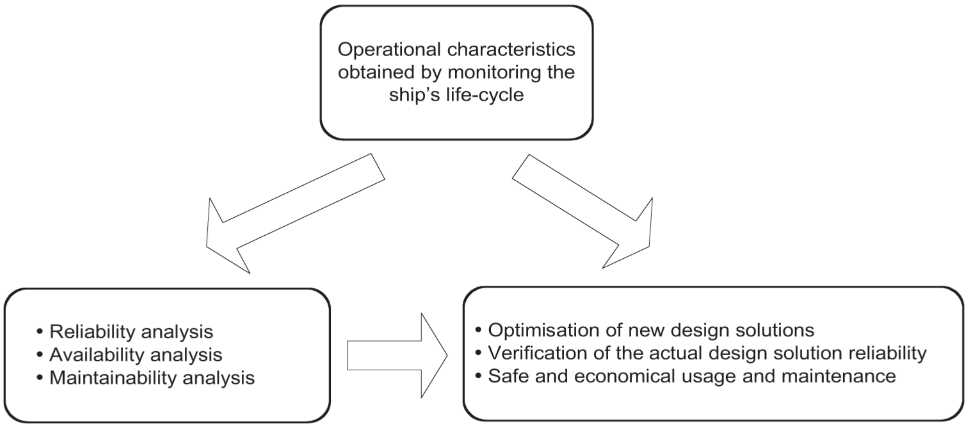


Figure 1 **The need for data**
Slika 1 **Potreba za podacima**

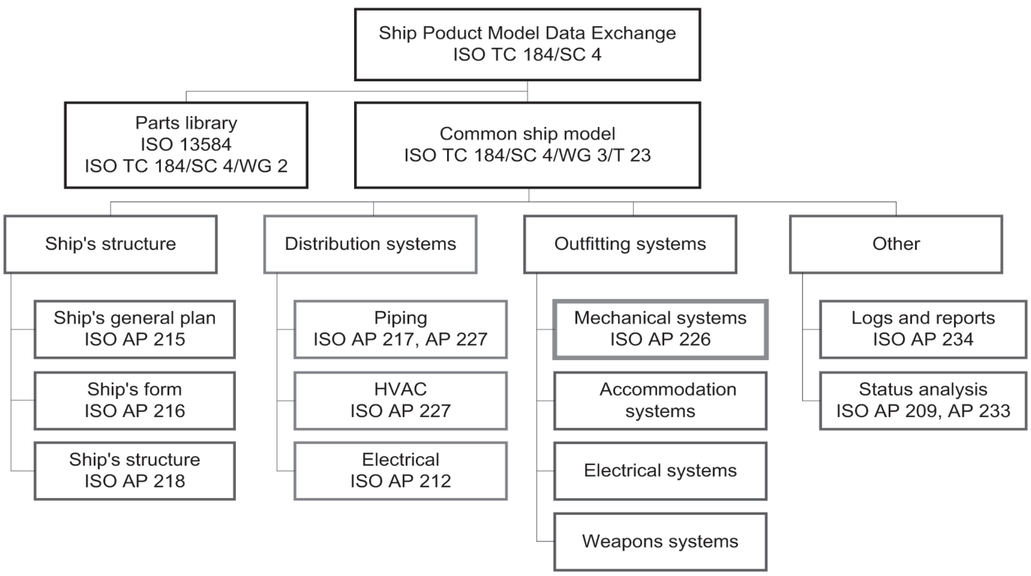
standard practice. In most cases, the analysis of reliability is carried out subsequently to the preliminary ship design. The quality of the design solution with respect to the reliability criterion is estimated on the basis of a comparison of the results obtained by a predetermined value of reliability. Modern methods of usage and maintenance of engineering systems include the analysis of reliability as one of relevant analyses in the optimisation of maintenance functions, logistic support and monitoring of the current and past state of the system. The impetus for the development of the *reliability based maintenance method* came through the realisation of the connection between reliability and maintenance.

One of the conditions for analysing and estimating a design solution or a maintenance function on the basis of reliability criterion is the existence and availability of data on operational characteristics (RAM characteristics of a marine power plant), Figure 1. In order to carry out the quantitative analysis of RAM characteristics of a particular system, we need input data that would describe the system, its components and operating conditions. The quantity of input data will depend on the purpose of the analysis of reliability to be carried out, or on the complexity of the system. The basic input data, required for any analysis, is the component failure intensity, and in the case when the maintenance process of the system is considered, the intensity of failure repair is also required. The process of obtaining an acceptable qualitative value of the input data is very lengthy because it should be based on as large a sample of same or similar components as possible. There is a tendency to standardise the procedures of collecting, calculating and analysing RAM characteristics, as well as their transfer from the level of a particular object (ship) to the level of a set of similar or same objects (fleet) for the sake of data compatibility. The ultimate aim is the generation of an integral system for the calculation of RAM characteristics, their analysis and transfer [6]. *Reliability Database* is one of the integral system modules used for collecting data, and for calculating and analysing RAM characteristics of every component of a marine power plant.

2 Uniform approach to the development of the database information model

Data normisation brings about numerous benefits, the most important ones being comparability and compatibility of data collected during the time of usage. These benefits enable a wide field of data application as the feedback information to the equipment manufacturers, shipyards and other organisations involved in a technological process. The creation of a wider network of organisations which apply standardised norms for monitoring the operational characteristics of different types of components, operating in different conditions, will result with a better estimation and the more precise determination of RAM characteristics. In order to achieve this aim, ISO, EMSA (European Marine STEP Association), IMO and other organisations co-operate on the adoption of standardised models. The aim is to obtain the

Figure 2 **Application protocols of the Ship Product Model Data Exchange**
Slika 2 **Aplikacijski protokoli modela za razmjenu podataka o brodu**



definition of elements in the process of monitoring and exploiting the ship features throughout the ship's life. The norm ISO 10303 – Product Data Representation and Exchange, or more precisely its application protocol AP 226 – Ship Mechanical Systems, is a significant contribution to the field directly related to marine power plants. The norm ISO 10303 – Product Data Representation and Exchange – defines a method for computer presentation and exchange of data on industrial products throughout their life, from the preliminary design till they are finally discarded. A section of ISO 10303 is Ship Product Model Data Exchange which divides the ship into several systems. Each of these systems represents one of key elements for completing the ship's mission (Figure 2). The sub-section AP 226 refers to the collection and exchange of data describing operational characteristics of ship mechanical systems throughout their service life. The systems included in this application protocol are ship propulsion system, ship auxiliary systems and marine power plants.

3 Functional phases in the development of the ReliBase model

Experience so far has shown that the most acceptable and the best quality data sources are those based on the data collected during the ship's usage, and those based on the data provided by shipbuilders and manufacturers of ship equipment. A marine power plant is a complex system which comprises heat engines, mechanisms, devices, appliances and systems used to carry out the process of energy conversion. The complexity of the marine power plant is determined not only by a large number of different types of equipment, devices and sub-systems, but also by various and specific tasks that the system has to perform in different conditions of ship usage [11]. Only an adequate information system can enable the collection, processing and analysis of RAM characteristics of such a complex system. *Reliability Database* is a module used for collecting data, calculating and analysing RAM characteristics of each component of the marine power plant [14]. The development of a computer system is divided into the following phases:

- Defining the level at which the system will be analysed;
- Defining operational characteristics of components to be collected;
- Defining the degree of precision for the description of a particular feature (characteristics);
- Defining a standard record in order to enable a simpler way of data transfer between all the participants in the process;
- Developing a database model;
- Defining methods for ensuring the integrity of data;
- Defining methods for protecting data.

The computer system has to fulfil the following requirements:

- The user interface of the system has to be simple as far as its installation, use and maintenance are concerned;
- The system has to be, at least to a certain level, compatible with the current systems for monitoring the operational characteristics of a marine power system.

3.1 Defining the set of component operational characteristics

A set of operational characteristics of components that must be recorded by the system is defined as a minimal set of input data required for the determining of the set of system output data (Figure 3). Therefore, the input data set is a function of the output data set. If the output set should contain the features of *reliability, availability and maintainability* of the marine power plant, then the following input data are required:

- *Characteristics of a single component or a "built-in component"*: function, class, type, total number of working hours in a given time.
- *Characteristics of failures:* the time of failure occurrence, classification of the failure according to its effects on the working capability of the system.
- *Characteristics of corrective maintenance:* the time of the start and completion of the repair, duration of a particular repair, downtime and its cause, result of the repair work.
- *Characteristics of preventive maintenance:* the time of the start and completion of the repair, result of the repair work.

3.2 Conceptual model of database

Conceptual data modelling takes the requirement specification of data structure and application as a starting point, and results with a generated conceptual data model. On the level of conceptual data modelling, key decisions on the real objects and events (entities) to be modelled and on the nature of connections between these entities have to be made. Conceptual model of database enables the grouping of all the data (attributes) describing one entity on one place without being dependent on the data describing another entity.

The process of conceptual data modelling consists of the following steps:

- Defining the need for data;
- Determining entities and their keys;
- Determining relationships.

Defining the need for data is a procedure of determining the minimal set of input data required for determining the output data set of the system. The minimal set of input data is defined in chapter 4.1.

Six *main entities* and all *auxiliary entities*, which are needed for a detailed description of a particular attribute of the main entity, or for the purpose of transforming one many-to-many connection into two one-to-many connections are defined at the level of conceptual modelling. The main entities are as follows:

- Entity *components,*
- Entity *failures,*
- Entity *corrective maintenance action,*
- Entity *preventive maintenance action,*
- Entity *voyages,*
- Entity *built-in component*.

It is necessary to determine *the key* of each entity. The entity key is a characteristic which differentiates each record in this entity from other records. The entity key has to be unique. The key can be, but not necessarily, an important attribute of the entity. For example, the key of the entity "component" will be the identification code of this component according to the standard code book of the marine power plant, while the key of the entity "failures" will be a simple ordinal number automatically given in ascending order to each new failure record in the database.

The procedure of *determination of relationships* between entities defines the interdependence of particular entities. In the

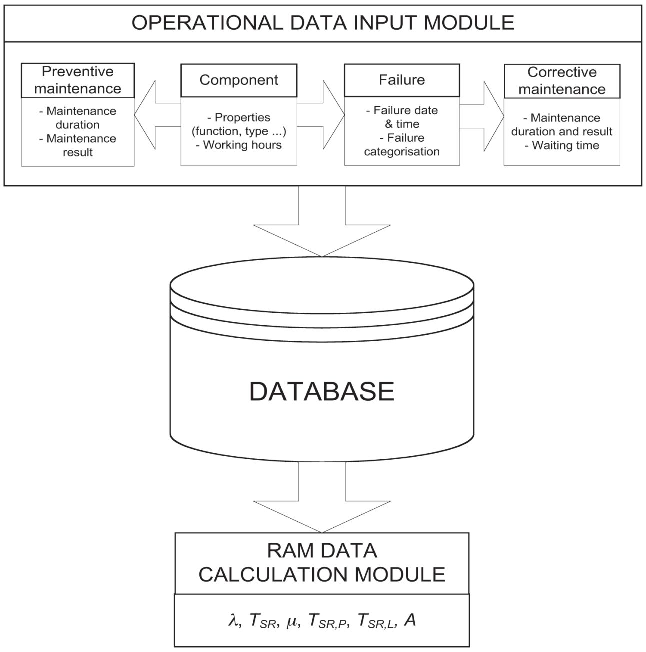


Figure 3 **Structure of the information system for determining the RAM characteristics**
Slika 3 **Struktura informacijskog sustava za određivanje RAM značajki**

process of determining connections between two entities it is of vital importance to identify the modes of interaction between these entities, i.e. the modes in which one entity affects the other, and *vice versa*. Thus, for example, each component from the entity *components* can have several *built-in components,* whereas every built-in component may belong to only one component – this is an example of the one-to-more connection. On the other hand, each component can be included in several ship's working regimes, and each working regime can be valid for several components: this is an example of the many-to-many connection, which must be transformed into two one-to-many connections as a new, common attribute has been formed. Figure 4 presents a complete conceptual model, with additional entities required for transforming the many-to-many connection, and entities required for description of particular attributes.

3.3 Logical model of a relational database

Logical or implementation model of database has been obtained by logical modelling and is based on the previously defined conceptual model. In accordance with the current state in the development of information technology, a relational model has been applied. This model was developed in theory by E. F. Codd in 1970, it was implemented in practice in the 1980s, and in the 1990s it became the most widely used model in practice. Its most important advantage is its simplicity: it is easily understood and used in practice. In order to produce a logical data model, it is necessary to:

- Define the indispensable tables on the basis of the entities defined in conceptual model,
- Define all indispensable columns in a table on the basis of entity attributes,
- Define the way of transferring the primary key of an entity into another,
- Define external keys and possible compound keys,
- Define interrelations between non-key columns within an entity.

Starting from a complete conceptual model, a logical model of a relation base has been developed.

4 Structure of the ReliBase database logical model

A database for collecting the operating characteristics of a marine power plant is described by six main entities (Component, Built-In Component, Voyage, Failure, Corrective Maintenance Action and Preventive Maintenance Action).

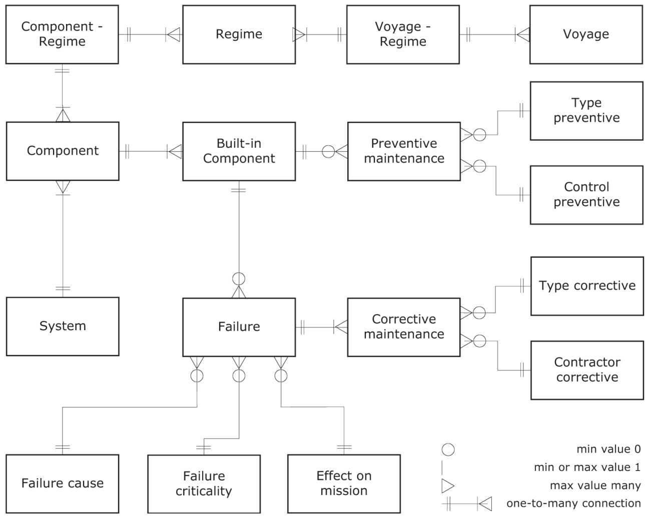
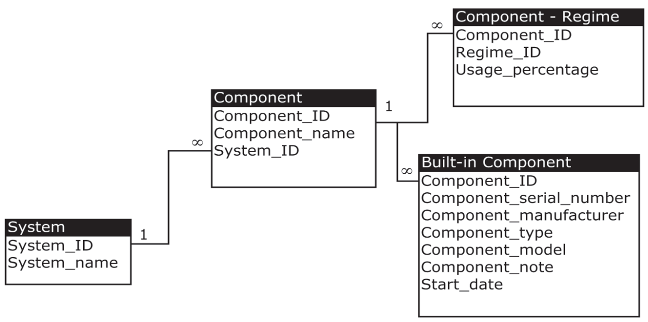


Figure 4 **Conceptual model of a database**
Slika 4 **Konceptualni model baze podataka**

4.1 Entities System, Component and Built-In Component

The Entities System, Component and Built-In Component belong to the category of basic data (Figure 5). When installing the information system, we input data that completely define each component or built-in component for which operating charac-

Figure 5 **Entities System, Component and Built-In Component**
Slika 5 **Entiteti Sustav, Sastavnica i Ugrađena sastavnica**



teristics are collected. Such division is necessary because of the possibility to replace the current active component in case of its irreparable failure, which directly affects operating characteristics of the component.

The most important fields of these entities are the following:

- **Component_ID -** Identity mark of a component: primary key of the entity Component which differentiates each single component of a marine power plant. Identification mark can be taken out from the standard component code book at the shipowner's disposal. Related to this field is the field System_ID which is taken from the entity System. This field defines the ship system which incorporates a particular component.
- **Component_Name and System_Name:** these two fields are descriptive fields which enable easier handling of the database and are related to the fields Component_ID and System_ID.
- **Component_Serial Number:** related to the field Component_ID, this field is a primary key of the entity Built-In Component, which differentiates a single presently built-in component at any spot in the system.
- **Component_Manufacturer, Component_Type, Component_Model, Component_Note:** these fields describe the built-in component under consideration. These fields enable to categorise the component among all the components to be taken into consideration by the information system.
- **Start_Date:** the date of starting recording (monitoring) the component operation. This date can either be the date when the new ship starts its exploitation life, or, in case of a ship that is already being used, the date of system installation.
- **Usage_Percentage:** this field is related to the entity Regime. It defines the percentage (0 -100%) of the component usage in a particular regime of navigation. This data is in turn used as the basis for estimating the number of working hours of the component.

4.2 Entities Voyage and Regime

The entity Voyage, as well as the entities Failure, Corrective Maintenance Action and Preventive Maintenance Action, belong to the category of entities which contain the transport data (Figure 6). Data concerning the duration of time periods in which the ship navigates in a particular regime during a particular voyage are recorded in this entity. The sum of these times, combined with the field Usage_Percentage which contains the percentage of usage of each component in each navigation regime, gives the total of working hours of the component in the interval of time under consideration.

The most important fields in these entities are the following:

- **Voyage_ID:** Identification mark of the voyage. The primary key of the entity Voyage in the proposed model is defined as an Autonumber (linearly ascending order which attributes to each record in a sequence an appropriate higher value of ordinal number).
- **Departure_Port, Arrival_Port:** feature of the route or its section. These fields are introduced for easier handling of the database when checking the operational characteristics of the ship.
- **Regime_Name, Regime_ID:** the name and identification mark (primary key) of each operation regime for which the percentage of component usage is defined. In the proposed model there are four possible regimes of ship operation, and it is also possible to define other operation regimes.
- **Start_Date, Finish_Date, Hours:** feature of the operation regime. These fields define the starting point and the finishing point of each operation regime, i.e. the duration of the regime which is automatically calculated from the first two fields.

4.3 Entity Failure

The entity Failure (Figure 7) is the basis of the entire information system for monitoring the operational characteristics of a marine power plant. Failure occurrences and the attributes of each failure are recorded in this entity. Each failure is related to one built-in component (and thus, in an intermediate way, to

Figure 7 **Entity Failure**
Slika 7 **Entitet Kvar**

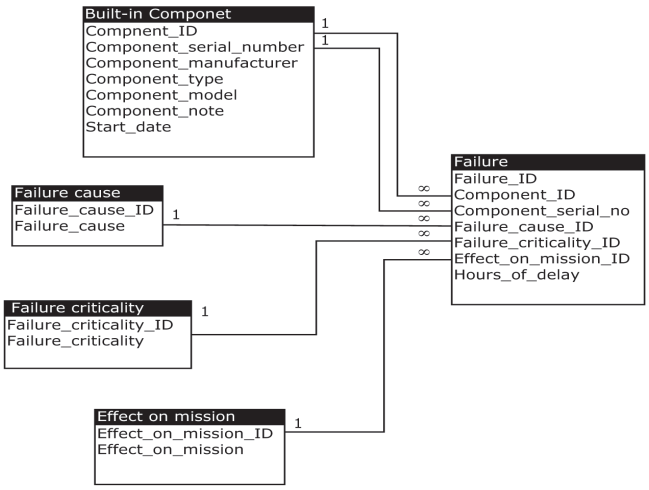
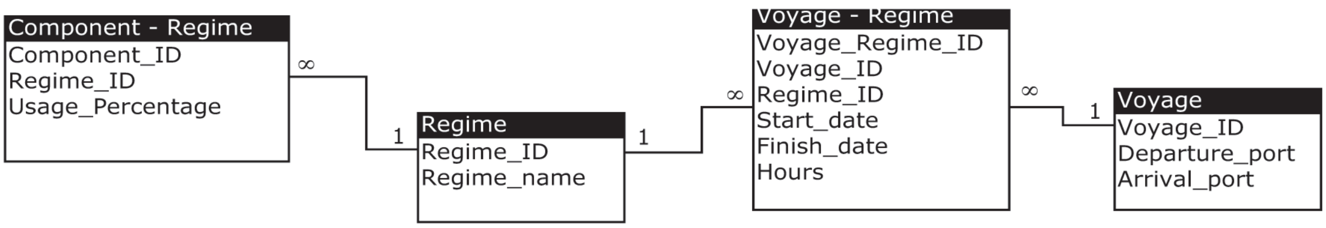


Figure 6 **Entities Voyage and Regime**
Slika 6 **Entiteti Put i Režim**



a component), and one or more corrective maintenance repairs are connected to each failure. Another possible definition of the failure occurrence can be derived from the above: a failure on a component occurred only in the case if it was followed by a corrective maintenance action. Three auxiliary entities are connected to the entity Failure: Failure Criticality, Failure Cause and Effect of Mission. Each of these auxiliary entities is defined by a set of basic values. The entities Failure Cause and Effect of the Mission are not indispensable for determining the basic set of RAM characteristics, but they have been introduced as an example of a possible extension of the system with the purpose of carrying out additional analyses on the ship usage.

Some important fields in these entities are as follows:

- Failure_ID: Identification mark of the failure. The primary key of the entity Failure in the proposed model is defined as Autonumber.
- Component_ID, Component_Serial _Number: external keys of the entity Failure. They determine a component or a built-in component on which a failure occurred.
- Failure_Criticality: the field which classifies a failure according to its effect on the operational ability of the system (Critical/Total Failure, Major Failure, Minor Failure).
- Failure_Cause: additional field introduced for the purpose of a possible analysis of causes of failures on a particular built-in component.
- Effect_On_Mission: additional field introduced for the purpose of a possible analysis of the failure effects on the ship's mission, or for the purpose of economic analysis of the ship usage.
- Hours of Delay: the field into which the hours of delay in fulfilling the ship's mission are recorded. This field also serves for the subsequent economic analysis.

4.4 Entity Corrective Maintenance Action

The data relevant for the corrective maintenance action are collected in this entity. These data are indispensable for determining the characteristics of maintainability and availability of a particular system component. The entity Corrective Maintenance Action (Figure 8) is connected to the entity Failure by the connection one-to-many because one failure can cause many corrective maintenance actions.

Two auxiliary entities, Corrective Result and Corrective Contractor, are connected to the entity Corrective Maintenance Action. The state of a component directly depends on the result of the corrective maintenance action: if the result of the corrective maintenance is the replacement of the component because its repair is impossible, a new record is opened in the entity Built-In Component in accordance with functional classification in which a built-in component replaces the component under consideration.

The most important fields in these entities are the following ones:

- Corrective_ID: Identification mark of a corrective maintenance action. The primary key of the entity Corrective Maintenance Action is defined as a sequential counter.
- Failure_ID: the external key of the entity Failure. It determines the failure which caused the corrective maintenance action.
- Corrective_Start_Date, Corrective_End_Date: defines the beginning and the end of the corrective maintenance action.
- Man_Hours, Waiting_Hours: define the duration of the corrective maintenance action normalised by the working hours of one man working on maintenance, or the duration of waiting for the logistic support. The field Man_Hours includes all working hours spent on the component failure action, including the time needed for the failure inspection, repair preparation and the making of special tools, etc.
- Result_Corrective: a field which describes the result of a corrective maintenance action.
- Contractor_Corrective: additional field introduced for the purpose of a possible analysis of failures on the basis of the corrective maintenance contractor.
- Detailed_Corrective: a field for a free input of the text which describes in detail the corrective maintenance action that has been carried out. For this field there is no obligation to input data.

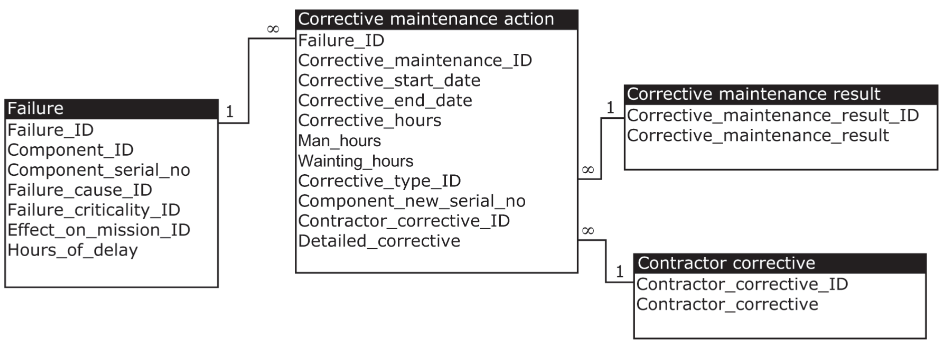
4.5 Entity Preventive Maintenance Action

The data relevant for the preventive maintenance action are collected in this entity (Figure 9). The key and the fields of this entity are similar to the entity Corrective Maintenance Action, with the difference that they are not connected to failures, but to the built-in component. Two auxiliary entities are connected to the entity Preventive Maintenance Action: Preventive_Type and Preventive_Control.

These entities include the following fields:

- Preventive_ID: Identification mark of the preventive maintenance action. The primary key of the entity Preventive Maintenance Action is defined as Autonumber.
- Component_ID, Component_Serial_Number: external keys of the entity Preventive Maintenance Action. They determine the built-in component and the component on which the repair is carried out.
- Preventive_Start_Date, Preventive_End_Date, Preventive_Hours: defines the beginning and the end of the preventive maintenance action, and the duration of the action which is calculated automatically from the first two fields.

Figure 8 **Entity Corrective Maintenance Action**
Slika 8 **Entitet Zahvat korektivnog održavanja**



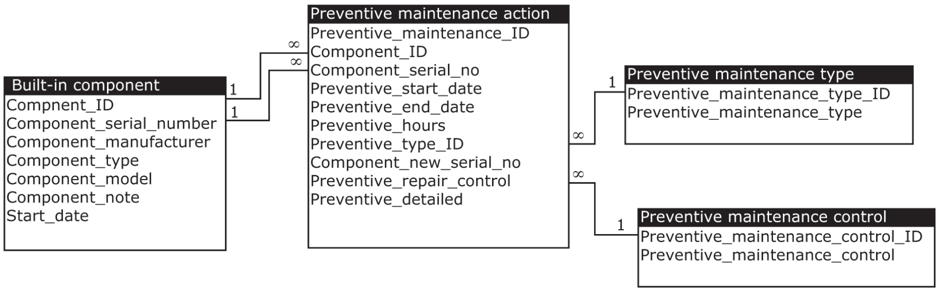


Figure 9 **Entity Preventive Maintenance Action**
Slika 9 **Entitet Zahvat preventivnog održavanja**

- Preventive_Type: describes the type of the preventive maintenance action.
- Preventive_Control: a field introduced for the purpose of a possible preventive repair analysis on the basis of the maintenance control contractor.
- Preventive_Detailed: a field for a free input of the text which describes in detail the preventive maintenance action that has been carried out.

Figure 10 presents the entity- relationship (E-R) diagram of the ReliBase database.

5 Operative characteristics input module

A module for the input of the ReliBase database operative characteristics consists of two submodules:

- a submodule for the input of basic data,
- a submodule for the input of transport data.

Each of these two submodules contains a number of forms that are used for inputting data into the database. The submodule for the basic data input contains two forms: Systems and Components. The former contains codes and names of all the systems of a ship, and the latter contains the information on components and built-in components, percentage of their usage in different operational regimes, etc. Data is input into these forms once, either at the moment of the program installation, or at the replacement of a built-in component (or a component, possibly). An example of the Components form is presented in Figure 11.

The submodule for transport data input contains three forms: a form for inputting data on the ship's voyage, a form for inputting data on a failure, and a form for inputting data on preventive maintenance. All three forms have implemented subforms: e.g. the form Failures (Figure 12) contains a subform Corrective Maintenance which describes a particular corrective maintenance action. In a similar way, the form Preventive Maintenance contains the information on all the repairs of preventive maintenance. As can be seen from the model presented in Figure 10, there can be more than one repair carried out on a component. The forms for data input are simple and well laid out. Automatic data input is provided wherever it is possible.

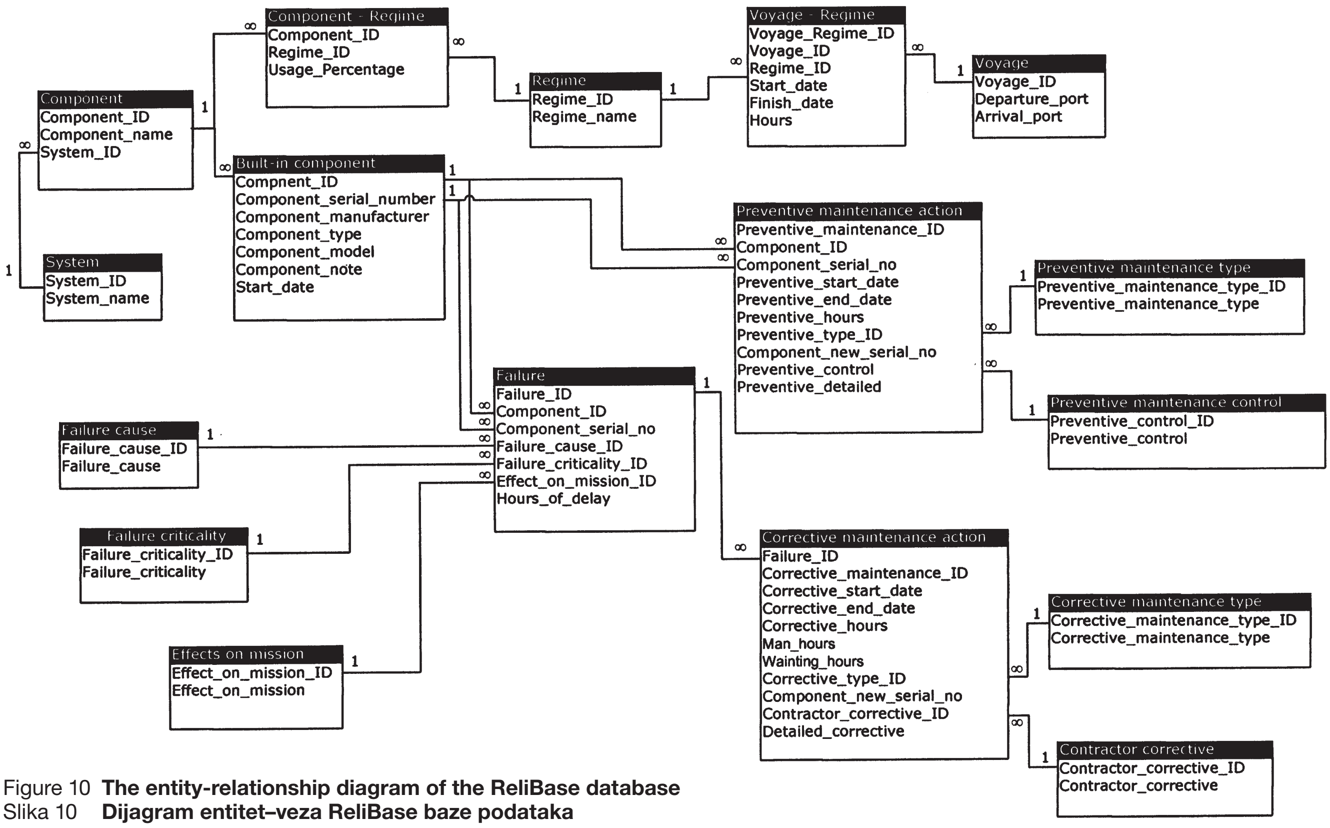


Figure 10 **The entity-relationship diagram of the ReliBase database**
Slika 10 **Dijagram entitet–veza ReliBase baze podataka**

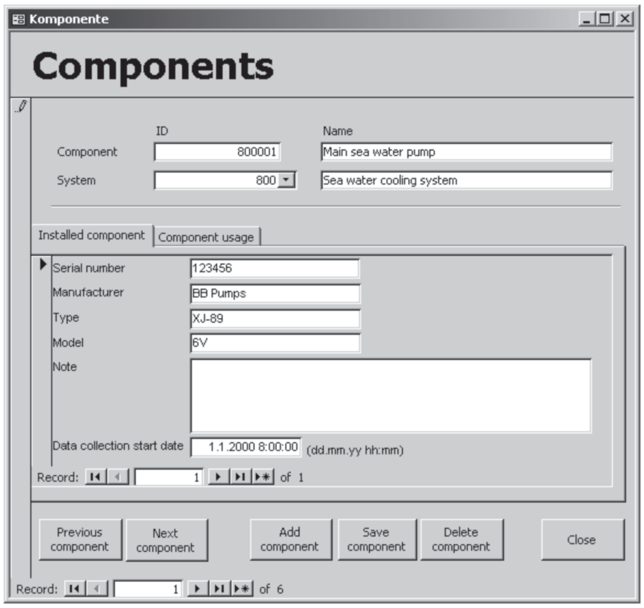


Figure 11 **The Components form**
Slika 11 **Obrazac Sastavnica**

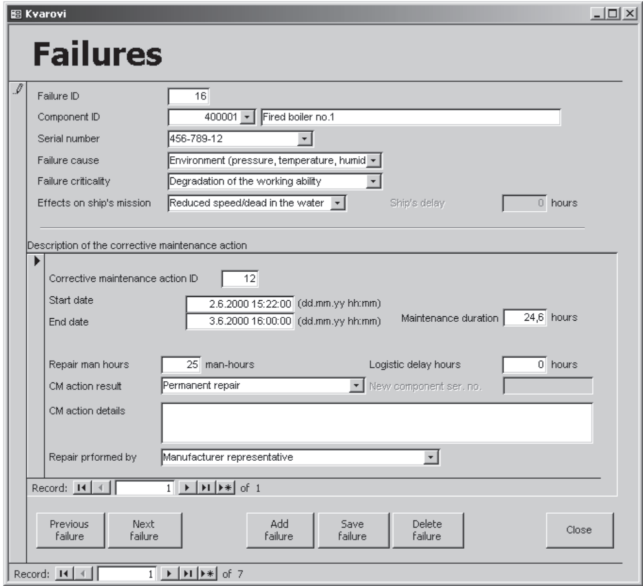


Figure 12 **The Failure form and the Corrective Maintenance subform**
Slika 12 **Obrazac Kvarovi i podobrazac Korektivno održavanje**

5.1 Integrated RAM Data Information System

To ensure the higher possible quality of use and interpretation of the RAM characteristics calculated on the basis of the collected operational data, a logical need arises for the integration of the data collected on the lower hierarchical levels (e.g. ships) to higher levels (e.g. classes of ships, fleets etc.), because this is the only way to, from the statistical point of view, obtain the biggest possible population of the sample set, i.e. the better possible estimation of the statistical distribution of a single RAM characteristic. For this purpose, it is suggested that the RAM data information system is organised in three hierarchical levels, as shown in Table I.

Table 1 **Levels of the RAM data information system**
Tablica 1 **Razine informacijskog sustava RAM podataka**

Level	User	Application	Purpose
3	Marine industry (shipyards, equipment manufacturers, classification societies)	ReliCalc (System RAM data)	Determination of the RAM data at the marine industry level
2	Owner/ Operator	ReliBase (Merged components RAM data)	Determination of the RAM data at the fleet level
1	Ship	ReliCalc (System RAM data) ReliBase (Components RAM data) ReliBase (RM data entry)	Determination of the RAM data at the ship level Collection of the RM data

- *The first hierarchical level*, the level of a single ship, is the most important level of the whole database system because this is the level on which the data are generated and collected. Because of its key importance for the subsequent data interpretation, the parts of ReliBase that cover this level were developed in the accordance with the requests mentioned in the opening chapter.
- *The second hierarchical level* can be the level of an Owner/Operator company, which should use the collected data for optimising the company's business strategy (spare parts policy, fleet maintenance program). This part of the system should be implemented in the company headquarters, with the possibility to monitor a single ship, and to integrate the RAM characteristic for a certain ship class (type), whole fleet, etc.
- *The third hierarchical level* can be the level of the marine industry, where a centralised system should integrate all the data collected on ships of all the participants in the process of operational data collection, with the purpose to improve the maintenance process, but also the design process of ship mechanical systems. The database system implemented at this level should be able to analyse, process and sort all the collected data, and it should grant to the involved organizations the access to the statistically processed data.

The integration of the data to higher hierarchical levels should improve the quality of the interpretation of data gained on lower levels. Here the term "integration" means mainly a collection of data from a greater number of various components installed in various systems, which should contribute to a better averaging of a calculated statistical value (primarily of the failure rate and repair rate), or to the reduction of time needed for the component monitoring.

In the process of collection and processing of data from various components installations it is necessary to pay special attention to the classification of components in similarity classes regarding their nominal characteristics, working conditions etc. According to some experiences the Mean Time Between Failure for one component can vary more than a decade from one installation to another.

6 Conclusion

The main obstacle to a wider application of the theory of reliability in the process of design and usage of marine power plants is the lack of reliable data on the RAM characteristics of marine power plant components. It is caused by the fact that the calculated RAM characteristics are not shared among all the participants in the process of design, usage, control and maintenance of the system.

The paper presents a methodology of creating a database for collecting the operational characteristics of the system components and the created database structure. Using the database structure, an information system that enables the determination of the RAM characteristics of a single marine power plant component has been designed. The information system has been developed in accordance with the proposed norm for sharing information on the ship's systems, ISO-WD 10303 / AP 226, which ensures its compliance with applications of the same purpose. The minimal set of essential operative characteristics has been determined, and the system has been conceived in such a way that it can easily encompass some additional characteristics with the purpose to extend its potential applications.

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