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AVAILABILITY MODEL OF COMMUNICATION NETWORK IN CONNECTING SHIP SYSTEMS USING OPTICAL FIBRE TECHNOLOGY

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Summary

For an efficient operation of a ship it is essential that all its systems work properly and reliably. In order to be able to control and monitor the systems, it is necessary to connect all of the systems' components with a communication network. To ensure effective and reliable connecting of ship systems, all the elements which constitute the optical communication network were analysed, and the elements whish affect the most the overall system's availability were identified. Based on these studies, a mathematical model of network has been developed. The model includes all the network's elements, and, based on the failure data; it calculates the input data required for the analysis of network availability. A novel method of calculation has been introduced, which includes the impact factors based on the cable network construction mode. In order to enable the usage of the network model for networks of different topology, size, construction modes and purposes, a novel algorithm for calculating the communication network's availability has been created. The availabilities of individual components and the whole network have been calculated, the impact of individual components' availability on the availability of the system has been established, and the methods of communication networks protection have been defined. Based on the conducted researches, the behaviour of the system in the event of failures and the possibility of finding optimal and reliable modes of connecting ship systems have been determined, thus contributing to the overall reliability of ship systems and of a ship as a whole.

Key words: *availability model; maritime transport; optical communication network; ship systems*

1. Introduction

Optical fibre technology, due to its advantages in data transmission and simplicity of performance as opposed to conventional technologies of information transmission, completely prevails in the area of telecommunications and computer networks. In addition to communication systems, optical fibres have started to be applied as sensors for various electrical and non-electrical values. In both cases their very small size and weight, simplicity of installation, insensitivity to external electromagnetic influences, large transmission capacity and good reliability justify the installation of optical fibre networks and sensors in very demanding environments, such as ships [1].

Optical technology is based on the emission, transmission and detection of light, i.e. on the generation of a light signal through an electrical impulse. Optical communication system transmits an optical signal through an optical fibre to a receiver. In the receiver the optical signal converts back into the original electrical signal.

In order to ensure an effective and reliable connection of ship systems, it is necessary to analyse all the system elements that make the communication system for the transmission of information between the system components, to determine which elements affect the most the overall availability of the system and on the basis of these studies to make a mathematical model of network availability. The availability of an optical communication network significantly affects the availability of complex technical systems, such as ship systems.

Availability model of optical communication network includes all network elements, and, based on failures data, it calculates input data required for the analysis of network availability. Apart from the standard method of calculating availability, a new calculation method is introduced and it impact factors based on the method of cable network construction.

In order to be able to use the network model for networks of different topology, size, method of construction and use, an algorithm is created which calculates the availability of a communication network. In addition to calculating the availability of the entire structure, the algorithm finds optimal paths in the network and calculates the attenuation of light signals for all the found paths.

Besides the application of the algorithm for calculating availability, few network models were analysed and the impact of failures and repair time of network elements, different network configurations and the application of protection methods on the overall availability of the network were considered.

The objective of the presented research is to model and analyse the availability of a network with the use of protection method and the introduction of additional parameters which describe a cable network construction method. The parameters are classified and evaluated through reviewing the existing communication networks, i.e. through different options of setting optical cables. The model determines the influence of the parameters of availability of individual system components on the overall availability of the network. This achieves for the mathematical model to come closer to the real situation in the network and a more accurate assessment of availability, which is proven by comparing the results of the calculation of availability for idealised and real network models.

The proposed model is heuristic because in practice we accept ‘good enough’ solutions which can be found quickly without expensive, sophisticated tools and software solutions. With heuristic model it is possible to calculate the availability of individual components and the whole network, to determine the impact of the availability of individual components on the system availability, to determine optimal ways of connecting and protection methods, and thereby to contribute to the overall reliability of ship systems and a ship as a whole.

2. Ship optical communication network

Modern ships are highly complex technical systems. They consist of major units, such as ship controlling system, propulsion system, power supply, and cargo handling system. All of these must operate properly and reliably for an efficient operation of a ship. The ship communications network is the essential part in management and control of the whole system. All components of the system are integrated with a communications network [2, 3 and 4].

In this paper, as a reference network we use the optical communication network on a passenger RO-RO ship or ferryboat. Optical communications network is used in a ship operation system for the transmission of information and measurement data required for the management and control of engine operation.

Because of its application, topology, construction methods, and built-in cables and devices, the described reference network can serve as a model for communication networks and other types of ship systems. This is possible due to the fact that optical signals transmission, transmission media, optical fibres and optical transceivers do not differ according to the type of application or end-devices which are connected with this network.

The ferryboat has got 4 master and 3 auxiliary engines. The communication network is designed for transferring information from the processors of the master and auxiliary engines into the main processor, which is located in the forward wheel-house.

Processors collect and process the measurement data from the engines (engines turns and temperature), and transfers them via electric connections to the optical line module (OLM). In the OLM, the electrical signal transfers into optical signal and the signals from all optical modules are transferred to the main processor through optical fibres (Fig. 1).

360 meters of Low-Smoke Zero Halogen (LSZH) fibre optic cable with 4 multi mode fibres of 50/125 μm diameter and 11 OLMs was built in the presented communication network of the ferryboat.

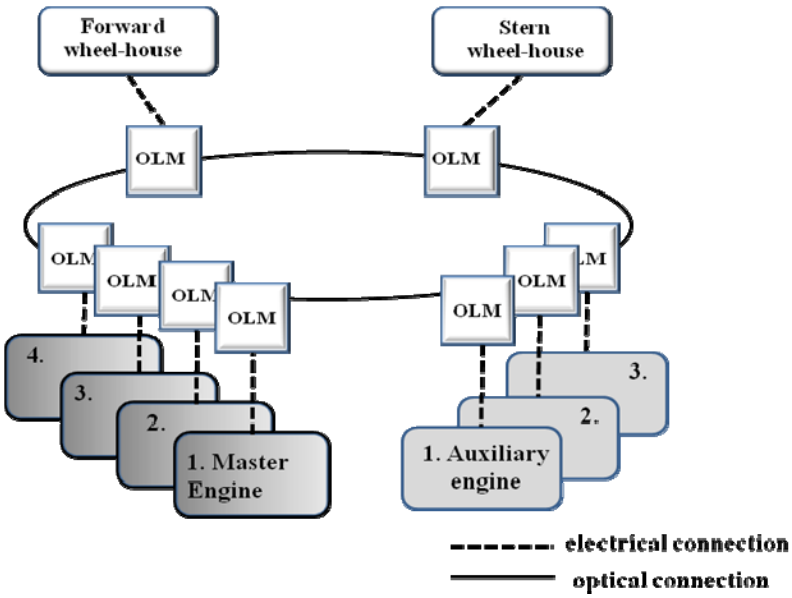

Fig. 1 Optical communication network for controlling ship engines

The basic components of ship optical communication networks are optical line modules, optical cables, and connecting materials (connectors, mechanical splices, panels for connecting cables). The OLM is used for converting electrical values into optical signals, and connecting several identical modules into a communication network with an optical cable. A complete network can be built with modules in line, star or ring topology. Each module has two or three mutually independent ports, which in turn consist of transmitting and a receiving component. In the presented ferryboat communication network, the optical line module has got one electrical and two optical inputs. They contain a LED as an optical source, which supports work at 660 nm, 860 nm and 1310 nm. The fibre types that can be used for signal transmission are standard glass fibres of 10/125, 50/125 and 62.5/125 μm diameters, polymer cladded fibres of 200/230 µm, and plastic optical fibres of 980/1000 µm. Standard OLM support data rates from 9.6 kb/s to 12 Mb/s. [5]

If we consider the reliability and availability of the network is certainly the best line modules connected in a ring topology (Fig. 2). An interruption of one or both optical fibres between two modules is detected by the OLM and the ring is transformed into an optical line. If one module fails only those terminals connected to this module are uncoupled from the ring. The remainder of the network itself continues to function as a line.

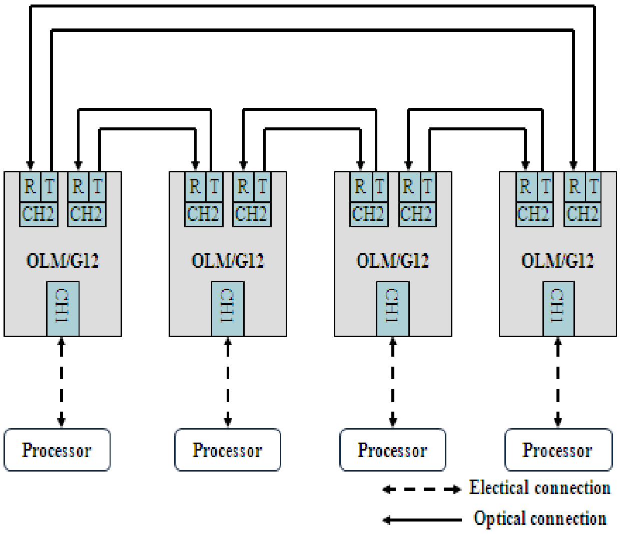

Fig. 2 Topology of the optical communication network for controlling the ship engines

Ship cables are grouped depending on their use and characteristics. Maximum lengths of cables installed on a ship for energy and signal cables range from 150 to over 250 kilometres. Telecommunication cables are mostly copper or coaxial. They can be replaced with optical fibres and thus, apart from increasing transmission capacity and reliability of the connection, they reduce the volume and weight of the cable for as much as 90% when compared to conventional copper cables. The optical cables are applied on the ship and offshore platforms because of their mechanically enhanced construction and signal transmission advantages over cooper cables. The following fibre cable construction for use in harsh environments is recommended: heavy-duty, low-smoke emission, zero-halogen, flame-retardant, and fire-resistant. Thermoplastic UV-resistant sheath insures overall maximum flexibility, oil and chemical resistance. The cable capacity is commonly from 2 to 48 single-mode or multi-mode fibres. [6, 7, 8] Optical, transmission and construction characteristics of the optical fibres are in accordance with ITU-T Recommendations. [9, 10]

On ships, the optical cables, along with the other electrical installations, are laid in metal carriers called cable paths (Fig. 3). The cables are in bundles, so called cable packages, laid without any additional protection. Typically, there are two main cable paths: the vertical path (linking superstructure and engine room) and the forward path (linking the bow and engine room) (Fig. 4).

Based on the cable book, which contains alpha-numeric list of cables, cable paths position schemes and cable plan, so-called cable packages are created, according to which cables are cut into appropriate lengths. After cutting, the cables are rolled on the reels in order reverse to deployment in the cable path. Deployment the cables in the cable paths is performed by unwinding the cable reels and stretching the cables in the cable path. Cables are not previously terminated on optical connectors, due to the inability of going through very limited spaces, and the connectors are made after the cables are pulled, at positions of OLMs mounting.

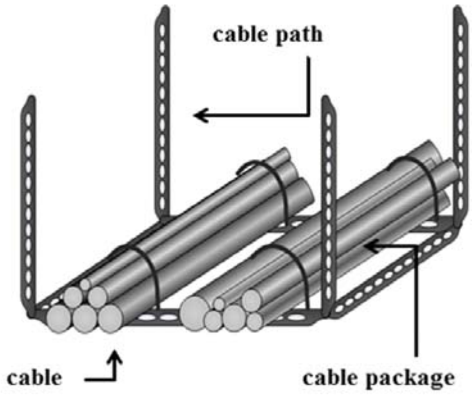

Fig. 2 Laying of cables in a cable path

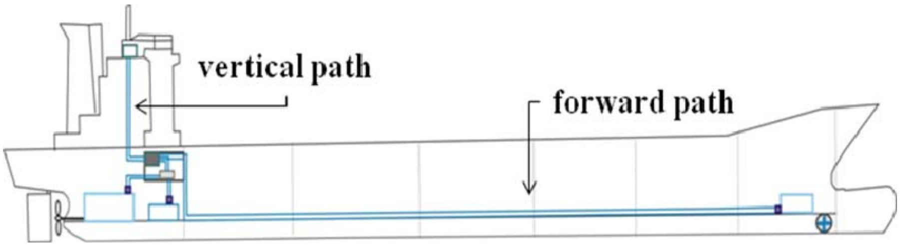

Fig. 4 Cable paths on a ship

3. Availability model of ship optical communication network

The availability of an optical communication network significantly influences the availability of complex technical systems, such as ship systems. Mathematical modelling of network availability significantly helps in inspecting the effectiveness of the proposed network architecture, in determining the availability of individual components and the whole system. Except for the fact that the models can show the planned state, the possibility of showing the real situation and thereby the possibility of predicting failures and identifying potential "weak links" in the network are of the utmost importance. A prerequisite for the creation of a realistic model of network availability is the analysis of network's behaviour when a failure occurs, as well as the detecting and evaluation of factors that affect the risk of failures.

In order to show the impact of cable path configuration on the overall network availability, we introduce new parameters called 'impact factors' in the availability calculation.

New method of calculating availability, which includes impact factors, achieves for the mathematical model to come closer to the real situation in the network and a more accurate assessment of availability.

Common method for calculating availability, mostly for telecom networks applications, is described in [11, 12].

The availability analysis is based on the reliability data of the elements of the system under consideration. These are failure rate λ, repair rate μ, mean time to repair *MTTR*, mean time to failure *MTTF*, and mean down time *MDT* [13, 14].

Failure rate λ is expressed in FITs (where 1 FIT represents one failure in period t=10^9 hours) and *MTTR* is expressed in hours.

Availability *A(t)* is defined as:

Availability is the probability of the system being found in the operating state at some time t in the future given that the system started in the operating state at time t=0. Failures and down states occur but maintenance or repair actions always return the system to an operating state.

$$\mu = \frac{1}{MTTR} \tag{1}$$

$$\lambda = \frac{1}{MTTF} \tag{2}$$

The term of unavailability *U* is the probabilistic complement to availability:

$$U = 1 - A \tag{3}$$

When describing system characteristics, unavailability is often presented as a mean time when the system is not working, i.e. mean down time *MDT*, and is expressed in hours per year (h/y).

$$MDT = 365 \cdot 24 \cdot U \tag{4}$$

In this paper we use data on ship network failures derived from practice, i.e. from shippers and companies which install and service ship electronic devices. The values of λ and *MTTR* for cables and OLMs are listed in Table 1, and apply to ships not older than 5 years.

Table 1 Availability data

	λ (FIT)	*MTTR* (hours)
Optical cable	500	10
OLM	2000	2

We will present the availability calculations for connections without path protection and for connections with the path protection.

In the model of network without path protection the elements of ship communication network (cable sections and OLMs) are connected in a series (Fig.5).

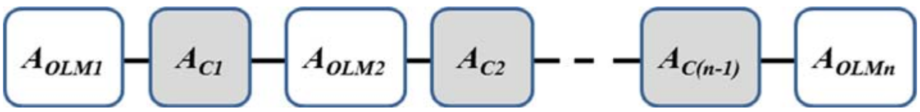

Fig. 5 Availability model for serial structure with *n* OLM elements and *(n-1)* cable sections

The availability of the non-redundant system (A_s) is calculated as a product of all individual availabilities, according to the formula (5), where A_{OLM} is the availability of OLM, and A_C is the availability of optical cable.

$$A_s = A_{OLM}^n \prod_{i=1}^{(n-1)} A_{C_i} \tag{5}$$

For the system with path protection, consisting of working and protection paths, the usual representation is the one with the elements in a parallel structure (Figure 6). In the presented configuration, protection path consists only of a cable section.

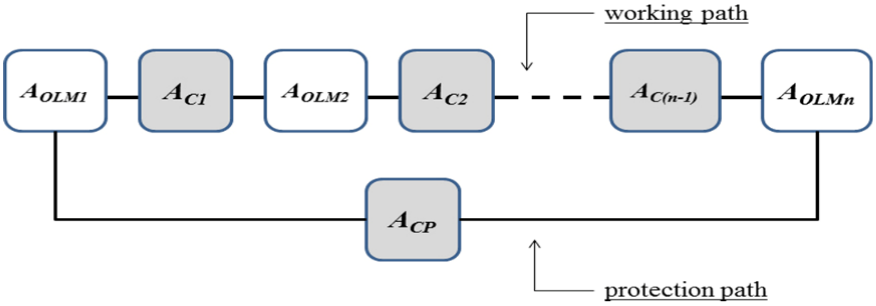

Fig. 6 Availability model for parallel structure with working and protection paths

For the given parallel structure (Fig. 6), the availability (A_{pp}) is calculated according to (6), where A_w is the availability of working path and A_p the availability of protection path.

$$A_{pp} = A_w + A_p - A_w A_p \quad (6)$$

Basically, the working and protection path consist of *n* OLM elements and (*n-1*) cable sections which are connected in series. The availability of A_w and A_p for the example of a ship network is calculated according to formula (5), and the protection path contains only the cable component. We used basic concept of availability calculation described in [13, 14] and also the definitions for unavailability and mean down time.

To prove the justification of introducing the protection strategy through the application of working and spare cable paths, according to equations (3-6), first the *MDT* will be calculated for the reference example of a ferryboat network without protection and for the network with working and protection paths, with the input data from Table 1.

The obtained results show that *MDT* for an unprotected network is 13.52 h/y, and *MDT* for a network with path protection is 0.02 h/y. The resulting difference in *MDT* of as much as 13.5 h/y justifies the designing and installation of multiple cable paths and laying the working and protection cable in separate cable paths.

The application of a path protection strategy significantly improves the overall availability of a communication network. Further calculation of availability will therefore be based on the application of path protection, according to Figure 6.

By analysing the database on failures of a real network with the use of path protected strategy, we have concluded that the duration of failures depends on the mode of construction and arrangement of working and protection optical fibres in cables, cable packages and cable paths. We have presented that dependence through the classification and numerical evaluation of impact factors and a new method of calculating availability. Based on the analysis of cable routes, we have discerned a division into four basic possibilities, on which working and protection fibres are distributed in cables, packages and cable paths. This also matches the description of the impact factors (IF) f_1- f_4 (see Tab. 2). Each cable section in the network is described with only one impact factor.

Table 2 Impact factors / cable path configuration

IF_n	Description of impact factors / cable path configuration	$MTTR_n$ (hours)	Impact Factors Amount
f_1	Working and protection fibres in one cable	72	7.2
f_2	Working and protection fibres in separate cables in the same cable package	58	5.8
f_3	Working and protection fibres in separate cables and cable packages in the same cable path	36	3.6

f_4	Working and protection fibres in separate cable paths	10	1

The practice confirms the mathematical calculation, showing that availability is the highest in the case of a completely physically separated working and protection paths. For that ideal case, the impact factor f_4=1. The numerical values of impact factors are calculated by (7) for n=1 to n=4 and $MTTR_4$=10 hours. Numerical values for $MTTR_n$ are derived from practice.

$$f_n = \frac{MTTR_n}{MTTR_4} \tag{7}$$

The previous results of the ship network availability analysis and the implementation of protection cable paths showed that the path protection significantly increases the overall availability of the network. The effect on the mean down time (*MDT*) of the failure rate λ for cables and OLMs have been analysed in [13, 14]. It was established that the failure rate of optical line modules has insignificant impact on *MDT*, and that the cable section has a much more significant impact on availability. The interruptions of cables have the greatest impact on the availability of the entire network. Therefore, it is important to always have an updated database of failures and to record the location, causes, types, and durations of failures.

The new method of calculating network availability introduces the application of new impact factors, based on the analysis of failures in real ship communications networks.

When calculating *A* and *MDT* for unprotected connection and with path protection, we set the input assumptions that all optical line modules and all cable sections have the same technical and structural characteristics.

The availability of a single cable path (*Acp*), which consists of *n* cable sections of different lengths *L*, taking into account the impact factors in individual cable sections, is calculated by (8) as:

$$A_{cp} = 1 - \left\{ \sum_{i=1}^{n} \left(L_i \lambda_c \frac{MTTR_c}{10^9} IF_n \right) \right\} \tag{8}$$

where: L – cable section length in meters, λ_C – cable failure rate, $MTTR_c$ - cable mean time to repair, IF_n – impact factor $f_1 - f_4$ amount.

4. The algorithm for calculating the ship optical communication network availability

A novel algorithm has been developed in which, besides the standard expressions for availability calculation, a new method which contains impact factors, is also incorporated. The algorithm serves for calculating the availability and finding the optimal paths in a network. It also allows the calculation of signal attenuation for all possible paths in the network. The algorithm can be applied to any network topology and can calculate the availability of individual paths in the network, as well as find the optimal working and protection paths according to previously selected criteria. The criteria for the selection of working and protection paths can, for example, be the maximum availability, the minimum path length, the minimum number of cable sections, the selection of paths with cable sections having certain impact factors, etc. The user defines numerical values of the input parameters (failure rates, mean time to repair, impact factors) based on the failure analysis for the observed network. This allows the use of availability calculation programs for networks of different structure, size and construction type. The basic function for availability and protection paths calculation is described in a pseudo code (Figure 7).

A. A pseudo code for the availability calculation function

```
    /*basic function for availability calculation for possible
backup path. The function is called in a loop, for all previously
determined paths from source to destination nodes. The
function also calculates attenuation of the light signal for a
chosen path.
    Parameters: idPath – id of the path (e.g. id of a record from
database or a pointer to a record in an array); idWorkPath – id
of a path previously marked as the work path (e.g. a path with
greatest availability).
    Notice: all valid paths from all start to all end points are
calculated by recursively traversing all possible connections
between links (with cyclic path protection)*/
function calculateAvailability(idPath, idWorkPath)
  begin
          /*calculation of OLM unavailability*/
          numberOfOLMs = sum_of_path_links +1
          OLMunavailability = numberOfOLMs *
OLM_availability * (OLM_MTTR / 1000000000);

          /*path availability calculation */
    linkUnavailabilitySameCable =
    sum (link_length * cable_lamda *
(cable_MTTR/1000000000) * factor_1)
    from path_links
    where id_path_link = idPath
    and path_links are in same cable as (path_links where
id_path_link = idWorkPath)
    linkUnavailabilitySamePackage =
    sum (link_length * cable_lambda * (cable_MTTR
/1000000000) * factor_2)
   from path_links
    where id_path_link = idPath
    and path_links are in same package as (path_links where
id_path_link = idWorkPath)
          and path_links are not in same cable as (path_links
where id_path_link = idWorkPath)
    linkUnavailabilitySamePathway =
          sum (link_length * cable_lambda * (cable_MTTR
/1000000000) * factor_3)
   from path_links
    where id_path_link = idPath
    and path_links are in same path as (path_links where
id_path_link = idWorkPath)
          and path_links are not in same package as (path_links
where id_path_link = idWorkPath)
          and path_links are not in same cable as (path_links
where id_path_link = idWorkPath)
    linkUnavailabilityDifferentPath =
          sum (link_length * cable_lambda * (cable_MTTR
/1000000000) * factor_4)
   from path_links
    where id_path_link = idPath
   and path_links are not in same path as (path_links where
id_path_link = idWorkPath)
          and path_links are not in same package as (path_links
where id_path_link = idWorkPath)
          and path_links are not in same cable as (path_links
where id_path_link = idWorkPath)
          /*total availability is calculated by subtracting sum of
unavailability from 1 (100%) */
    availability = 1 - linkUnavailabilitySameCable -
linkUnavailabilitySamePackage - linkUnavailabilitySamePath
- linkUnavailabilityDifferentPath
    return availability;
  end function
```

B. A pseudo code for the best backup path determination function

```
    /*function which traverses all determined (calculated) paths
from source to destination nodes. Function determines best
backup path and total availability of work and backup path.*/

function calculateAvailabilities()
  begin
          idBackupPath = 0
          backupPathAvailability = 0
    /*getting determined (calculated) work path*/
    idWorkPath = (get id_path from project_paths where
project_path is marked as workpath)
    /*if backup path is not defined, go through all paths and
find the most appropriate one */
    if (get id_path into idBackupPath where project_path is
marked as backup_path) not exists then
      loop
      (get id_path into idPath where project_path is not marked
as workpath)
        tempAvailability = (call calculateAvailability(idPath,
idWorkPath))
        save tempAvailability (idPath as key) into
availability_array
          /*saving into array for result display for example*/
        if tempAvailability greather than backupPathAvailability
then
          backupPathAvailability = tempAvailability
          idBackupPath = idPath
        end if
      end loop
    else
      /*if the backup path is already determined, calculate its
availability */
                    backupPathAvailability = (call
calculateAvailability(idBackupPath, idWorkPath))
   end if
    /*Availability of the workpath is calculated by switching
positions for calculateAvailability function. Finally, we
determine total availability*/
    workPathAvailability = (call
calculateAvailability(idWorkPath, idBackupPath))
    availabilityTotal = (workPathAvailability +
backupPathAvailability) -(workPathAvailability *
backupPathAvailability)
  end function
```

Fig. 7 A pseudo code for the basic function for availability and protection paths calculation

The algorithm consists of the following steps:

1) Defining source and destination nodes.
2) Finding all possible paths between source and destination nodes.
3) Calculating the availability for all the paths with standard availability data (λ, *MTTR*, cable section length), also including the new parameters (impact factors). These results are stored in a database.
4) Defining the working and protection paths according to the previously defined criteria.
5) Calculating the total availability for the connection with the implementation of path protection.
6) Calculating the total attenuation for all cable paths in the network.

The results obtained using the described algorithm are: individual values of working and protection path availability and the availability of all other paths in the network, the total availability of the network with path protection with the printout of all cable sections in the network and the associated paths, and signal attenuation values on all cable paths in the network.

5. Network availability models

The network availability models are based on the network failure analysis of real communication networks and calculating availability with the introduction of impact factors. To calculate the availability, we used expressions (1-8), as well as the values of failure rate and the mean time to repair optical line modules and optical cables from Table 1.

All the models are made with following assumptions: OLMs, optical fibres and cables, as well as the connection material have the same construction and transmission characteristics; each element in the block diagram of availability has two states: operating state and failure state. The duration of components working without experiencing failure and repair time are statistically independent; each element of the system works until it experiences failure; when the system experiences failures, it is led into working condition with the help of repairs and the errors which occurred when the system was in the state of failure are not considered; the repaired element is considered to be ‘as good as new’; the availability of the team and spare parts required for the repair is unlimited.

Model 1

In Model 1, we observe effect of the protection path length on the overall availability and *MDT*. The network structure consists of working and protective cable routes. Working path is 300 meters long and the length of protection path length varies from 0 up to 300 m. Ten OLMs are mounted in the working path.

MDT is significantly reduced when the strategy of path protection is applied, even as much as 13.5 hours per year (Fig. 8). The difference in the amount of MDT_{uk} when increasing protective route from 10 to 300 meters is negligible, only 1.2 minutes per year. Such a result justifies the need for planning and construction of protective paths, which are completely physically separated from the working paths and form a network with a parallel structure.

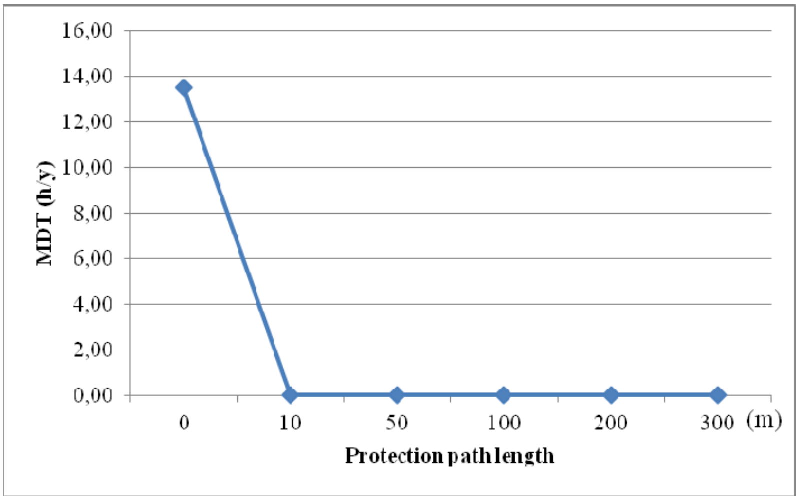

Fig. 8 *MDT* vs. Protection path length

Model 2

In Model 2 we observe parallel network structure with working and protection paths of equal length of 300 meters. Ten OLMs are mounted in the working path. To determine the influence of numerical values of impact factors $f_1 - f_4$ on the overall availability and mean down time, we change the values of IF_n by a factor of 0.1 to 10. A parameter variation factor labelled 1 in Fig. 9 represents the values of IF_n in Table 2.

The diagram in Fig. 9 shows a significant increase in *MDT* when the values of impact factors f_1, f_2, f_3 and f_4 are increased by 10 times. In relation to the values of IF_n obtained by analysing *MTTR* of a real network, the increases of *MDT* are 100 times. On the other hand, if the value of impact factor is decreased by 10 times in relation to the nominal value, the differences of 1 hour to 1 minute per year occur.

The results also show significantly lower values of *MDT*-f_4 in relation to *MDT* for other three impact factors. Reducing and increasing the amount of f_4 of 10 times change *MDT*-f_4 for only 2 hours a year. This means that if the time to repair increases 10 times and the network have a protection path, *MDT* will not increase significantly.

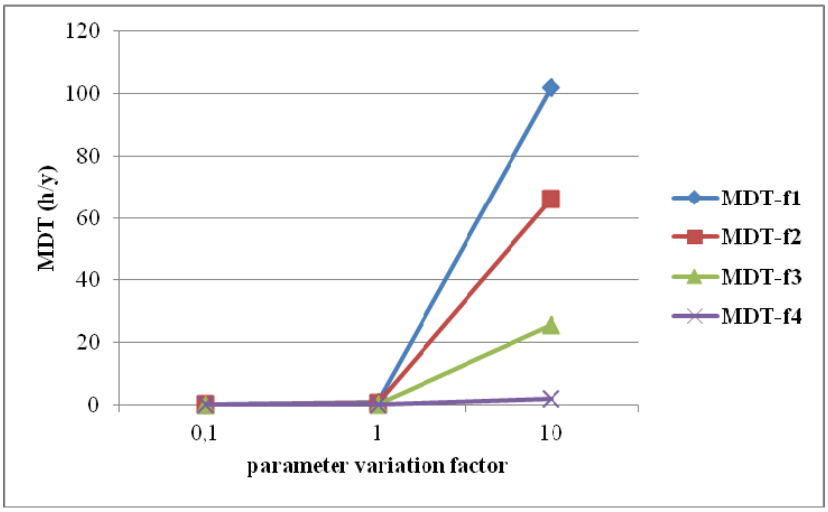

Fig. 9 *MDT* vs. IF_n parameter variation factor

Model 3

Typical constructions of ships' communication networks are done with connecting the optical line modules in a serial structure shown in Figure 5.

In this model, we compare the cases with parallel structure with working and protecting path and double OLMs. In case **a)** ten OLMs are connected to a 300 m long working cable connection and the protection path is also 300 meters long. In case **b)** we observe the working and protection cable route of equal lengths of 300 m, and in each route 10 OLMs are mounted. In case **a)** only the cable segment is doubled, while in case **b)** both cable and the device segment of the network are doubled.

The results of calculations show negligibly small change of *MDT* with the doubling of optical line devices (Fig. 10). However, we also noticed the improvement of *MDT* with impact factor f_4, which represents completely physically separated working and protection paths. Such a result shows the dominant impact of the cable segment on the network availability.

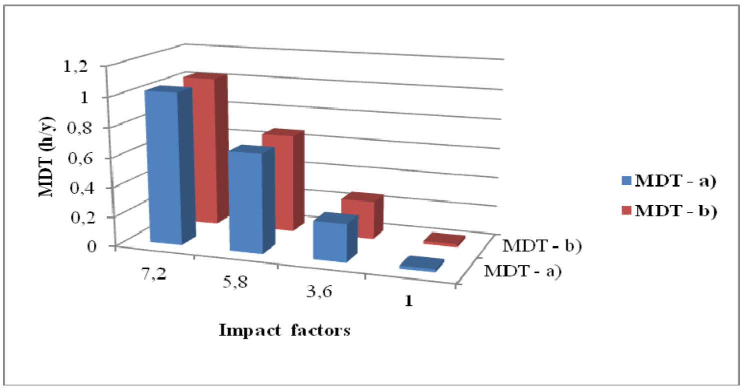

Fig. 10 The comparison of the calculation of *MDT* with the equipment doubling

Model 4

Model 4 describes a specific example of the use of communication network for controlling the bow thruster. The OLMs are placed on the bow thruster, the main control desk in the engine room and the master bridge (Fig. 11). The vertical path is 40 m long, and the forward path is 150 m long. In this model, three cases of network configuration are observed: with no protection, with path protection with working and protection fibres in separate cable paths and the OLMs connected in the working path, and with path protection with installation of OLMs in the working and protection paths. In both cases of the use of path protection, working and protection paths are of the same length of 190 m.

The results of calculations of *MDT* for Model 4 show the difference of $MDT_{unprotected}$, and both cases $MDT_{path\ protected}$ and $MDT_{doubling}$ of 8 hours per year (Fig. 12). The difference between $MDT_{path\ protected}$ and $MDT_{doubling}$ is negligible, which confirms the unprofitability of installing dual optical line modules.

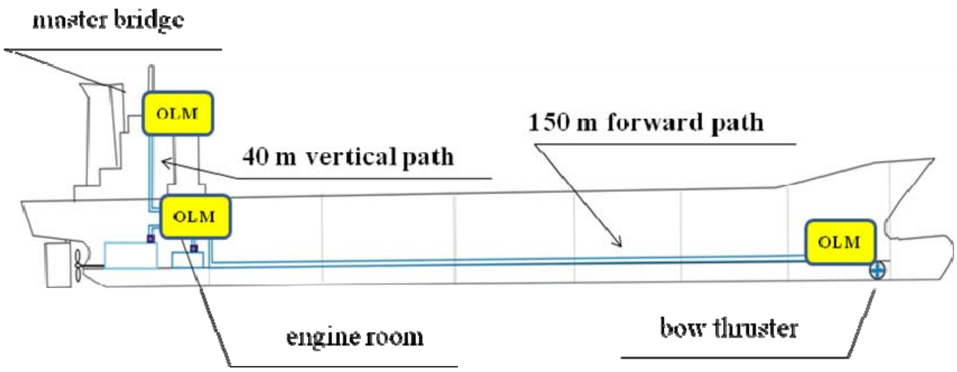

Fig. 11 Communication network for controlling the bow thrusters

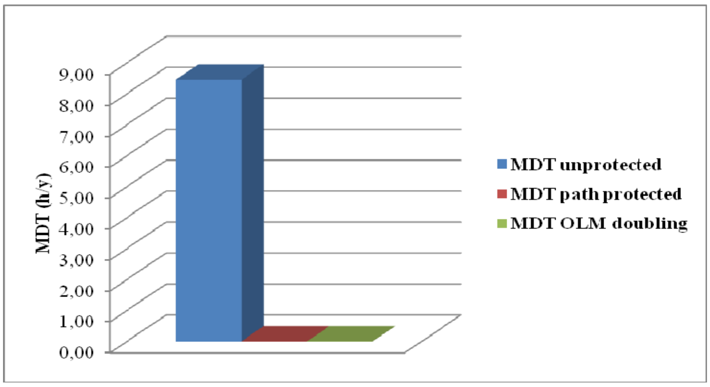

Fig. 12 The results of *MDT* calculation for Model 4

6. Conclusion

This paper presents optical communication network for connecting ship systems and the mathematical model of network availability. With a new method of calculating availability, which includes impact factors, and with the application of methods for increasing the resilience of a network, the availability of different network topologies was analysed. In addition to the standard parameters required for the calculation of availability, additional factors that affect the overall availability based on the method network construction were defined and evaluated. The introduction of impact factors contributes to the fact of the mathematical model coming closer to the realistic network and thus to a better and more accurate calculation of network availability.

A prerequisite for creating a realistic model of network availability is the analysis of network behaviour in the case of a failure, as well as the detection and evaluation of factors that influence the risk of failures. This has been done by using data on a ship network failures derived from practice, i.e. from the shipping companies and the companies that install and service ship electronic devices, and this refers to ships not more than 5 years old. This has accomplished one of the paper’s goals, which is to create real database necessary for further academic research, by linking data from the practice with current research in the field of the resilience of optical networks.

The paper describes the mathematical model of availability with the use of protection methods for increasing the resilience of the network. The results of calculating the availability of a network with and without protection paths were compared. The results showed that the application of path protection significantly increases the overall availability of a network.

The analysis of reported failures on optical communication networks constructed using optical technology on ships found that the mean time to repair depends on the method of cable network configuration. Based on this, four basic ways of cable configuration were defined and evaluated, as well as the ways to distribute working and protection fibres in cables, cable packages and cable paths. Also, mean time failure rate for each case was calculated. Specific conditions incurred in the construction of cable networks which have working and protection paths match the description of impact factors.

In order to show the impact of the configuration of cable paths on the overall availability of a network, new parameters called ‘impact factors’ have been introduced into the calculation of availability. The results of availability calculation with the inclusion of impact factors show that the method of cable paths construction and cable laying, as well as the selection of working and protection fibres also affect the overall availability of a network. Based on the results it is evident that in order to increase network availability one should take into account the construction of cable paths as early as in the design phase, and the proposed method of protecting cable paths with redundant paths. Also, a complete physical separation of working and protection fibres would significantly contribute to the overall reliability of ship networks.

By using the novel algorithm for availability calculation, several network models were analysed. Through these models, the influence of the application of protection route was shown, as well as the changes in values of impact factors, doubling of optical line modules and cables, and the impact of different lengths of a cable network on the overall availability of connections.

The current technology of ship communication networks construction, as well as their availability calculation, can be improved by applying the model presented in this paper, both when designing new networks or when analysing the existing ones.

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