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The radio operator decision support system model

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Abstract

The article proposes a model of the system supporting the decision-making process relating to the radio operator on board a ship after a distress alert is received by a Digital Selective Calling (DSC) controller working on VHF channel 70. The model is aimed at the implementation into the system of radiocommunication event management. The system takes into account the existing Radio Regulations. The model makes use of Petri nets, which are elements of graph theory. The time domain is comprised in the developed graph, and the states (places) and transitions capable of autonomous functioning are separated, as are those places and transitions requiring direct operator action based on empirical knowledge.

Introduction

The main function of the Global Maritime Distress and Safety System (GMDSS) is transmitting signals from ships in distress to coastal radio stations and Rescue Coordination Centres (RCC) (Czajkowski, 2002; SOLAS, 2009; Uriasz & Majzner; 2013). The system is composed of 10 subsystems:

1. Digital Selective Calling (DSC);
2. Radiotelephone in the VHF band;
3. Radiotelephone in the MF/HF band;
4. NBDP;
5. Inmarsat;
6. Cospas-Sarsat;
7. Navtex;
8. SART;
9. MSI;
10. EPIRB.

DSC is the principal subsystem, which allows:

- sending ship-to-shore and ship-to-ship alerts;
- initiating urgency and safety messages, subsequently broadcast via radiotelephone;
- establishing routine ship-to-ship and ship-to-shore communications.

Alarming by DSC is simple for operators. Problems arise when a ship on a sea voyage receives an alarm on its DSC controller from another vessel in distress. In such as case, the procedure after the receipt of a distress alert is defined by the Radio Regulations (RR). Despite the full operation of the GMDSS system for over 18 years, the interpretation of regulations in practice, particularly under stress, may result in operator errors that will lead to a delay in, or even the failure of, effective search and rescue operations by marine rescue services.

It has been indicated in articles (Lisaj & Majzner, 2014; Majzner & Mąka, 2014; Lisaj, Majzner & Maka, 2015) that it is purposeful to develop a Radiocommunication Events Management System (REMS) at sea. One major component of such a system would be a radio operator decision support system.

Characteristics of DSC VHF

Maritime VHF comprises the 156–174 MHz band. The band is divided into channels, of which the most important are:

- Channel 70 – designed for DSC, and the only DSC channel in this band;
- Channel 16 – designed for distress, urgency and safety radiotelephone communications.

In theory, the range of ultra short waves is restricted to line-of-sight. In practice, however, it is much larger, thanks to the tropospheric refraction and diffraction. The range of V-band communications (in nautical miles) is expressed by means of the following equation (Czajkowski, 2002):

$$D = 2.5\left(\sqrt{h} + \sqrt{H}\right) \tag{1}$$

where:

h – height of the transmitting antenna;
H – height of the receiving antenna;
V – band communication range modelling consists of the determination of a circle of radius and D.

The basic information unit in the DSC is a word consisting of 10 bits, of which the first seven are information, and the last three represent the number of zeroes found in the information. The information part may contain numeric values in the 0–127 range. The values 0 to 99 are interpreted as numbers, e.g. Maritime Mobile Service Identity (MMSI) number, coded position, etc., whereas values from 100 to 127 have special meaning depending on their position in the message.

The distress alert of DSC consists of 12 elements:

- dot pattern;
- phasing signal;
- format specifier;
- address;
- category;
- self-identification (MMSI number of the ship);
- message 1 – the nature of distress;
- message 2 – the position of a ship in distress;
- message 3 – the time of the position of a ship in distress;
- message 4 – the kind of communication after sending the distress alert;
- end of sequence;
- error check symbol.

A DSC message is repeated twice with 33.(3) ms delay and the whole distress alert is sent within approximately 0.5 seconds. The message contains information automatically appended by the controller connected to a VHF radiotelephone and a system providing a ship's position, but may also contain information specified by the operator, such as the nature of distress, and an updated position.

The Radio Regulations

The procedures for emergency situations and for such events as the reception of a message from a ship in distress are set forth in the RR (Salmonowicz, 2001).

The operator of a vessel in distress, after sending a distress alert by DSC VHF controller in automatic or extended mode, prepares for communication by switching to radiotelephone channel 16; this may also be done automatically, as in most of today's ships. The DSC controller will automatically send an alarm at approximately 4-minute intervals containing all the items listed above, until receiving acknowledgement from the coast station. Such acknowledgement should be sent by the coast station immediately upon receipt. The acknowledgement is addressed to all ships and should not be sent by an operator of another ship. Next, the operator on the ship in distress may send a distress message via a radiotelephone as defined by the RR (COMSAR.1 Circ 45). Currently the RR define only the

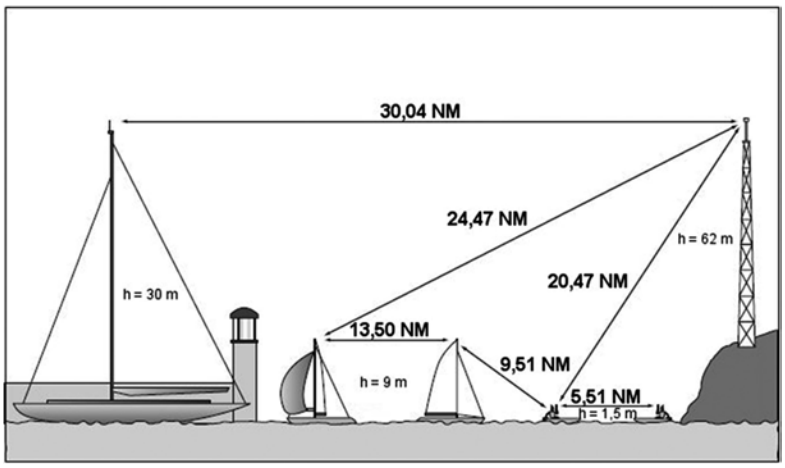

Figure 1. Ranges of VHF band frequencies as a function of the height of the antenna (EGMDSS, 2017)

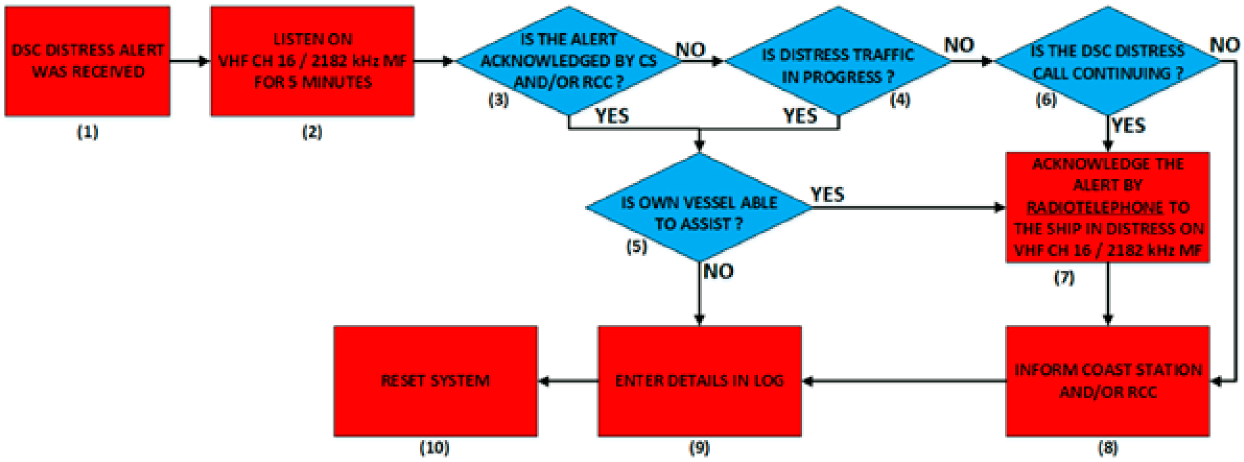

Figure 2. A flow chart of a radio operator's actions after a DSC VHF distress alert receipt (ITU-R M.541, 2004, (Annex 3) flow diagram 1)

form of further communication between the participants in the rescue operation, the form of imposing silencing on stations which interfere with the traffic, and the form of finishing radio silence. The actions of the rescue operation participants are determined by the existing situation and IAMSAR regulations (IAMSAR, 2001).

In a distress situation, the behaviour of radio operators on ships in the vicinity is of particular importance after they receive a DSC VHF distress alert. The operational procedures are set forth in *ITU-R M. 541 (Annex 3)*, illustrated in Figure 2.

This procedure is the same for the receipt of a distress alert by a DSC in the VHF and in MF bands.

The operator on the ship, after receiving a DSC VHF distress alert (block 1 in Figure 2), should get ready for distress communication by ensuring sure that VHF channel 16 is switched on with the noise reduction disabled (block 2, Figure 2). Then the operator should wait for a maximum of five minutes. In the meantime, s/he will check:

- if any coast station has acknowledged the alert to the ship in distress via DSC (block 3, Figure 2); or
- if any distress traffic can be heard (block 4, Figure 2).

An affirmative answer to any of the two checks creates a situation in which the radio operator should assess the possibility of providing effective assistance to the ship in distress (block 5, Figure 2). If the assessment by the ship's captain, watch officer or radio operator is positive, i.e. the ship receiving the distress alert is able to provide effective assistance to the ship in distress and its crew, the ship acknowledges receipt of the alert in line with the following form (block 7, Figure 2):

MAYDAY
Name, call sign, MMSI (if the initial alert is sent by DSC) of the ship in distress
This is
Name, call sign, or other identification of the ship which received the distress alert
Received
MAYDAY

In addition, radio operators should transmit to the ship in distress information on their present position, course and speed, and estimated time of arrival at the distress position. Then the radio operator should notify the nearest coast station of such communication events, enter the details of communications in the radio log and reset the system. In the radio space, the distress communication should continue, depending on the actions of rescue operation participants and IAMSAR regulations (IAMSAR, 2001).

If the assessment by the ship's captain, watch officer or radio operator is negative, i.e. the ship that received the distress alert is not able to provide effective assistance, the radio operator should only enter the details of communications in the radio log (block 9, Figure 2) and reset the system (block 10, Figure 2).

If after five minutes the DSC controller has not received acknowledgement of the distress alert sent by the coast station and the radio operator has not heard on channel 16 any distress message, but has again received a DSC distress alert (block 6, Figure 2), s/he should acknowledge receipt to the ship in distress (block 7, Figure 2), notify the coast station of the communication events, (block 8, Figure 2), enter the details of the communication in the radio log (block 9, Figure 2) and reset the system (block 10, Figure 2).

In a situation in which a distress alert has been received only once, the radio operator who received the alert should notify the coast of the communication events (block 8, Figure 2), enter the details of communications in the radio log (block 9, Figure 2) and reset the system (block 10, Figure 2).

According to the above description, the operator's conduct upon reception of a distress alert by means of the DSC controller is complex, and requires making quick and accurate decisions and the proficient operation of radio equipment in distress communications. Even small mistakes by the radio operator can result in interference with, or failure to carry out, the rescue operation.

A model of the decision-making process based on Petri nets

The decision process resulting from the binding procedure has been defined herein using the methods and tools typical of process exploration, Petri nets in particular (van der Aalst, 1998; 2013).

The Petri net (Jensen & Kristensen, 2009; Jensen & van der Aalst, 2009) is the five:

$$PM = (P, T, A, W, s_0),$$

where:

P – (finite) set of places;

T – (finite) set of transitions;

$A \subseteq P \times T \cup T \times P$ – set of arcs;

W: $A \rightarrow N$ – function of weights ascribing labels (natural numbers) to each arc;

s_0: $P \rightarrow {}^*N$ – function describing the initial marking, where $^*N$ is the set of non-negative integers, i.e. $N^* = N \cup \{0\}$.

It is assumed that for each net specified as above this condition is fulfilled:

$$P \cap T = \varnothing \;\&\; P \cup T \neq \varnothing.$$

In the process of modelling, we initially assumed that the individual components of the developed net are:

- places – states, individual actions essential for the process;
- transitions – changes of a state, completion of actions, decisions made;
- tokens and their location – information, representation of the status of the decision-making process referring to a specific distress situation;
- input – reception of a radio message (DSC and voice);
- output – completion of distress communications;
- state of a Petri net – set of actions taken at a given instant, representing the status of the decision-making process.

Denotations in Figure 3 represent, respectively:

- places:
  - p1 – received a DSC distress alert;
  - p2 – listening on VHF channel 16;
  - p3 – analysis of the possibility of coming to assistance;
  - p4 – acknowledgement to the sinking vessel;
  - p5 – notification of the coast station;
  - p6 – entry made in the radio log. Reset the system;
- transitions:
  - t1 – setting channel 16;
  - t2 – repeated receipt of a distress alert;
  - t3 – five minutes elapsed;
  - t4 – received acknowledgement from the coast station;
  - t5 – distress communication in progress;
  - t6 – commencement of rescue operation;
  - t7 – no rescue actions taken, continuing with the voyage;
  - t8 – acknowledgement sent to the ship;
  - t9 – notification sent to the coast station.

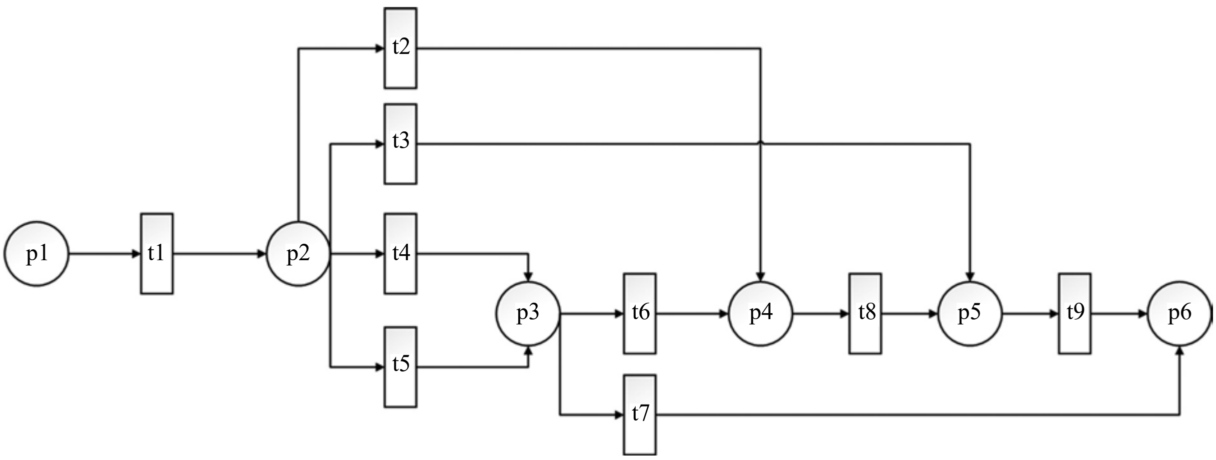

Figure 3. The Petri net – operator's actions after the receipt of a DSC VHF distress alert

This interpretation of the procedure diagram in Figure 2, presented in the form of a Petri net (Figure 3), reflects the correct course of action in the decision-making process after the receipt of a DSC VHF distress alert. The net presented in Figure 3 allows us to directly implement the application, an element of the REMS presented in the next chapter. In addition, the net model thus developed helps to isolate elements which indicate:

- actions carried out autonomously by the radiocommunication equipment, (col. 3, Table 1);
- elements of the decision-making process which currently require operator activity and may be executed in the newly developed REMS system (col. 4, Table 1);
- elements of the decision-making process which require direct actions to be taken by the operator (col. 5, Table 1).

Table 1 illustrates elements of the decision-making process from Figure 2, decomposed in the Petri net from Figure 3.

Table 1. Some decision process elements

No.	Block number in Figure 2	Radiocommunication units' autonomous actions	REMS' autonomous actions	Operator's actions
(1)	(2)	(3)	(4)	(5)
1	Block 1	p1		
2	Block 2	p2, t1		
3	Block 3		t4	
4	Block 4		t5	
5	Block 5			p3, t6
6	Block 6		t2, t3	
7	Block 7			p4, t8
8	Block 8			p5, t9
9	Block 9		p6, t7	
10	Block 10		p6, t7	

The above Petri net, however, does not provide the proper opportunities for proper analysis of the net in the time domain. It is necessary to adjust the net to a form in which places and tokens located in them will represent only statuses of the decision-making process and the termination of each action essential for the process. Transitions will be changes of the state, individual actions and decisions made (Figure 4).

Denotations in Figure 4 represent, respectively:

- places:
  - p1 – received a DSC distress alert, START;
  - p2, p3, p4, p5, p6, n – statuses of the decision-making process;
  - p8 – completion of the decision-making process. STOP;
- transitions (C – actions, D – decisions):
  - t1 – C: checking if channel 16 is set/setting channel 16;
  - t2 – C: start listening on channel 16;
  - t3 – C: repeated receipt of a distress alert;
  - t4 – C: five minutes elapsed (waiting);
  - t5 – C: received acknowledgement from a coast station;
  - t6 – C: distress communication in progress;
  - t7 – D: making a decision to provide assistance;
  - t8 – D: making a decision not to provide assistance and continue the voyage;
  - t9 – C: sending an acknowledgement to the ship in distress;
  - t10 – C: notification of the coast station;
  - t11 – C: entry in the LOG. Reset the system.

In the net thus defined, all time parameters are associated only with transitions. It is then much easier to analyse the whole process in the time domain, the basis for the presentation of the whole procedure in the form of an event-decision diagram. It is also a basis for planned research into the optimisation of the process in the time domain.

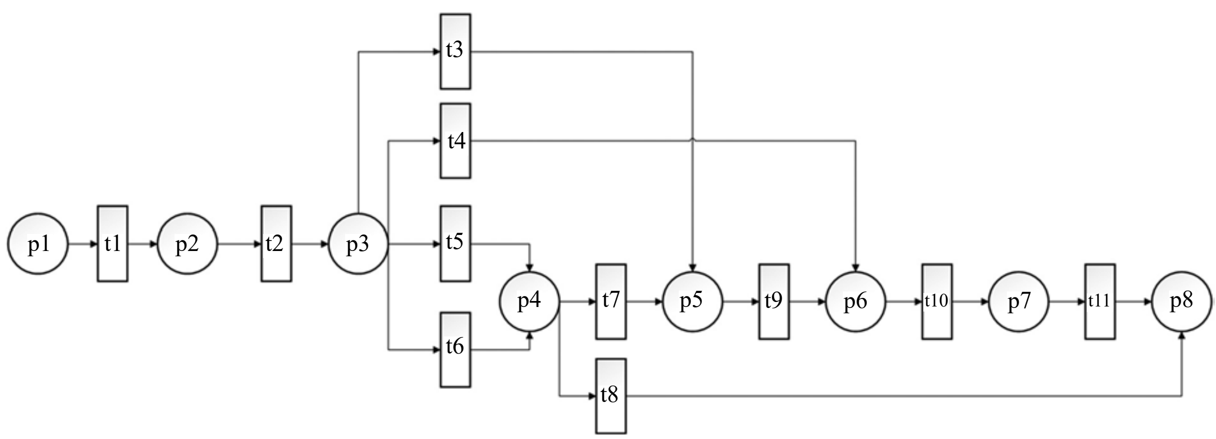

Figure 4. A modified Petri net

Implementation of the decision-making process model

Taking into account the binding procedure scheme (Figure 2) we have developed an application supporting the operator in making decisions on the ship. The application defines subsequent stages of the decision-making process, the scope of decisions and the decision-making procedures followed when assistance is provided in accordance with the RR. This requires defining the criteria, derived from the procedure, for the situation analysis and assessment, including the possibility of providing assistance to the ship in distress. The key steps in the process are the user's decisions – responses to system-generated questions concerning the course of action in the situation of providing assistance. To facilitate responses, apart from the questions generated by the system, the application presents a procedure diagram, as required by regulations, in the event of distress alert reception (Figure 5).

The data source for the REMS subsystem and subsequently generated event-decision diagram are streams of random events, related and not related to radiocommunication, internal and external.

The questions and suggestions for further actions, generated by the system, are displayed to the navigator in the proper sequence, making it easier for him or her to make an appropriate decision (Figure 6). Decisions and actions that the navigator/GMDSS operator has to take are marked with colours, in accordance with the procedure diagram (Figures 2 and 5).

The presentation and archiving of the decision-making process makes use of the event-decision diagram proposed previously in articles (Majzer & Mąka, 2014; Lisaj, Majzner & Mąka, 2015).The diagram presents and allows us to archive questions concerning necessary decisions, directed to the system operator, and the solutions developed by the REMS subsystem.

The process of creating the diagram shown in Figure 7 is based on the previously described Petri net and the fundamental procedure for actions after the receipt of a DSC VHF distress alert (Figure 2).

The diagram in Figure 7 illustrates a fragment of communication, in which the respective actions are as follows:

1. We receive on DSC VHF channel 70 an alert transmitted by a ship in distress.
2. We make a decision / answer the question: 'Is the alert acknowledged by the coast station?'.
3. We receive the distress alert acknowledgement sent by the coast station on VHF channel 70.
4. We receive a distress call and message sent subsequently by radiotelephone on VHF channel 16.
5. We receive a distress relay transmitted by the coast station by radiotelephone on VHF channel 16.

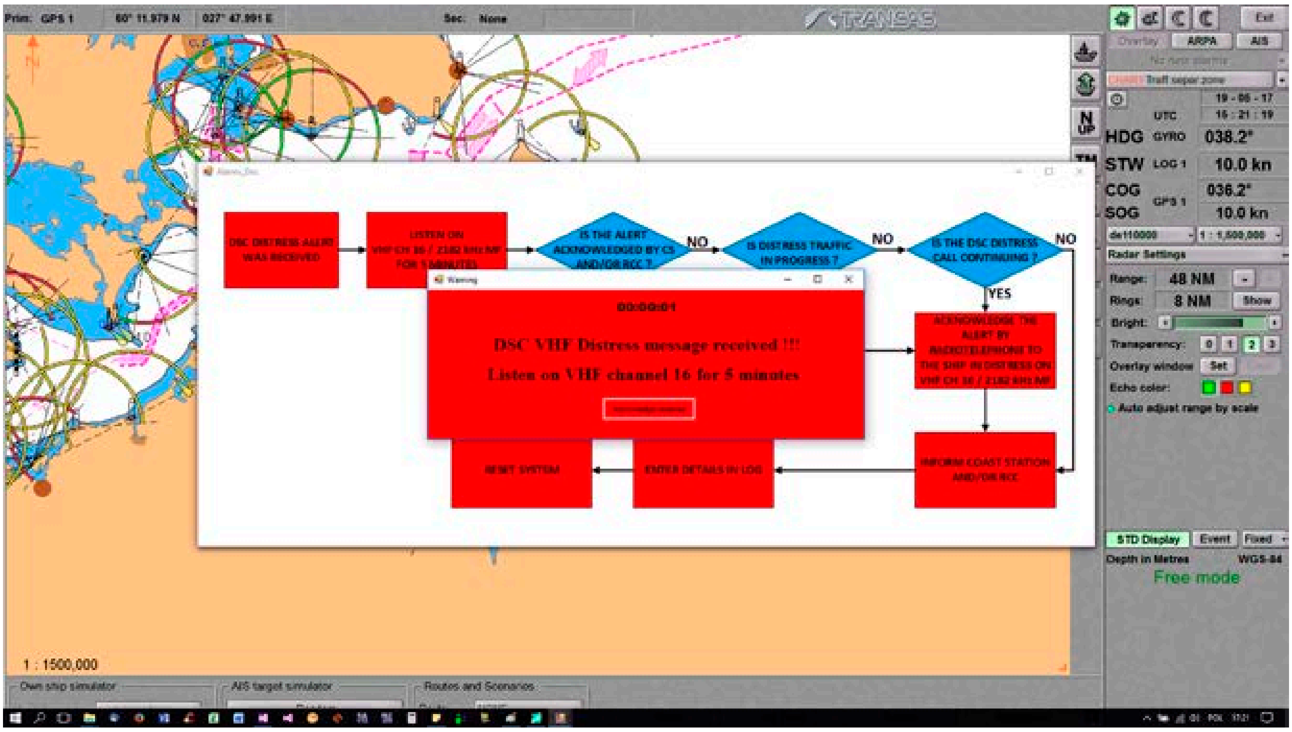

Figure 5. Fragment of the screenshot from the programme of operator decision support immediately after alert receipt

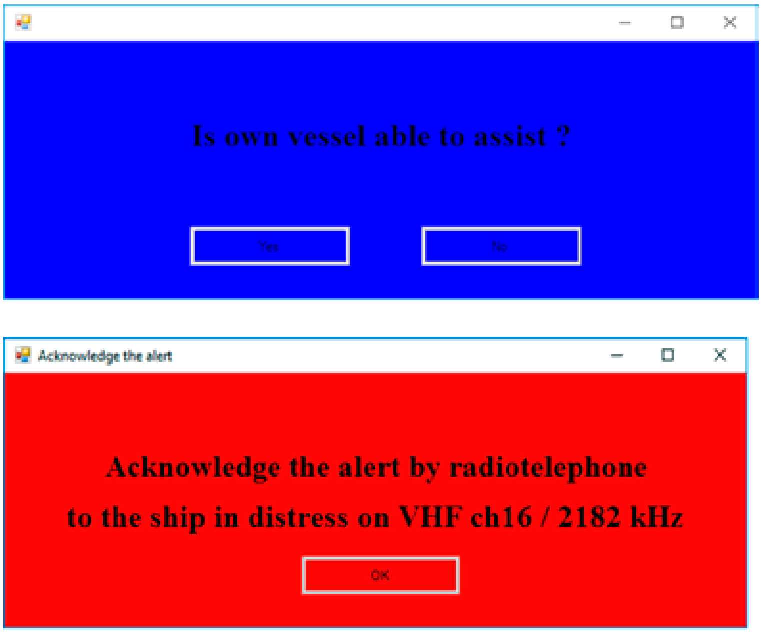

Figure 6. Fragment of the screenshot of the programme for operator decision support, showing blocks 5 and 7 from Figure 2

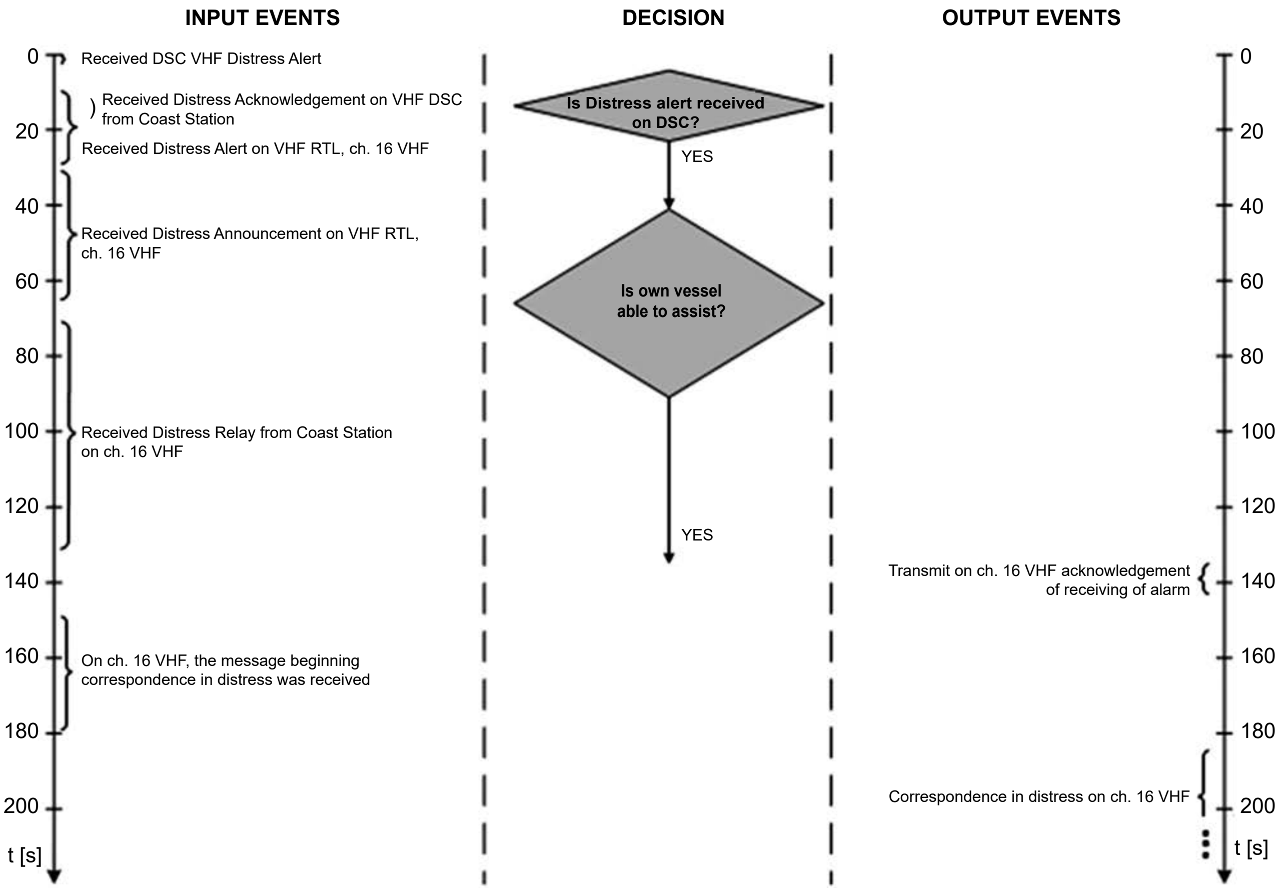

Figure 7. Time-decision diagram for the decision-making process, based on Figures 2 and 4

6. During the actions under pp. 5 and 6 we make a decision on the possibility of providing assistance.
7. We can provide assistance; therefore, in accordance with the diagram in Figure 2, we have sent an acknowledgement of distress alert receipt by radiotelephone on VHF channel 16.
8. The coast station begins distress communication and coordination of the rescue operation.

Conclusions

The article presents a model of the decision support system aimed at assisting the radio operator on a ship after receipt of a distress alert by DSC VHF on channel 70. The following conclusions can be drawn:

- The process of decision making involving the radio operator on a ship after distress alert reception by means of the DSC VHF controller is complex and may turn out difficult, even for experienced users. The operator has to be competent and proficient in handling the device.
- While developing the graph of the Petri net, these authors took into account the states executed automatically by the equipment, states that may be a component of an autonomous REMS and states dependent on operator intervention.
- The two models of the Petri net allowed the modelling of the decision-making process, which resulted in the development of operator decision-making support and the generation of a time diagram.
- Based on the Petri net, the proposed system of operator decision-making support allows the time the radio equipment is handled to be shortened, thus giving more time for heuristic analysis of the existing situation and optimising decisions for the most effective rescue operation.

These conclusions confirm that there is a need to conduct further research in order to develop a radio operator decision support system as an integral part of the REMS.

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