RISK BASED DECISION AID FOR DAMAGE CONTROL

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ABSTRACT

The current trend in ship design is to reduce the crew. Special attention should be paid to damage control, which is a labour intensive task. Having less crewmembers implies that more tasks have to be automated. It also means a reduction of the available 'human sensors', which leads to difficulties with the situation assessment. Lots of hi-tech sensors and actuators are commercially available, but are they affordable and do they lead to a well balanced system?
This paper provides a proposal for a 'Risk Based Decision Aid for Damage Control'. The aid can be used in the design phase to optimize, among others, the sensor suite and automated damage control systems. Subsequently, the decision aid can provide the basis of a decision support system as part of the monitoring an control systems.
The emphasis is on modelling the operational decision making process and incorporating it into the design philosophy. The resulting design will ensure that the damage control systems are deployed like the designers intended.
The Netherlands Organization for Applied Scientific Research and the Royal Netherlands Navy work together to refine the method.

KEY WORDS

Decision-Making, Damage Control, Uncertainty, Expected Damage, Risk, Ship Design

1 INTRODUCTION

Nowadays an important topic in designing navy ships is reduced manning. On current frigate sized ships about 100 people can be involved in damage control actions including the treatment of casualties and battle damage repairs. Next generation frigate sized ships are planned to be lean manned with a total complement of about 80 people. It is clear that far less people are available for damage control actions/functions, so more should be done by automated systems. However, as you will see in the given example below, automated systems might inflict more damage to equipment than fire-fighting parties:

Consider you are on board a navy frigate and you are on duty in the ship's control center. Suddenly, an alarm sounds and a flashing light indicates: 'fire in the helicopter hangar'. What are you going to do?

- Activate the built-in foam installation immediately? It seems to be the right decision, but in case of a false alarm the helicopter will be out of order for a while due to the foam. On the other hand, if there is a real fire, the foam will extinguish the fire very quickly.
- Gather more information to confirm the fire before taking action. This takes of course some time. In case of a false alarm there is no damage at all. On the other hand, when the fire is real, the fire might be grown too large to extinguish the fire manually by the time someone arrives at the hangar. You have to activate the foam installation in the end. Unfortunately, the fire has grown and therefore the damage is larger compared with the situation when you had activated the foam installation immediately.

The information available to you is incomplete for a good situation assessment (false alarm or real fire) and you only have one immediate damage control option available (foam), which for sure causes collateral damage. Both decisions (immediate action or gather information) can lead to unnecessary damage (collateral damage in case of a false alarm or too much damage due to the grown fire). A result of this dilemma will probably be that the foam system in the hangar will not be activated when the alarm sounds, or at least not right away. The foam system is therefore not being used effectively.

Increased automation and mechanization requires a better understanding of the relation between sensing, acting and consequences. At present, people are often used as sensors. For instance, fire-fighting teams can see for themselves what type of fire they are dealing with and will decide on the appropriate course of action. In lean manned situations, not enough people are available to determine the state of the fire. Therefore adequate sensor systems must be installed to compensate for the lack of information.

Both in sensing and acting are a lot of hi-tech solutions available to get the best performance of your system. The best thing to do: design the perfect ship in terms of vulnerability, survivability and sustainability, which is hardly possible and costs a huge amount of money! The question is: What are you willing to pay? And is it cost-effective? You want to know where to put the taxpayers' money: what combination of sensors, actors and people? Therefore the next best thing to do is: assist the ship designers to optimize the ship at all her facets and provide the operator with adequate advice concerning its damage control options incorporating the available incomplete information.

This paper provides a proposal for a 'Risk Based Decision Aid for Damage Control' that is useful during both the ships design phase and the operational phase. During the design process, the method can be used for optimizing of, among others, the sensor suite, automated damage control systems, the layout of the ship and her systems and the combustible content of compartments. At any stage of the optimizing process, the effects of incomplete information on the decision-making process are made clear. The expertise gathered during the design process can be used as part of a decision support system. The key factor in this proposed method is that we incorporate operational decision making, rather than design-time decision making.

2 STRUCTURE

As the name of the method tells, risk is an important variable of the method. Risk in this paper will be used to express the unnecessary extent of damage. The unnecessary damage is often the result of wrong decisions, made due to uncertainty about the situation such as the size of the fire, poorly designed damage control options and, most likely, the combination of both.

The risk of choosing the wrong action (which causes too much damage) determines to a large extent the amount and the kind of information required. For example, one of the first actions to perform after a fire alarm is crash stopping the ventilation. No matter if there is no fire or a real fire regardless the size, no damage is involved in this action; thus the activation threshold is very low. The release of CO_2 as an extinguishing gas in an occupied machinery room will cause serious damage to personnel (fatalities). If you don't have enough information to be absolutely sure that there is nobody present in the room, the risk is unacceptable. As the risk grows, the decisions get harder.

To decide what damage control action is the best option given the level of information available, we first need to estimate the expected damage for all damage control options in combination with all possible sizes of fire (states of nature). Then we need a decision-making strategy.

The risk based damage control method will be explained in the following steps:

(1) Determine the possible states of nature given the available information,
(2) Determine the possible damage control options,
(3) Determine the expected damage in all situations given the available information,
(4) Choose the best option according to a decision-making strategy.

Every step of this process will be explained in the following sections. In this paper we concentrate on a single fire as the calamity, but the method is not limited to fire. We conclude this paper with some considerations concerning the application of the proposed method.

3 STATES OF NATURE

The state of nature is in this method mainly characterized through the size of the fire. To express the size of the fire, we will, in this paper, use a classification already used by the Royal Netherlands Navy (RNLN). This classification consists of four types: small, medium, large and very large fires. For the following analyses we add another category: a false alarm. In this case damage control actions can be taken against a fire that does not exist. Each size of fire is characterized by the fraction of volume (or surface area) of the concerning room that is occupied by the fire. Table 3.1 shows the classification.

Size of fire	**Fraction of the room**
False alarm	0
Small fire	0.05
Medium fire	0.25
Large fire	0.8
Very large fire	>1

Table 3.1. Classification of fires within RNLN

Very large fires are most likely to occur as a result of missile hits or other external triggers. In naval ship design it is therefore an important state of nature. Because of the huge damage from the start (fixed fire fighting systems are likely to be damaged and a lot of personnel might be wounded or killed), the emphasis in this category is on containment of the fire, not on extinguishing it. Therefore we will dismiss the very large fire category as an initial state in the following analyses. Nevertheless, the very large fire can of course be a final state in later analyses.

If a fire alarm sounds, there is an uncertainty about the state of nature that is present. A smoke sensor could have detected the smoke of a small fire in a trashcan or a rapidly spreading liquid fire. It could even be possible that you are already dealing with a very large fire if not every room is equipped with a sensor. If the sensor-suite improves, the uncertainty about the states of nature decreases. Most of time it means that one or some states of nature can be excluded because it is certain that those states cannot be present. If your sensor-suite is very good, you might even reach the point of absolute certainty that only one state of nature can be present.

In the examples of this method we assume that the probability of occurrence for a particular state of nature is unknown. However, in practice experts could give an indication of the probability of occurrence for a particular state of nature, that can be used for improving decision-making strategies.

4 DAMAGE CONTROL OPTIONS

The damage control options comprise all the possible decisions (actions) that can be made. Examples are: decide to do nothing (unwise), gather more information, take preventive actions such as crash stop ventilation, scramble fire-fighting parties or decide to activate a sprinkler system immediately. The list of possible decisions might contain a few dozen of actions and therefore is most times too cumbersome to take into account completely. In common practice it is however possible to make a short list by striking the irrelevant and nonsense options out. Maybe a dozen or less relevant actions might be left.

Every damage control option has its own risk, namely the risk of not being (most) effective which results in a larger damage due to the fire and/or the risk of causing more collateral damage than necessary. Some risks are very low, like starting the fire-fighting pumps and crash stop ventilation. Some risks are fairly important, like switching off electricity in the calamity area, which could cause functional loss of an indispensable system. Other risks are unacceptable, like (in peacetime) activating the CO_2 installation while the information about the presence of people in the room is incomplete. Every relevant option can be taken into account, but in the examples in this paper we limit the number of possible options by looking at direct fire-fighting actions only.

There are still many ways to fight a fire. In order not to complicate things too much, we again categorize all the options into a limited number of categories. The list is presented in table 4.1

Portable hand extinguishers
Human attack teams
Room filling Foam installation
Room filling Sprinklers
Room filling Inert gas installation

Table 4.1 Fire extinguishing equipment

To estimate the damage at the end of a fire-fighting action, we need to know some characteristics of the option. The following characteristics should be taken into account: response-time, effectiveness with a given state of nature and the side effects on different kinds of contents of the affected room. Some examples to illustrate: the response time of a human attack team is much larger (scramble, dress up, collect equipment) than the response time of a sprinkler installation (push a button). The effectiveness of water on a liquid fire is very bad, in fact, it is probably going to worsen the damage. CO_2-gas is lethal to present people (which in this sense are contents as well).

5 EXPECTED DAMAGE

Part of the damage is caused by the fire itself and part of it is caused by the damage control action. In the following paragraphs we will successively deal with these two parts, but first we need to define ‘damage’. When looking at all contents of a room as abstract object, one sees the physical damage: irreparable, reparable, no damage. In practice however you are not interested in the physical damage directly: you want to know how much it costs to get the damaged object working again and in battle more important: what operational functions are affected. Another difference between theory and practice is that personnel can morally not be regarded as an abstract object. Besides that, the economical and functional damage of persons are hard to define. Therefore we will consider personnel damage separately.

5.1 Damage due to fire

The extent of the fire-inflicted damage is defined as the fraction of the total volume (or surface area) that is damaged by the fire. If more rooms/compartments are damaged, we use a number larger than one. An indication of the damage caused by the fire is presented in table 3.1.

After a while the size of the damaged fraction depends on a number of variables, which for this calculation are: the (initial) size of the fire, the rate of growth of the fire, and the response time of the damage control action. Given the physical damage we can calculate the economical and functional damage (see 5.5). Separately we look at injuries and fatalities directly due to the fire. In paragraph 5.2 (collateral damage), we also account for personnel damage, but at that point as a resulting from the extinguishing agent.

The initial size of the fire (at the moment the alarm sounds) is given as an uncertain state of nature as explained in chapter 3. The rate of growth of fire depends on the sort of combustibles in the room. In a room with highly flammable combustibles, the fire will grow more rapidly. The response time of the damage control action is determined by the organization of means and personnel and the effectiveness of the extinguishing agent/method in combination with the combustible (chapter 4). If we combine this variables and calculate/estimate the physical damage due to the fire, we get for example: a medium fire in a machinery room with high flammable liquids that is extinguished by a human attack teams with a response time of several minutes, will grow rapidly and end up with a large fire, or even a very large fire. Table 5.1 shows an example of the expected damage due to fire as a result of a damage control action on a state of nature in a specific compartment, with a given sort of combustible (in this case a machinery room and an oil-fire)

The values of the physical damage are for now just estimates, to be used for illustrative purposes only. We have not put any effort in finding more realistic methods to determine the amount of damage. More work still has to be performed, for instance by analyzing fires in the past, perform simulations or asking expert opinions.

Size of the fire	CO_2-gas	Attack team	Sprinklers
False alarm	0	0	0
Small fire	0.05	0.4	0.15
Medium fire	0.25	0.8	0.4
Large fire	0.8	>1	0.8

Table 5.1 Expected damage due to an oil-fire

5.2 Collateral damage

In order to determine the damage caused by the extinguishing action, one must consider the inventory of the room in which the fire-fighting action takes place, the extinguishing agent and the procedure used to deploy the agent. For instance, large amounts of water can cause serious damage to electrical systems, but will extinguish the fire. Water from a sprinkler system is deployed in the whole room without regard to the state of nature, but water deployed by the attack teams can be directed to the fire only. Therefore a human attack team fighting a small fire will inflict less collateral damage than a sprinkler would do on a small fire.

The tolerance of the inventory for the extinguishing agent is of great importance. As mentioned before: water and electricity leads to larger collateral damage than CO_2-gas and electricity. A helicopter covered with foam leads to larger collateral damage than using water on a helicopter (we assume a helicopter can fly through rain without damage).

The use of harmful or even lethal extinguishing agents will lead to injuries and fatalities (personal damage) in case people are present and trapped in the compartment. Releasing CO_2 in a sealed machinery-room, before being absolutely sure that there is nobody trapped in the room, could lead to a fatality. In this method we account for personal collateral damage in the tables. Whether an injury or even a fatality is acceptable depends on, among others, the operational circumstances. The more unacceptable the higher the damage-figures are (see 5.5), for example a fatality could be expressed as a ‘damage’ of 10 (compared with 1 for damage to a whole compartment). Nevertheless, the chosen decision-making strategy will finally determine whether you choose for such an option or not.

Table 5.2 shows the collateral damage for the same scenario as in table 5.1. In this example no people were present in the machinery room. If people were present, the collateral damage figures in the column of the extinguishing gas (CO_2) would have been (very) high. Notice that the extinguishing gas causes collateral damage in none of the states of nature. The collateral damage caused by the human attack team consists of, among other, electrical problems caused by the water. As the covered area increases, the damage increases, but water doesn’t damage all the contents of the compartment (maximum 0.5). Given figures are just examples.

Size of the fire	CO_2-gas	Attack team	Sprinklers
False alarm	0	0	0.5
Small fire	0	0.2	0.5
Medium fire	0	0.3	0.5
Large fire	0	0.5	0.5

Table 5.2 Collateral damage after an oil-fire

5.3 Total expected damage

The total expected damage in a compartment is defined as the total physical damage as a result of a specific action taken on a specific state of nature and comprises both the damage due to fire as the collateral damage. The total expected damage at the end of the damage control action is calculated beforehand for each combination of possible state of nature and possible damage control action.

We can combine the fire damage and the fire fighting damage in several ways. Simply adding the two would not be fair, since the fire would inflict some of the damage caused by the fire fighting actions anyway. For now, we take the maximum of the two. In the future we may have to come up with a better combination rule.

Table 5.3 shows the total expected damage of the example of an oil-fire in the machinery room. The table is constructed through combining table 5.1 and 5.2.

Size of the fire	CO_2-gas	Attack team	Sprinklers
False alarm	0	0	0.5
Small fire	0.05	0.4	0.5
Medium fire	0.25	0.8	0.5
Large fire	0.8	>1	0.8

Table 5.3 Total expected damage after an oil-fire

5.4 Combining DC actions

By combining several different ways to fight a fire, the advantages of successively performing different fire fighting actions can be exploited. At present, this is already

done in navy ships. Hand extinguishers are never the only course of action; one always follows up with fire hoses. One can imagine that if one tries to fight a large fire with only hand extinguishers, the result will be that the ship will be completely lost, not end up with (very) large damage
One can also combine fire-fighting actions with preventive actions like stopping the ventilation and boundary cooling. This presents us with far more opportunities to compare different fire fighting strategies.
The way we can do this is to add more columns for each different fire fighting strategy. We can for example add a column for the strategy ‘attack teams + boundary cooling’. The boundary cooling teams will have no effect on the damage within the burning compartment, but they will be able to prevent the fire from spreading to other compartments. The damage will therefore not be greater than 1.

Another strategy might be to combine sprinklers and hand extinguishers. Instead of turning on the sprinklers at the first sign of trouble, one would send a man with a hand extinguisher to investigate. If he finds a small fire or no fire at all, he would take care of it himself, in the other cases he would turn on the sprinkler. This course of action would significantly reduce the damage caused by sprinklers in the smaller fire cases (down to the hand extinguisher level), but would marginally increase it in the larger cases because of the increased reaction time. It could even become greater than 1 because of smoke damage etc.
When we add extra columns, the table could look like this:

Size of fire	**Hand ext.**	**Sprinkler**	**Hand ext. + Sprinkler**
False alarm	0	0.5	0
Small fire	0.1	0.5	0.1
Medium fire	>>1	0.5	0.6
Large fire	>>1	0.8	1.2

table 5.4 Total expected damage example case combining actions

Table 5.4 shows dramatically improved results. If the fire fighting actions are combined in a sensible way, the low damage values are copied from the columns in question. The possibilities to combine actions are virtually endless.

5.5 Perceived damage

The fact that the contents of a compartment are damaged doesn’t say much. Therefore we have to introduce perceived damage, which considers the damage as a function of economical, functional and personal damage. The importance (or weight) of each of these factors can vary according to the circumstances, for instance, wartime vs. peacetime. These various angles will be described in this paragraph.

If we assume that the inventory of a room is evenly distributed over the room and is roughly equal in value, we can simply calculate the economical damage as a multiplication of physical damage and value of the room. In a later stage in the design process, more information about distribution, value and vulnerability of the contents in a room may be available. At that time you can adjust the expected damage figures based on the information and expert opinions. This detailed phase also gives you the opportunity to show the effects of knowing the exact location of the fire in a room and having the opportunity to use a restricted and directed action (zoom in as you gain more detail).

To determine the functional damage we need to know more details about the ship and her systems as a whole. Variables that affect the functional damage are: the extent of the physical damage and the functions of the damaged inventory and contribution of that function to other (higher level) functions. With only a functional breakdown it is not possible to calculate a single figure for the functional damage. We need weight factors to indicate which (sub)functions are more or less important, given the actual operational environment or action involved in. For example: when under attack by missiles, the importance of the self-defense functions is higher than the importance of the submarine warfare-functions. Therefore the same physical damage can lead to different operational damages in different circumstances. Redundancy within a (sub)function must be calculated in the contribution of that function to a higher level function.

The Netherlands Organization for Applied Scientific Research (TNO-PML) and the Royal Netherlands Navy (RNLN) have already developed a method to construct a functional breakdown, starting with systems and ending up with operational availability. This method could be used to estimate the functional damage needed for this method.

In determining functional damage we could also take reparable damage into account. In most cases the fire will destroy the inventory in such a way that it cannot be retrieved or repaired. But when the damage consists of a soot-deposit or water in the installation, it can be repaired in certain time. In this case the time to repair and the urgency to get the function available in the scenario are counting. For example: in a direct missile-threat a repairable damage to the self-defense system is functionally of the same magnitude as an irreparable damage because you need the system right at this moment and not in one hour or so. On the other hand, with the same threat, an easy repairable damage to the sonar is of lower magnitude than a completely destroyed sonar because the ship can continue her operation in all warfare domains after repair.

The value of human life will vary as well. Under peacetime conditions, losing a crewmember is considered unacceptable. The personal damage in that case is very high. In wartime however, the survival of the ship takes precedence over the survival of one single crewmember. The personal damage is then reduced to the functional damage of that particular crewmember (loss of the function that crewmember carries out).

6 DECISION-MAKING STRATEGY

In order to incorporate the operational decision making in the design of a new ship, we require a model of the decision-making strategy of the people aboard. We believe that decision analysis techniques can provide a relatively accurate model.
Decision analysis techniques can be used to determine optimal strategies when a decision-maker is faced with several decision alternatives and an uncertain or risk-filled pattern of future events or states of nature. One of the first steps in many decision strategies is to create a so-called payoff table. This payoff table provides estimates of the gains for all combinations of decision alternatives and states of nature. The next step is choosing the best alternative. Concerning our damage control situation: we are faced with uncertain information on the size of the fire (state of nature) at the moment that the alarm sounds, and we have to make a decision on which damage control action to choose.
Various decision strategies exist for making this decision. We have selected a set of decision strategies that does not require knowledge of the probability of occurrence of a certain state of nature. The set consists of a combination of best and worst case analyses, with relatively simple arithmetic. For our damage control situations we believe that these types of analyses are the best choice. There are numerous other decision analysis techniques, ranging from simple expected value analysis up to complex utility analysis and Bayesian analysis. In the future, we may perform more research into the consequences of the decision strategy, where we will include these more complex decision strategies.

The proposed set of strategies will be presented below.

6.1 Optimistic

The optimistic method, also called the MiniMin method, tries to minimize the minimal damage a calamity will cause. For every damage control action, the best “payoff” or minimal expected damage is determined and the action with the lowest minimal damage is chosen.
In other words, the *mini*mum of the *min*imal payoffs (expected damage) is selected. The rationale behind this is that one assumes the fire is always still small when one attacks it and that the damage control action is always successful. This is an optimistic view on life and is unfortunately not always the case.

Consider the following example:

	Hand ext.	Team	Sprinkler
False alarm	0	0	0.5
Small fire	0.1	0.3	0.5
Medium fire	4	0.7	0.8
Large fire	4	1.2	1
Min damage	0 or 0.1	0 or 0,5	0,5

table 6.1 Total expected damage example case

The optimistic method will select the option with minimum damage. As can be seen in table 6.1, there are actually two damage control actions with minimum damage; both hand extinguishers and attack teams have zero damage in case of false alarms. We can conclude that it does not matter if we use hand extinguishers or attack teams and we can choose either one. If we want a definite answer, we can move on to the next best minimum: the 0.1 damage of the hand extinguisher in case of a small fire. This is the option we will select with the optimistic method.

6.2 Conservative

The conservative method, also called the MiniMax method, in contradiction with the optimistic method, always assumes the worst case. It tries to minimize the maximum damage for each possible action. For each action, the maximum expected damage is calculated (see the bottom line of table 6.2). Finally, the action with lowest maximum damage is selected. In other words, the *mini*mum of the *max*imal payoffs is selected. Consider the same example:

	Hand ext.	Team	Sprinkler
False alarm	0	0	0.5
Small fire	0.1	0.3	0.5
Medium fire	4	0.7	0.8
Large fire	4	1.2	1
Max. damage	4	1.2	1

table 6.2 Total expected damage example case

The conservative method will go for the option with the minimum of the maximum damage. For the hand extinguishers the maximum is 4, for the attack teams this is 1.5 and for the sprinkler this figure is 1. The lowest of these damage figures is 1 for the sprinkler and therefore this is the option we select with the conservative method.

6.3 MiniMax Regret

The MiniMax Regret method tries to minimize the maximum regret of a decision. Regret in this sense can be regarded as the consequences (damage) of a wrong decision. One wants to minimize the damage resulting from a wrong decision. We will illustrate the process by means of the example payoff table 6.3. First, for every state of nature the action with minimal damage is determined. This step is indicated by the bold figures in table 6.3.

	Hand ext.	Team	Sprinkler
False alarm	**0**	**0**	0.5
Small fire	**0.1**	0.3	0.5
Medium fire	4	**0.7**	0.8
Large fire	4	1.2	**1**

table 6.3 Total expected damage example case

Next, for every combination of DC action and state of nature, the regret is defined as the extra damage caused by the action relative to the action with minimal damage for that particular state of nature, i.e. the damage of that option minus the minimum damage. The results of these calculations are presented in table 6.4. The final decision is to select the action with the minimum regret.

	Hand ext.	Team	Sprinkler
False alarm	0	0	0.5
Small fire	0	0.2	0.4
Medium fire	3.3	0	0.1
Large fire	3	0.2	0
Max. regret	3.3	0.2	0.5

table 6.4 Total regret example case

As can bee observed, the attack teams have the lowest maximum regret (0.2). Our final decision will therefore be to choose attack teams.

6.4 Which strategy to choose

Each of the methods has its advantages. It is quite conceivable that we let the decision about which method to choose depend on the operational circumstances in which we have to make the decision about the damage control actions. For instance, the pessimistic method is the safest way to ensure survivability of the ship, but might not be the most economical. The optimistic method is quite risky because there is a danger that the chosen method of attack is not strong enough to extinguish the fire. It is suitable in cases where one has a lot of backup options to minimize the danger that the fire can grow out of control. It is also applicable in situations where one has a good understanding of the situation (fire size); i.e. the risk of a wrong decision is minimal.
The MiniMax regret method seems to combine the best of both the other methods and is overall the most promising. It might be possible to refine the method by using weight factors to represent fore knowledge about the chance of a particular type of fire occurring in a certain compartment. Other factors we can account for using weight factors are the chance of failure of a certain damage control action and the amount of faith in sensor knowledge. The RNLN and TNO will, in close co-operation, put more research effort in determining the best decision strategy.

One thing that is important is that when an actual strategy has been chosen, one has to ensure this strategy is used in all the possible phases of the ship's life. It would be illogical to design a ship using one strategy and then using a completely different strategy once the ship is in service. The operational procedures on the ship must reflect this. The ship is after all designed that way.

7 APPLICATION IN SHIP-DESIGN

The operational use of the ship's systems is often different from the designer's intention. Consider for instance an incident in a usually unmanned machinery room. The best course of action from a designer's point of view might be to install a CO_2 system, because of the low expected damage. Under operational circumstances however, there are no guarantees that nobody is present in the machinery room. Therefore, especially under peacetime conditions, nobody will dare to activate the CO_2 system because *if* there are people present, they will most certainly die. This in effect means that the expensive CO_2 system will probably never be used, which is a most uneconomical situation. The designer should be aware of the operational decision strategy. This can be modeled in the risk based decision aid.

When the designer uses this operational risk based decision aid, he finds out that under operational conditions, the CO_2 system will be used only when the operator is absolutely sure that the machinery room is unoccupied. The designer can, based on this knowledge, for instance decide to install an adequate personnel detection system in the machinery room.

Then the usual design questions arise whether such a sensor system is cost effective. Installing the sensor system is only cost effective if the gain, i.e. the lower resulting damage, is higher than the cost of the investment in the sensor system.

Let us illustrate this by assuming the expected damage figures in the table below. We only consider a small fire. Under unmanned conditions, the expected damage is only 0,1 if the CO_2 is used. Under manned conditions the expected damage is 10 (we assume that people are trapped in the machinery room). If Attack team are used, the expected damage will be 1 in both manned and unmanned condition. The low expected damage in the manned condition is a result of ability of the team to rescue trapped people.

		CO_2	Attack teams
Small fire	unmanned	0.1	1
	manned	10	1

Table 7.1 Expected damage machinery room

Let us further assume that the machinery room is vacant for 90% of the time. Without a personnel detection system, the CO_2 system will (should) never be activated and attack teams will be chosen. The damage is always 1 (This is a result of the Risk Based Decision Aid). With an adequate personnel detection system, the operator will decide to deploy the gas 90% of the time, the other 10% of the time we will still have to decide to deploy the attack teams. The average expected damage can than be expressed as: 0.1*1+0.9*0.1 = 0.19, which is significantly better than 1.

For this analysis to be complete, we have to account for the economic value of the damage, which in this case is difficult because the value of a human life is hard to define. Once we can calculate the economic value, we can compare the investment and the expected damage. We must also account for the expected number of fires in the machinery room over the economic lifetime of the ship. This is in effect lifecycle costing, which we will not go into any further.

The same analysis can be performed to determine the benefits of installing better sensor systems to detect the size of the fire. Another, but similar, analysis can be performed to determine the benefits in choosing between two different forms of fire-fighting, for instance attack teams for small and medium fires and sprinklers for large fires. If small and medium fires have a low probability of occurring (because of the relatively low response time of the teams, the fire has grown), the extra cost of having extra personnel and equipment aboard may become too high and using the sprinklers for every type of fire might be more cost effective.

Once each of the ship's compartments is optimized with respect to the damage control systems, one can increase the scope of the method to include the whole ship. One wants to avoid sub-optimization because of large differences in design solutions in some of the compartments. For instance, we could come up with the solution that in all but one of the compartments sprinklers are to be installed, and in the remaining compartment attack teams are best. The extra cost of maintaining an attack team (5-7 people, large amounts of equipment, etc.) probably outweighs the extra damage due to a sub-optimal solution in only that compartment. One would probably install sprinklers throughout the entire ship. This is again a matter of economics and we will not discuss this any further.

As can be observed in many of the examples, the risk based decision aid depends on the estimation of the expected damage. In the forward design phase, the designer should be able to weigh global several design options against each other. One can make adequate estimates of the damage by using historical data and expert opinions. Later on in the design process, more detailed simulation of fire growth and fire-fighting might be performed in order to assess the expected damage. The ACDC simulation framework might be used for this purpose.

A further useful simplification during the design process is the categorization of the compartments in for example a dozen representative compartments. This significantly increases the usability of the method in the early design stages.

8 APPLICATION IN OPERATION

During the design phases, the required data is generated using the Risk Based Decision Aid (RBDA). For example, the possible states of nature (possible types of fire) as function of the sensor data will be known. Also, as the inventory of rooms is better known, the expected damage for all kinds of situations will be assessed.

The RBDA could be implemented within a decision support system for damage control. Especially when it is real time connected with sensor states and the availability of automated damage control systems. The RBDA should also be dependent on the operational readiness state of the ship because the risks are different between peace and wartime operations.

At the moment of publishing this paper, a lot of research has to be done to improve and refine the method. Results regarding usability of the method in the operational phase are not obtainable until the method is used in an actual design process. Nevertheless we think that if the method can be applied successfully in the design phase, there is a great chance for success because all the needed (and valuable) information is going to be available.

9 FINAL REMARKS

One of the challenges we faced in the past was the multitude of damage control actions we are dealing with. For each combination of action and state of nature, the expected damage must be adequately determined. Until recently, no suitable method was available to assess the expected damage, and therefore the application of the risk based decision aid has never been possible. Now however, new technologies are emerging which enable us to accurately estimate the damage of a calamity. One such technology is the ACDC simulation framework, developed by TNO. It simulates the growth pattern of a fire on a ship, accounting not only for structural design measures but also for the damage control actions taken by the crew. With such technologies, the RBDA has now become a feasible design tool.

At the moment the Netherlands Organization for Applied Scientific Research (TNO-FEL) and the Royal Netherlands

Navy (RNLN) are working together in a multidisciplinary team to improve the RBDA. The goal is to implement and test the method within a new building project in the RNLN.

The risk based decision aid provides a suitable design tool for comparing and evaluating new, highly automated, damage control concepts. It helps to determine the appropriate fire-fighting systems as well as the need for adequate sensor systems to compensate for the reduced number of people acting as sensors. Finally, because the method incorporates operational decision making, it also ensures that the damage control systems will be used as the designers intended.

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BIOGRAPHY AND CONTACT INFORMATION

Martien P.W. Gillis MSc MBA started his research career in 1985 at TNO in the field of terminal ballistics. One of his research subjects was the evaluation of the effectiveness of the goalkeeper (a close in weapon system) munitions against missiles. In 1989 he was a member of the International Program Office at Picatinny Arsenal, USA for the APGM (Autonomous Precision Guided Munitions) project. From 1990 until 1995 he was occupied with vulnerability studies at TNO making frigates less vulnerable for missile attacks. Between 1995 and 1999 he had several managerial positions within TNO. In 1999 he returned to the military research. Now he is involved in improving the damage control function of navy ships.

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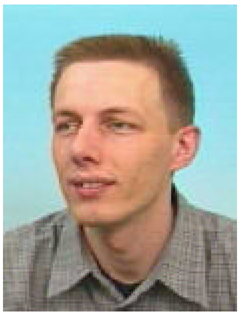

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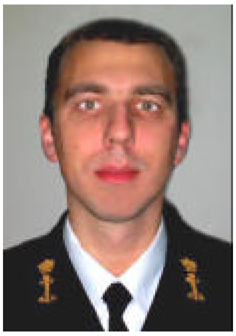

Joost L. Meesters, Lieutenant (Engineering branch) joined the Royal Netherlands Navy in 1991. After his study at the Naval Institute, with specialization in electrical energy technology, he had several functions ashore and on board of a frigate. Since 2000 he works at the Directorate Materiel, Department of Naval Architecture and Marine Engineering in the Design Group Platform Management. The main part of his job consists of developing 'lean manning' concepts and working out the conditions to achieve those concepts.

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