Simulation Based Performance Assessment for a Future Class of Patrol Ships

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ABSTRACT

This paper presents the process and results of a Simulation Based Performance Assessment (SBPA) study for a future class of Patrol Ships (PS). The study has analysed the speed requirement of this ship class for the Royal Netherlands Navy. Although speed is an important cost driver, such an analysis has never been reported.

The simulation study addresses counter-drug operations and models all its relevant aspects. These include operational and tactical aspects, e.g. deployment of the organic high-speed Rigid Hull Inflatable Boat (RHIB) and helicopter. Moreover, seakeeping behaviour is included in the analysis as well, i.e. the influence of sea state on the sustainable speed of the PS and RHIB.

This case study has resulted in valuable insights. Analysis of the simulation runs clearly showed the influence of the PS's characteristics (speed and length) on the operational performance. The results also illustrate that simulation is an extremely useful tool for executing performance assessments. Simulation does not only give insight, but also provides usable, quantitative answers to acquisition related questions.

1.0 INTRODUCTION

The Dutch Defence Materiel Organisation is currently involved in the acquisition process of a new class of Patrol Ships (PS), see Figure 1, for the Royal Netherlands Navy (RNlN) [1]. An important task of this PS will be performing counter-drug operations around the Netherlands Antilles and Aruba, in close cooperation with its organic high-speed Rigid Hull Inflatable Boat (RHIB) and its organic helicopter.

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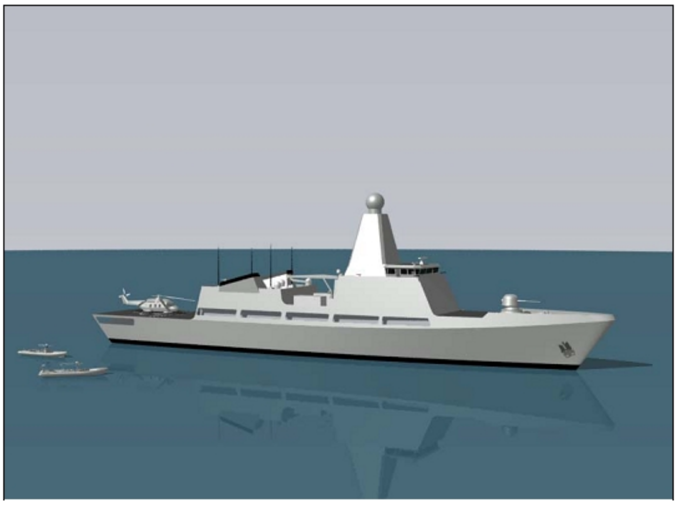

Figure 1: Artist impression of a design variant of the RNlN Patrol Ship

The current coastguard cutters of the RNlN, also employed for counter-drug operations, are each equipped with another type of high-speed RHIB. Experience has shown that the maximum sustainable speed of both the coastguard cutter and its RHIB significantly influence their overall operational performance. Since the PS will, unlike the coastguard cutters, be equipped with a helicopter, it was questioned whether the PS's speed would still have such a significant influence.

Besides, the maximum sustainable speed directly influences the acquisition costs of propulsion machinery and fuel costs during exploitation. However, lengthening the ship according to the so-called Enlarged Ship Concept [2] has proven to be a successful concept resulting in a significant increase in operability, a small increase in building costs, but simultaneously in a significant decrease in required installation power and fuel consumption. Hence, concerning the PS it was questioned in what way the maximum sustainable speed and the ship length would influence both operational performance and life cycle cost.

Simulation has established itself in recent years as a powerful tool in the acquisition process for military materiel. The Simulation Based Performance Assessment (SBPA) methodology, developed by TNO Defence, Security and Safety, combines simulation with an objective and systematic assessment of operational performance versus life cycle cost of a platform [3].

The SBPA methodology is part of the development loop in which design alternatives can be compared and can be used to make well-informed and well-founded acquisition choices. It is defined in a ready to use step-by-step execution plan, and it provides typical guidelines and important considerations.

The assessment of operational performance is based on a platform's Mission and Task Tree, of which an example is shown in Figure 2. Simulation models are employed to analyse the performance of individual tasks. SBPA explicitly considers operational, survivability aspects as well as sustainability aspects. It determines the life cycle cost using, for example the technique of Activity Based Costing. Finally, it performs a cost effectiveness analysis, weighing the operational performance against the life cycle cost.

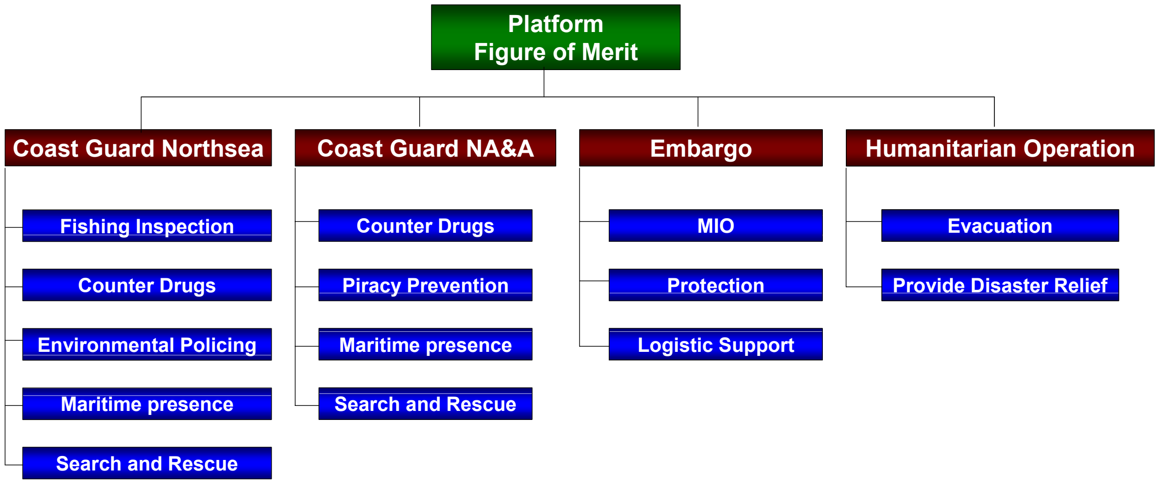

Figure 2: Example of a Mission and Task Tree

The SBPA methodology is validated against various case studies. One of these case studies analyses the influence of the PS's maximum sustainable speed and length on the overall operational performance, without taking the life cycle cost into account. This case study simulates a Maritime Interdiction Operation (MIO) focussing on drug interdiction, a task for which it was anticipated that the PS's maximum sustainable speed could influence the operational performance. The lessons learned from these cases are used to further improve the SBPA methodology.

The remainder of this paper is structured as follows. Section 2 introduces the MIO scenario, addressing all relevant operational aspects. Section 3 presents the way in which these aspects are incorporated into the simulation. Section 4 gives the results from the analysis of the simulation runs. The paper concludes with conclusions and future work in Section 5.

2.0 THE MARITIME INTERDICTION OPERATION SCENARIO

In the MIO scenario the PS has a certain area under surveillance in which suspicious traffic (drugs smugglers) is intercepted and boarded when necessary. The surveillance area is a funnel-shaped area that represents a choke point, see Figure 3.

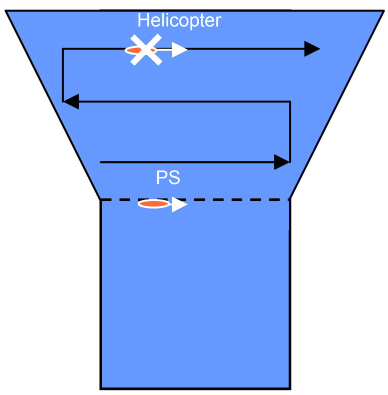

Figure 3: Top view of the operation area

The PS has two organic units: a helicopter, which is able to identify and track targets way beyond the PS's horizon, and a high-speed RHIB, which is used to board a fast sailing drugs smuggler or so-called go-fast, after tactical positioning of the PS.

Patrolling in the surveillance area is performed by the PS and its organic helicopter. The PS patrols back and forth along an (imaginary) border, depicted as a dashed line in Figure 3. The helicopter (repeatedly) sweeps the area ahead of the imaginary border using a ladder search pattern. We assume that intelligence in advance, other than the knowledge that go-fasts are passing the area, is not available.

The Measure Of Effectiveness (MOE) of the task is defined as the percentage of the go-fasts that are successfully boarded.

2.1 Units

The PS and helicopter are equipped with radar for detection and localisation of shipping and an infrared sensor for recognition. In addition, the helicopter can perform recognition using information from visual observations.

The flight deck of the PS enables the helicopter to operate up to sea state 5, day and night. The PS is also able to launch and recover the RHIB up to sea state 5.

The PS is able to force the target to stop by using the naval gun at a certain (maximum) shooting range. Within that shooting range, the PS and helicopter use machine guns in order to respond to violence, to intercept rapidly manoeuvring ships, in order to force the target to stop given the applicable Rules of Engagement (for example by eliminating the outboard engines), and to cover the boarding team. The RHIB is equipped with machine guns as well.

After the helicopter has landed on the PS, it is not available for a certain time due to refuelling and/or crew rest times. Furthermore, the helicopter crew is available only for a limited amount of time per day, depending on day or night time operations. Such resting times do not apply for the crew of the RHIB.

The availability of the organic units is dependent on sea state, just like the maximum sustainable speeds of all vessels sailing through the surveillance area. The endurance of the helicopter is also taken into account.

2.2 Sequence of events

For the sequence of events in this MIO scenario, the following four steps are distinguished:

1. detection,
2. recognition,
3. interception,
4. boarding.

In the following subsections, these steps are described in detail.

2.2.1 Detection

The first step is detection of shipping. As already mentioned, the PS patrols along an (imaginary) border and the helicopter flies a ladder search pattern. Both the PS and the helicopter use their radar for detection.

Figure 4 shows the helicopter flying its search pattern and detecting a go-fast using its radar.

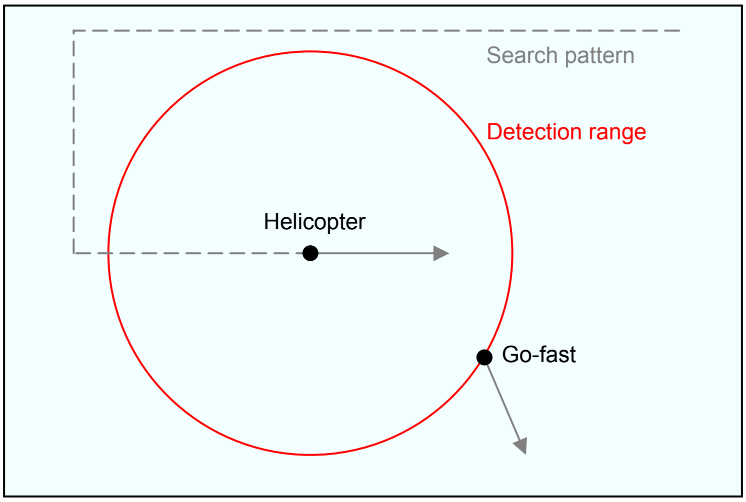

Figure 4: Detection of a go-fast by the helicopter

When a ship is detected, the recognition step is executed.

2.2.2 Recognition

The unit that detected a ship, or so-called contact, generally performs the recognition step as well. If the helicopter detected the contact but has insufficient endurance however, the PS performs the recognition. The PS resumes the detection step anyway if it appears not to be fast enough for successfully recognising the remote contact.

Recognition is performed by moving towards the contact until its ship type has been determined. The actual identification is carried out visually or by infrared.

Figure 5 shows the helicopter moving towards the contact and recognising the go-fast using its visual or infrared sensor.

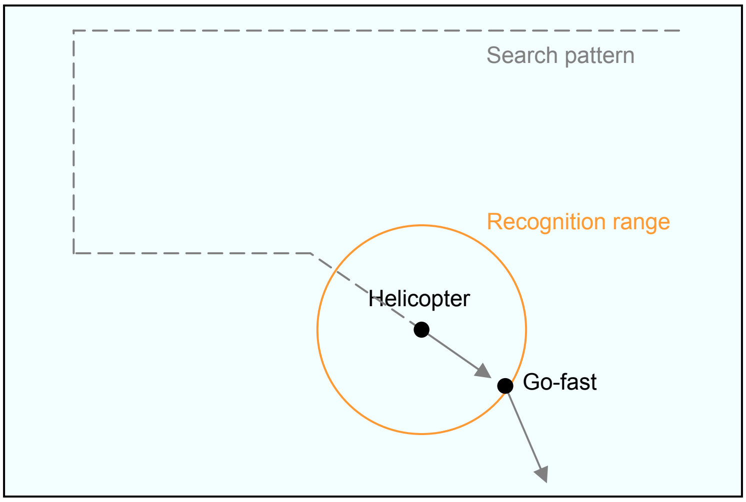

Figure 5: Recognition of a go-fast by the helicopter

If a contact has been recognised as go-fast, the interception step is executed. In all other cases, the detection step is resumed.

2.2.3 Interception

Either the PS or helicopter performs the interception step. The helicopter performs the interception when it is available and has sufficient endurance, and the PS performs it otherwise.

If the helicopter performs the interception, it moves towards the go-fast and takes position right above the go-fast (within a certain range). At the moment that the helicopter starts the interception, the PS accelerates and sails continuously at maximum speed towards the expected position of interception.

Figure 6 shows the interception of the go-fast by the helicopter.

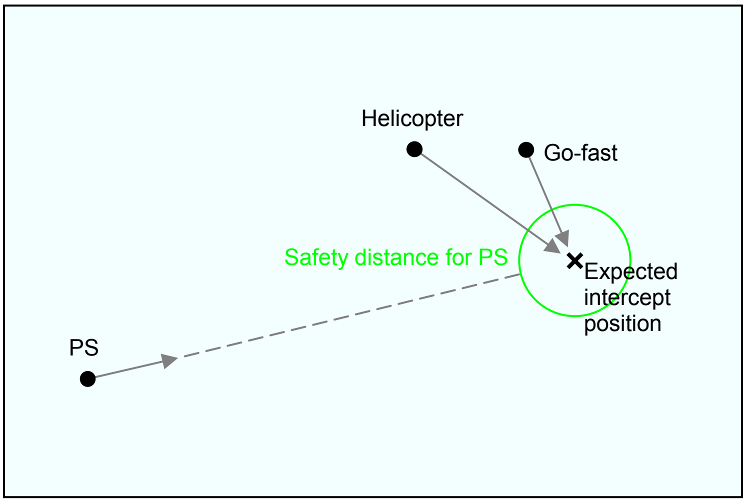

Figure 6: Interception of a go-fast by the helicopter and approach of PS

If the PS performs the interception, it stops the go-fast at a distance on which the PS has the go-fast within shooting range, but also has a safe distance from it.

If the go-fast has been intercepted, the boarding step is executed. If the interception failed (for example if the helicopter has insufficient endurance and the PS is too far away), the detection step is resumed.

2.2.4 Boarding

The boarding team resides in the PS, and approaches the go-fast using the RHIB which is launched from the PS. The PS itself only provides cover to the boarding team.

The RHIB is launched only when the go-fast has been successfully intercepted and stopped. If the PS performed the interception, the RHIB may be launched from the position at which the PS stopped the go-fast. If the helicopter performed the interception, the RHIB may be launched from its maximum employment range. If, however, the RHIB's maximum sustainable speed is less than that of the PS due to the sea state, then the RHIB is launched only at the moment that the PS stops at the (minimum) safe distance from the go-fast.

Figure 7 shows the situation that the helicopter has stopped the go-fast and has taken position right above it. The RHIB has been launched from the PS and is on its way to board the go-fast.

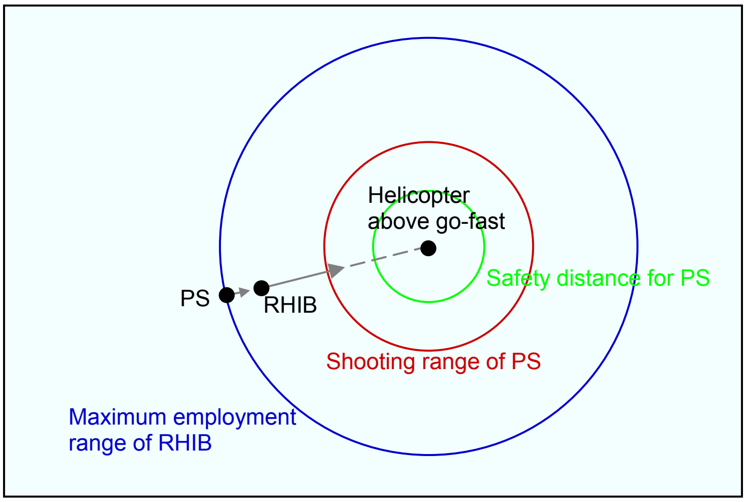

Figure 7: Boarding of a go-fast by the RHIB and approach of PS

After the go-fast has been boarded, the RHIB sails back to the PS and the helicopter resumes the detection step when possible. The RHIB is recovered when approaching the PS. Notice that the PS may not have reached its safety distance yet. If the crew of the go-fast must be arrested and the go-fast needs to be confiscated, then the go-fast will be handed over to the relevant authorities.

3.0 SIMULATION

For simulation of the MIO scenario an appropriate simulation model had to be obtained. During the last years TNO has developed several defence-oriented models, which can be used in the different military domains and for various applications. TNO's simulation model SURPASS, see below, is a model for the analyses of surface surveillance and was selected as the most suitable candidate for reuse.

3.1 SURPASS

SURPASS (acronym for 'SURface Picture ASSessment', see [4], [5], [6]) is a Monte Carlo computer simulation model that gives insight in the process of maritime surface surveillance, see Figure 8. It has been developed by TNO under guidance of and in cooperation with the RNlN.

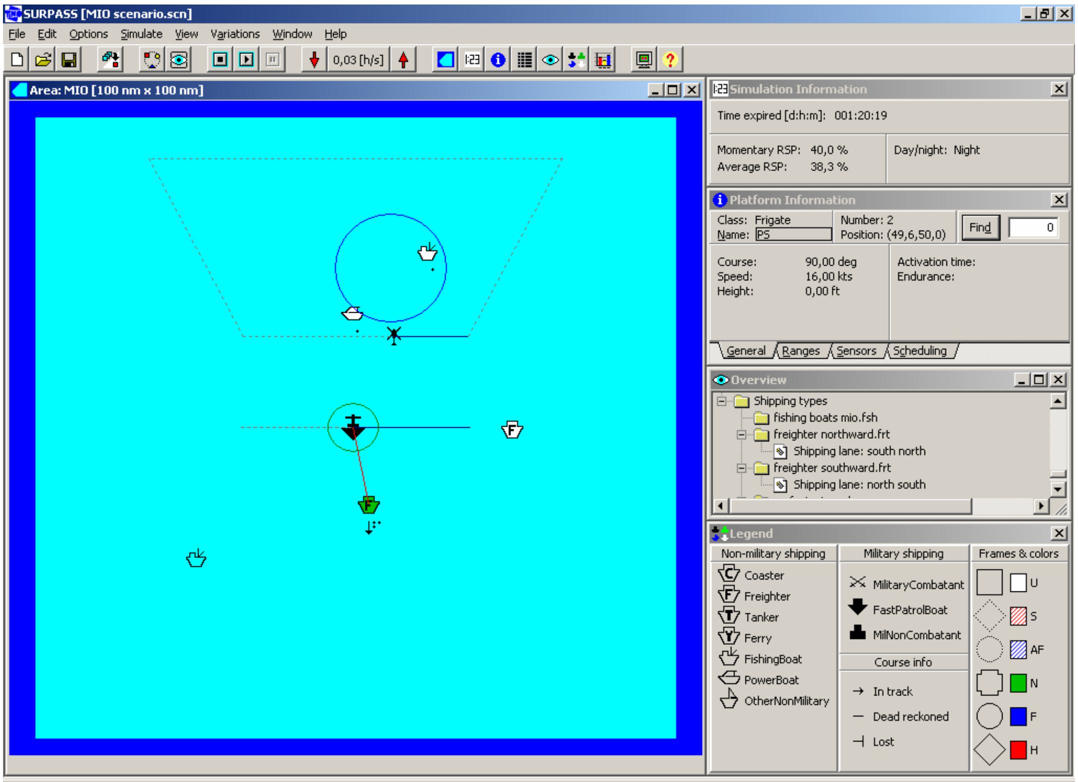

Figure 8: SURPASS

The main assets considered in SURPASS are frigates, helicopters and maritime patrol aircraft, along with their sensors (including radar, visual means, infrared systems and passive sonobuoys). Information gathered from other assets such as satellites and submarines can also be taken into account and collated into the surface picture.

SURPASS supports all phases of maritime surface surveillance: detection, localisation, recognition, identification and tracking. Detection is the search and discovery of new contacts. The localisation process involves determining the contact’s position, course and speed. Recognition means establishing the characteristics of the ship like its type or its individuality (name/number). Identification is the process of assigning a standard identity (or a Maritime Interdiction Force identity) to a ship based on the identification criteria (IDCRITS) specified by the user. At times, proper identification may involve the boarding of potential embargo violating vessels to look for forbidden cargo. Tracking is the process of following the contact once detected.

SURPASS provides a scenario editor allowing the user to define the area of operation, the shipping lanes, the shipping and the surveillance units operating there. The model can distinguish between different ship types such as military combatants, tankers, coasters, fishing-boats and go-fasts. The surveillance units are defined by parameters such as speed and availability, and by their sensor suite. Each sensor is characterised by the ranges at which it can detect and recognise the different ship types. Detection and recognition ranges in SURPASS are of the cookie-cutter type.

For this case study, the existing boarding process in SURPASS has been extended. The first extension was the addition of the organic RHIB. Secondly, the interception of a moving go-fast by a helicopter or a frigate has been modelled.

3.2 Modelling the MIO scenario

The Maritime Interdiction Operation scenario as explained in Section 2 has been modelled in SURPASS. All parameters of the operation were fed into SURPASS. Examples of these parameters are the time it takes to board a go-fast and parameters for the surveillance units (PS and helicopter) and the RHIB, such as the actual patrol speed as function of the sea state and a scheduling mechanism. This scheduling mechanism contains the rules on how to engage (recognise and intercept) a suspicious ship.

For detecting and recognising ships, the sensors onboard the frigate and helicopter must be defined. This is done by characterising the sensors by means of the distances on which the various ship types can be detected or recognised. Although SURPASS supports four levels of recognition, using one level was sufficient for this MIO scenario. Variations in altitude and day or night are taken into account. Although not explained in more detail, the gathering of validated sensor values is very important and should not be underestimated. Most of the sensor data used in SURPASS is gathered using other, more detailed, sensor models.

The scenario has been simulated for several sea states, which was assumed to be constant during a simulation run. Sea state can cause a significant degradation of speed, and therefore this speed reduction was modelled explicitly for each of the different ship types. Some of the manoeuvring that is required in reality due to sea state was not modelled explicitly as it was found that it did not significantly contribute to the results. In reality however, during helicopter take-off and landing the PS might have to manoeuvre to ensure an adequate relative wind angle and to guarantee a stable flight deck, and concerning launch and recovery of the RHIB the PS might have to change speed and course temporarily.

Two variants of the PS were taken into account, the original PS and an extended PS. The extended PS has better seakeeping behaviour and, as a result, has better speed performance in higher sea states.

The traffic (shipping) in the surveillance area consists of various ship types. In addition to the go-fast, other ship types are present as well: (foreign) military combatants, freighters following a northward or southward route, and fishing boats. Their occurrence and sailing behaviour is based on known traffic in the simulated area. SURPASS consists of a mechanism to control the generation of shipping entering the area. This mechanism uses stochastic distribution functions. The shipping density of the vessels in the surveillance area was varied between low, medium and high.

In practise, forcing a go-fast to stop may involve the use of (non-lethal) weapons etc. This stopping process has not been modelled explicitly in SURPASS. Instead, after taking position, it takes the PS or helicopter a certain (average) time to make the go-fast stop. It is assumed that the PS and helicopter always succeed in forcing the go-fast to stop. Moreover, the process of handing a go-fast over to the relevant authorities after arresting the smugglers, is not modelled in SURPASS.

4.0 ANALYSIS

With the simulation model SURPASS the MIO scenario has been analysed. To do so many simulation runs were defined based on the scenario ingredients depicted in Table 1:

Table 1: Scenario ingredients

PS variant	Maximum speed PS	Helicopter availability	Sea state	Shipping density
Original PS	low	partly available	1	low
Extended PS	medium	not available	2	medium
	high	available 24 hours per day	3	high
			4	
			5	

In order to determine the influence of helicopter availability (as described in Section 2) on the overall operational performance, simulation runs have been performed in which the helicopter is partly available, in which the helicopter is not available, and finally in which the helicopter is available all the time.

In total this leads to 270 different simulation runs (i.e. 2 (PS variant) × 3 (maximum speed PS) × 3 (helicopter availability) × 5 (sea state) × 3 (shipping density)). Each of those was simulated for 1000 days with SURPASS. As representative illustration of the results, this paper presents the results for sea state 3.

4.1 MOE

Whereas the MOE in Section 2 was defined as the percentage of go-fasts that have been successfully boarded, that performance indicator needs to be defined more specifically here for comparison purposes. The MOE should be defined as:

$$MOE_{MIO} = \frac{Boarding\ fraction}{Detection\ \ fraction}$$

The *Boarding fraction* is the number of successfully boarded go-fasts divided by the total number of go-fasts sailing through the surveillance area. The *Detection fraction* is the number of detected go-fasts divided by the total number of go-fasts sailing through the surveillance area.

In order to compare the results of all different simulation runs, the effect of maximum sustainable speed on the overall operational performance needs to be independent of the detection capabilities. In other words, the overall operational performance needs to be related to detection performance, i.e. the number of detected go-fasts[1]. The MOE should equal one if all detected go-fasts are successfully boarded, and the MOE should equal zero if none of the detected go-fasts are boarded.

4.2 Results

In this section the results of the data analysis are displayed graphically. On the horizontal axis of each graph, the different maximum sustainable speeds of the PS are shown (low, medium and high speed). Given the maximum speed of the PS, three different scenarios are considered based on shipping density (low, medium and high). The result of a scenario is represented into a bar indicating the MOE. For each sea state this results into 9 bars of MOE information.

The three figures below show the situations in which the helicopter is partly available (Figure 9), in which the helicopter is not available (Figure 10), and in which the helicopter is available all the time (Figure 11).

[1] Notice that during the detection and recognition phases, the PS sails at patrolling speed and never sails at maximum speed.

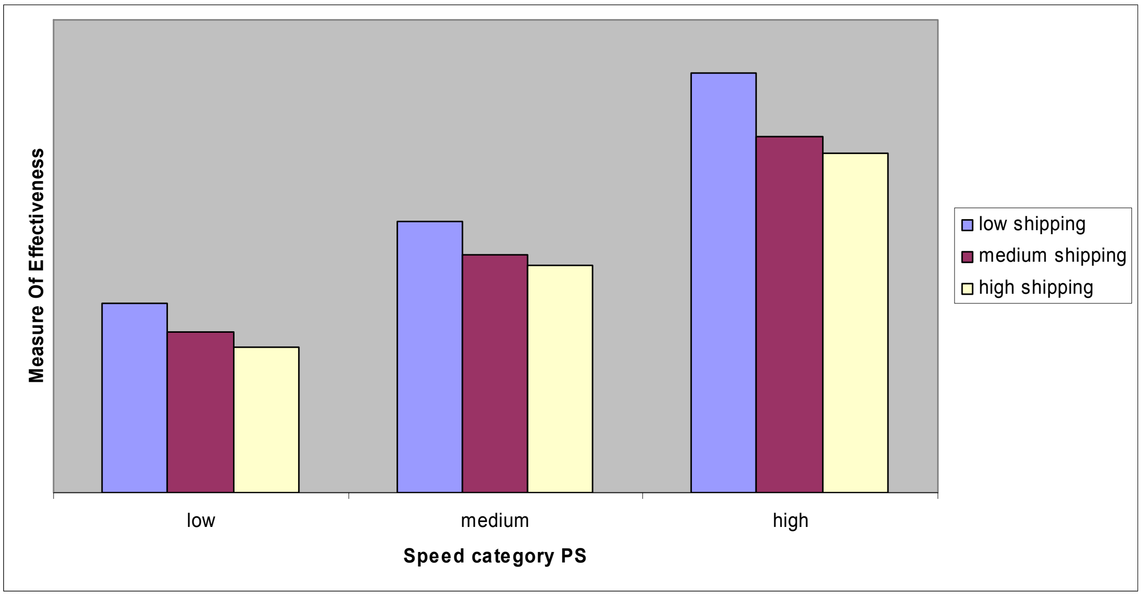

Figure 9: Results of PS and partly available helicopter (sea state 3)

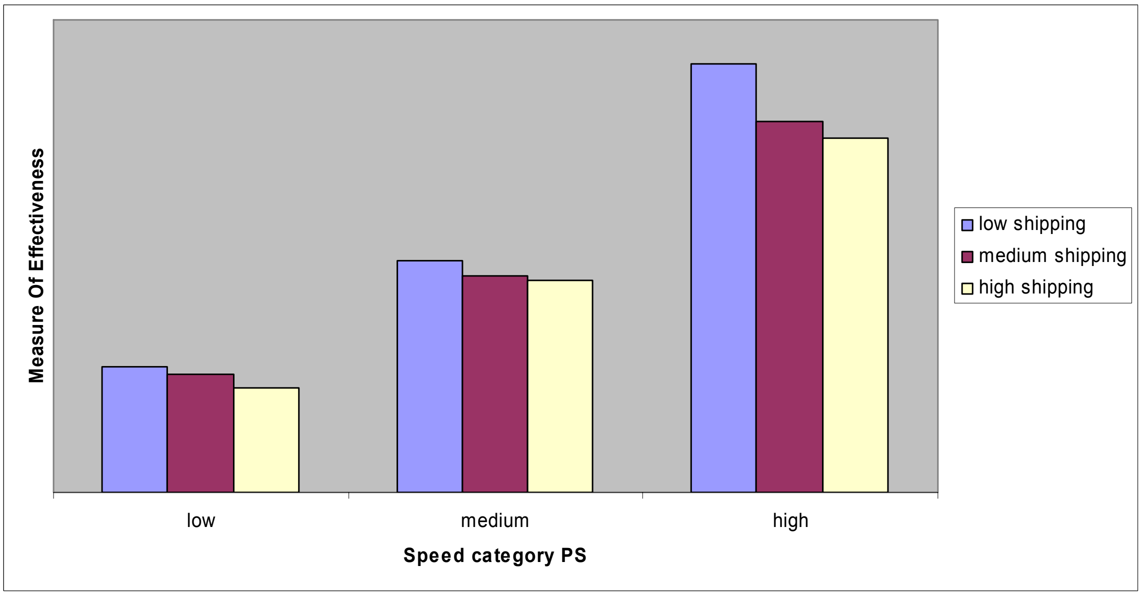

Figure 10: Results of PS only (sea state 3)

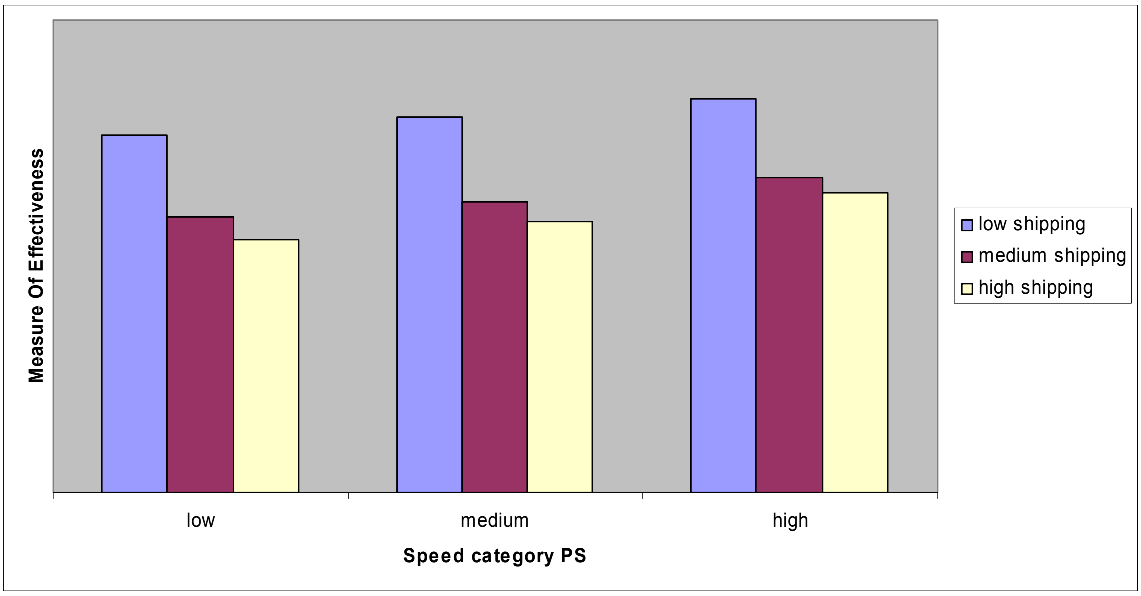

Figure 11: Results of PS and fully available helicopter (sea state 3)

The following conclusions may be drawn out of the analysis:

1. The increase of maximum sustainable speed from low to high results in an increase of more than 100% effectiveness in the situation of a partly available helicopter, see Figure 9. Notice that such helicopter availability is not uncommon in reality.

2. The increase of effectiveness is very high if no helicopter is available, see Figure 10.

3. The increase of effectiveness is minimal if making use of a helicopter continuously, see Figure 11. In this case it does not matter if the speed of the PS is low, medium or high. The explanation is that once a contact has been detected by the helicopter, it can be boarded at all times regardless of the time needed. The helicopter forces the contact to stop and wait for the PS.

Generally it is concluded that the overall operational performance considering a MIO scenario increases significantly when the PS is able to sail at higher maximum sustainable speeds.

5.0 CONCLUSIONS AND FUTURE WORK

This paper reports on a case study that is based on the Simulation Based Performance Assessment (SBPA) methodology developed by TNO. This methodology enables to make an integral performance assessment of an existing or future platform. The assessment is based on the platform's Mission and Task Tree and it employs simulation to analyse the performance of individual tasks.

In this case study, the SBPA methodology has been applied to a future class of Patrol Ships of the Royal Netherlands Navy. It has researched one important factor in ship design: the requirement on maximum sustainable speed. This case study considered the Maritime Interdiction Operation (MIO) scenario as it was anticipated that the influence of maximum sustainable speed on the overall operational performance could be significant.

From the analysis of the MIO scenario it is concluded that the ship speed is very important when assessing the mission effectiveness. The organic helicopter plays an important role as well, since it is operated as a high-speed, remote sensor and forces suspicious vessels to stop. Accounting for a realistic availability of the helicopter, it is concluded that a moderate increase of the maximum sustainable speed of the Patrol Ship already doubles the overall operational performance.

Recommendations regarding the execution of the MIO scenario can be derived from this study as well. Since the helicopter availability appeared to be a limiting factor, it is recommended to have multiple helicopter crews (and maintenance teams) onboard the Patrol Ship.

Concerning future work in the area of SBPA, a follow-up project is planned to model the main assumptions in the MIO scenario more explicitly. This may include the effects of certain countermeasures that smugglers may take. The SURPASS simulation model will be applied in other studies as well addressing the maritime surface surveillance area.

6.0 REFERENCES

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