Realism of TRANSAS NTPRO 5000 Radar Simulation in Search and Rescue Training Exercises

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In this study, the results of an evaluation of current navigational simulator Transas NTPRO 5000 ability of realistic training in search operations by radar has been presented. By testing the performance of detecting different targets at various distances from the vessel model and comparing the results to the theoretical models of radar limitations from the literature, we found that the equipment can be used in search and rescue training, but with several important limitations. Some aspects of radar simulation in the current simulator version is considered as acceptably realistic, but we identified several points where the results showed significant deviations from the theoretical models. Those points limit the equipment's ability to perform some aspects of search-by-radar training, and the instructors are advised to carefully set up exercises in a way that those shortcomings are avoided during student training.

KEY WORDS

~ Navigational simulator
~ Search and rescue training
~ Transas NTPRO 5000
~ Radar detection

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1. INTRODUCTION AND BACKGROUND

Around 360,000 lives are lost by drowning every year (WMRC, 2019). The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), adopted by the International Maritime Organization (IMO), requires that all navigational officers must undergo training procedures for search and rescue operations.

In typical SAR operations at sea, both visual and instrumental lookout takes place during area sweeps. However, when visibility is poor, either because of searching for the unlit object during night hours or during the day, in fog or precipitations like rain and especially snow, we cannot rely on visual search methods. In such a situation, different onboard equipment like the vessel's radar, infrared search devices, video cameras, and similar tools might be used to enhance the chances of target detection. Of these, the vessel's radar will be of highest value, given that the target's radar cross-section (RCS) is large enough compared to environmental clutter RCS.

Specialized navigational watch officers' training using navigational simulators is today an industry-wide accepted training method that accelerates gaining experience in handling dangerous situations that can be met in the real world. This method of training is particularly useful when onboard training is either not possible or would be too impractical or expensive. Many papers state that simulator training is an effective means to improve SAR efficiency (Kobylinski, 2011, Feng 2013).

Using simulators in the SAR training has a particular value because of very high costs, potential risks in the real world SAR exercises, and a limited number of participating personnel (Lubcke, 2016). However, despite having many advantages in navigational officers' training, simulators used in such a way must be very realistic and present reality accurately (Sorensen, 2006). In case of an unrealistic simulation, the training process will be less than optimal and in some cases even impossible, or the experience can be misleading if training is conducted using unrealistic equipment.

The goal of this study is to determine the ability of current nautical simulator equipment commonly found in the Croatian maritime training centers to be used in SAR operations training when the primary way of search is the vessel's radar observation.

As the simulator is a commonly used tool in students' training and a potentially excellent tool for search and rescue exercises, we state our hypothesis that the simulator used must be able to realistically display radar targets regarding the radar sensitivity to target the echo strength and respecting sea horizon limitations.

In this paper, we evaluate the accuracy and limitations of Transas NTPRO 5000 navigational simulator in simulating target detection using radar to test our hypothesis of the product's usability in students' training for search operations by radar. The realism of this particular aspect of the simulator has been tested against the theoretical model of radar detection. The particular tested version of the simulator did not include a special SAR module. The experiments showed mixed results compared to the theoretical models.

2. METHODS

In radar theory, the ability of a radar system to detect a particular object at a certain distance is determined using the basic radar range equation. The basic radar equation is given by (ex. Skolnik, 1981; Gržan, 2012

$$SNR = \frac{P_S}{P_N} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 k T_0 B F_n L} \tag{1}$$

where SNR is the signal-to-noise ratio (dB), P_s is the signal power (W), P_N is the noise power (W), P_T is the radar peak transmit power (W), G_T and G_R are the transmitting and receiving gain of the antenna and are usually expressed in (dB), λ is the radar wavelength (m), σ is the target's radar cross-section (m^2), R is the range from the radar to the target (m), k is the Boltzman constant, which equals 1.38x10^{23} W/(Hz K), T0 is the ambient temperature (K), B is the effective noise bandwidth of the radar (Hz), F_n is the radar noise figure (unitless), and L accounts for all the losses in the system (dB).

From Equation 1, by shifting terms the range equation can be derived. It is the maximum range at which the probability of detection of the target is high enough. To quantify the term "high enough", the SNR threshold is regularly used and usually set around 13 dB (Matika, 2013; Budge, 2011). In the literature, this value is also commonly referred to as the detection threshold, and the value around 13 dB is the threshold that represents the probability of 50 % for the target to be detected by the system.

$$R = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 (SNR)\, k T_0 B F_N L} \tag{2}$$

Apart from radar's ability to detect the echo returned from the target, there is also the limitation of range due to the radar horizon that results from the Earth's surface curvature (Bole, 2005). From ray geometry, the equation for the radar horizon can be derived. In normal atmospheric conditions, with standard refraction, the radar horizon distance equals

$$RHD = 4.12 \cdot \sqrt{H} \tag{3}$$

where the variable H is the height in meters of the radar scanner above the sea level, and the result is expressed in kilometers (ex. Briggs, 1996). When searching for a target floating on the sea surface, the target's height (h) accounts for the increased maximum range for the target to be above the horizon:

$$RHD = 4.12 \cdot (\sqrt{H}+\sqrt{h}) \tag{4}$$

The radar horizon distance expressed in nautical miles should be multiplied with the factor of 2.22 in Equation 4, which yields:

$$RHD=2.22 \cdot (\sqrt{H}+\sqrt{h}) \tag{5}$$

The radar will be able to detect the target if it is within its radar horizon distance (Equation 5) and within its maximum detection range (Equation 2).

In this paper, using Equations 2 and 5, different case scenarios have been simulated to provide an insight into the maximum range of radar detection. The calculated figures are compared to the observed maximum values using the simulator's radar equipment.

The tested Transas simulator was NTPRO 5000 version 5.35. Apart from the 5 different standalone types of radar simulation (Bridge Master, Bridge Master E, Bridge Master E Tactical, Furuno and Nucleus), the NTPRO 5000 features also a new, Multifunctional Display (MFD) integrated, chart-radar version, which we used in this study. The tested version was MFD 4000 v3.00.340 – MSN-34, build 5225.

Simulation parameters for SAR scenario experiments are given in Table 1. The radar values are copied from simulator settings and the documentation for both X-band and S-band radar models used. The missing values that are not documented are taken from the literature examples (Matika, 2013; Gržan, 2012) assuming the standard maritime radar equipment on large commercial vessels, and those are given in italics inside Table 1.

Table 1.
Simulator radar equipment parameters for X-band and S-band model used. Values for S-band model that are different from X-band are given in parenthesis.
Source: simulator's documentation, Matika, 2013, Gržan, 2012.

Parameter	Value	Unit
Peak transmit power	10,000 (30,000)	W
Antenna gain - transmit	*813*	*W/W*
Antenna gain - receive	*813*	*W/W*
Operating wavelength	0.0315 (0.0983)	m
Ambient temperature	290	K
Effective noise bandwidth	*2x106*	*Hz*
Radar noise factor	*3.98*	*W/W*
All losses	*5.01*	*W/W*
SNR detection threshold	*13*	*dB*

The simulator tested scenarios consisted of setting up target objects at small distance increments away from the stationary vessel model. The maximum distance has been noted for the radar model to be able to detect objects. The radar models were set up in an attempt to get the strongest target echo on the screen, still clearly discernible from the radar noise. The gain setting has been adjusted to 85%, anti-clutter sea and rain settings to 0%, pulse length to long, and echo accumulation filter to off. The radar scale setting was set to 24 nautical miles. The variable range marker tool has been used for distance measurements.

Four different vessel models with significantly different height above the sea surface have been chosen to assess the ability of the simulation to simulate the effects of the radar horizon accurately. The chosen vessel models with their particulars are given in Table 2. The eye height and air draft are taken from the simulator's documentation, whereas the radar antenna height is not documented, so we assumed some additional distance above the eye height (above wheelhouse) depending on the vessel type as the typical radar mast installation, but at a height that is lower than the vessel air draft value.

Both the X-band and S-band models of radar have been used to evaluate their simulated performance. The default simulator radar values have been accepted for X-band and S-band radar models tested, as presented in Table 1.

The radar's ability to detect the total of 5 different target objects (Table 4) has been evaluated. Of those, neither X-band nor S-band radar have been able to detect two objects regardless of the distance from the vessel, vessel model used or number of the same objects grouped together. Those were "Man overboard" and "Lifebuoy". The rest of the objects have been detected by both radar models from all the vessel models, and the obtained figures of maximum distances are presented in the results section.

The simulated environmental conditions were set to calm sea, no wind, and no precipitation, in order to avoid influence

Table 2.
Vessel models used for simulation exercises with particulars concerning estimation of radar antenna height over sea surface.
Source: Simulator documentation and author's estimation.

Abbreviation	Name	Eye height (m)	Air draft (m)	Radar antenna height (m)
BC7	Bulk Carrier 7 Panamax	22	49	35
LNG1	LNG 1	42	67.4	55
RRF6	Ro Ro Ferry 6	6	10.6	8
PBS	Patrol Boat Shkval	2	4.6	4

of the radar clutter on the experiment results, as the theoretical model equations we used do not account for clutter effects..

The radar cross-section (RCS) of a target is the fictional area intercepting the amount of power which, when scattered equally in all directions, produces an echo at the radar equal to that from the target (Skolnik, 1980). Some RCS measurements of real objects floating on the surface of the sea have been documented in literature and examples are shown in Table 3 (Williams, 1978). As the RCS value is highly dependent on the target aspect, there is a range of values for each target, but for this calculation purposes an approximate medium value is selected from the given ranges in the literature.

Table 3.
Typical RCS values for common SAR targets.
Sources: (Williams, 1978; Gržan, 2012).

Example target	Typical RCS value (m^2)
Inshore fishing boat / life boat	5
Small open rowing boat	1
Small to medium size metal ship	100
Life raft	0.5
Man overboard	0.1

The RCS values of objects in the simulator are not documented, so we assumed the typical values given in the literature (Williams, 1978; Gržan, 2012) for floating objects similar enough to those used in testing. For the purpose of calculating the maximum theoretical range limited by the radar characteristics and target RCS value ignoring radar horizon limitation, we assumed the RCS value for the target objects as given in Table 4.

It should be noted that non-conductive materials like the ones used for life-buoys have much lower reflection of the radar pulses than conductive materials like metal. So, life-buoy and man overboard object should have small RCS value and, consequently, be much harder to detect on the radar screen. Still, we argue for them having non-zero RCS value that should be at least barely detectable in the environment where no clutter is present and the radar gain setting is maximized. The fact that radar can be used for bird detection has been known for a very long time (Lack and Varley, 1945). Also many radar manufacturers are currently advertising "bird mode" for fishing purposes. So, if radar is able to detect birds at more than several nautical miles away, we claim that it should also be able to detect human head floating above the surface since it is of a size comparable to that of a bird and also because humans and birds share similar tissue properties. Therefore, we hypothesize that the marine radar should be able to detect at least a group of several people floating together around a life buoy if not a single person alone. However, the best method to verify the hypothesis that the marine radar should be able to detect a man overboard or a life-buoy on calm sea would be to perform the actual testing on board vessel (not performed in this study).

Table 4.
Simulator objects used as targets in tests. Target names are from simulator documentation and RCS values are estimated by the authors.

Target object name	Estimated RCS (m^2)	Notes
Life raft	4	Assumed that a medium-size passive radar reflector effect is simulated
Cardinal buoy	2	Assumed that a small-size passive radar reflector effect is simulated
Pella boat	1	
Man overboard	0.1	
Life buoy	0.1	

3. RESULTS

The results of radar ability to detect small targets at a certain distance from the targeted vessels are presented in Table 5. The figures are given as the maximum observed range at which visual detection was still possible for a particular model of the vessel, using X and S-band radar for each type of the target, with the values expressed in nautical miles. In addition, an approximate maximum theoretical distance due to radar horizon in standard atmospheric conditions is given for each combination of radar antenna height and target object height, calculated by using Equation 5, where target height is set to be 1.5 meters above the sea level for all the three detectable target objects, as there is no documented height for those objects in the simulator. Non-detectable objects (man overboard and life-buoy have not been used in the further range calculations). For S band radar, coefficient from Equation 5 is slightly larger than for the X band radar because of increased diffraction of larger wavelength, but the difference is small and insignificant for the results presented. So, we assumed 2.22 coefficient for both radar bands.

Table 5.
Observed maximum radar ranges for targets used for both X-band and S-band radar models. Results are given for all vessel models used. RHD column is radar horizon distance calculated for vessel model antenna height and target object height using the theoretical equation. Two objects that are not detectable at all regardless of distance are left out of the table.
Source: authors' observation.

	Observed max. values (NM)						Theoretical max. values (NM)
Target	Life raft		Cardinal buoy		Pella boat		RHD
	X	S	X	S	X	S	
Vessel model							
BC7	8.5	14	7.5	12	6.7	10.5	15.9
LNG1	8.6	13.5	7.4	11.8	6.2	10.8	19.2
RRF6	8.6	13.4	7.5	11.4	7.1	10.2	9
PBS	8.5	14.1	7.6	12.2	6.5	10.9	7.2

As shown in the table above, there is virtually no observed difference in the maximum range between vessel models for a particular type of radar. However, the simulated detection range significantly surpasses radar horizon distance for the vessel models with low antenna height above sea level. Those findings lead to a conclusion that the radar horizon effect is either not simulated properly or most probably not simulated at all in this particular version of the simulator.

With those figures, documented radar particulars and Equation 2, we calculated the maximum theoretical distance for each combination of radar type and target object. The results are given in Table 6.

In Figure 1, the observed maximum distances of the target objects tested are compared with the theoretical maximum distances depending on target RCS values for both simulated radar models. The theoretical maximum distance lines are calculated using Equation 2 and they ignore the effects of the radar horizon. The observed maximum distances are plotted as scatter plot (dots). The comparison shows an acceptable level of agreement between the theoretical model and the observation on the simulator.

Table 6.
Maximum theoretical range for target objects calculated using radar equation.
Source: authors' calculation.

Life raft		Cardinal buoy		Pella boat		Man overboard / Life buoy	
X	S	X	S	X	S	X	S
7.2	16.8	6.1	14.1	5.1	11.9	2.9	6.7

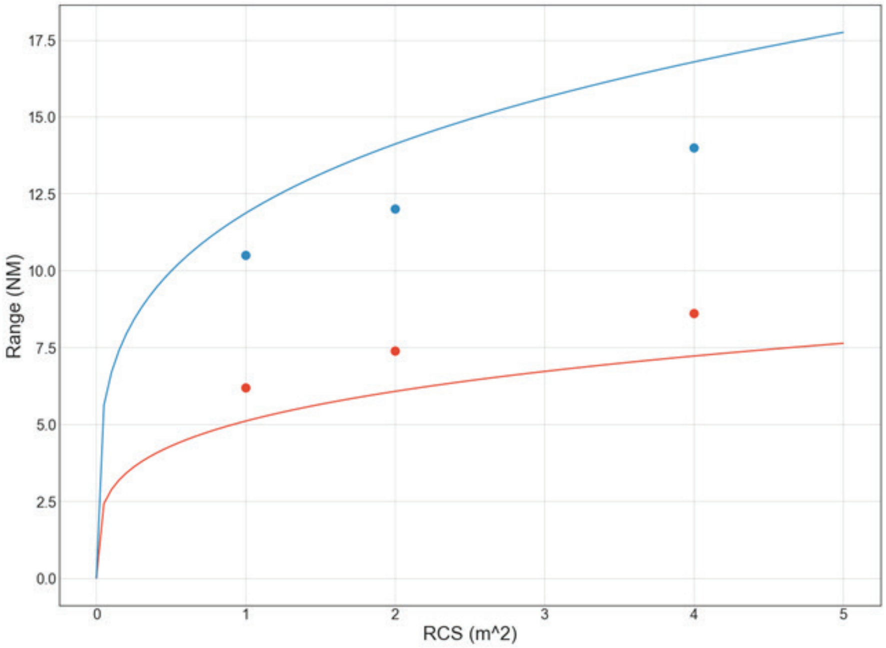

Figure 1.
Comparison of theoretical maximum radar range for a given target RCS value, calculated using radar equation (solid lines, blue for S-band, red for X-band model), with observed maximum distances (dots, blue for S-band, red for X-band model) for three detectable targets at RCS 1 m^2 ("Pella boat"), 2 m^2 ("Cardinal buoy") and 4 m^2 ("Life raft").

4. DISCUSSION, CONCLUSIONS AND FURTHER WORK

The results of the study experiments on the Transas NTPRO 5000 simulator show several shortcomings that can be important for SAR exercise training. In the conducted tests, the simulator was completely unable to detect some target objects like "Man overboard" and "Lifebuoy" regardless of their distance from the vessel. There is a high probability that those objects are not simulated within radar simulation at all and can be used in SAR exercises using visual lookout only. Failure to display those targets on the radar screen makes them unusable for SAR exercises where radar equipment is used, which is practically in all SAR exercises.

Another important problem with realism that we have found out in this study is the radar's inability to simulate the effects of the radar horizon. The results from Table 5 show that no amount of change in radar antenna height above the sea level impacts any results on the maximum detectable distance for low-height objects like small targets used in SAR exercise operations.

On the positive side, the effects of the maximum range depending on the target RCS seem to be simulated with acceptable realism as shown on Figure 1. As target RCS data is not recorded in the simulator documentation, we estimated it and, because of that approximation, it is not possible to comment on the small differences found between the maximum theoretical range and the maximum observed range on the simulator radar screen. However, the general agreement of the results of both X-band and S-band observations vs.(versus???) equation suggests that radar sensitivity and dependency on target RCS are simulated well enough.

Our results show that in simulated SAR exercises on the tested type of simulator the instructor must be aware of its limitations and set up exercises so that the aspects that are not simulated with acceptable realism will not impact the exercise and the training outcomes. In particular, we suggest that objects like "Man overboard" and "Lifebuoy", which cannot be detected on the radar screen at all even in ideal search conditions, are not used in SAR exercises. Also, instructors are advised to pay particular attention to limitations due to the simulator's failure to simulate the radar horizon effect on detectable distances of low-height objects. Special attention has to be put to situations where small vessels are used as SAR units because in such situations targets can appear on the radar screen much farther away than they should as radar horizon limitations have not been simulated. This problem is pronounced with S-band radar simulation because of its ability to detect small RCS targets at much larger distances.

In order to validate some parts of our hypothesis, apart from comparing simulator results to the theoretical models, a comparison with onboard equipment would have been necessary. This refers particularly to our viewpoint that actual onboard radar should be able to detect life-buoy and man overboard floating on the calm water surface as we are not aware of any study that confirms or rejects this hypothesis. So, that can be a good direction for further research in the area. Also, the real measurement at sea could improve our understanding of radar's maximum detectable range of objects that are detected in simulator tests such as a life-raft and small non-metal boats.

We also suggest that the simulator manufacturer should provide a patch in the future product updates to properly simulate radar horizon effects in the simulation.

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