Counter piracy surveillance requirements for early detection, military rescue, or evasion

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COUNTER PIRACY SURVEILLANCE REQUIREMENTS FOR EARLY DETECTION, MILITARY RESCUE, OR EVASION

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Abstract: *Best practice for protection against pirates includes coordination with the military forces operating in the area, constant watch against the approach of pirates, and measures to prevent or delay their boarding. The time won by the early detection of distant pirates and by the delay of boarding increases the chance that the military can intervene before pirates can get on board. Increased speed along an evasive course also increases the chance that pirates will break off the chase because it is taking too long or it is consuming too much fuel. Rough seas can slow pirate skiffs, adding significantly to the response time won by early detection. A probabilistic model is developed here for estimating the detection range required for escape from approaching pirates prior to boarding, either by military rescue or by evasion. The parameters in the model are taken from reports of pirate behaviour and from military coverage of the Internationally Recognized Transit Corridor (IRTC). The detection-range requirements depend strongly on the response time of military forces. For large merchant ships with maximum speeds on the order of 17 to 22 knots, the range requirements given 20-minute military response time in the IRTC are estimated to be on the order of 6.0 km. In regions outside military coverage, the ship's crew may try exhausting pirates in the chase, but it is found that the detection-range requirements given calm seas are difficult to achieve in practice. The model could be applied to faster or slower vessels and military response, and to rough sea conditions to explore a wider range of situations. The assumption is that military rescue or evasion is preferred above response by armed guards.*

Keywords: *Piracy, Counter Piracy, Merchant Ship Self Defence, Surveillance Requirements, Early Detection and Evasion*

1. INTRODUCTION[1]

Protection can be defined many ways. Here we assume it means the prevention of *close engagements with pirates* through either:

1. timely intervention by military forces in counter-piracy operations—the arrival of military forces before pirates come alongside the merchant vessel to board the vessel, forcing the pirates to give up the chase;
2. evasion of pirates—pirates break off the chase of their own choice, because they see they have lost the element of surprise, they find the crew is vigilant against attack, the chase is taking too long, it is consuming too much fuel, or they are not gaining on the vessel because seas are too rough, and so forth.

Preventing close engagements with pirates avoids exposure to close-range pirate weapon fire and boarding. If it is possible to do this reliably, then it naturally reduces the risk of harm and liability so far as the merchant vessel, its crew and its stakeholders are concerned. It would therefore be protection of a high standard. Such protection has implications on the requirements for the early detection of pirates.

2. CHASE SCENARIO

A chase can be uncertain and complicated in many ways. Our approach will be 1) to work with observable parameters only, and 2) to estimate the most salient requirement of any surveillance, namely its *coverage range*, in a way that military rescue or evasion are expected outcomes.

An idealized chase scenario is shown schematically in Fig. (1).

1. At times $t < t_0$, the merchant ship is underway in open waters with steady course and speed (assumed). It is assumed that the pirates detect the merchant before the merchant detects the pirates.
2. At time $t = t_0$, the pirates enter into the merchant's surveillance coverage range D_M. They are detected and the chase begins. The merchant immediately calls for assistance from the military, increases speed maximum v_M, and changes to a maximally evasive course heading directly away from the pirates.
3. The chase ends at some later time $t = t_0 + T$, and it ends happily if the merchant's surveillance system has been properly designed, with

   a. the military arriving to force the pirates to break off their chase, in which case $T = T_I$, or
   b. the pirates giving up the chase by their own choice, with $T = T_P$.

The surveillance coverage range D_M must be great enough to ensure that, for given merchant and pirate speeds v_M and v_P respectively, the pirates have not reached vessel

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[1] The present work is an extraction from [1].

before one or the other of those outcomes have been achieved. For simplicity, constant speed and heading are assumed for the merchant and pirates throughout the chase (after time t_0). The distance travelled by the pirates from their detection to breaking off the chase will be $v_P T$, with $T = T_I$ or T_P. In the worst case, the pirates have virtually reached the ship when they break off the chase, having travelled, as we can see from Fig. (1), a distance of $D_M + v_M T$. This limiting case sets a bound on D_M inasmuch as

$$D_M + v_M T > v_P T, \tag{1}$$

whereby

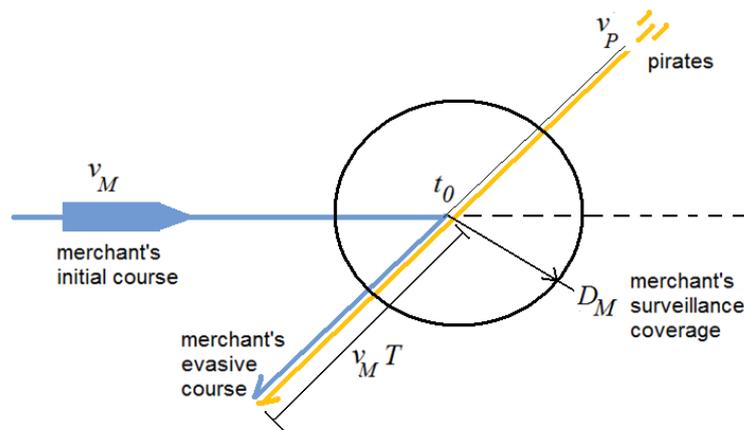$$D_M > T(v_P - v_M), \qquad T = T_I \text{ or } T_P. \tag{2}$$

Figure 1: *At time t_0 the watch on board the merchant ship detects the approaching pirates at range D_M, takes a maximally evasive course, and calls for military assistance. Intervention Scenario: The military arrives at time $T = T_I$. Evasion Scenario: The pirates give up the attack on their own at time $T = T_P$. The merchant's distance travelled during the chase is $v_M T$.*

The instantaneous sharp turn of the vessel indicated in Fig. (1) is of course unrealistic for any vessel. It may furthermore be inadvisable insofar as turns dramatically reduce the speed of the escaping vessel. The tight turn is used here for simplicity and generality. Turning radius, load conditions, and sea state are deliberately ignored. Among the many assumptions made in this analysis, this may be the most troubling for mariners because it touches their experience most directly. Our intent, however, is not to make recommendations to merchant mariners regarding evasive manoeuvres. It is not recommended here that merchants rely on evasion as a key part of their security plan, for instance. The intent is simply to estimate lower bounds on the distance at which merchants must recognize pirates as such if a security plan relied heavily on evasion as a means of escape. Reliance on evasion is only justified insofar as it can be supported by early detection. The results derived here calibrate our appreciation of the challenges imposed on surveillance by reliance on evasion. The methodology provides quantitative information for scoping what sensors might be considered for estimating their overall cost, and for judging the overall feasibility of evasion, at an early stage, before security plans are drafted or sensor procurements are made. They bring us into the ballpark of surveillance

requirements inasmuch as smaller detection ranges (smaller than those determined using a method like that given below) cannot be expected, as a rule, to support evasion.

3. EFFECTIVENESS OF EARLY DETECTION

Equation (2) is a surveillance system requirement. The surveillance must be able to detect and recognize pirates as such at distances greater than indicated by the right-hand side. All of the parameters on the right are uncertain. Assume that the parameters on the right in (2) are independent random variables distributed uniformly between lower and upper bounds, such as:

- merchant vessel top speed (constant) uniformly distributed between 17 and 22 knots;
- pirate skiff top speed (constant) uniformly distributed between 20 and 30 knots;
- time to pirate exhaustion uniformly distributed between 30 to 90 minutes;
- military response times uniformly distributed between the limits indicated for each curve

  - 15 to 25 minutes, average 20 minutes (solid line)
  - 25 to 35 minutes, average 30 minutes (dashed)
  - 35 to 40 minutes, average 40 minutes (dash-dot)
  - No military response available (infinite response time in effect) (dotted)

We can estimate an effectiveness E for a given coverage D_M by analyzing a large population of randomized trials (Monte Carlo method)

$$E(D_M) = \frac{1}{N}(number\ of\ trials\ in\ which\ D_M > T(v_P - v_M)\ ). \qquad (3)$$

The fact that the military might have intervened in some cases when the pirates would have eventually given up the chase by their choice must be included. The effectiveness $E(D_M)$ is the portion of merchant ships who escape a close engagement with the pirates due to early detection of the approaching pirates because the pirates have been detected at a distance D_M from the ship, either by military intervention or by outrunning the pirates.

The result is plotted in Fig. (2). We used $N = 20000$ trials throughout this work. It is clear from the graph that the effectiveness of a given coverage range D_M increases as the response time of military forces increases. The effectiveness of 4 km coverage, for instance, goes from about 16 % without military coverage (merchant relies only on outrunning pirates) to a 60 % effectiveness when sailing in areas where a 20-minute (15 to 25 minute) military response time can be expected. The reason is that early detection is more likely to prevent a close engagement when military are near at hand to respond than when military are not available to respond. What the analysis provides, however, is the quantitative degree of the improvement.
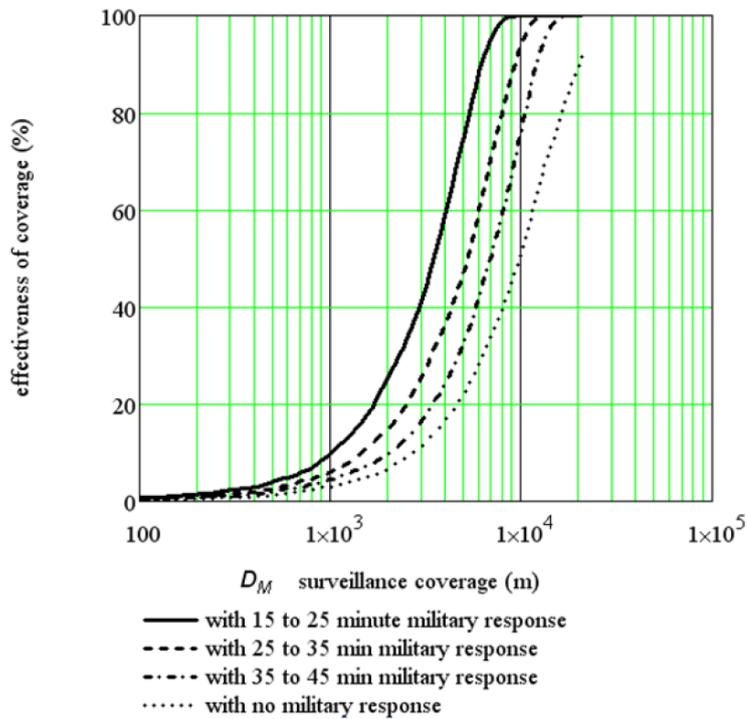
Figure 2: *The effectiveness of early-detection coverage as a function of the range of surveillance coverage. The curves terminate on the left at a distance D_M equal to the line-of-sight distance to the horizon from a point 30 m above the water—a nominal upper bound for the coverage range for shipboard surveillance.*

If we define low, medium, and high performance by the 10, 50, and 90 % adequacy levels, then Table (2) summarizes the respective minimum coverage requirements. As a rule of thumb, the range requirement in an area with 20-minute military response time (like the IRTC) is about 1/3 that when sailing without military protection.

effectiveness E		min. coverage range D_M (km)	
		with 20-min military response	without military response
level	%		
low	10	1.0	2.3
medium	50	3.3	10.0
high	90	6.0	20.0

Table 1: *Minimum surveillance coverage ranges (in km) for low, medium, and high levels of effectiveness when sailing through area with 20-minute military response time (military operations column) and without military operations.*

The present analysis has so far assumed that the probabilities of target detection and recognition are both 1.00 at the range D_M, which is unrealistically optimistic. It is often possible to estimate such probabilities for more realistic modes of surveillance by experimentation or physical modelling. Fig. (3) illustrates nominal detection and

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recognition curves for X-band radar (estimated by computer models [2]), FLIR camera (estimated by Johnson Criteria [3] and manufacturer's specifications [4]), and human vision (estimated by Johnson Criteria applied to human vision by the authors) under good conditions.

An estimate of a sensor's overall effectiveness $S(D_M)$ for providing early detection for avoiding close engagement with pirates is product of its performance probability $P(D_M)$ and the effectiveness $E(D_M)$ from above,

$$S(D_M) = P(D_M)\, E(D_M) \tag{4}$$

This might be called the *joint probability of effectiveness* for a given sensor performance *P* in range against pirate skiffs. It is the probability of both detecting pirates and escaping them by military intervention or evasion, given that pirates are approaching from a large distance. *S* is plotted in Fig. (4) and (5) with and without military response given the radar, FLIR, and human vision for use in early detection of pirates considered in Fig. (3). *S* gives a good indication of the adequacy of each sensor in terms of their overall effectiveness for merchant ship self protection in counter piracy.

Sensors generally perform better at short distances than at long, while early detection requires sensors that perform better at long distances than at short. These two obvious but competing principles are brought together quantitatively in Fig. (4) and (5). Long-range sensors tend to be more expensive. The overall sensor effectiveness *S* in Fig. (4) and (5) can be used in cost-benefit comparisons for surveillance system design or procurement.
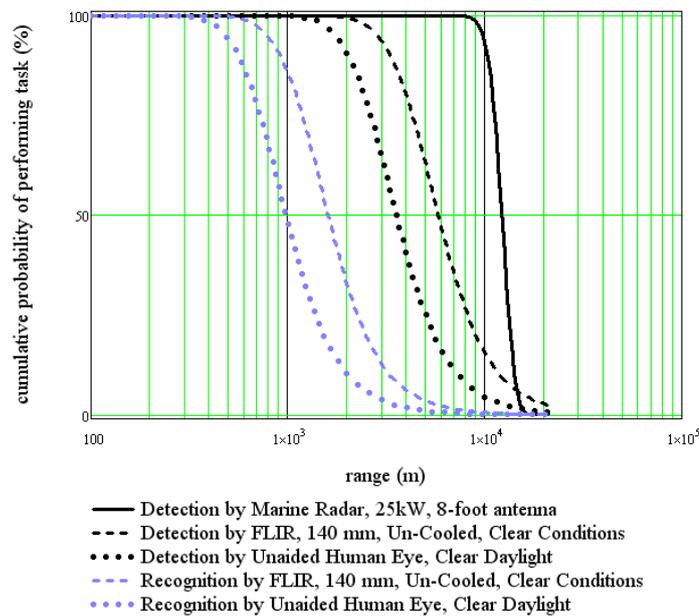

Figure 3: *The estimated performance probability in range using a nominal marine radar, FLIR camera, and unaided human vision.*

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With 15 to 25 Minute Military Response Time

Detection by Marine Radar, 25kW, 8-foot antenna
Detection by FLIR, 140 mm, Un-Cooled, Clear Conditions
Detection by Unaided Human Eye, Clear Daylight
Recognition by FLIR, 140 mm, Un-Cooled, Clear Conditions
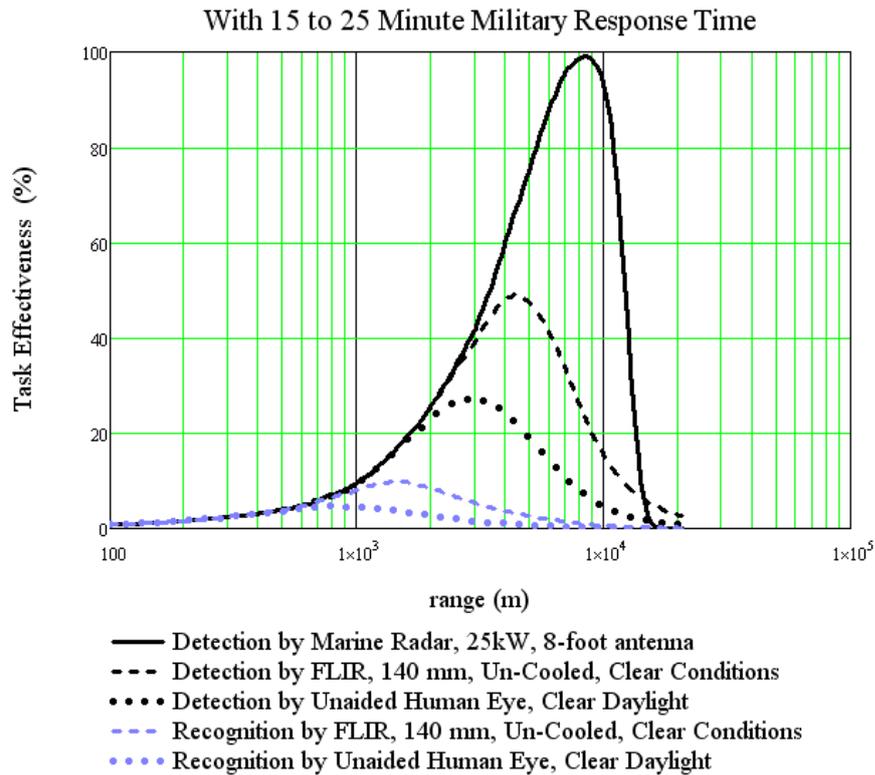Recognition by Unaided Human Eye, Clear Daylight

Figure 4: *The estimated task effectiveness of the nominal means of surveillance featured in Fig. (3), for use in early detection and recognition of pirate skiffs when sailing in areas where the military response time is expected to be 20 minutes, as in the IRTC.*
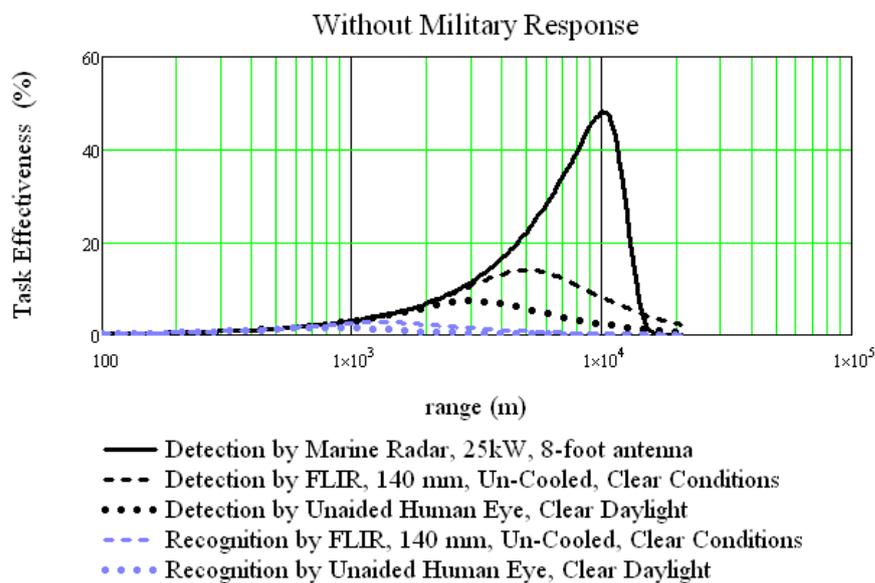
Without Military Response

Detection by Marine Radar, 25kW, 8-foot antenna
Detection by FLIR, 140 mm, Un-Cooled, Clear Conditions
Detection by Unaided Human Eye, Clear Daylight
Recognition by FLIR, 140 mm, Un-Cooled, Clear Conditions
Recognition by Unaided Human Eye, Clear Daylight

Figure 5: *The estimated task effectiveness of the nominal means of surveillance featured in Fig. (3), for use in early detection and recognition of pirate skiffs when sailing in areas where the military is not operating, and one intends to evade pirates by outrunning them.*

4. DISCUSSION

Of the three nominal modes of surveillance used to illustrate the method here, the radar provides the best early detection with 100% overall effectiveness given 20-minute military response (Fig. (4)). That effectiveness drops to about 50% (maximum) in areas without military coverage (Fig. (5)). Unfortunately the detection of distant radar contacts will generally be insufficient to justify a call for military assistance and a change of course and speed. This would be true in fishing areas or coastal waters for instance, where many fishing boats may be encountered. The merchant must then acquire more information about distant objects that justifies resource-affecting decisions such as changing alert stance, calling for military assistance, and changing course and speed. This may be by behaviour analysis or visual cues by electro-optics or by the watch.

The effectiveness of the FLIR camera in this example is much less than the radar. Indeed, if recognition is required to justify response measures, then the surveillance effectiveness of the radar-FLIR combination is reduced to 10% given 20-minute military response (blue dashed line in Fig. (4)). Effectiveness is reduced to 3% given no military response (blue dashed line in Fig. (5)). In that case attempting to outrun pirates may be generally advisable, but it cannot be a pillar in one's security plan.

This may be true more generally given affordable pirate-recognition capability for merchant mariners. Hence close engagements must be expected under clear conditions, and additional anti-boarding protection measures must be designed accordingly, perhaps by including armed guards on board. Rough seas hamper pirates and can provide significant advantage. They could be included if the pirate speed for a given sea state were estimated.

There are other factors than coverage range to be considered in surveillance, such as 360-degree coverage—straightforward for radar perhaps, but a degree complication for some electro optics. The watch keeper must also be attentive to the sensors with unflagging vigilance. Otherwise automatic detection algorithms and alarms to the bridge must be used.

5. CONCLUSIONS

The minimum detection range requirements D_M for early detection for rescue from a pirate attack by timely military intervention or evasion of pirates were found to be

- 6 km (3.2 nmi) in areas where 20-minute military response is available, and
- 20 km (10.8 nmi) where military intervention is not available.

The first (6 km) is higher than the 4 km (2.2 nmi) estimated by Tsilis [5] for merchants in a convoy with one military vessel. It can be shown that Tsilis estimates the onset of effectiveness (50%), where high effectiveness (90%) was used here The Tsili requirement is nevertheless consistent with the present results.

The method illustrates that surveillance requirements and the mode of response are strongly interdependent. Thus the effectiveness of military intervention depends strongly on the surveillance capability of merchant shipping, and *vice versa*. Military effort

obviously improves protection by intervention, but it also reduces the surveillance requirements and hence the cost of early detection for merchants.

It was shown how the effectiveness of early detection is the outcome of two competing tendencies: 1) early detection being more effective at long ranges, versus 2) shipboard surveillance being more effective short ranges. Surveillance and response are mismatched insofar as these competing tendencies cancel each other out. The analysis casts their match or mismatch quantitatively in the analysis of overall protection.

For system developers it shows how sensors can be assessed for counter piracy, and how incremental changes in sensors can be compared quantitatively in terms of overall effectiveness. The analysis can therefore be used in cost-benefit analyses. For military operations it provides a measure of effectiveness. It shows their effectiveness can be high. For merchant mariners it shows how challenging early detection can be in practice. In the absence of very exceptional surveillance capability, close engagements with pirates must generally be expected in calm seas. Additional anti-boarding protection measures must be considered. Different requirements result if merchants opt to face pirates with armed guards in close-range confrontation.

6. REFERENCES

[1] Kessel, R.T., and de Rosa, F. "Merchant Mariner Surveillance Range Requirements for Avoiding Close Engagements with Pirates", NATO Undersea Research Centre, Full Report, NURC-FR-2012-002, Apr 2012.

[2] SSR Engineering, "Marine Radar Detection Performance Comparison", Technical Note, SSR Engineering Inc., Anaheim, California, 12 July 2011

[3] Holst, G., Electro-Optical Imaging System Performance, 4th Edition, SPIE, JCD Publishing, FL, 2006

[4] FLIR, Voyager II Brochure, FLIR Systems Inc., Breda, Netherlands, 2009.

[5] Tsilis, T., "Counter-Piracy Escort Operations in the Gulf of Aden", Thesis, Naval Post Graduate School, Monterey California, June 2011

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