



# A Metric for Maritime Intelligence, Surveillance, and Reconnaissance (ISR) - Probability of Identification

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**Defence R&D Canada**  
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**Defence R&D Canada – CORA**

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## Abstract

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The Probability of Identification ( $P_{ID}$ ) metric is a method for measuring and scoring the quality of maritime Intelligence Surveillance and Reconnaissance (ISR) activities in an operational context. The metric presents a clear, easy to interpret, quantitative measure of effectiveness of maritime ISR activities over a defined period of time, and has been adopted by Canada's regional operational commands as one of the standard metrics for maritime ISR reporting. The aim of this paper is to describe the theoretical and technical underpinnings of the  $P_{ID}$  metric for a scientific audience. The current metric serves as a starting point for evolving a much more comprehensive metric for maritime ISR.

## Résumé

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La mesure de la probabilité d'identification ( $P_{ID}$ ) est un mode de mesure et de pointage de la qualité des activités de renseignement, de surveillance et de reconnaissance (RSR) maritimes dans un contexte opérationnel. La méthode présente une mesure facile à interpréter, claire et quantitative de l'efficacité des activités RSR maritimes pendant une période définie. Elle a été adoptée par les commandements opérationnels régionaux du Canada comme l'une des mesures normalisées du signalement RSR maritime. Le présent document vise à décrire les piliers théoriques et techniques de la mesure PID pour un auditoire scientifique. La mesure actuelle sert de point de départ à la mise en place d'une mesure globale des activités RSR maritimes.

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# Executive Summary

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## A Metric for Maritime Intelligence, Surveillance, and Reconnaissance (ISR) - Probability of Identification

S.A. Horn, N.L. Carson, A.F. Wind; DRDC CORA TM 2009-037; Defence R&D Canada – CORA; September 2009.

**Background:** There is an operational requirement for the Canadian Forces (CF) to maintain maritime Intelligence Surveillance and Reconnaissance (ISR) capability in support of Canadian national defence and Canadian national security. The information collected from maritime ISR activities is compiled into the Recognized Maritime Picture (RMP) through Command Control Communications Computers (C4) activities. Strategically, the Canadian Navy has been modernizing by combining information from new sensor technologies and Other Government Department (OGD) sources, with data being shared through Marine Security Operations Centre (MSOC) activities. Improving the quantity and quality of data from activities such as this also results in an improved RMP, and the benefits of these new activities can and should be measured.

The information being reported to the operational commander must be useful. Probability of Identification ( $P_{ID}$ ) is a fundamental metric that not only indicates the effect of surveillance, but it also represents identification: the first step to a threat assessment. Visual identification was requested by the operational commander as the most trusted form of surveillance information, even though other sensors can provide the identity of targets.  $P_{ID}$  starts to give the operational commander a true sense of the risk associated with gaps in maritime surveillance.

**Principal results:**  $P_{ID}$  is calculated based on the frequency of patrols ( $\tau_{regular}$ ), the transit times of maritime targets ( $T$ ), the effectiveness of a surveillance patrol ( $\eta$ ), and noting that multiple detections and identifications do not add any additional information about the identity of the interrogated target. Considering a single target in one area yields:

$$P_{ID} = \begin{cases} \frac{T}{\tau/\eta} & T \leq \tau \\ 1 - (1 - \eta)^{T/\tau} & T > \tau \end{cases}$$

The definition is then expanded to incorporate multiple patrol areas, and multiple traffic routes.  $P_{ID(Route\ Average)}$  is a cumulative result, which simplifies interpretation of the effect of multiple patrols and ISR activities over time.

$$P_{ID(Route\ Average)} = \frac{\sum_{i=1}^{N_R} P_{ID(Route)_i}}{N_R}$$

Where  $P_{ID(Route)_i}$  is the  $P_{ID}$  of all traffic on route  $i$  over all transited patrol zones and there are  $N_R$  routes.

**Significance of results:** Because averaged route  $P_{ID}$  directly measures the effect of surveillance activities, the identification of vulnerabilities is reduced to simply observing a  $P_{ID}$  map of the Area of Responsibility (AOR). It is a number that can be easily compared over different times of year, and different areas.  $P_{ID}$  is simply a number for each zone indicating the percent of incoming vessels within that zone that are expected to be identified, it is not dependent on how many vessels are transiting within the zone, and there is no need to understand the specific traffic patterns within the AOR to properly interpret its meaning. The metric presents a clear, easy to interpret, quantitative measure of the maritime ISR activities over a period of time.

**Future work:** With constant addition of new sensors and fusion tools, it will be important to evolve the ISR effect metric to account for these new capabilities. Although the  $P_{ID}$  metric presented here is calculated for visual identification, an extension of the metric that incorporates an information trust coefficient will enable  $P_{ID}$  reporting of non-visual ISR activities. Work towards defining empirical coefficients through data collection is being pursued by the Joint Task Force (Pacific) (JTFP) Operational Research Team (ORT).

The next step in advancing the utility of  $P_{ID}$  is to create a definition that will enable approximate real time and high resolution  $P_{ID}$  reporting including the extrapolation of  $P_{ID}$  into the near future. This capability is being developed by the Joint Task Force (Atlantic) (JTFA) ORT.

This paper addresses the identification component of surveillance. Measuring the tracking component of surveillance is also important, and the definition of a quality of tracking metric which can be reported in parallel to  $P_{ID}$  will significantly add to the ability to measure surveillance effect. A quality of tracking metric has yet to be formally defined. Work to define a complete set of metrics is being done jointly by JTFA and JTFP OR teams.



# Sommaire

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## A Metric for Maritime Intelligence, Surveillance, and Reconnaissance (ISR) - Probability of Identification

S.A. Horn, N.L. Carson, A.F. Wind ; DRDC CORA TM 2009-037 ; R & D pour la défense Canada – CARO ; septembre 2009.

**Contexte :** Les Forces canadiennes (FC) ont besoin d'une capacité de renseignement, de surveillance et de reconnaissance (RSR) maritime à l'appui de la défense et de la sécurité du Canada. Les renseignements recueillis à partir des activités RSR maritimes sont compilés dans le tableau de la situation maritime (TSM) par le biais d'activités de commandement, de contrôle, de communications et d'informatique. Sur le plan stratégique, la marine canadienne s'est modernisée en combinant les renseignements obtenus des nouvelles technologies des capteurs et d'autres ministères, les données étant partagées par le biais d'activités du Centre des opérations de sécurité maritime (COSM). L'amélioration de la quantité et de la qualité des données tirées de telles activités débouche également sur l'amélioration du TSM. Les avantages de ces nouvelles activités peuvent et doivent être mesurés.

Les renseignements signalés au commandant opérationnel doivent être utiles. La probabilité d'identification ( $P_{ID}$ ) est une mesure fondamentale qui, non seulement montre les effets de la surveillance, mais représente aussi l'identification, la première étape de l'évaluation d'une menace. Le commandant opérationnel estime que l'identification visuelle est la forme de renseignement de surveillance la plus digne de confiance, même si des capteurs peuvent fournir l'identité des cibles. La  $P_{ID}$  commence à fournir au commandant opérationnel un sens réel du risque associé aux lacunes de la surveillance maritime.

**Résultats principaux :** La  $P_{ID}$  est calculée à partir de la fréquence des patrouilles ( $\tau_{regular}$ ), du temps de transit des cibles maritimes (T), de l'efficacité d'une patrouille de surveillance ( $\eta$ ) et en notant que des détections et des identifications multiples n'ajoutent aucun renseignement supplémentaire sur l'identité de la cible interrogée. En tenant compte d'une cible unique, dans un seul domaine, on obtient :

$$P_{ID} = \begin{cases} \frac{T}{\tau/\eta} & T \leq \tau \\ 1 - (1 - \eta)^{T/\tau} & T > \tau \end{cases}$$

La définition est alors élargie de manière à intégrer des zones de patrouille et des routes de navigation multiples. Le  $P_{ID(Route\ Average)}$  est un résultat cumulatif qui, avec le temps, simplifie l'interprétation de l'effet des patrouilles multiples et des activités RSR.

$$P_{ID(Route\ Average)} = \frac{\sum_{i=1}^{N_R} P_{ID(Route)_i}}{N_R}$$

$P_{ID(Route)_i}$  est la  $P_{ID}$  de tout le trafic sur l'itinéraire  $i$  (toutes les zones de patrouille étant traversées), et il y a au total des routes  $N_R$ .

**Pertinence des résultats :** Étant donné que la ( $P_{ID}$ ) de la route moyenne mesure directement les effets des activités de surveillance, l'identification des vulnérabilités est réduite à la simple observation d'une carte  $P_{ID}$  de la zone de responsabilité (ZR). Il s'agit d'un nombre pouvant être facilement comparé à différentes périodes au cours d'une année et à différents secteurs. La  $P_{ID}$  est un nombre attribué à chaque zone indiquant le pourcentage de navires entrant dans cette zone qui doivent être identifiés ; elle n'est pas reliée au nombre de navires qui transitent dans la zone et il n'est pas nécessaire de comprendre la circulation particulière de la ZR pour bien en comprendre la signification. La méthode présente une mesure facile à interpréter, claire et quantitative de l'efficacité des activités RSR maritimes pendant une période définie.

**Recherche future :** Avec l'ajout constant de nouveaux capteurs et d'outils de fusion, il sera important de développer la mesure des effets RSR afin de prendre en compte les nouvelles capacités. Bien que la mesure de la  $P_{ID}$  présentée ici soit en fonction d'une identification visuelle, un élargissement de la mesure intégrant un coefficient de renseignement permettra le signalement  $P_{ID}$  d'activités RSR non visuelles. L'équipe de recherche opérationnelle (ERO) de la Force opérationnelle interarmées du Pacifique (FOIP) continue de travailler à définir des coefficients empiriques par le biais de la collecte de données.

La prochaine étape pour faire avancer l'utilité de la  $P_{ID}$  consiste à formuler une définition qui permettra temps réel le signalement à haute résolution, et au temps réel, de la  $P_{ID}$ , incluant l'extrapolation de la  $P_{ID}$  dans un avenir rapproché. L'équipe de recherche opérationnelle (ERO) de la Force opérationnelle interarmées du Pacifique (FOIP) travaille à l'élaboration de cette capacité. Le présent document porte sur l'élément identification de la surveillance.

La mesure du suivi de la surveillance est également importante. La définition d'une mesure de suivi pouvant être parallèle à la  $P_{ID}$  ajoutera, de manière significative, à la capacité de mesurer les effets de la surveillance. Une qualité de la mesure du suivi reste à formuler. Le travail de définition d'un ensemble complet de mesures est exécuté conjointement par les équipes de recherche opérationnelle de la FOIA et de la FOIP.

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# 1 Introduction

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The work presented in this paper stems from Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) support to the Canadian Forces (CF). There is an operational requirement for the CF to maintain Intelligence Surveillance and Reconnaissance (ISR) capability in support of Canadian national security and Canadian national defence. ISR is a core role of the Canadian Navy, and the importance of improving Canada's ISR capability is outlined in the Canadian Navy's ISR Blueprint to 2010 [1]. Although maritime ISR enhancement has recently come to the forefront of the Navy's priorities, supporting maritime ISR enhancement activities has been an ongoing role of DRDC CORA over the past decade. Unfortunately, there is little open source academic literature on measuring the ability, effects and performance of ISR activities. As such, this work integrates and builds upon multiple pieces of previous work, several of which will be outlined and referred to within this report. The main sources for this research were DND internal reports.

This paper is one of three unclassified papers on this topic that are directed to different audiences. Here, the theory and method behind the Probability of Identification ( $P_{ID}$ ) metric is described for the scientific community. This metric was developed in support of Concept of Operations (CONOP) LEVIATHAN and further refined by Joint Task Force (Atlantic) (JTFA) and Joint Task Force (Pacific) (JTFP) OR Teams. A second paper describes the OR support for the development of JTFA CONOP LEVIATHAN [2], and how the  $P_{ID}$  metric is used to report on ISR activities to the commander [3]. The third paper documents the Surveillance Analysis Workbook (SAW) for the military operators for use as a general background and instruction manual for the generation of reports [4]. The SAW paper also describes the method used to implement the  $P_{ID}$  metric describing how data is input, processed, and the results visualized. A fourth classified Technical Note documents the method that was used to derive traffic routes for the JTFA and JTFP implementations of the  $P_{ID}$  metric in SAW [5].

## 1.1 Maritime ISR

Maritime ISR is a part of Command Control Communications Computers (C4) ISR, also referred to as C4ISR, and is accounted for under an umbrella concept called Maritime Domain Awareness (MDA). Maritime ISR is a feedback system in which the deployment of surveillance assets is planned or cued, the assets are deployed, and the collected information from these assets is compiled into a Recognized Maritime Picture (RMP). In addition to providing current situational awareness, the RMP guides command and intelligence activities for future ISR planning (in both the near and far term). Within this loop, the quality of the RMP is key to the CF being able to achieve its security goals. Therefore, improving the efficiency of maritime ISR is one path to improving the RMP.

The RMP is compiled from ISR activities through C4. Strategically, the Canadian Navy has been modernizing its C4 capabilities by combining information from new sensor technologies and Other Government Department (OGD) sources, and sharing data through Marine Security Operations Centre (MSOC) activities<sup>1</sup>. Improving the quantity and quality of data from activities such as

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<sup>1</sup>The MSOC consists of Department of National Defence (DND), Transport Canada (TC), Royal Canadian Mounted

these also results in an improved RMP, and the benefits of these new activities should and can be measured.

Maritime ISR activities conducted by JTFA and JTFP are a fundamental component for the mitigation of risk from maritime threats to Canada. Maritime surveillance is conducted by a combination of assets including Long Range Patrol Aircraft (LRPA) missions, contracting commercial flights (such as Provincial Aerospace Ltd. (PAL)), surface patrol vessels, collecting unclassified position reports, and using other national and international assets. OGDs, such as DFO and TC, also conduct maritime surveillance activities, in support of their respective mandates.

## 1.2 History

Maritime ISR research has been an active area of research within DRDC CORA for many years. The requirement to improve ISR capability was highlighted in the late 1990's, when several vessels were discovered transporting illegal immigrants from Asia to the west coast of Canada. In response, the JTFP Operational Research Team (ORT) supported the Canadian Navy in the creation of Operations Plan (OPLAN) "SEA LION" [6]. The JTFP OP SEA LION work by Gauthier et al. resulted in the most recent ISR reporting templates to the JTFP operational commander [7].

SEA LION reported the performance of ISR activities by defining a minimum and desired standard for the frequency of maritime patrols. These revisit requirements were defined by asserting a fundamental level of ship detection within the Area of Responsibility (AOR), and from that calculating the corresponding level of surveillance required to achieve that level of detection.

Following up on the success of OP SEA LION, the JTFA ORT began work on a similar plan for the East coast with JTFA CONOP LEVIATHAN [2]. The work highlighted avenues for improvement to this type of ISR activity and reporting. Improvements included a re-vamping of the reporting templates, and redefining the standard metric from revisit to  $P_{ID}$ . Calculating and reporting  $P_{ID}$  is a significant improvement to ISR reporting, however there still remains significant room for further improvements.

Shortly after the implementation of the  $P_{ID}$  metric, the JTFA and JTFP operational commanders requested that the ISR reporting templates be consolidated. During this consolidation, the SAW tool was developed to enable the Regional Joint Operations Centers (RJOCs) to generate reports with a common look and feel. The implementation of SAW is discussed in another paper [4]. Because of the simplicity of the implementation, and the success of the metric,  $P_{ID}$  is now used by both JTFP and JTFA to report on ISR activities.

## 1.3 Why Probability of Identification

The information being reported to the operational commander must be useful. Visual identification was requested by the JTFA operational commander as the most trusted form of surveillance information, even though other sensors can also help identify targets. Identification is the first step to a

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Police (RCMP), Canadian Border Security Agency (CBSA) and Department of Fisheries and Oceans (DFO), which is represented by both the Conservation and Protection (C&P) and Canadian Coast Guard (CCG) divisions.



threat assessment, and therefore,  $P_{ID}$  also provides an indication of the ability to make threat assessments from the RMP. For this reason, the  $P_{ID}$  metric starts to give the operational commander a true sense of the risk associated with gaps in maritime surveillance. The  $P_{ID}$  metric indicates the risk of an incoming vessel not being identified, and therefore the risk of the vessel not being assessed as a threat.

While identification alone provides the information vital to making a threat assessment, tracking is also required to respond to any threats. Both known and unknown vessels are tracked in the RMP, and identification is not always required for tracking. A good example of this is the Multi-sensor Integration within a Common Operating Environment (MUSIC) Technology Demonstration Program (TDP) in tracking, as the MUSIC algorithms track known unknown vessels in addition to known vessels [8]. Ideally, given sufficient update rates, vessels that are identified only once can be tracked in the RMP without the need for additional visual identification. Although tracking is important for acting on a threat assessment, the tracking component of the surveillance analysis is not discussed in this paper.

The metrics for identification and tracking have been effectively de-convolved in the following discussions. However, quality of tracking is not ignored; instead, it is to be dealt with in future work. Separate metrics for tracking and identification effectiveness simplifies the problem, allowing a divide and conquer approach. The metric with the highest impact for reporting ISR effect, the  $P_{ID}$  metric, was chosen as a first approach. By using only a  $P_{ID}$  metric, it is assumed that targets are tracked, but the effectiveness of the tracking is not considered when calculating and reporting  $P_{ID}$ .

## 1.4 Aim and Intent

The aim of this paper is to outline a method for measuring and scoring the quality of ISR activities in an operational context. The  $P_{ID}$  metric was identified as an effective measure of the desired effects of ISR, and has been adopted by Canada's regional operational commands as a standard method of ISR reporting. The derivation of the  $P_{ID}$  metric and the method of calculation is presented and discussed in the following chapters.

While this paper is intended for the scientific community, the theoretical basis presented here is intended to serve as a reference for other papers. An operational discussion intended for a military audience describing the use of  $P_{ID}$  for operations is described in a CONOP LEVIATHAN paper [2, 3]. The implementation of the metric as a computer program is described in the SAW paper which is tailored for operators [4]. The marine traffic models used in SAW are available in a classified Technical Note [5].

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## 2 Methods

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This chapter walks through the process of deriving the  $P_{ID}$  metric. It begins with a general description of maritime ISR metrics, and then introduces the concepts of patrol effectiveness and then  $P_{ID}$  for random and regular patrols. The  $P_{ID}$  metric is then developed further through its calculation over time, through multiple areas, and across multiple routes.

### 2.1 Metrics

Metrics for ISR have been extensively studied and discussed in previous papers [9–13]. Some of the detailed discussions in those papers are classified, but the portions covered here are not. An organizational layout of the metrics has already been established [11].

Maritime ISR metrics can be divided into two general levels: low-level metrics, which assess the capabilities inherent to ISR systems, and high-level metrics, which assess the achievements and outcomes of ISR objectives. A low-level metric is generally called a Measure of Performance (MOP), and a high-level metric is called a Measure of Effectiveness (MOE). It has been noted elsewhere that “of prime importance to measuring effectiveness is a clear statement of objectives” [10]. This quote serves to both define an MOE and identifies the reason why they are difficult to define. One does not always have the luxury of a precise statement of objectives, as the commander’s guidance is usually very general.

Because measuring effect is generally a difficult task, using specific MOPs for measuring effect has been proposed [10]. For example, to acquire a general picture of vessel activity, one can look at the number of incoming reports and the coverage of those reports. Unfortunately, while this may provide some indication of effectiveness, it fails to address how operational objectives are being met.

Revisit is a measure of presence and employment of assets and is considered an MOP; it will not be discussed in detail in this paper. The  $P_{ID}$  metric measures identification, and identification supports the Navy’s ISR objective of identifying potential threats, thus reporting the *effect* of surveillance activity. Therefore,  $P_{ID}$  is considered a MOE.

Since April 2008, the reporting and assessment of maritime ISR activities, via OP SEA LION and CONOP LEVIATHAN, is accomplished using two metrics. They are: 1) the previously used revisit metric and 2) the newer probability of (visual) ID metric, or  $P_{ID}$ .

Reporting of maritime ISR activities using both effect and performance measures provides information to the command on how efficiently assets were utilized, and the output of their use. While both aspects of maritime ISR reporting are important, this paper focuses on the effects based metric,  $P_{ID}$ . The following sections will walk through the derivation of the  $P_{ID}$  equations.

### 2.2 Patrol effectiveness

The effectiveness of a maritime surveillance patrol is represented by the coefficient of effectiveness,  $\eta$ , which represents the probability of detecting/identifying a vessel that is present in the zone

during a surveillance flight. As a pre-cursor to calculating the  $P_{ID}$  of a vessel, the effectiveness of patrols is considered. There are three dependencies to the effectiveness of a patrol: the fraction of an area covered by the patrol (*Coverage*), the probability of detecting a vessel if the patroller is in range ( $P_D$ ), and the probability of identifying a detected vessel ( $P_{ID|D}$ ). The effectiveness coefficient, described in detail below, is used later when calculating the probability of identifying a vessel.

$$\eta = Coverage \cdot P_D \cdot P_{ID|D} \quad \eta \in [0, 1] \quad (1)$$

### 2.2.1 Probability of Detection

In Equation 1, Probability of Detection ( $P_D$ ) is a detection coefficient generally based on anecdotal<sup>2</sup> assessments about LRPA flights. The probability of identification of a vessel while it is in the surveillance area is dependent on the ability to detect the vessel (which may be done with non-LRPA resources) and then subsequently identify the vessel, all while the patroller and the vessel are still in the surveillance area.  $P_{ID|D}$  is based on the number of detected vessels that are identified. For the purposes of this report, the assumptions are that all detections are identifications ( $P_{ID|D} = 1$ ) and they are done by the same platform (i.e. a surveillance aircraft). For vessels within a patrol zone, the combination of  $P_D$  and  $P_{ID|D}$  gives the probability that a patrol will identify vessels when given the opportunity.

Partial identification is the detection of contacts for which we know where they may be, but not who they are (i.e. no name) where detection only refers to knowledge of where a contact is. The detailed discussion on the criteria for partial identification, given detection, is beyond the scope of this paper. Partial identifications will not provide improvements to the  $P_{ID}$  metric used here because, as stated earlier, tracking is de-convolved from identification. However, partial identification provides a benefit to the RMP when tracking vessels and fusing multiple data sources. The contribution of partial identification to surveillance would be captured in a quality of tracking metric, to be addressed in subsequent papers.

### 2.2.2 Coverage

The “coverage” of the patrol is the percentage of the surveillance area that is covered for which the probability of detection coefficient is valid (i.e. the patroller is actively observing). This is usually accomplished at a simplified level by combining a cookie-cutter model of radar coverage and the surveillance flight path. Consequently, the value obtained for patrol effectiveness calculated this way should be viewed as an estimate and not a precise, scientifically derived value.

Typically, surveillance planning is done based on predefined surveillance areas, with no overlap between areas; i.e. a gridded surveillance area. Within these areas the crew attempts to detect and identify all vessels. The fraction of the assigned areas covered during the patrol is called the coverage scaling factor. If a portion of an area is not searched, then any vessels in the missed area

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<sup>2</sup>The  $P_D$  value is determined through observations by surveillance experts. This is done by a comparison of visual and radar observations during LRPA flights.  $P_D$  is estimated by the percent of expected vessels that were detected and identified.

can not be detected and identified. For consistent ISR planing and reporting, the AORs for each coast have been divided into standard patrol areas, or zones. A surveillance flight may be tasked to search an area that may not be a complete zone but rather a partial area of one or more zones. In this case, for reporting purposes, the coverage factor for each partially or completely covered zone is determined. During maritime surveillance patrols, it is important to keep track of the amount of the assigned surveillance area that is covered. A single surveillance patrol is considered successful when 100% coverage is achieved for an assigned area. When a surveillance patrol covers less than the assigned area, the amount of area not covered will reduce the patrol effectiveness in a linear manner.

If the patrol asset always covered the entire assigned zones, then the coverage factor would become binary and one would simply need to know which zones were covered. This would continue to be the case even if the zones were replaced by either very small areas or continuous functions rather than discrete areas. To model the covered area as either continuous functions or finite elements would require detailed information on the flight path and swath width throughout the flight.

The gridded surveillance area approach is currently easier for planners to manage, but it also means that measurement of patrol effectiveness is limited to the preset surveillance area. It is conceivable that areas of interest could also encompass portions of a single or multiple surveillance areas, so there is no easy way to reflect patrol effectiveness based on coverage other than for a single full area.

If the surveillance area is not gridded, then surveillance areas can be dynamically assigned based on priorities of that week, with a fall back position to “pseudo-gridded” surveillance areas if current events do not dictate specific actions. Due to the nature of a dynamic surveillance area (i.e. an irregular shaped area), it is important to capture the flight path and surveillance swath of each patrol in sufficient detail to allow the flight to be reconstructed to estimate the coverage of the dynamic surveillance area. This method is technically feasible but very challenging to implement, so it is not currently done as a standard practice. The real coverage is an area for future development towards more detailed planning and reporting that would not depend on large and arbitrary standard zones.

## **2.3 Probability of Intercept**

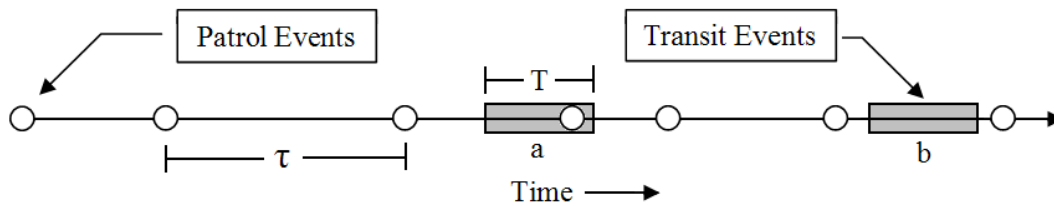
Let us now consider the surveillance of a single area over a period of time with a transiting vessel. For any vessel within the area, the probability of identification of that vessel is dependent on not only the ability to detect the vessel (using whatever detection means possible), but also the chance that a patrol will be in the area before the vessel completes its transit through the area. This means that the frequency of patrols and the time it takes for the vessel to transit through the area are important factors for calculating the probability of identifying a vessel.

On the ocean, the time it takes for a vessel to transit through a designated surveillance area is usually significantly larger than the time it takes to complete a surveillance flight. This is because an aircraft in the air is much faster than the standard vessel on the water and the aircraft will complete its flight much faster than the vessel can transit through the patrol zone. For this reason, it is a reasonable assumption that the aircraft patrols are essentially instantaneous compared to the vessel

transit time [7]. It follows that the probability of intercepting a vessel during its transit of the surveillance area is therefore essentially the same as the probability of a patrol happening.

The time between patrols is of high interest because it is during this time that a vessel has a chance to “sneak by” undetected. Let us then define the time between successive patrols to be the *revisit time*, which is constant for regular patrols and not constant for random patrols. Although the revisit times are not constant for random patrols, the average revisit time over a significantly long period of time is assumed to be constant. Pseudo-random patrols are more difficult to understand than purely regular or random patrols. Instead of directly modeling pseudo-random patrols, the purely random and purely regular cases are modeled, with the model for the pseudo-random patrols case falling somewhere between these two extremes.

There are many factors that contribute to patrols not being random: patrols happen mostly in daylight, they are constrained to aircraft servicing schedules, and the patrols themselves are scheduled. An example of the pseudo-randomness is shown in Figure 1 using a time line of patrol events. Label a indicates a transiting ship (taking a time  $T$  to transit) which was intercepted by a patrol and Label b indicates a transiting ship that was not intercepted.



**Figure 1:** Distribution of fictional patrol events on a line plot showing a) an intercepted transit, and b) a missed transit.

### 2.3.1 Random Patrol Intercept

For random patrols over time, patrols happen independently of one another with a constant Mean Revisit Time (MRT), denoted by  $\tau$ , between patrols. The average rate of patrols is then  $\lambda = \frac{1}{\tau}$ . The MRT is the average amount of time between patrols and should not be mistaken with the revisit rate ( $\lambda$ ), which is the average number of patrols in a given time.

Now consider the following scenario. A ship enters the patrol zone where random patrols happen with a MRT of  $\tau$ . If this ship was gambling on not being detected, the longer the ship stays in the patrol zone, the more likely that a random patrol is going to happen. In this particular case, the patrol has an instantaneous revisit time of  $\tau_i$ , which is not necessarily equal to  $\tau$ . To “sneak by” undetected, the ship has to make it through the patrol zone before the next patrol, and the longer it takes to do it, the more likely the ship will be caught. Also, the longer it takes, the probability that there has not yet been a patrol decays exponentially, and the ship’s odds of success decays exponentially. After a time  $t$  in the patrol zone, the probability that there *has not* yet been a patrol is given in Equation 2.

$$P(\tau_i > t) = e^{-\frac{t}{\tau}} \tag{2}$$

The probability of a random patrol happening after a time  $t$  is then simply 1 minus the probability that a patrol has not happened, as shown in Equation 3.

$$P(\tau_i \leq t) = 1 - P(\tau_i > t) = 1 - e^{-\frac{t}{\tau}} \quad (3)$$

Making the assumption that patrols are relatively instantaneous, the probability of intercept becomes the same as the probability of a patrol happening during the transit period. If the transit time of the ship through the patrol zone is  $T$ , then the probability of intercept is simply the probability of a patrol within that transit time. This is the same as Equation 3 evaluated at  $t = T$ .

$$P_{I_{rand}} = 1 - e^{-\frac{T}{\tau}} \quad (4)$$

Equation 4 is the probability of intercepting a ship that takes a time of  $T$  to transit the patrol zone using purely random patrols with a MRT of  $\tau$ .

### 2.3.2 Regular Patrol Intercept

For regular patrols, the revisit time is constant, and each instantaneous revisit time  $\tau_i$  is equal to  $\tau$ . Now, if a ship enters the patrol zone which is patrolled with a regular revisit time of  $\tau$ , the ship can only “sneak by” if there is no patrol while it is transiting the patrol zone. If the time between patrols ( $\tau$ ) is less than the time that it takes for a ship to transit the patrol area ( $T$ ), then there is no chance for the ship to transit unnoticed. The probability of intercept will always be 1 when  $T > \tau$ . However, if the transit time is less than the revisit time, then there is an opportunity for the ship to “sneak by” if the ship times its transit just right.

For the ship to make it through the patrol zone without being intercepted, the window of opportunity is right after a patrol. However, assuming that the time the ship enters the patrol zone is random (i.e. the ship does not know the patrol schedule, and the aircraft does not know the ships transit schedule), then the probability of the ship entering the patrol zone outside of the window of opportunity is simply the ratio of the transit time and patrol revisit time. The probability of intercepting is simply the fraction of time that the window of opportunity is not open. Equation 5 gives the probability of intercept for regular patrols with a revisit time of  $\tau$  and a ship’s transit time of  $T$ .

$$P_{I_{reg}} = \begin{cases} \frac{T}{\tau} & T \leq \tau \\ 1 & T > \tau \end{cases} \quad (5)$$

### 2.3.3 Alternate Patrol Intercept Method

There are a few models to calculate the probability of interception. Martel and Nguyen formulated the probability of intercepting intruders using a combinatorial method [9]. They assume the probability of detecting a portion of transiting vessels was a binomial distribution with a mean probability based on the patrol frequency and patrol effectiveness. Their formulation is given in Equation 6, in which  $I$  is the traffic volume,  $c$  is the number of vessels intercepted,  $P(c = i)$  is the probability of

intercepting  $i$  vessels, and  $P_c$  is the probability of detecting a vessel for a given patrol frequency and transit time. Because their formulation depends on the volume of traffic in the patrol area, it models both the increased load on individual patrollers to detect vessels and the effect of diminishing returns from additional flying hours. However, their formulation requires a priori knowledge of the traffic volume to calculate the probability of intercept, even though traffic is what the flight is meant to assess.

$$P(c = i) = \binom{I}{i} (P_c)^i (1 - P_c)^{I-i} \quad (6)$$

The binomial nature of their formulation assumes that patrols over time are randomly binned. In reality, patrols are only pseudo-random.

## 2.4 Probability of Identification

The next step in the analysis is to make the connection going from a probability of intercept to a probability of identification. In Section 2.2, the patrol effectiveness coefficient  $\eta$  was introduced in Equation 1 which captured the various components required to go from intercepting a vessel to identifying a vessel. One way to account for patrol effectiveness in  $P_{ID}$  is to consider the  $P_I$  with a scaled revisit time. This way, the probability of identification is the probability of intercept with the revisit time divided by  $\eta$ . This works for the random revisit time equation, and the regular revisit time equation for  $T \leq \tau$ . In other words, the  $P_{ID}$  contribution from a patrol with a low effectiveness is modeled as a completely effective patrol with an increased revisit time. In effect, this modifies the contribution of each revisit towards identification.

$$P_{ID} = P_I(\tau')|_{\tau'=\tau/\eta} \quad (7)$$

For random patrols, the  $P_{ID}$  is:

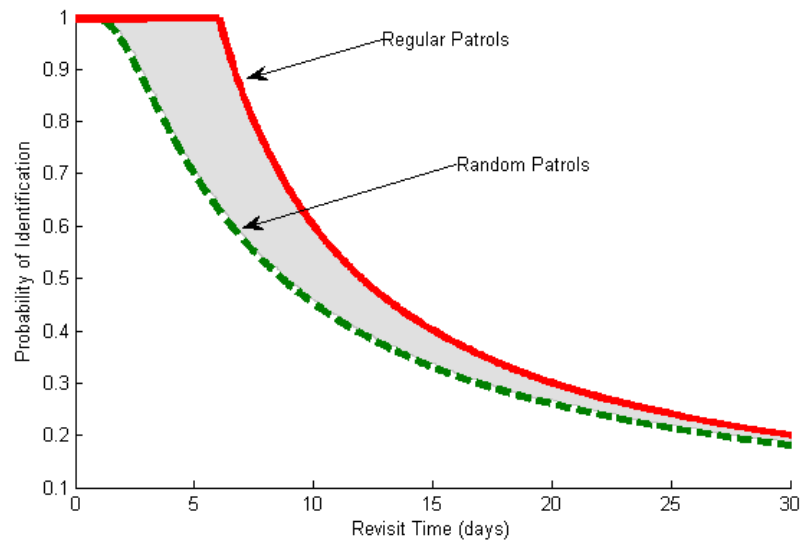
$$P_{ID_{rand}} = 1 - e^{-\frac{T}{\tau/\eta}} \quad (8)$$

For regular patrols in which  $T > \tau$ , this method does not work because we have already assumed that if the transit time is larger than the revisit time, then the probability of intercepting should be 1. Additionally, for frequent patrols, there is a chance that the vessel will be intercepted multiple times. It is expected that the probability of multiple intercepts increases as  $\tau \rightarrow 0$ , and the model for the probability of identification should approach 100%. The  $P_{ID}$  when  $T > \tau$  is modeled by combining the patrol effectiveness from multiple intercepts. With this model, flying more frequently increases the probability of identification when there are multiple opportunities for intercept. Equation 9 gives the formulation used for the regular patrol  $P_{ID}$ .

$$P_{ID_{reg}} = \begin{cases} \frac{T}{\tau/\eta} & T \leq \tau \\ 1 - (1 - \eta)^{T/\tau} & T > \tau \end{cases} \quad (9)$$



where  $1 - \eta$  is the probability of not detecting a ship and  $T/\tau$  is the expected number of revisits during a transit. To help understand what these functions look like, it is useful to visualize the shape of the functions. Figure 2 illustrates, with  $\eta = 1$ , and a transit time  $T = 6$ , the  $P_{ID}$  for random and regular patrols. It may at first appear counter-intuitive that random patrols provide lower  $P_{ID}$  than regular patrols, but this makes sense due to the uncertainty in revisit times. As stated before, patrols are neither purely regular nor random. However, patrols are arguably more regular than random, especially when analysing the  $P_{ID}$  over a short period of time. Figure 2 is a good illustration of the upper and lower bounds of  $P_{ID}$ , with the real world  $P_{ID}$  from pseudo-random patrols likely closer to the upper curve. For the  $P_{ID}$  metric, the regular  $P_{ID}$  formula (Equation 9) is used to calculate the probability of identification.



**Figure 2:**  $P_{ID}$  with  $\eta = 1$  for random and regular patrols (for a vessel requiring 6 days to transit an area ( $t = 6$ ), as a function of revisit time,  $\tau$ ).

In this formulation, it can be seen that the maximum value of  $P_{ID}$  is 1. This makes sense because successive identifications of the same vessel does not produce any new information about its identity. This is because it is assumed that once a vessel is identified, if it is of interest, it will be tracked using non-visual sensors and not require a successive mission to detect and identify the vessel again. The ability to continue to track a vessel of interest is important, but the quality of that tracking is not measured through the  $P_{ID}$  metric.

It should be noted that the formula for  $P_{ID}$  does not take into account the time it takes to patrol the area, as it was assumed earlier that the patrols could be taken as instantaneous. The accuracy of Equation 9 is reduced when the time it takes to conduct a patrol is of the same magnitude as the time it takes to transit an area. An example of when this may happen is when the transit time for a vessel is fast, on the order of a few hours, or the surveillance of the area takes a long time (e.g. surface combatant).

### 2.4.1 Verification of Probability Distributions

To verify that Equations 8 and 9 are valid probability distributions, one can show that there exists a probability density function for each, and that the probability density functions are normalized under the condition that the transit time  $T > 0$  and revisit time  $\tau > 0$ .

For Equation 8, the probability density function is the derivative with respect to  $T$ .

$$f_{rand} = \frac{d}{dT}(P_{rand}) = \frac{\eta}{\tau} e^{-\frac{T}{\eta}} \quad (10)$$

Equation 10 can be shown to be normalized over all  $\tau > 0$  by integrating for all possible transit times.

$$\int_0^{\infty} f_{rand} dT = 1 \forall \tau > 0 \quad (11)$$

For Equation 9, it is more tricky to find the probability density function. The probability distribution is piece-wise continuous, and can therefore be written as a single expression using step-functions.

$$P_{ID_{reg}} = \left( \frac{T}{\tau/\eta} \right) \cdot H(\tau - T) + (H(T) - H(\tau - T)) \cdot \left( 1 - (1 - \eta)^{\frac{T}{\tau}} \right) \quad (12)$$

The probability density function for Equation 9 is now derivative of Equation 12 with respect to  $T$ .

$$f_{reg} = \frac{d}{dT}(P_{ID_{reg}}) \quad (13)$$

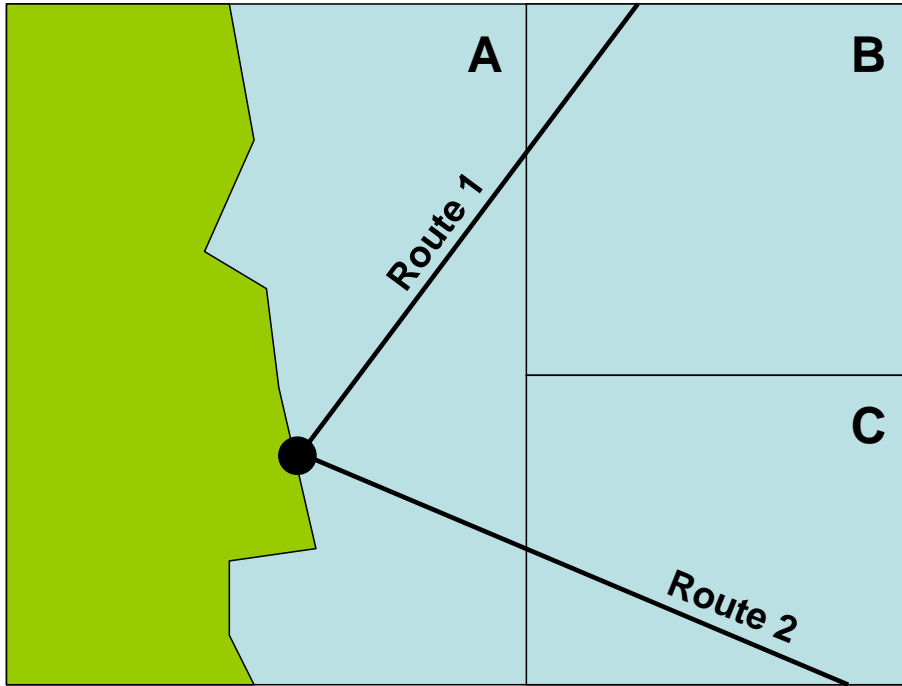
Equation 13 can be shown to be normalized for all  $\tau > 0$  by integrating for all possible transit times.

$$\int_0^{\infty} f_{reg} dT = 1 \forall \tau > 0 \quad (14)$$

The probability density functions for both models are normalized for all physically valid parameters for  $\tau$  and  $T$ . Therefore, both Equations 8 and 9 are valid probability distributions.

## 2.5 Probability of Identification Within a Patrol Area

Using Equation 9 ( $P_{ID}$  for regular patrols), it is straightforward to calculate the probability of identification for a single patrol area. Figure 3 shows a fictitious surveillance area and two traffic routes



**Figure 3:** Example map showing three surveillance regions (A,B, and C) and two threat routes (1 and 2)

which will be used to illustrate the method for calculating  $P_{ID}$ . The methodology for defining the traffic routes for a real-world AOI is described in Section 2.8.

To start, the  $P_{ID}$  in region A along route 1 will be calculated first without considering the surveillance activities in B and C. Afterwards, the metric will be expanded to capture the contribution from multiple regions and then multiple routes. Using Figure 3, if the period for surveillance patrols for region A is 48 hours, the average time for a vessel to transit region A along route 1 is 12 hours, and the patrol effectiveness is 50%, then the  $P_{ID}$  is:

$$\begin{aligned}
 P_{ID(Region:A)} &= \frac{12}{48/0.5} \\
 &= 0.125
 \end{aligned}$$

While this works for calculating  $P_{ID}$  for a single surveillance area and one route, it does not account for surveillance in adjacent routes. The case of incoming traffic routes transiting multiple zones is considered next.

## 2.6 Probability of Identification through Multiple Areas

Up to this point, the  $P_{ID}$  values were calculated for a single surveillance area. When a vessel transits through multiple contiguous patrol zones, the  $P_{ID}$  calculation can be modified such that it becomes

the probability of detecting the transiting vessel within any one of the zones on its course. This is called the route  $P_{ID}$  and is denoted  $P_{ID(Route)}$ . The benefit of  $P_{ID(Route)}$  is that it provides a measure of identification for all incoming vessels that are transiting through a route, accounting for those that may have already been identified previously. One must take care when reading a  $P_{ID(Route)}$  value because the route  $P_{ID}$  reflects identification from surveillance activities in multiple zones. Increasing surveillance in adjacent zones will increase the route  $P_{ID}$ .

The route  $P_{ID}$  for  $N_A$  areas is simply one minus the product of not detecting the vessel within any of the patrol zones along its path and is given by the following formula<sup>3</sup>:

$$\begin{aligned} P_{ID(Route)} &= 1 - (1 - P_{ID_1}) \times (1 - P_{ID_2}) \times \dots \times (1 - P_{ID_{N_A}}) \\ &= 1 - \prod_{i=1}^{N_A} (1 - P_{ID_i}) \end{aligned} \quad (15)$$

Equation 15 can be interpreted as the  $P_{ID}$  of a vessel along a route. From Equation 15, it follows that increasing the  $P_{ID}$  in any area along the vessel's route will increase the  $P_{ID(Route)}$  in all subsequent surveillance areas the vessel transits en route to its destination. From the offshore domestic security perspective, most of the threats are incoming (i.e. transiting into Canadian waters). By limiting the routes to consider only incoming vessels, the calculation is greatly simplified.

As an example, consider route 1 in Figure 3 that crosses both regions A and B. Each of these regions will have a  $P_{ID(Route:1)}$ , which indicates the probability of detecting incoming vessels along route 1 that terminate in that region. The transit time across region A is 12 hours and for region B, it is 6 hours. The period for surveillance patrols for region A is 48 hours while for region B it is 12 hours. Both flights have a patrol effectiveness of 50%. To calculate the route 1  $P_{ID}$  terminating in region A, the vessel must transit first through region B, and then A. The  $P_{ID}$  values from regions A and B are therefore used.

The route 1  $P_{ID}$  is calculated as follows for region A:

$$\begin{aligned} P_{ID(Route:A1)} &= 1 - (1 - P_{ID_A}) \times (1 - P_{ID_B}) \\ &= 1 - \left(1 - \frac{12}{48/0.5}\right) \times \left(1 - \frac{6}{12/0.5}\right) \\ &= 1 - (1 - 0.125) \times (1 - 0.25) \\ &= 0.344 \end{aligned}$$

It is easy to see from these calculations that increasing  $P_{ID}$  in region B has the effect of increasing the route  $P_{ID}$  in region A. This relationship occurs because the  $P_{ID}$  metric accounts for vessels that have already been identified prior to entering the latest surveillance zone. Specifically, in this example, the metric accounts for increased identification of incoming vessels within region A if they have already been identified in region B. In other words, identified vessels along route 1 in

<sup>3</sup>It should be noted that the average time for a vessel to transit a surveillance area is dependent on the route that it is following and therefore the transit times have to be calculated for each route.

region A includes those vessels that were identified within region A and those that were identified within region B.

Calculating the route  $P_{ID}$  for region B is much simpler. Because the method only considers incoming routes, there is no need to consider the  $P_{ID}$  from region A, as that would be an outgoing route. The only identified vessels in region B will be those that were identified directly within region B. The route  $P_{ID}$  in region B therefore only considers the effect of surveillance activity within its own zone:

$$\begin{aligned} P_{ID(Route:B1)} &= P_{ID_B} \\ &= 0.25 \end{aligned}$$

The  $P_{ID}$  for route 2 is calculated in an identical way as for route 1 above, but using region C vice B. In the real world traffic model, there may be many routes entering and transiting through a surveillance zone. The next step is to account for all ways that traffic may enter a surveillance zone by considering the effect of all of the routes that transit into and through each zone.

## 2.7 Average Probability of Identification Considering Multiple Routes through Multiple Areas

To measure the average  $P_{ID}$  of all routes that cross or terminate in a surveillance area, the  $P_{ID}$  will depend not only on the surveillance activities within an area, but also on the  $P_{ID}$  on routes before traffic enters the surveillance area. The average of all route  $P_{ID}$ s in a surveillance zone gives an overall measure of identification of vessels in the zone. Therefore, the averaged route  $P_{ID}$  is the effect from all surveillance activities in the Area of Interest (AOI). For a region with  $N_R$  routes terminating in it, the  $P_{ID(Route\ Average)}$  is:

$$P_{ID(Route\ Average)} = \frac{\sum_{i=1}^{N_R} P_{ID(Route:i)}}{N_R} \quad (16)$$

While one is interested in identifying all incoming vessels, one is not concerned where along the route that vessel was identified. Therefore, the  $P_{ID(Route\ Average)}$  is actually the probability of the vessel being identified before it exits through the surveillance zone, or region, no matter which route that vessel is traveling on.

If there is information available on a known threat, or knowledge of the probability of a threat along each route, then a future improvement to calculating the  $P_{ID(Route\ Average)}$  might be to add a weighting to each route indicating the likelihood of the threat using that route. An implementation of this weighting may take advantage of Bayesian methods to allocate threat probabilities along the routes. However, the information required to assign a weighting will often not be available. The simplest and most straight forward method is to assume that a threat can come from anywhere, and to calculate  $P_{ID}$  along the major traffic routes to maximize the number of interrogated vessels.

Of the various probabilities and metrics introduced in this chapter, the  $P_{ID(Route\ Average)}$  is the most important value to the operational commander. It is a number that can be easily compared over

different times of year, and different areas.  $P_{ID(Route\ Average)}$  reduces the  $P_{ID}$  concept to a number for each zone indicating on average the percent of incoming vessels within that zone that are identified, it does not matter how many vessels are transiting within the zone, and there is no need to understand the traffic patterns within the AOR to correctly interpret its meaning.

Again referring to Figure 3, the transit times along route 2 is 8 hours through region A and 12 hours through region C. The period for surveillance patrols for region C is 24 hours, but has an effectiveness of 75%.

The route 2  $P_{ID}$  for region A is:

$$\begin{aligned} P_{ID(Route:A2)} &= 1 - (1 - P_{ID_A}) \times (1 - P_{ID_C}) \\ &= 1 - \left(1 - \frac{8}{48/0.5}\right) \times \left(1 - \frac{12}{24/0.75}\right) \\ &= 1 - (1 - 0.083) \times (1 - 0.375) \\ &= 0.427 \end{aligned}$$

And then the averaged route  $P_{ID}$  for region A from Equation 16 is:

$$\begin{aligned} P_{ID(Route\ Average:A)} &= \frac{\sum_{i=1}^2 P_{ID(Route)_i}}{2} \\ &= \frac{1}{2}(0.344 + 0.427) \\ &= 0.386 \end{aligned}$$

Therefore, the average  $P_{ID}$  for identifying threats in surveillance zone A is roughly 39% along routes 1 and 2. This fictitious example served to illustrate how the  $P_{ID}$  metric is calculated for a given surveillance grid and traffic routes. The next section describes the methodology for defining real world traffic routes.

## 2.8 Identifying routes for $P_{ID}$

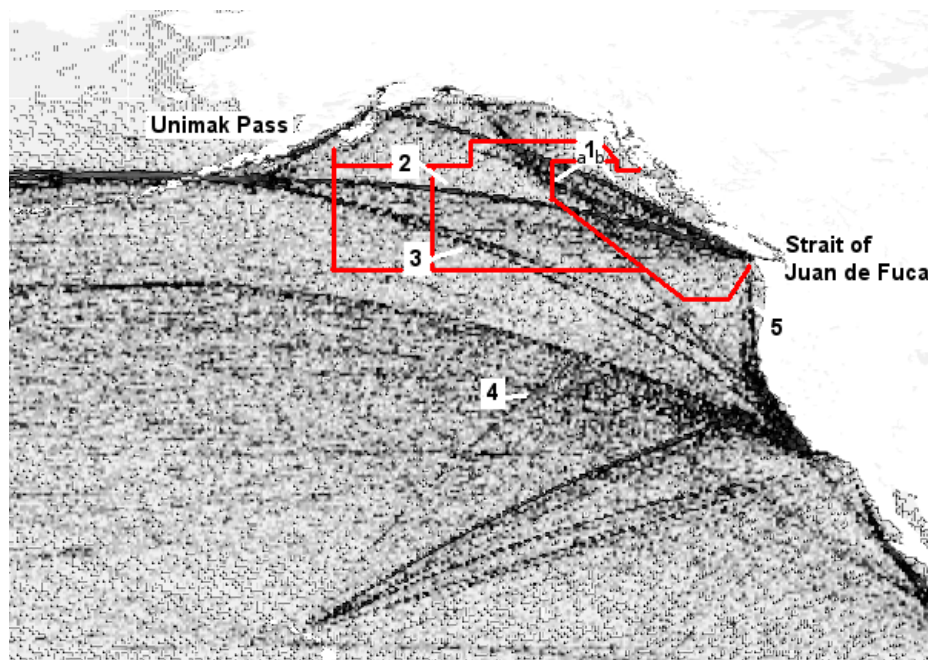
In a marine environment, there are nearly an infinite number of routes vessels can follow. However, to make a first order approximation of the majority of traffic, a logical approach is to define a few major traffic routes for an AOI. Although not all traffic will follow these routes directly, they do capture the majority of transiting vessels and the typical time required to transit through an area. Once several routes are defined, the overall flow of traffic in the AOI is captured, and the distribution of the traffic through the patrol zones can be approximated by the identified routes.

To save fuel, most traffic crosses the ocean via great circle routes. Although, inexperienced navigators can use rhumb line routes, commercial shipping transits along great circle routes to reduce time and distance between ports. Additionally, because of natural choke-points, many routes are often

funneled together to reduce the number of routes to major ports (e.g. Unimak Pass<sup>4</sup> or the Strait of Belle Isle<sup>5</sup>). For the case of Unimak Island, the routes move south in the winter months to avoid severe winter conditions along the Aleutians. This highlights the need to periodically update the traffic model used for  $P_{ID}$  to match the observed traffic patterns. Another factor influencing traffic routes are local laws such as the west coast tanker exclusion zone that forces tankers to stay well offshore of Vancouver Island.

The best way to outline the major routes (which could change seasonally) is to observe a map of RMP traffic over a significant period of time and highlight the most dense routes. Ideally, the period of time should be long enough to collect data, but short enough to observe seasonal traffic variances. A period of three to four months of data is usually sufficient to pull out the major routes. Once the routes are mapped, then it is straightforward to measure intersection of the routes with the predefined surveillance zones used for patrolling. The distance each route travels through each zone is measured, and used as an input for the calculation of  $P_{ID}$ .

Figure 4 shows a contrast enhanced map from an open source image obtained on-line from the European Commission Global Environment Monitoring website [14]. The authors of the image describe their method in a paper [15]. The image was generated from one year of voluntary reporting captured in the World Meteorological Organization Voluntary Observing Ships Scheme beginning in October 2004.



**Figure 4:** Map of open source shipping data for the NW Pacific Ocean. The JTFP outer, middle, and inner surveillance zones are shown (from left to right)

<sup>4</sup>Unimak Pass is a strait near Unimak Island in the Aleutian chain of islands off of Alaska. Traffic from Asia following the North Pacific great circle route transits through this pass.

<sup>5</sup>The Strait of Belle Isle is between Labrador and Newfoundland and connects the Gulf of St. Lawrence to the Atlantic Ocean.

From this data, five major incoming routes are pointed out with white boxes and lines in Figure 4. Label 1 points to the northern shipping routes from Alaska. There are two sub parts to this route, the 1-a line points to the modified tanker traffic routes which are diverted due to the voluntary tanker exclusion zone. The 1-b line are the main shipping routes from Alaska, particularly Valdez in the north east. Label 2 points out the northern great circle route that is squeezed through Unimak Pass and terminates in the Strait of Juan de Fuca. Label 3 is the southern great circle route which is traffic headed to the United States, but passes through the JTFP AOR. Label 4 points to the traffic from Hawaii, and Label 5 shows the coastal traffic.

For each of these routes shown, the distance through each zone is measured and used as the transit distance for the  $P_{TD}$  equation above. For example, the northern great circle route (Label 2) transits approximately 260 nautical miles (nm) through the outer zone, 380 nm through the middle zone, and 520 nm through the inner zone. The transit distances for each route through the surveillance zones are calculated in a similar manner. These transit distances are then used to estimate the typical transit time in Equation 9. Equations 15 and 16 are then used to calculate the route average  $P_{TD}$  for each zone.

Note that the methodology for defining traffic routes described here is based off of open source unclassified data. A detailed description of the route methodology used for operations will be calculated in a classified DRDC CORA Technical Note [5].



## 3 Discussion

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Using route averaged probability of identification as the primary metric for ISR reporting has several advantages and limitations. This chapter discusses these, as well as possible applications.

### 3.1 Advantages

A major role of maritime ISR activities is to identify vessels on the ocean, therefore, measuring the percent of vessels that are theoretically identified is a direct measure of the effect of ISR activities and their contribution to building the RMP. The identification of vessels in the RMP is the first step required for a threat assessment.

Government mandated and voluntary Automatic Identification System (AIS) information has many implications for ISR and RMP quality [16]. Although AIS provides information on the identity of vessels, the source can be altered, so the level of trust in the data source comes with uncertainty.  $P_{ID}$  with visual identification mitigates the risk introduced by blindly following AIS reported information. The limitations of other identification methods, such as AIS, can be avoided by introducing caveats to the  $P_{ID}$  calculation such as visual identification, or if available, multiple sensor fusion.

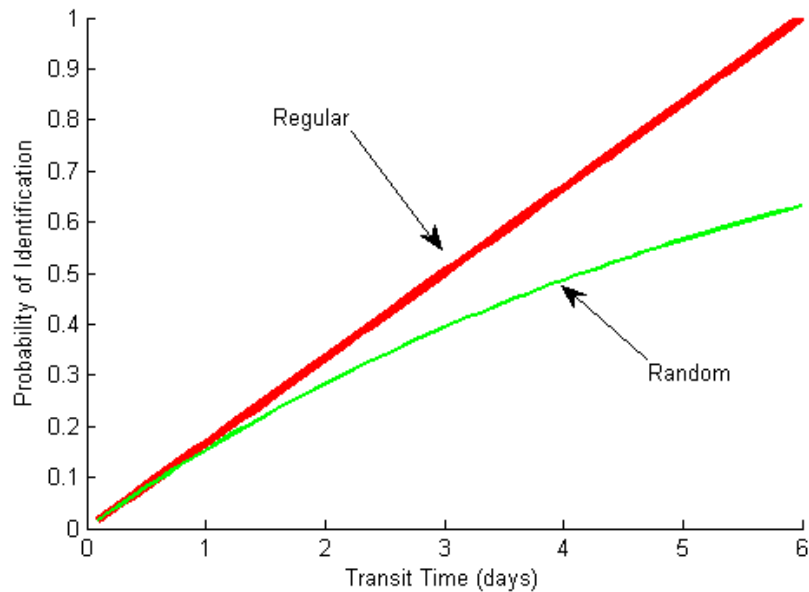
The chance that a threat to Canadian national security is not identified, and thereby not responded to, is of great concern. A worst case scenario is a non-emitting vessel transiting through the AOR with hostile intent. Using visual  $P_{ID}$  as the primary metric to assess ISR effect directly addresses this threat to Canada by indicating the effectiveness of surveillance in identifying the non-emitting incoming vessels. The  $P_{ID}$  metric simplifies the task of identifying ISR vulnerabilities to observing a  $P_{ID}$  map of the AOR.

### 3.2 Limitations

The only accepted way to detect a non-emitting vessel is by active observation, and visual identification ( $P_{ID}$ ) is presently the only sure way to detect and identify a non-emitting vessel. Because visual  $P_{ID}$  is directed to addressing the worst case scenario, using  $P_{ID}$  as the sole measure for ISR effect can have the effect of making the RMP quality appear worse than it may actually be for everyday intelligence activities. This leads to a risk of under-estimating the overall surveillance performance when visual identification is not required to identify the threat.

The route averaged  $P_{ID}$  metric alone does not provide a complete measure of surveillance effectiveness. The quality of tracking a vessel has not yet been considered, and the development of a quality of tracking metric in combination with the  $P_{ID}$  metric would provide a more complete measure of surveillance effectiveness. Also, measuring the function and impact of intelligence in the threat analysis is not captured in this metric. Measuring the ability to produce a threat assessment is complicated and involves many components including identification, tracking, and analysis.

The  $P_{ID}$  calculation is dependent on knowledge of traffic patterns in the surveillance area. However, the actual incoming threat may not follow traditional traffic patterns. This limitation is mitigated by the fact that reporting  $P_{ID}$  for the major traffic routes maximizes the number of vessels considered



**Figure 5:** Effect of transit time for random and regular patrols on  $P_{ID}$  with a revisit time of 6 days.

identified. Also, by defining many routes, the typical transit distance through surveillance zones is averaged to somewhat account for traffic that is not on the major routes.

The  $P_{ID}$  calculation is dependent on knowledge of the speed of an expected threat. Figure 5 shows how the  $P_{ID}$  equations depend on the theoretical speed of the vessel (shown as transit time). Changing the value of the transit time in Equation 9 has a significant impact. Because of this strong dependence, the reported value of  $P_{ID}$  for a patrol zone should also be associated with a threat speed to indicate that it is only accurate for a specific case. As long as the threat speed is not extremely high or extremely low, the  $P_{ID}$  value will be a close approximation of the chance of identifying a threat traveling a different speed than expected.

### 3.3 Applications

There are several applications for the  $P_{ID}$  metric in planning, reporting, and analysis. Most obviously,  $P_{ID}$  can be used as a measure of operational effect of ISR activities. In this way it could report the average probability over a weekly or quarterly period. It could also be used as a quantitative measure to compare different ISR activities, platforms, or techniques.  $P_{ID}$  could also be used in planning to set a goal for operational achievement [4].

For ISR planning, having a base measure such as  $P_{ID}$  provides a means to quantitatively define what the desired ISR effect should be. For example, one could determine a desired  $P_{ID}$  level for an area, and then calculate the actual value resulting from the implementation of the ISR plan. This could identify a capability gap or an area for improvement.

It could also be possible to develop an instantaneous geographically distributed value of  $P_{ID}$ . This

would require knowing the actual flight times and defining a temporal dispersion or decay function of the  $P_{ID}$ . The temporal function would define how the instantaneous  $P_{ID}$  would move along a threat course over time and/or whether the total probability would begin to spread out or decay over time.

Finally, historic records of  $P_{ID}$  values can provide some indication of risk. By comparing the levels of  $P_{ID}$  at various times of the year, the relative difference in risk can be inferred. Consider the hypothetical example that if the typical  $P_{ID}$  in a zone is 50% in the winter and 80% in the summer, then one could note that there is a higher risk in the winter that a non-emitting vessel will transit undetected. This could allow the  $P_{ID}$  metric to contribute to a larger measure of risk. The concept behind quantifying risk has not yet been developed, and is currently being explored by Canada Command.

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## 4 Summary

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An initial metric for measuring the effect of ISR activities has been presented. The averaged route  $P_{ID}$  metric presents a clear, easy to interpret, quantitative measure of the ISR activities over a period of time. The  $P_{ID}$  metric contributes to the reporting aspect of ISR and it can also provide guidance for planning. When measuring  $P_{ID}$ , the dependence on vessel traffic routes and speeds must be kept in mind.

This paper provided the theoretical foundations for the  $P_{ID}$  metric. It is one of four papers, each of which is tailored to a different audience. A paper on adapting the metric for operations is described in a paper by Carson [3]. The implementation of the metric as a computer program is described in a paper by Wind and Horn [4]. A classified Technical Note outlines the calculated results for traffic routes for the JTFA and JTFP AOR [5].

### Future Work

The theoretical basis laid out in this paper will serve as a starting reference for future papers extending this work. A technical paper on the operational implementation of the  $P_{ID}$  metric will follow, along with a paper on how to take advantage of this metric for the refinement and development of maritime ISR plans.

The next step in advancing the utility of  $P_{ID}$  is to create a fine-time definition that will enable approximate real time  $P_{ID}$  reporting. The availability of that type of information will shorten the Observe Orient Decide Act (OODA) loop by significantly improving short-term RMP planning. This capability is being developed by the JTFA ORT. Additionally, the development of a quality of tracking metric to be reported in parallel to the  $P_{ID}$  metric will significantly improve the overall surveillance effectiveness measure. JTFA and JTFP ORTs are currently working on this additional tracking metric to be reported in parallel to  $P_{ID}$ .

With constant addition of new sensors and fusion tools, it will be important to evolve the ISR effect metrics to account for these new capabilities. Although the  $P_{ID}$  metric presented here was for visual identification, an extension of the metric that incorporates an information trust coefficient would enable  $P_{ID}$  reporting of non-flight ISR activities such as Synthetic Aperture Radar (SAR) data and Long Range Identification and Tracking (LRIT). Work towards defining empirical coefficients through data collection is being pursued by the JTFP ORT.

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## List of abbreviations

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|                |  |
|----------------|--|
| <b>AIS</b>     | Automatic Identification System                                |
| <b>AOI</b>     | Area of Interest   |
| <b>AOR</b>     | Area of Responsibility   |
| <b>C4</b>      | Command Control Communications Computers                       |
| <b>C4ISR</b>   | Command Control Communications Computers ISR                   |
| <b>CBSA</b>    | Canadian Border Security Agency                                |
| <b>CCG</b>     | Canadian Coast Guard   |
| <b>CF</b>      | Canadian Forces  |
| <b>CONOP</b>   | Concept of Operations  |
| <b>CORA</b>    | Centre for Operational Research and Analysis                   |
| <b>C&amp;P</b> | Conservation and Protection                                    |
| <b>DFO</b>     | Department of Fisheries and Oceans                             |
| <b>DND</b>     | Department of National Defence                                 |
| <b>DRDC</b>    | Defence Research and Development Canada                        |
| <b>ISR</b>     | Intelligence Surveillance and Reconnaissance                   |
| <b>JTFA</b>    | Joint Task Force (Atlantic)                                    |
| <b>JTFP</b>    | Joint Task Force (Pacific)                                     |
| <b>LRPA</b>    | Long Range Patrol Aircraft                                     |
| <b>LRIT</b>    | Long Range Identification and Tracking                         |
| <b>MDA</b>     | Maritime Domain Awareness                                      |
| <b>MOE</b>     | Measure of Effectiveness                                       |
| <b>MOP</b>     | Measure of Performance   |
| <b>MRT</b>     | Mean Revisit Time  |
| <b>MSOC</b>    | Marine Security Operations Centre                              |
| <b>MUSIC</b>   | Multi-sensor Integration within a Common Operating Environment |
| <b>OGD</b>     | Other Government Department                                    |

|                       |                                  |
|-----------------------|----------------------------------|
| <b>OODA</b>           | Observe Orient Decide Act        |
| <b>OPLAN</b>          | Operations Plan                  |
| <b>ORT</b>            | Operational Research Team        |
| <b>PAL</b>            | Provincial Aerospace Ltd.        |
| <i>P<sub>D</sub></i>  | Probability of Detection         |
| <i>P<sub>ID</sub></i> | Probability of Identification    |
| <b>RCMP</b>           | Royal Canadian Mounted Police    |
| <b>RMP</b>            | Recognized Maritime Picture      |
| <b>RJOC</b>           | Regional Joint Operations Center |
| <b>SAR</b>            | Synthetic Aperture Radar         |
| <b>SAW</b>            | Surveillance Analysis Workbook   |
| <b>TC</b>             | Transport Canada                 |
| <b>TDP</b>            | Technology Demonstration Program |

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The  $P_{ID}$  metric is a method for measuring and scoring the quality of maritime ISR activities in an operational context. The metric presents a clear, easy to interpret, quantitative measure of effectiveness of maritime ISR activities over a defined period of time, and has been adopted by Canada's regional operational commands as one of the standard metrics for maritime ISR reporting. The aim of this paper is to describe the theoretical and technical underpinnings of the  $P_{ID}$  metric for a scientific audience. The current metric serves as a starting point for evolving a much more comprehensive metric for maritime ISR.

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