Measures of Effectiveness and Performance for the Northern Watch Station

David Waller
S&T OR Team

Matthew R. MacLeod
DRDC Ottawa OR Team

Talia McCallum
Canadian Forces Maritime Warfare Centre OR Team

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Defence R&D Canada
Centre for Operational Research and Analysis

Science & Technology Operational Research Team
Director General Science and Technology Operations

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Defence R&D Canada – CORA

Matthew R. MacLeod
Defence R&D Canada – CORA

Talia McCallum
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Principal Author

Original Signed by David Waller

David Waller

DRDC CORA Defence Scientist

Approved by

Original Signed by Thierry Gongora

Thierry Gongora

S&T OR Team Leader

Approved for release by

Original signed by Dale Reding

Dale Reding

DRDC CORA Chief Scientist

Defence R&D Canada – Centre for Operational Research and Analysis (CORA)

Abstract

This study documents the provisional measures of effectiveness (MOEs) and measures of performance (MOPs) for the Northern Watch Technology Demonstration project. Their primary purpose is to quantify the ability of the suite of sensors at the Northern Watch Station (NoWS) to conduct maritime surveillance at a choke-point in Canada's Northwest Passage. The values of these metrics should be determined from a combination of live trials in the Arctic and simulation studies. The MOEs and MOPs include the ability of the NoWS to detect, classify, identify and track maritime vessels, false alarm rates, and the impact of the NoWS on remote surveillance operators. Northern Watch's adoption of these metrics will influence what data are collected at the Arctic trials. The metrics will also help to determine cost-effective options for Arctic maritime surveillance.

Résumé

La présente étude porte sur les mesures provisoires d'efficacité et de rendement du projet de démonstration de technologies de surveillance du Nord. Ces mesures visent principalement à quantifier la capacité de l'ensemble de capteurs de la station de surveillance du Nord (NoWS) à effectuer de la surveillance maritime dans un goulet du Passage du Nord-Ouest du Canada. Les valeurs de ces mesures devraient être déterminées au moyen d'une combinaison d'essais sur le terrain dans l'Arctique et d'études par simulation. Les mesures de rendement et d'efficacité comprennent la capacité de la NoWS de détecter, de classifier, d'identifier et de poursuivre les navires, les taux de fausses alarmes ainsi que les répercussions de la NoWS sur les opé rateurs de surveillance à distance. L'adoption de ces mesures par le projet de surveillance du Nord influera sur le choix des données à recueillir au cours des essais dans l'Arctique. Ces mesures aideront également à cerner des options rentables de surveillance maritime dans l'Arctique.

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Executive summary

Measures of Effectiveness and Performance for the Northern Watch Station

David Waller, Matthew R. MacLeod, Talia McCallum; DRDC CORA TM 2008-053; Defence R&D Canada – CORA; July 2009.

Background: The main goal of the Northern Watch Technology Demonstration project is to determine cost-effective options of sensor-platform combinations for maritime surveillance of Canada's Arctic. One of the sensor-platform combinations that might contribute to these cost-effective options is the Northern Watch Station (NoWS). A NoWS consists of a variety of static, ground-based and underwater surveillance systems that work together to monitor maritime traffic at a choke-point in the Canada's North. Candidate sensor technologies for the NoWS will be demonstrated in three trials at Barrow Strait in the Northwest Passage.

Scenarios: Five Arctic maritime surveillance scenarios are considered in this paper to determine surveillance goals for the NoWS. The surveillance goals are used to determine what measures of effectiveness (MOEs) and measures of performance (MOPs) are most appropriate for assessing the ability of the NoWS to conduct choke-point surveillance.

Measures of Effectiveness and Performance: The following list summarizes the MOEs and MOPs that we propose measuring (at trials and in simulation) for the NoWS. The MOEs are dependent on the sensor, fusion and operator MOPs.

MOEs
- Probabilities to detect, classify and identify different targets of interest during transit through a specific choke-point (e.g. Barrow Strait), under a variety of weather conditions;
- False detection rates;
- Mis-classification probabilities; and,
- Mis-identification probabilities.

Sensor MOPs
- Contour plots showing the ranges at which detection, classification and identification are achieved at different levels of confidence (50%, 90%, 95%, 99%); and,
- Minimum, median and maximum ranges for detection, classification and identification at 99% confidence level.

Fusion MOPs
- Number of correctly associated track segments per vessel transit in Area Of Responsibility;
- Percentage of transit with correctly associated track(s); and,

– Percentage of transit with incorrectly associated track(s).

Operator MOPs

– Percentage of time that system can run autonomously;
– Ease of use by operator; and,
– Operator confidence in system.

Recommendations: This paper lists the metrics that we believe are most pertinent for assessing the ability of the NoWS to conduct maritime surveillance at a choke-point. We recommend that these provisional metrics be adopted by the project. They have already influenced the first trial's data collection plan. The values of these MOEs and MOPs and the estimated cost of an operational NoWS will ultimately lead to the decision whether NoWSs are a viable part of the solution to monitoring and maintaining sovereignty over Canada's North.

Sommaire

Measures of Effectiveness and Performance for the Northern Watch Station

David Waller, Matthew R. MacLeod, Talia McCallum ; DRDC CORA TM 2008-053 ; R & D pour la défense Canada – CARO ; juillet 2009.

Introduction : Le principal objectif du projet de démonstration de technologies de surveillance du Nord est de cerner des options rentables pour un ensemble plateforme-capteurs destiné à la surveillance maritime de l'Arctique canadien. La station de surveillance dans le Nord (NoWS) est une de ces options. Une NoWS est un ensemble de divers systèmes de surveillance statiques, basés au sol et sous-marins, qui fonctionnent en coopération pour surveiller le trafic maritime dans un goulet du Nord canadien. Des technologies de détection qui pourraient être utilisées dans la NoWS seront mises à l'épreuve au cours de trois essais dans le détroit de Barrows du Passage du Nord-Ouest.

Scénarios : Cinq scénarios de surveillance maritime dans l'Arctique sont étudiés dans le présent article afin de déterminer les objectifs de surveillance de la NoWS. Ces objectifs de surveillance sont utilisés pour déterminer quelles mesures d'efficacité et de rendement sont les plus appropriées pour évaluer la capacité de surveillance d'un goulet de la NoWS.

Mesures d'efficacité et de rendement : La liste suivante résume les mesures d'efficacité et de rendement que nous proposons d'utiliser (au cours des essais et dans les simulations) pour la NoWS. Les mesures d'efficacité dépendent des mesures de rendement à l'égard des capteurs, de la fusion et de l'opérateur.

Mesures d'efficacité

- Probabilités de détection, de classification et d'identification de différentes cibles d'intérêt au cours du passage dans un certain goulet (le détroit de Barrows), dans diverses conditions météorologiques ;
- taux de fausses alarmes ;
- probabilités de classification erronée ;
- probabilités d'identification erronée.

Mesures de rendement à l'égard des capteurs

- Tracé des courbes montrant les portées auxquelles la détection, la classification et l'identification sont effectuées avec différents niveaux de confiance (50%, 90%, 95%, 99%) ;
- Portées minimales, médianes et maximales de détection, de classification et d'identification avec un niveau de confiance de 99%.

Mesures de rendement à l'égard de la fusion

- Nombre de segments de piste correctement associés par passage de navire dans la zone de responsabilité ;

– Pourcentage de passage ayant une ou des pistes correctement associées ;
– Pourcentage de passage ayant une ou des pistes incorrectement associées.

Mesures de rendement à l’égard de l’opérateur

– Pourcentage du temps où le système peut fonctionner de façon autonome ;
– Facilité d’utilisation par l’opérateur ;
– Confiance accordée par l’opérateur au système.

Recommandations : Le présent article donne une liste des mesures que nous croyons être les plus pertinentes pour l’évaluation de la capacité de la NoWS à effectuer la surveillance maritime dans un goulet. Nous recommandons que ces mesures provisoires soient adoptées par le projet. Elles ont déj à influé sur le plan de collecte de données du premier essai. Les valeurs de ces mesures d’efficacité et de rendement et le coût estimé d’une NoWS opérationnelle permettront en fin de compte de déterminer si les NoWS sont un élément viable de la solution de surveillance et de maintien de la souveraineté dans le Nord canadien.

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Acknowledgements

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1 Introduction

The goal of the Northern Watch Technology Demonstration (TD) project is “to identify and characterize combinations of sensors and systems to develop a cost-effective Recognized Maritime Picture (RMP) for the unique maritime environment of the Canadian Arctic” [1]. This goal will be achieved by studying:

- surveillance of a choke-point in the Northwest Passage with a variety of static land and water-based sensors; and
- wide-area maritime surveillance of the Arctic.

The surveillance of a choke-point will be investigated by conducting (1) technology demonstrations in the Arctic and (2) computer simulations of the sensors and target vessels. The integrated system of sensors that will be demonstrated is called the Northern Watch Station (NoWS). Arctic wide-area maritime surveillance will be studied through simulation. The data collected by the NoWS in the Northern Watch trials will be used in the wide-area simulations to provide a realistic model of the NoWS.

In order to compare different combinations of sensors and systems properly, common measures of effectiveness (MOEs) and measures of performance (MOPs) must be used. This is true for both the choke-point and wide-area surveillance studies. This paper proposes the MOEs and MOPs that quantify the ability of the NoWS to conduct choke-point surveillance. A future paper will discuss the metrics for wide-area maritime surveillance in the Arctic.

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2 Background

An essential element of Canada's assertion of sovereignty over the waterways in the Canadian Archipelago is its ability to monitor maritime traffic. Until recently, Canada's Arctic waterways have had too much ice in them to allow significant maritime traffic. However, climate change resulting from global warming, which is particularly acute in the Arctic, is causing this situation to change rapidly. Although the projected rate of summer ice reduction is uncertain, and the ice extent fluctuates significantly from year-to-year, the trend is clear: the extent of Arctic summer ice is reducing rapidly. In fact, the smallest ice extent ever measured by satellite occurred in 2007. The minimum ice extent in 2007 was 4.28 million km^2; this was 23% smaller than the previous minimum (5.57 million km^2 in 2005) [2]. Figure 1 shows the Arctic ice extents for 2007, 2008 and the average extent from 1979 to 2000. There is significant variance among various ice models with respect to when the Arctic will first be ice-free during the summer, but the earliest prediction is 2013 from Maslowski [4]. The Maslowski model is the only one that comes close to predicting the recent reduction in summer ice extent; however, even this model underestimated how much ice would be lost by 2007.

It should be noted that a reduction in overall Arctic ice extent does not necessarily mean there is a loss of ice extent in Canadian Arctic waters; however, it has historically been the case that as the overall extent shrinks, so does Canada's ice extent (including the Northwest Passage). Most important of all, once *all* the Arctic summer ice is gone, Canada's waterways will be free of ice.

For the next decade or two, the summer is the only time when significant shipping might be expected in the North. Whether (or when) shipping will be possible outside of the summer is not known at this point in time.

As there are thousands of kilometres of waterways to monitor, maritime surveillance in the Arctic is very challenging. The most important of these waterways is the Northwest Passage: the family of routes that allow ships to travel between the Atlantic and Pacific Oceans. The routes that are best-suited for navigation by large ships are indicated in Figure 2. There are a number of narrow (less than 100 km wide) portions of the Northwest Passage that could provide good locations for ground- and underwater-based surveillance sensors. The choke-point between Devon and Somerset Islands, Barrow Strait (see Figure 2), will be the area of interest for the Northern Watch TD trials.

Four Defence R&D Canada (DRDC) centres are participating in Northern Watch. Table 1 shows the main responsibilities of the centres. Northern Watch will conduct its first technology demonstration in August 2008. This trial will focus on the effectiveness and performance of individual sensors. The follow-up trials in 2009 and 2010 will focus on the effectiveness and performance of the integrated NoWS. After the trials are complete, the measurements will be used as input for the surveillance simulations, which in turn

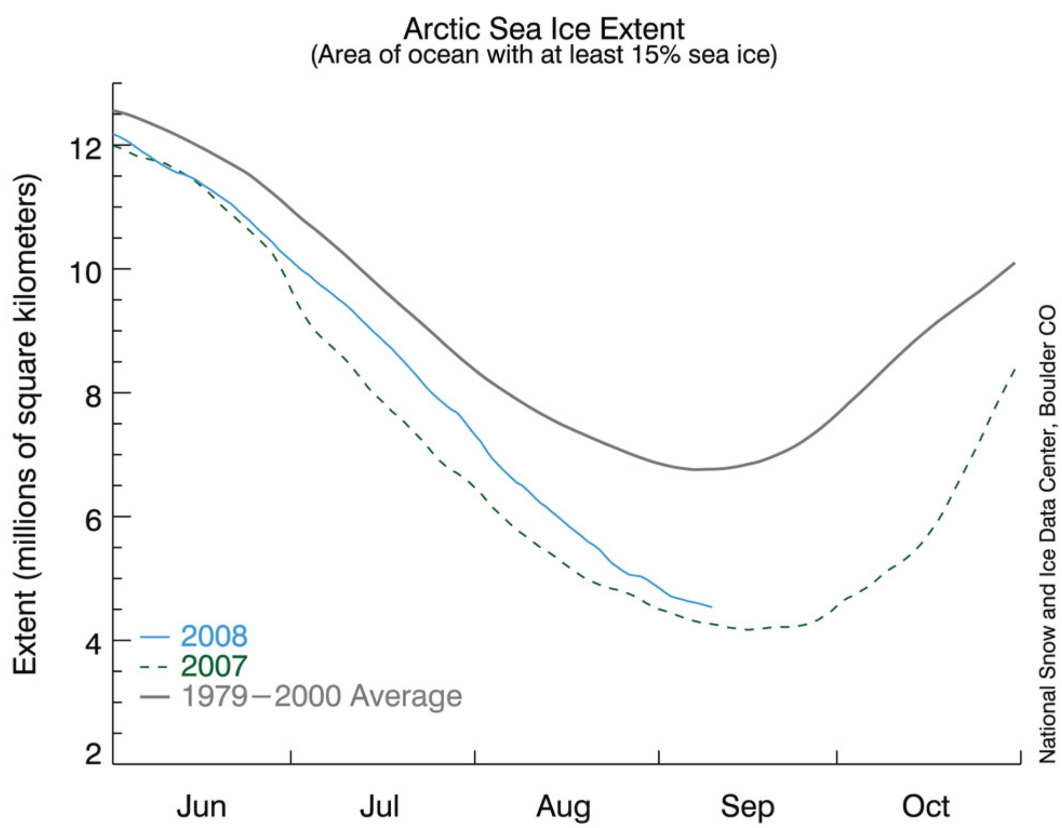

Figure 1: *The Arctic ice extents for 2007, 2008 and the mean of 1979-2000 [3]. These data suggest the amount of summer Arctic ice is decreasing at a rapid rate.*

Figure 2: *The red lines show the most likely Northwest Passage routes between the Atlantic and Arctic Oceans [5].*

Table 1: *Participating DRDC Centres and their responsibilities.*

DRDC Centre	Responsibilities
Ottawa	Maritime Surveillance Radar Electronic Intelligence Automatic Identification System Systems Integration Common Operating Picture
Valcartier	Electro-optical/Infra-red camera, Meterology
Atlantic	Underwater acoustic and electro-magnetic sensor arrays, trial logistics
Centre for Operational Research and Analysis	Operational Research and Analysis

will be used to generate recommendations on cost-effective options for wide-area maritime surveillance of Canada's Arctic.

Metrics for maritime surveillance have been studied previously by DRDC Centre for Operational Research and Analysis (CORA) and elsewhere. For a recent review of intelligence, surveillance and reconnaissance (ISR) metrics, see Reference [6]. This review and [7] were consulted extensively in the development of the MOEs and MOPs for this paper. Due to the static nature of the NoWS sensors, not all the standard ISR metrics are applicable (e.g. revisit rate); however many standard metrics can be used (e.g. probabilities to detect, classify and identify vessels [1]).

In the future, a detailed study of the dependence of the NoWS MOEs and MOPs on different variables (lower-level metrics, e.g. sensor ranges, duty cycles, signal-to-noise ratios; environmental factors, e.g. local topography, precipitation, sea-state) will be vital for optimizing the effectiveness of the NoWS for choke-point surveillance. It will be particularly important to identify regions of high sensitivity where a small change in a variable can have a large effect on the MOEs and MOPs.

1. For this document, classifying a vessel is defined as correctly determining its generic class (e.g. cruise ship, oil tanker, small pleasure craft, surface military vessel, submarine, etc.). Identifying a vessel is defined as determining its unique identity. This is usually indicated by a number on the hull of the ship (e.g. an International Maritime Organization number for passenger ships over 100 gross tons and cargo ships over 300 gross tons).

3 Surveillance scenarios, goals and concept of operations

3.1 Scenarios

Five different scenarios were considered in order to determine the MOEs and MOPs for the NoWS. These scenarios cover:

- declared shipping and cruise traffic through the Northwest Passage;
- undeclared maritime traffic;
- undeclared pleasure craft;
- pollution from a ship; and,
- willful, unannounced incursion by a foreign military vessel.

The first four scenarios were chosen as they include the types of activity that are typically of interest to those tasked with surveillance of the North: the CF, including Joint Task Force North, and other federal government departments [8]. The CF is involved in a wider variety of domestic tasks in the North than in the rest of the country due to the limited resources of other government departments. The last scenario was chosen as it represents a severe test of Canada's ability to assert sovereignty in its northern territory.

3.1.1 Declared shipping and cruise traffic through the Northwest Passage

A vessel can voluntarily provide information about itself through a number of different means. It can report its position via:

- Automated Identification System (AIS);
- the Canadian Coast Guard (CCG) Marine Communications and Traffic Services (MCTS);
- NORDREG (Arctic Canada Traffic System) vessel monitoring;
- own ship weather messages; and
- commercial fishing vessel location reports.

AIS is a collision avoidance system that requires periodic reports from vessels that are over 300 gross tons [9]. The CCG's MCTS optimizes maritime traffic movement and facilitates merchant ship-to-shore communications [10]. Ships that participate in NORDREG report their intention to enter Canadian Arctic waters (latitudes north of 60^0 N) 24 hours before they expect to enter. Compliance with this system is very high as it assures vessels that are travelling through the ice-filled Arctic waters that the CCG knows of their whereabouts, and it gives compliant vessels access to ice reports. An operational NoWS would complement information provided by these self-reporting systems by increasing confidence in the data that are provided by self-reporting ships. This leads to improved maritime domain awareness and a clearer Recognized Maritime Picture (RMP).

3.1.2 Undeclared commercial traffic

Vessels bound for a Canadian port are required to file a 96-hour Pre-Arrival Information Report to meet the Canadian Marine Transportation Security Regulations [11]. Also, a Vessel Traffic Services Offshore Report must be filed at least 24 hours before the ship enters a Canadian Vessel Traffic Services Zone to satisfy the Canada Shipping Act. Any vessel that fails to do so may be infringing on Canadian sovereignty [11]. Non-reporting vessels must be prosecuted to protect Canadian sovereignty. Naturally, the first step required in prosecuting non-reporting vessels is detecting them. Ideally, these ships should be detected as soon as they enter Canadian waters. Since the current surveillance of Arctic waters is not persistent in all areas, a NoWS could provide the first opportunity to detect non-reporting vessels. The sooner the NoWS can detect, classify and identify the non-reporting vessel, the better. Detection of a non-reporting vessel is not sufficient in this scenario as at least the class (and probably the identity) of the ship should be determined to know whether the ship is one that reported its intentions to enter Canadian waters.

Since the previous scenario deals with ships that are generally quite large (e.g. merchant and cruise ships), this scenario assumes a smaller, undeclared vessel: a 20 m fishing vessel.

3.1.3 Undeclared pleasure craft

Undeclared pleasure craft tend to be small. They can be as small as a 15 m sail boat [8]. Also, they are less likely to report their locations via self-reporting systems like NORDREG and AIS. They also tend to be more difficult to detect and identify due to their reduced size. As a result their inclusion in the RMP is challenging. Given that, even a detection by the NoWS would provide information that is not currently available, increasing picture completeness. If a NoWS could classify and identify these vessels, that would be ideal.

3.1.4 Polluting vessel

A NoWS might be able to contribute to the identification and future legal prosecution of a ship responsible for polluting in Canadian Arctic waters. Although it is unlikely that a NoWS would witness the act as it happens, it might be able to provide valuable information about the location and identification of a vessel as it passes through Canadian waters. For instance, if an oil spill is detected by RADARSAT or RADARSAT 2 [12], it may be possible to correlate the imagery with data from the NoWS. The radar on the NoWS also might be capable of detecting oil spills in the water. The more NoWSs that are operational, the more likely that at least one of them will be able to provide useful information. Ideally, data that are collected should be admissible as evidence in a court of law.

3.1.5 Foreign military incursion

Along with the detection of small pleasure craft, the detection, classification and identification of a willful, unannounced incursion by a foreign military vessel is one of the most challenging scenarios that is considered. A foreign military vessel may be actively avoiding detection, so the sensing capabilities of the NoWS will be challenged more than in the other scenarios. In this scenario, it is especially important that the vessel be detected and classified as early as possible. Operators must also be alerted with minimal delay, so that the Canadian Forces can react as quickly as possible.

3.2 Surveillance goals

The surveillance goals are derived from each of the scenarios listed in the preceding sections. The Area of Responsibility [2] (AOR) is considered to be the part of Canada's Northern Waters immediately around a NoWS. The AOR extends across the full width of the choke-point that is monitored by the NoWS (or group of NoWSs if more than one NoWS monitors the same choke-point).

For the first scenario (declared maritime traffic) the goals of the NoWS are to detect, classify, identify and track declared shipping and cruise traffic within the AOR of the NoWS. The performance of a NoWS for detection, classification, identification and tracking will be range-dependent, so the performance should be determined at enough distance intervals to have a good understanding of the overall effectiveness of the NoWS. There may also be some azimuthal dependence for some of the sensors (due to the local topography or the nature of the sensors), so the surveillance metrics should be defined to take this into consideration.

A wide range of weather conditions can be encountered in the North during the shipping season (currently summer and early fall). As a result, it is important that a NoWS is able to accomplish its surveillance goals in a variety of conditions: from fair weather, to storms with high winds and precipitation.

Besides sensing real targets, the NoWS should have a low false alarm rate. If false alarms from the NoWS are too frequent, remote operators might ignore all alarms, real and false, from the NoWS. This would result in real targets being missed. Also, reacting to an alarm may involve sending a plane or ship to the Arctic. This is extremely expensive, so it is not acceptable to have a high false alarm rate. What rate is acceptable will depend on the number of NoWS that are active. The acceptable rate will also depend on the type of ship that is associated with a false alarm. False alarms that indicate a hostile foreign military vessel are more serious than false alarms that indicate a small pleasure craft.

2. Area of Responsibility is usually defined as the geographical area within which a military unit is designated to provide alerts and response; however, since the NoWS operates autonomously, no unit is physically present to respond in its Area of Responsibility.

The scenarios listed in Sections 3.1.2 to 3.1.5 have very similar goals in that they all require the NoWS to detect, classify, identify and track different types of vessels. The only difference between the goals for the scenarios is the type of vessels that must be sensed. Additional goals apply to the polluting vessel scenario (Section 3.1.4) as the NoWS should collect data that can be used in a legal case against a polluting vessel.

To summarize, the surveillance goals are:
- detect vessels;
- classify vessels;
- identify vessels;
- track vessels;
- minimize false alarm rates; and
- collect evidence of pollution by specific vessel.

These vessels range from small pleasure craft (15 m) to large ice breakers that have been converted to cruise ships (140 m) [8]. Additionally, these goals must be accomplished in the full range of weather conditions that are expected in the North during shipping season. These goals will be used to determine the MOEs and MOPs for the NoWS.

3.3 Concept of operations for NoWS

In addition to determining surveillance scenarios and goals, one must assume a concept of operations for the station in order to determine what metrics are most relevant for the NoWS. This section provides a brief concept of how an operational NoWS would be operated.

One of the key features of a NoWS is that it will operate without any personnel located at the station. The NoWS must also operate as autonomously as possible to minimize the amount of work required by remote operators. Both of these requirements are driven by the current lack of personnel to perform additional surveillance duties for the Arctic.

Ideally, a NoWS should be able to operate whenever maritime traffic is present. As the presence of surface traffic is dependent on the ice (and hence weather) conditions, the sensors for surface traffic do not need to operate during the coldest months when the waterways are ice-locked. However, the sensors that can detect sub-surface vessels should be capable of functioning year-round.

The NoWS should be able to detect and classify vessels passing through the choke-point that it monitors. The probability for detection and correct classification should be very high as the NoWS will be most useful if it can meet all the surveillance requirements in its AOR without help from other surveillance assets. Some choke-points where NoWSs could be located are very wide, so it might be necessary to have multiple NoWSs monitoring a single AOR. With NoWSs at many different Arctic choke-points, it should be possible to maintain awareness of maritime traffic throughout the Arctic.

Sensors should be able to cue each other so that contacts with one sensor can be cross-checked. Performing correlations of contacts will increase confidence in detections and reduce false alarm rates. A NoWS should also be able to perform track fusion autonomously so that the workload of remote operators is not increased. Given the relatively low density of traffic in the Arctic, autonomous track fusion should be achievable.

The NoWS should be able to identify self-reporting ships that have already voluntarily reported their locations to the Canadian Coast Guard. Identification by the NoWS will increase the confidence in the RMP for the Arctic. Unfortunately, this does not significantly improve maritime domain awareness. The NoWS should also be capable of identifying non-reporting vessels in the Arctic. This is a much more challenging requirement as non-reporting vessels might be actively avoiding detection and/or identification. The range and performance of the NoWS sensors should ensure that a non-reporting vessel can not pass through a choke-point without being detected (at a minimum), classified (preferably) and identified (ideally). This information should be sent to an appropriate operator so that follow-up analysis can be performed if required. The outcome of this analysis could lead to further surveillance assets being assigned to an area and/or target of interest.

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4 Metrics

The metrics which quantify the ability of the NoWS to conduct Arctic maritime surveillance are divided into MOEs and MOPs. The MOEs are directly related to the surveillance goals listed in Section 3.2. The MOPs provide additional, objective information on the performance of the system (detection, classification, identification and tracking) plus the operators' subjective assessment of the performance of the system.

4.1 Measures of effectiveness

According to Gauthier et al. [6], surveillance "MOEs measure the ability of a given architecture to meet well defined [surveillance] objectives within the operational context". As a result, we use the surveillance goals from Section 3.2, which were derived from specific scenarios, to determine the MOEs for the NoWS. In fact, regarding the determination of MOEs, Gauthier et al. observe "normally, it is simply a matter of restating the objective as a measurable quantity". For example, one of the surveillance goals is to detect undeclared pleasure craft transiting a choke-point in all environmental conditions; the corresponding MOE is the probability, under all environmental conditions, to detect an undeclared pleasure craft while it transits a choke-point. Obviously, this probability will vary with the environmental conditions, so a number of MOEs can be defined to cover the range of weather conditions.

4.1.1 Probabilities to detect, classify and identify

All the scenarios in Section 3.1 have as surveillance goals the ability to detect, classify, identify and track vessels in a variety of weather conditions during their transit through the AOR of a NoWS (a choke-point in the North West Passage). The only difference from scenario to scenario is the type of vessel of interest. Consequently, the main MOEs will be the probabilities that vessels of the different classes are detected (P_{det}), classified (P_{cl}), and identified (P_{id}) as they pass through the AOR of the NoWS. The tracking of vessels will be dealt with in Section 4.2.2. The probability to identify vessels has been given paramount importance amongst the surveillance MOEs that are currently employed by Joint Task Force Atlantic (JTFA) [13] and is a standard metric used by Canada's regional operational commands [14]. As a result, decision makers are likely to focus on this MOE more than any other. The identification of vessels is the most demanding of the surveillance goals for a NoWS.

The probability MOEs for a NoWS at a specific location (e.g. Barrow Strait) can be summarized in a single table like Table 2. The probabilities are averaged over all the expected vessel routes through the AOR. They represent the probability that a vessel will be correctly detected, classified and identified during the transit through the AOR. The probabilities depend on a number of factors. The smaller the vessel, the more difficult it will likely be to

Table 2: *MOEs for NoWS at a specific site. The small and large vessels to which the probabilities pertain, and the ideal and poor conditions are defined in the text.*

	$P_{det}(\%)$		$P_{cl}(\%)$		$P_{id}(\%)$	
Conditions	small	large	small	large	small	large
ideal						
poor						

detect. Here, a "small" vessel is assumed to be the 15 m sail boat from the undeclared pleasure craft scenario (Section 3.1.3). A "large" vessel is assumed to be a 140 m ice breaker that is being used as a cruise ship [8] (Section 3.1.1). The probabilities also depend on the weather and the conditions on the water (sea-state and ice). We consider two extreme weather and water conditions: "ideal" and "poor." For ideal weather and water conditions there is full daylight on a clear day with sea-state 1 and no ice. For poor conditions there is darkness, snowfall, sea-state 3, and moderate ice conditions (50% ice coverage, Canadian Ice Service colour code yellow: 40% to 60% of ice is thicker than 15 cm [15]).

The pollution scenario had an additional surveillance goal: "collect evidence of pollution by a specific vessel". This goal requires the NoWS to identify a polluting vessel correctly. As mentioned previously, it is unlikely that a NoWS will witness a ship in the process of polluting the water (e.g. dumping oil). Instead information collected from another source (e.g. RADARSAT imagery) must be correlated with a ship identification by a NoWS. Consequently, the MOE that is related to this surveillance goal is, again, the probability to identify a ship during its transit through the choke-point. This MOE is identical to the identification probability MOE that has already been mentioned, so no additional MOEs are required for the pollution scenario surveillance goals.

4.1.2 False alarms

One of the surveillance goals listed in Section 3.2 is "to minimize false alarm rates". False alarms can be divided into three categories: (a) the NoWS "detects" a target when none are present; (b) it mis-classifies a target; or (c) it mis-identifies a target.

The rate at which false detections occur depends on a number of factors [6]. The false detection rate depends on (a) the vessel size (small or large); (b) the weather, sea and ice conditions (ideal or poor); and (c) the apparent range of the target. The range can affect the signal-to-noise ratio so that more false detections are expected at long range for fixed detection criteria. This occurs because the signals from distant targets are usually much weaker than signals from closer targets.

The false detection rate can be provided for two ranges: "near" (7 km) and "far" (35 km). The near range is chosen to be 7 km as this is the nearest range at which some NoWS sen-

Table 3: *False detection rate MOEs for the NoWS. The terms small, large, ideal, poor, near and far are defined in the text.*

		$Rate_{FA}$ [#/day]	
Conditions	Range	small	large
ideal	near		
	far		
poor	near		
	far		

sors can detect ships. This limitation is due the location and height of the sensors at the Northern Watch trials and the local topography; the sensors are set back approximately 100 m from the steep cliffs which overlook the strait. The far range is chosen to be 35 km as this is the half-way point across Barrow Strait. If NoWS were installed on both sides of the choke-point, each would need to be able to monitor out to the middle of the strait. Table 3 shows an example of how the false detection MOEs can be presented.

The second type of false alarm occurs when real targets are mis-classified. The mis-classification probability, $P_{\overline{cl}}$, can be expressed as a single number which averages over all the possible ways that a target can be mis-classified, or it can be expressed as a matrix (see Table 4) where all the possible (mis-)classification probabilities are given. The matrix provides more information about the types of mis-classification that occur, so the matrix should be used for this MOE.

Table 4: *Average (mis-)classification probabilities for the NoWS with four vessel classes (a,b,c,d). $P_{\overline{cl}}^{ij}$ $(i \neq j)$ is the probability to mis-classify type i as type j. The diagonal elements represent the probabilities to classify each of the four vessel classes correctly. The classification probabilities can be range- and condition-dependent. For further granularity of this MOE, additional tables can be produced.*

		detected class			
		a	b	c	d
true class	a	$P_{\overline{cl}}^{aa}$	$P_{\overline{cl}}^{ab}$	$P_{\overline{cl}}^{ac}$	$P_{\overline{cl}}^{ad}$
	b	$P_{\overline{cl}}^{ba}$	$P_{\overline{cl}}^{bb}$	$P_{\overline{cl}}^{bc}$	$P_{\overline{cl}}^{bd}$
	c	$P_{\overline{cl}}^{ca}$	$P_{\overline{cl}}^{cb}$	$P_{\overline{cl}}^{cc}$	$P_{\overline{cl}}^{cd}$
	d	$P_{\overline{cl}}^{da}$	$P_{\overline{cl}}^{db}$	$P_{\overline{cl}}^{dc}$	$P_{\overline{cl}}^{dd}$

The third type of false alarm is due to the mis-identification of a vessel. The MOE for mis-identification is a straightforward probability: either a ship is correctly identified or it is not. As with the other MOEs, the values of the MOE vary with vessel class, range and conditions. Table 5 shows how the mis-identification probability can be presented for "small" and "large" vessels.

Table 5: *Mis-identification probabilities for the NoWS for "small" and "large" vessels. The probabilities depend on target range (near or far) and environmental conditions (ideal or poor).*

		$P_{\overline{id}}$(%)	
Conditions	Range	small	large
ideal	near		
	far		
poor	near		
	far		

4.2 Measures of performance

Reference [6] states that "MOPs are used to measure the performance of individual components of [a surveillance] architecture or the performance of the architecture as a whole". Since we are concerned with the NoWS, we will focus on the performance of the system as a whole. The performance of the individual sensors is dealt with in [16]. We propose measuring system MOPs for the following two reasons:

1. to understand better the values of the MOEs obtained for the NoWS at Barrow Strait (Section 4.1); and,
2. to allow the estimation of MOEs for other choke-points through simulation.

The probability MOEs (detection, classification and identification) we proposed in the previous section are averaged over all the possible routes through a specific choke-point. We propose measuring MOPs that provide more detail on the performance of the NoWS. This helps to understand the values of the "averaged" (and site-specific) MOEs. Also, the MOPs measured at one choke-point can be input into computer models that can be used to estimate the values of the MOEs at other choke-points. This is extremely valuable information as it is not feasible to perform trials at multiple choke-point locations. If the MOPs are not determined, it will not be possible to infer the values of the MOEs at other choke-points.

4.2.1 Sensor system MOPs

The probabilities to detect, classify and identify vessels depend on the range and azimuth from the NoWS to the target, so the range and azimuth dependence of these MOPs should be represented in tables or plots. Contours on a map of the NoWS AOR showing where the probabilities have specific values (e.g. 50%, 90%, 95%, 99%) are particularly informative. Figure 3 shows an example of what these contours might look like for the Barrow Strait trial site. The location of the contours will also depend on the type of target and the environmental conditions. Multiple plots can be generated for a range of target classes and environmental conditions. It is not always practical to present several plots to high-level decision makers, so the information should be conveyed in a more compact manner as well.

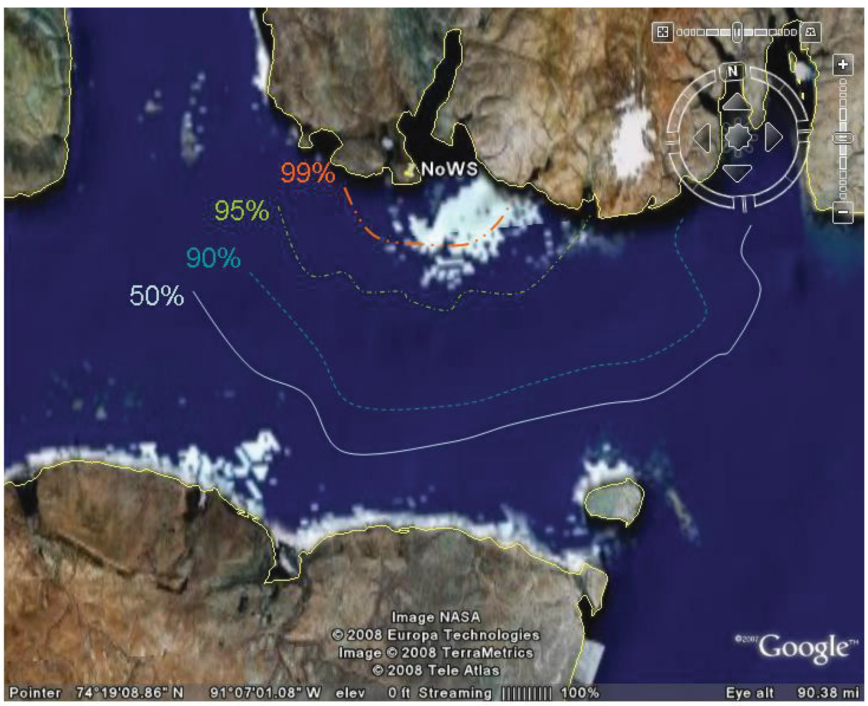

Figure 3: *Hypothetical contours for probability of identification of a large vessel by the NoWS.*

Reducing the amount of information must be done carefully so that the information that is most operationally relevant is preserved as much as possible.

From an operational perspective, the information that is likely to be of greatest relevance are the ranges at which the NoWS has various levels of effectiveness. For this reason, the information contained in each contour can reasonably be collapsed into three numbers:

1. the minimum range at which the probability to detect, classify or identify is a fixed value;
2. the maximum range for this same probability; and,
3. the median range for this same probability.

These three numbers should give decision makers a good idea of the performance of the NoWS in different scenarios. If the azimuthal dependence is not strong (i.e. the difference between the maximum and minimum ranges is very small), then only the median range needs to be quoted. It must be stressed that these ranges will depend on the specific location of a NoWS.

These site-specific MOPs are useful for determining where future NoWS should be located. Table 6 shows how P_{det}, P_{cl}, and P_{id} can be conveyed in a compact manner. The table shows the minimum, median and maximum ranges at which small and large vessels are correctly detected, classified, and identified with 99% probability. For now, the choice of 99% probability is somewhat arbitrary; the exact probability will be determined when the operational requirements are defined more specifically.

Table 6: *An example of more detailed MOPs for a NoWS. "Small" and "large" vessels are defined in the text. This table pertains to a single set of weather, sea-state and ice conditions. Additional tables would be presented to a decision maker to show the performance of the NoWS over a range of conditions.*

	R_{min}(km)		R_{med}(km)		R_{max}(km)	
	small	large	small	large	small	large
$P_{det} = 99\%$ $P_{cl} = 99\%$ $P_{id} = 99\%$						

4.2.2 Tracking MOPs

In addition to performing detection, classification and identification of vessels, one of the surveillance goals for the NoWS, listed in Section 3.2, is the ability to track a vessel as it passes through its AOR. Tracking (or fusion) MOPs measure "the ability of a system or task group to amalgamate time-stamped data received from multiple sources in order to create and characterize individual target representations (tracks)" [6]. Since the quality of tracking is assessed with MOPs in Reference [6], we will refer to tracking MOPs (as opposed to MOEs) to be consistent.

The ability of the NoWS to track vessels depends on the performance of all the sensors in the NoWS. The quality of the measurements determines how well the new measurements can be matched to an existing track (or how well a new track can be created). This is referred to as "association performance" in [6]. The quality of the measurements also affects how likely it is that tracks from one vessel will be mis-associated with another vessel. This is referred to as "track purity" in [6].

A number of different MOPs can be defined to quantify the performance of the tracking provided by the NoWS:

1. number of correctly associated track segments per vessel transit in AOR;
2. percentage of transit with correctly associated track(s); and,
3. percentage of transit with incorrectly associated track(s).

The first tracking MOP quantifies the association performance. Ideally, each vessel should have one track associated to it as it passes through the AOR. At worst, a vessel's transit will have no track segments associated with it. It is also possible that a single vessel will have multiple tracks associated with it as it passes through the AOR. This will happen (1) if there are long gaps between track updates so that track segments can not be associated with each other, or (2) if some of the track segments are poorly measured so that the segments are not correctly correlated with each other.

The second tracking MOP is another way of quantifying association performance. The percentage of a vessel's transit through the AOR with correctly associated tracks gives a good idea of how much of the transit was properly tracked. It complements the first MOP (number of track segments) as the first MOP could show that there are many track segments, which by itself would reflect poorly on the tracking of the NoWS, however, if a very large fraction of the transit has associated tracks, the tracking could be deemed to be effective.

The third tracking MOP is a measure of track purity. The percentage of a vessel's transit with incorrectly associated tracks indicates how likely it is that a surveillance operator might become confused by the information given by the NoWS. It also indicates how poorly the track location correlates with the true vessel location. Mis-association of tracks can also result from the mis-classification or mis-identification of a vessel for a portion of its transit through a choke-point. It is unlikely in the near future that there will be many occurrences of multiple vessels transiting an Arctic choke-point at the same time (except when CCG icebreakers accompany a vessel), so it is unlikely that there will be significant problems related to mis-assigning tracks. As a result, this MOP should be given lower importance compared to the first two tracking MOPs.

4.2.3 Operator MOPs

Operator surveys or interviews are often associated with the assessment of a new surveillance system. An example of operator assessments for a recent DRDC ISR project is given in Reference [17]. Since the concept of operation for the NoWS (see Section 3.3) is to run as autonomously as possible, the operator MOPs that are most pertinent relate to the degree to which surveillance tasks can be performed without the operator. The operators' perception of the effectiveness of the NoWS is also very importance as they will only use information from the NoWS if they are confident that it is of high quality. Any new surveillance system must also be easy for operators to use as they can not devote significant amounts of time to new systems as they are already very busy with their current duties [17]. To quantify the operators' assessment of the NoWS, surveys or interviews can be conducted whose results can be used to determine the following MOPs:

1. percentage of time that the system can run autonomously;
2. ease of use of NoWS information by the operator; and
3. operator confidence in the system.

The surveys or interviews should be administered immediately after operators have had experience conducting their jobs with a data feed from a real or simulated NoWS.

The first MOP can be determined either by questionnaires (self-assessment by the operator) or by observing operators working. The time that they spend reacting to the system will depend on the amount of traffic (if the system does not operate fully autonomously) and the rate of false alarms (if an operator is required to react) at the NoWS. Consequently, it might be necessary to observe the operators over an extended period (or have the survey cover an extended period) to get an accurate idea of how much time the system can run autonomously. An extended period of observation might not be practical, so surveys may be the preferred method of obtaining these data.

An alternative to using real data is to simulate traffic and false alarms from a NoWS and determine how much time an operator must devote to each vessel's transit across the NoWS's AOR and each false alarm. The percentage of time that the system runs autonomously can then be calculated by estimating the real rate of false alarms and the real number of vessel transits for a fixed period of time:

$$P_A = 1 - \frac{t_{TR} Rate_{TR} + t_{FA} Rate_{FA}}{1440} \tag{1}$$

where t_{TR} is the operator time per transit in minutes, $Rate_{TR}$ is the number of transits per day, t_{FA} is the operator time per false alarm in minutes, $Rate_{FA}$ is the number of false alarms per day, and 1,440 is the number of minutes per day.

A simple way to assess the operator ease-of-use and level of confidence in the NoWS is to ask operators to rate these MOPs using multiple choice questions [18]. After the operators have experience reacting to data from a real (if operators participate in a Northern Watch trial) or simulated NoWS, they can be asked the following questions:

- How do you rate the ease-of-use of the NoWS system and the information provided by the NoWS?
  1. very easy to use
  2. somewhat easy to use
  3. somewhat difficult to use
  4. very difficult to use
- What is your level of confidence in the system?
  1. very confident
  2. somewhat confident
  3. somewhat sceptical
  4. very sceptical

Operators can also be asked to provide answers to open-ended questions which ask them to elaborate on their ease-of-use and confidence ratings. This information could be very valuable to the developers of the NoWS, as it could provide useful ideas for improving the usability of the system.

4.3 NoWS configurations for testing MOEs and MOPs

Besides knowing the surveillance capability of the full suite of sensors at a NoWS, it is also very important to assess the impact that a specific sensor system has on the overall effectiveness or performance of the NoWS. This impact can be assessed by determining the change in the previously listed MOEs and MOPs (which apply to all the sensors of the NoWS) when a single sensor is removed from the NoWS. The relative impact of each sensor on the metrics will form an important part of a cost-benefit analysis of the sensors that are candidates for inclusion in an operational station.

In addition to studying the effectiveness of the NoWS with a single sensor removed, all the other possible sensor combinations can be investigated. With up to N_s different sensors to choose from, the number of different configurations, N_{config}, is given by the sum of the binomial coefficients:

$$N_{config} = \sum_{i=1}^{N_s} \frac{N_s!}{i!(N_s - i)!}. \qquad (2)$$

So for N_s = 5, N_{config} = 31. However, due to limited time and resources for the live Arctic trials, the configuration of the sensors for the NoWS will not be varied. Instead, different configurations can be studied by analyzing the sensor data offline. Different subsets of sensors can be assumed to be available. This will complicate the analysis of the trial data but will ensure that a clear understanding of the merits of the different sensors is obtained.

Simulation studies will also allow one to study the importance of each sensor systematically. The number of different configurations is large (31), but it is feasible to investigate each configuration separately. If computing resources are too limited for performing separate simulations for each NoWS configuration, a single set of simulations with all sensors can be run. These runs can then be analyzed in the same manner as the real trial data: by selectively ignoring data from different sensors so that all sensor combinations can be studied.

The studies of different configurations will lead to a determination of the best mixture of sensors for a NoWS at a specific site. For each configuration, variables such as the cost (capital, operating and maintenance), power, and bandwidth requirements should be calculated (in addition to all the aforementioned MOEs and MOPs) to facilitate detailed optimization studies.

Different cueing strategies can also be investigated to determine their effect on the effectiveness of the NoWS. This requires re-running the simulations with the different cueing strategies. The change in the MOE and MOP values will indicate the success (or lack thereof) for different strategies.

4.4 MOE and MOP summary

The following list summarizes the provisional MOEs and MOPs that we propose determining (at trials and in simulation) for the NoWS:

MOEs
- Probabilities to detect, classify and identify different targets of interest during transit through a specific choke-point (e.g. Barrow Strait), under a variety of weather conditions;
- False detection rates;
- Mis-classification probabilities; and,
- Mis-identification probabilities.

Sensor MOPs
- Contour plots showing the ranges at which detection, classification and identification are achieved at different levels of confidence (50%, 90%, 95%, 99%); and,
- Minimum, median and maximum ranges for detection, classification and identification at 99% confidence level.

Fusion MOPs
- Number of correctly associated track segments per vessel transit in AOR;
- Percentage of transit with correctly associated track(s); and,
- Percentage of transit with incorrectly associated track(s).

Operator MOPs
- Percentage of time that system can run autonomously;
- Ease of use by operator; and,
- Operator confidence in system.

Since the primary goal of the Northern Watch TD is to determine cost-effective options for Arctic maritime surveillance, these metrics will ultimately be used to determine what NoWS configuration(s) is most effective for surveillance [3]. To do this, the relative importance of the different MOEs will have to be determined so that they can be combined into a single measure that determines the overall effectiveness of different configurations. The relative importance of the MOEs and MOPs can be determined by assessing the relative importance of each scenario, and the importance of each metric to each scenario. This assessment can be done by subject matter experts from the CF (possibly surveillance experts from Joint Task Forces Atlantic, Pacific and North, and the Chief of Force Development). The metrics and additional variables (e.g. power consumption, communications bandwidth requirements) can be treated as weighted criteria that are combined using a multi-criteria decision method such as the CORA-developed MARCUS program [19, 20]. MARCUS could compare the rankings of the different configuration options across the different criteria (metrics and other variables) and determine the overall ranking of the options. This approach was used in a weapons mix study by members of CORA's Land Forces ORT [21]. The costs of the different options can also be considered so that the ranking of the options can be based on cost-effectiveness.

3. Note that the "best" configuration depends on which choke-point is being studied. Also, this discussion assumes that the most effective NoWS option for choke-point surveillance will also be the most effective option for wide-area maritime surveillance.

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5 Recommendations

The main goal of the Northern Watch TD project is to determine cost-effective options of sensor-platform combinations for maritime surveillance of Canada's Arctic. One of the sensor-platform combinations that might contribute to these cost-effective options is the NoWS. The NoWS technologies will be demonstrated in three annual trials during the project. In order to assess the effectiveness and performance of the NoWS for choke-point surveillance, appropriate metrics must be chosen and their values must be determined. This paper recommends the provisional MOEs and MOPs to assess the ability of the NoWS to conduct maritime surveillance at a choke-point. These metrics have already influenced the development of a data collection plan for the trials [22] and we recommend that they be used for all future studies of the NoWS. The final decision on which MOEs and MOPs are adopted (and their relative importance) will be up to the military sponsor of Northern Watch (currently the Chief of Force Development's Director of Military Capability Management). The values of these metrics and the estimated cost of an operational NoWS will ultimately lead to the decision of whether or not NoWSs are a viable part of the solution to monitoring and maintaining sovereignty over Canada's North.

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List of Abbreviations

AIS	Automated Identification System
AOR	Area Of Responsibility
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CCG	Canadian Coast Guard
CORA	Centre for Operational Research and Analysis
DND	Department of National Defence
DRDC	Defence Research and Development Canada
ISR	Intelligence, Surveillance and Reconnaissance
JTFA	Joint Task Force Atlantic
MCTS	Marine Communications and Traffic Services
MOE	Measure Of Effectiveness
MOP	Measure Of Performance
NORDREG	Arctic Canada Traffic System
NoWS	Northern Watch Station
NW	Northern Watch
OR	Operational Research
ORT	Operational Research Team
P_{cl}	Probability of Classification
P_{det}	Probability of Detection
P_{id}	Probability of Identification
R_{med}	Median Range
R_{min}	Minimum Range
R_{max}	Maximum Range
$Rate_{FA}$	Rate of False Alarms
RMP	Recognized Maritime Picture
S&T	Science and Technology
TD	Technology Demonstration

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This study documents the provisional measures of effectiveness (MOEs) and measures of performance (MOPs) for the Northern Watch Technology Demonstration project. Their primary purpose is to quantify the ability of the suite of sensors at the Northern Watch Station (NoWS) to conduct maritime surveillance at a choke-point in Canada's Northwest Passage. The values of these metrics should be determined from a combination of live trials in the Arctic and simulation studies. The MOEs and MOPs include the ability of the NoWS to detect, classify, identify and track maritime vessels, false alarm rates, and the impact of the NoWS on remote surveillance operators. Northern Watch's adoption of these metrics will influence what data are collected at the Arctic trials. The metrics will also help to determine cost-effective options for Arctic maritime surveillance.

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MOE
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