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Multistatic Planning Requirements

Cristina D. S. Tollefsen
DRDC – Atlantic Research Centre

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Abstract

The effective employment of multistatic active sonar by the Royal Canadian Navy (RCN) and Royal Canadian Air Force (RCAF) will require the development of new thinking, new doctrine, and new tactics, activities for which multistatic sonar performance prediction tools will be a key enabler. In order to guide the development of new tools, a four-level taxonomy of sonar performance prediction tools was developed, with each level differing in purpose, user group, and requirements: research (Level I), tactics development (Level II), mission planning (Level III), and tactical decision-making (Level IV). A comprehensive list of requirements was specified for each tool level, and organized to allow for comparison and evolution of specific capabilities across levels. Additional considerations including trust and user interface were discussed. Existing monostatic and multistatic sonar performance prediction tools were categorized according to the new taxonomy. It was concluded that no one tool will be able to provide the functionality required at all levels, and it is recommended that this report be used to foster critical discussions within user communities at each level regarding their unique requirements before specific tools are provided for general operational use.

Significance for defence and security

Multistatic sonar performance prediction will be a key enabler for the effective employment of multistatic active sonar in the Canadian Armed Forces. By defining a four-level taxonomy of sonar performance prediction tools, clearly identifying user groups, and categorizing requirements, this paper provides a starting point for discussions of detailed requirements at each level.

Résumé

L'emploi efficace du sonar actif multistatique par la Marine royale canadienne (MRC) et l'Aviation royale canadienne (ARC) nécessitera l'élaboration de nouvelles idées, d'une nouvelle doctrine et de nouvelles tactiques, activités pour lesquelles des outils de prédiction du rendement des sonars multistatiques seront essentiels. Pour orienter le développement de nouveaux outils, on a élaboré une taxonomie à quatre niveaux des outils de prédiction du rendement des sonars dans laquelle chaque niveau varie selon l'objectif, le groupe d'utilisateurs et les besoins : recherche (niveau I), élaboration de tactiques (niveau II), planification des missions (niveau III) et prise de décisions tactiques (niveau IV). Une liste exhaustive des besoins pour chaque niveau d'outil a été dressée et organisée pour permettre la comparaison et l'évolution des capacités particulières entre les niveaux. D'autres aspects, comme la confiance et l'interface utilisateur, ont été abordés. De plus, les outils de prédiction du rendement des sonars monostatiques et multistatiques actuels ont été classés selon la nouvelle taxonomie. Enfin, on a conclu qu'aucun outil ne possédait les fonctionnalités nécessaires à tous les niveaux, et on recommande d'utiliser le présent rapport pour susciter les débats critiques au sein des communautés d'utilisateurs sur les besoins particuliers de chaque niveau avant de fournir des outils particuliers à des fins opérationnelles générales.

Importance pour la défense et la sécurité

La prédiction du rendement des sonars multistatiques sera primordiale pour l'emploi efficace d'un sonar actif multistatique dans les Forces armées canadiennes. Grâce à la définition d'une taxonomie à quatre niveaux pour les outils de prédiction du rendement des sonars, à la détermination claire des groupes d'utilisateurs et à la catégorisation des besoins, le présent document constitue un point de départ aux discussions sur les besoins précis de chaque niveau.

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1 Introduction

Multistatic active sonar has the potential to improve anti-submarine warfare (ASW) operations by exploiting the advantages of using multiple spatially-separated sonar sources and receivers, compared with using traditional monostatic active sonars. The potential to experience multiple detection opportunities per ping should result in increased ability to detect and track targets through the combination of greater geographic coverage and increased likelihood of strong scattering from directional targets. However, the corresponding increase in the complexity in command and control may be one of the disadvantages of operational employment of multistatic sonar.

The effective employment of multistatic active sonar by the Royal Canadian Navy (RCN) and Royal Canadian Air Force (RCAF) will require the development of new thinking, new doctrine, and new tactics. As part of the Force ASW Project, the need for 'mission planning' for multistatics was identified but not further defined [1]. In an attempt to clarify the requirement and understand the needs of the end-users, discussions were held with a variety of Canadian Armed Forces (CAF) communities: defence scientists at Defence Research and Development Canada (DRDC), and personnel (civilian and military) of various CAF units including the Canadian Forces Maritime Warfare Centre (CFMWC), the Acoustical Data Analysis Centre (ADAC), 415 Squadron[1] at 14 Wing Greenwood, the Canadian Forces Air Warfare Centre (CFAWC), and 1 Canadian Air Division Headquarters (1 CAD HQ).

Although this report originates from an RCN project, in practice the RCN and RCAF would be collaborating when employing multistatics operationally through the use of the CP-140 and the CH-148 in conjunction with RCN vessels. The only unit in the CAF that has gained true operational experience with multistatic ASW is 415 Squadron, through their experience testing the low-frequency multistatic sonobuoy sources and receivers currently under development. The CFMWC is just beginning to explore multistatic capabilities from an operations research perspective, while the Canadian Forces Air Warfare Centre (CFAWC) focuses mainly on technological readiness and applicability for future force development and has not yet been involved in studies of multistatic active sonar [2].

1.1 The current state of sonar performance prediction in the CAF

Current practices and operational experience in monostatic sonar performance prediction will influence future sonar performance prediction approaches and requirements. In the CAF, monostatic sonar performance prediction consists of widespread use of the concept of 'range of the day' (ROD or ROTD) as a sonar performance metric. A distinction is made between 'predicted range' and 'actual range': the predicted

[1] formerly Maritime Proving and Evaluation Unit (MPEU)

range is the largest [source-to-target] range at which the sonar signal excess (SE) is positive and is calculated using acoustic range prediction software and knowledge of the potential target, sensor, and system capabilities in a representative environment, while the actual range (generally what is meant by ROD) is the best range held on a contact of interest [3]. Probability of detection and area coverage are other performance metrics that can be calculated in some models and they are commonly used in a variety of contexts but ROD is by far the most widely used and understood sonar performance metric [3]. ROD is not simply descriptive of general sonar performance: it is used to make operational decisions that may affect other aspects of the mission such as, for example, determining track spacing during CP-140 aircraft manoeuvres, and the inter-sensor spacing and sensor depth in sonobuoy fields.

Currently, operational (monostatic) range prediction is performed using a variety of tools, including AESS[2], EMM[3] on MAPS[4]-equipped vessels, and the ARP[5] software module included in the (Block-III-equipped) CP-140 sensor suite. The CFMWC uses the ODIN torpedo engagement model which includes both monostatic and multistatic sonar prediction capability [4, 5]. The multistatic modelling components of ODIN have been delivered and have been subject to initial validation and verification as of January 2015 [6, 7].

With the imminent roll-out across the CAF of the mission planning tool NITES2R[6], which will have an acoustic range prediction tool called ASPECT[7] [5] and is also expected to include a multistatic planning component called MPACT[8], a multistatic mission planning capability will theoretically be available to all ships and deployed air detachments. Several NITES2R systems were being employed operationally as of December 2015; however the ASPECT module has not yet been released to Canada; however it will eventually be available to Canadian users [8]. The multistatic mission planning capabilities of NITES2R are not clear at the time of the writing of this report.

In the meantime, some operational experience has been gained with the DRDC-developed TacTool [9] which can provide multistatic tactical decision-making support with a Maritime Air focus. The Multistatic Tactical Planning Aid (MSTPA) is a tool developed at the North Atlantic Treaty Organization's (NATO) Centre for Maritime Research and Experimentation (CMRE) that has been used by DRDC scientists to advise military clients on multistatic sonar performance. Both TacTool and MSTPA

[2] Allied Environmental Support System
[3] Environmental Model Manager
[4] Maritime Acoustic Processing System
[5] Acoustic Range Prediction
[6] Navy Integrated Tactical Environmental System, 2nd Revision
[7] Active System Performance Estimate Computer Tool
[8] Multi-Static Planning Acoustics Toolkit

are complicated software tools that require expert scientific users and a lead time of several days to generate meaningful results [10, 5].

2 Definitions

In the early stages of discussion it became apparent that different users had wildly divergent ideas of what 'multistatic planning' entailed and what a planning tool might be used for. The potential uses that people envisioned depended on their role, their current job, and previous experience.

In order to focus the discussions, a taxonomy for multistatic sonar performance models was developed by considering four hierarchical levels of tools, organized in order of decreasing distance from an actual multistatic ASW mission:

(I) Research tools (Section 2.1)

(II) Tactics development tools (Section 2.2)

(III) Mission planning tools (Section 2.3)

(IV) Tactical decision aids (Section 2.4)

The requirements for each level of tool will differ, depending on the user's objectives; their degree of understanding of the underlying physics, doctrine, and tactics; the time constraints on setting up scenarios and generating output; and the type of output desired. Within this paper, the general term for any type of multistatic planning tool will be 'multistatic sonar performance model'.

Most sonar performance modelling tools are implemented using similar approaches to generating performance predictions, which can be broken down into three components, although the details and levels of fidelity may differ:

1. **Scenario definition:** requires specification of
   (a) environment (surface, bottom type, bathymetry, sound speed profile)
   (b) sensors (type, location, movement, ping schedule)
   (c) targets (location, movement, scattering characteristics)
2. **Acoustic model:** calculates signal excess, and can include
   (a) propagation loss (modelled)
   (b) ambient noise (modelled or measured)
   (c) reverberation (modelled)

(d) target strength (modelled or measured)

3. **Performance metrics:** provides a measure of expected sonar performance, using one or more of
   (a) range of the day or area coverage
   (b) probability of detection (instantaneous or cumulative)
   (c) target tracks (Monte Carlo simulations, may include reactive behaviour)
   (d) track initiation probability (requires assumptions about tracking 'rules')
   (e) additional (possibly novel) performance metrics (e.g., those described in [3])

However, there are requirements that are non-negotiable for all levels of multistatic sonar performance model:

- The acoustic model should provide predictions for passive detection as well as active detection. Operationally, passive detection is often the first approach used.
- The acoustic model should be range-dependent. For advanced users it may be useful to allow switching between range-independent and range-dependent modes to examine the effect of range-dependent environments on sonar performance.
- The acoustic model should correctly take ping type into account (at a minimum, frequency-modulated [FM] and continuous-wave [CW] pings) in order to allow for investigations of the effects of ping choices, although different users may be examining different aspects of ping choice and scheduling.
- Representative target types need to be available at every level to make the tools useful when detailed target information is not available, or if a user wishes to create a reasonably realistic but unclassified scenario.
- Monostatic range of the day and area coverage should always be calculated and presented to the user, because of the existing general familiarity with both concepts.
- Instantaneous and cumulative probability of detection should always be calculated where possible (depending on time constraints). In most cases the cumulative probability of detection is the definitive measure of sonar system performance, and there is existing general familiarity with the concepts.

Table 1 contains an overview of the potential requirements or components of multistatic sonar performance models and how each one fits into the levels of tools described above. The list provided in Table 1 is not intended to be exhaustive, and there will always be differences of opinion within each user community as to the details; however, the information in Table 1 is intended to be a starting point for discussion. Detailed discussion of the requirements specific to each level of tool are provided in Sections 2.1 through 2.4.

2.1 Level I: research

The Level I category of multistatic sonar performance model would be a research-level tool that supplies the maximum flexibility in all components (scenario definition, acoustic model, and performance metrics). The end-users for Level I tools are the community of scientists, engineers, and operations researchers who need complete control over the models underlying the tool. Research is undertaken in support of a wide variety of activities, for example, specifying requirements for new vessels or sensors, exploring new approaches to sensor deployment, testing new ping types, or detecting new target types.

A Level I tool would require an expert user who is able to make decisions about and make changes to the computer program code itself in order to obtain meaningful results. The code should be accessible to the user so that it can be changed without negotiating with the vendor or owner, and should be version-controlled, so that users can make changes to the code, add features, and fix bugs as necessary.

Scenario definition in a Level I tool would allow the user to fully specify the environmental parameters, sensors, and targets needed for a scenario, likely via detailed configuration files. Such a tool would allow the user to model scenarios with sonar systems that are not currently in use for evaluation of potential future purchases or to model potential new capabilities to be built into existing systems. In addition, it would be useful to link a Level I tool to appropriate databases for environmental parameters, specifications of sensors in current operational use, and realistic target characteristics to allow for easy set-up of operational scenarios. The acoustic model should allow for sufficient specification of the detailed sub-model underlying each term in the sonar equation, and the acoustic model results should be available for troubleshooting, calculating performance metrics, developing novel performance metrics, and testing optimization routines.

DRDC has access to a Level I tool called Performance Assessment for Tactical Systems (PATS), although it does not currently have all the functionality that the research community requires (based on an informal poll of end-users). DRDC scientists have already used PATS for diverse tasks, including providing advice on the requirements for the Canadian Surface Combatant with respect to future multistatic capabilities

Table 1: *Summary of tool requirements by type: Level I (research), Level II (tactics development), Level III (mission planning), Level IV (tactical decision-making).*

	Level			
Feature	**I**	**II**	**III**	**IV**
Interface				
Modifiable code	✓	✓[1]		
User-friendly interface		✓[2]	✓	✓
Scenario: environment				
Arbitrary	✓	✓		
Historical (databases)	✓[3]	✓	✓	✓
Predicted (model)	✓[3]	✓	✓	✓
Measured (real-time)				✓
Range dependent	✓	✓	✓	✓
Scenario: sensors				
Arbitrary	✓	✓		
Operational	✓	✓	✓	✓
Ping type and scheduling	✓	✓	✓	✓
Scenario: targets				
Arbitrary	✓	✓		
Representative	✓	✓	✓	✓
Operational (measured or modelled)		✓	✓	✓
Acoustic model				
User-selectable acoustic model	✓			
Arbitrary model inputs	✓			
Limited model inputs		✓	✓	✓
Performance metrics/tracking				
Range of the day/area coverage	✓	✓	✓	✓
Detection probability	✓	✓	✓	✓
Track initiation probability	✓	✓		
Monte Carlo tracks	✓	✓	✓	
Reactive tracks	✓	✓		
Novel metrics	✓	✓	✓[4]	✓[4]
Optimization routines	✓[5]	✓[5]	✓	✓
Time scale for results	day(s)	day(s)	hour(s)	minutes

[1] Physics, sensor, platform, weapon, and target models should in locked modules, but the scenario setup may require programming skills

[2] Option to enable ‘advanced user’ mode that has more detail but may be less user-friendly

[3] Desirable but not essential

[4] Only if the novel metrics are well-understood and intuitive

[5] Design of optimization routines to take place in Levels I and II, for eventual implementation in Levels III and IV.

and participating in the Advancing Multistatic Operational Capabilities (AMOC) international collaboration on multistatic sonar performance prediction [11, 12].

MSTPA has also been used in a research capacity at DRDC; however the model is used under license from CMRE. Changes to the program code itself cannot be made by DRDC users therefore it cannot be characterized as a true Level I tool [13], although work is being planned during 2016 to modularize parts of the MSTPA code to allow users to use their own acoustic model or tracker within the MSTPA framework [14]. The fact that both PATS and MSTPA are used as research tools is a concrete reminder that the tradeoff between acoustic model accuracy and speed needs to be considered even at the research level. PATS uses the validated US Navy Comprehensive Acoustic Simulation System (CASS) model [15] as the acoustic propagation engine, which can take hours to days to run, while MSTPA uses the much faster ARTEMIS [16] model. However, the ARTEMIS model has not yet been subject to the same extensive validation as the CASS model; therefore the potential limitations of the ARTEMIS model are not as well-understood.

2.2 Level II: tactics development

A Level II multistatic sonar performance model would be used for tactics development. Tactics are developed through extensive testing of existing and potential new tactics and comparisons of the efficacy of different tactics in different situations. Tactics development for the RCN currently takes places in the CFMWC, with strong linkages to the Operational Force Development (OFD) Flight at 415 Squadron who also develop and test new tactics for the multistatic-capable Block III CP-140. The users of Level II tools would be military personnel responsible for tactics development who have a wide variety of operational experience in ASW, as well as the civilian personnel who work alongside them in the units.

The users of tactics development tools have a sophisticated understanding of the whole battlespace, and thus require transparency and maximum flexibility in sensor specification and placement, and environment complexity. The acoustic model need not be as flexible as in a Level I tool because the Level II user does not have the same deep understanding of the underlying physics; default settings and parameter ranges should be controlled so that the acoustics model does a reasonable job of representing the acoustic propagation and does not provide unphysical results. For tactics development, a Monte Carlo approach is often used, where hundreds of thousands of model runs that vary slightly in some way are used to test the robustness of a tactic. Novel performance metrics may be used in a Level II tool along with legacy metrics such as ROD, area coverage, and probability of detection. In addition, optimization routines could be developed and tested. The tool would have to model more components of a scenario than a research tool: adaptive behaviour, platform movements, and mutual interference; as well as non-acoustic or non-ASW aspects such as magnetic anomaly detection (MAD) performance, radar performance, communications, interoperability, or torpedo defence.

A Level II tool would allow creativity in developing new tactics as well as to allow users to develop ‘intuition’ for multistatics through experimentation, beginning with testing the performance of existing tactics when used multistatically in simple environments, adjusting the tactics to take advantage of the multistatic approach, and then increasing environmental, sensor, and target complexity to understand the effect of realistic environments on the tactic under investigation.

The CFMWC currently uses ODIN as a tactics development tool. Originally developed as a torpedo engagement model, ODIN is capable of simulating complex underwater warfare scenarios involving multiple components of the battlespace and has recently had its multistatic modelling capability upgraded [6, 17]. The CFMWC has indicated that they are satisfied with the way ODIN is currently being used, through close collaboration between military personnel and (civilian) programming experts, and their intention is to use ODIN for all tactics development going forward [4]. Although some work has been performed at CFMWC using MSTPA in the past, the expectation at CFMWC is that any additional multistatic capabilities going forward would be built into ODIN.

2.3 Level III: mission planning

Level III multistatic sonar performance models would be used specifically for mission planning, that is, applying existing tactics and doctrine to a specific mission with well-defined objectives. Currently, the only CAF end-users for a multistatic mission planning tool are the OFD Flight at 415 Squadron; however, the RCN is intending to introduce multistatic capability. It is expected that the use of multistatics will become routine in both the RCN and the RCAF and there will ultimately be a broad audience of mission planners.

A Level III tool would require the ability to include historical or predicted environmental data, characteristics of anticipated target types, and knowledge of available platforms. Optimization routines in a mission planning tool should be based on existing tactics and should include constraints, for example, optimizing spacing for a pre-determined sonobuoy pattern without changing the pattern shape or number of sonobuoys, or limiting platform movements to realistic speeds and turn rates.

The user interface, ease-of-use, repeatability, and reliability of results for a Level III tool are crucial to its acceptance as a legitimate mission planning tool. Speed is important because the mission planning process comprises multiple tasks occurring in the space of an hour or two; therefore, results from a Level III tool within 15 minutes would be desirable. A user may be willing to wait for results that are known to be reliable and useful, but won't bother using the tool if the results are regularly misleading or inaccurate. The tool should make it easy for the user to select from existing sensors and tactics (e.g., drop-down menus of sensor types) with the additional ability to set up arbitrary scenarios and platform movements available in an 'advanced user' mode. Ideally the tool would prevent 'tunnel vision' on the part of the operator by suggesting possible tactics, given the scenario and mission objectives. Novel performance metrics should only be included in a Level III tool if they are intuitive and easily understood.

Some existing models cannot provide results in a meaningful timeframe when more than a few sensors are involved. However, aircraft are capable of deploying and monitoring dozens of sensors and unlike ship-based sensor deployment, when sonobuoys fail, they can be redeployed very rapidly over a large area. Therefore, any Level III (or IV) tool provided to the RCN should include functionality appropriate for the RCAF as well.

Currently in the CAF there are no multistatic mission planning tools that are designed for use by mission planners or sonar operators[9]. Both NATO's MSTPA and DRDC's TacTool have been used as mission planning tools but, because both tools require expert users, DRDC scientists actually ran the tools on behalf of the end-user.

2.4 Level IV: tactical decision-making

The last category (Level IV) of multistatic sonar performance models are tactical decision aids (TDAs). A TDA provides useful answers at an operational tempo to allow a sensor operator to make quick assessments about effective sensor placement and employment (e.g., sonobuoy spacing, ping sequencing, source depth).

The physical environment on ships and aircraft can be very rough, therefore, the TDA interface should be extremely user-friendly and not excessively complicated. It should be able to ingest, and allow for quality control of, the latest environmental and sensor information and provide results to the operator in minutes. The input choices should be limited so as to speed up the setup process and improve the likelihood of obtaining an informative result. In addition, the output of a TDA should be intuitive to understand and easy to communicate up the chain of command [18]. Optimization routines would be useful for such tasks as fine-tuning details of sensor placement, or choosing appropriate ping types and sequencing. Just as for mission planning tools, novel performance metrics should only be included in a TDA if they are intuitive and easily understood.

An example of simple but useful capability for a Level IV tool would be a map or tactical plot overlaid with the coverage area (area for which $SE \geq 0$) for a deployed

[9] with the possible exception of ASPECT within NITES2R, when it is eventually released to Canada

sonobuoy field [19]. The operator would be able to manually remove from the map the buoys that failed and the updated coverage would be re-calculated and displayed. Then the operator would be able to tell, at a glance, where additional sonobuoys would need to be deployed to fill in coverage gaps, and as the buoys were deployed the map would update again, keeping the operator up-to-date and allowing for quick decision-making. Operators could select a 'slice' through the map between two geographic locations and transmission loss plots for different sensor depths would display in a separate window, allowing the operator to choose the best depth before deploying additional buoys.

As with mission planning tools, currently in the CAF there are no multistatic tactical decision aids available for use by a sonar operator[10].

3 Additional considerations

Throughout the conversations that led to this report, concerns, ideas, and viewpoints were brought up that are related to but separate from the specific tool requirements at different levels. It should also be noted that different individuals have different and sometimes conflicting views. Any ranked list of proposed priorities or requirements would spark a lively discussion as users personally have different priorities depending on their roles, education, and experience.

3.1 Trust

Several people expressed concern about whether this report would result in a 'solution looking for a problem'. The requirements must originate from the users, with additional scientific input to guide tool definition and selection to meet the requirements. With the taxonomy of multistatic sonar performance models introduced in Section 2, the potential users and their goals are now clearly defined.

On a related note, if a tool produces misleading results, works too slowly, or has an unwieldy interface, then the users may simply not use it at all and instead they will continue to plan missions in the way that they are accustomed to. If that were the case, multistatic capabilities would not be fully exploited due to insufficient understanding of how best to do so, which would lead to a general sentiment of, 'Why bother with multistatics? It doesn't seem to work anyway,' and rapid loss of belief on the part of the users.

Another issue related to trust is that of so-called 'black boxes', where a result is presented to the user but the user has no useful mental model of how it was obtained.

[10] again with the exception of ASPECT within NITES2R: see Sections 1.1 and 2.4

At any of the four levels, users do not trust black boxes. Researchers dislike them because they want to understand the physical and mathematical underpinnings of the model and they are rightly concerned with ascertaining that the computations have been correctly implemented. In addition, many users are insulted when presented with an algorithm that performs 'magic' for them, but aren't told how it works, because the unspoken implication is that the users are not intelligent enough to understand a complicated algorithm. Some examples of current 'black boxes' are the Data Quality Index (DQI) and 'energy maps' provided on the CP-140 sensor suite, most trackers, and some of the range prediction tools currently in use. An effort should always be made to provide a simplified explanation of algorithms used in order to maximize their exploitation.

3.2 Interface

Any tool (especially Levels III and IV) needs to include capabilities and outputs that the users expect for technologies currently in service so that the user doesn't need to use multiple tools. Therefore, the tools must reliably handle passive acoustics and medium-frequency monostatic active sonar (e.g., passive sonobuoys, hull-mounted sonars, towed arrays, and DICASS sonobuoys) and provide outputs in a familiar format (e.g., figure of merit for detection range calculations). Furthermore, the input and output units of measurement should be user-selectable, because most operational data is in imperial or maritime units: knots, nautical miles, feet, yards, kiloyards, degrees Fahrenheit. If the tool (and the scientist) does not 'speak the language' of the user it will be ignored; in a worst-case scenario, errors can result if units are improperly converted (e.g., [20]).

In fact, the outputs for any potential tool must be carefully defined by the users, because different communities require different outputs as inputs to decision-making. Single numbers, such as detection range or detection probability, are both useful and required, but users also gain information and insight from 2-D performance data overlaid on a map or tactical plot. Examples of 2-D performance data are area coverage (the area over which the signal excess is positive) or a 'threat density probability map' (TDPM, [21, 22]) which displays the probability of targets remaining in an area after a specified amount of time spent searching.

In terms of interface and ease-of-use, it should be easy to save interface settings (including but not limited to choices of measurement units, display colours, and window positioning) as well as environment settings into files for reloading in later sessions or sharing with colleagues. A laborious interface set-up process involving multiple tick-boxes and drop-down menus will reduce the perception of usability of the tool.

Several people independently suggested that some levels of tools should be part of a single suite, or that tools should be 'skinnable', i.e., the interface simplified to be usable at an operational level while using the same software engine from a research level. If there were linkages between Level I and Level II tools, then results from research advancements could be more rapidly implemented in the tactics development tools. If there were linkages between Level III and Level IV tools, which have a similar user base, the familiarity with the tools would be transferable when operators were posted to different roles, and the 'look and feel' of the scenario setup and outputs would allow for more efficient work and better understanding. In addition, there are potential feedbacks and synergies among users of Level II and Level III tools. In military units responsible for operational testing and evaluation, a Level III tool would be used for mission planning, but the users would be in frequent contact with tactics development units (Level II) to report on the efficacy and feasibility of existing or proposed tactics. The robustness required for truly operational tools makes it unrealistic to have all four levels linked together, but it would be worthwhile to design software architectures with potential transferability between levels where it makes sense to do so. Part of this concern may stem from previous experiences with potential users becoming excited about new research going on at DRDC, who are subsequently frustrated at the delays in getting useful functionality available at the operational level.

4 Conclusion and recommendations

Successful exploitation of multistatic sonar technologies will require appropriate multistatic sonar performance models. A taxonomy for multistatic sonar performance models was developed, comprising four levels of tools: Level I (research), Level II (tactics development), Level III (mission planning), and Level IV (tactical decision-making). Most sonar performance models consist of three components: scenario definition (environment, sensors, and targets), an acoustic model (propagation loss, ambient noise, reverberation, and target strength), and performance metrics and tracking (ROD, area coverage, and probability of detection).

Requirements common to all levels include: passive performance prediction, range-dependent acoustic propagation calculations, proper handling and scheduling of CW and FM pings, a library of representative target types, and basic metrics including ROD, area coverage, and probability of detection (instantaneous and cumulative). In addition to the common requirements, a list of requirements was organized by tool level (I–IV) under the categories of interface (modifiable code, user-friendliness), environment (arbitrary, historical, predicted, and measured), sensors (arbitrary and operational), targets (arbitrary, representative, and operational), acoustic model (user-selectable, arbitrary or limited model inputs), and performance metrics and tracking (ROD, area coverage, detection probability, track initiation probability, Monte Carlo tracks, reactive tracks, novel metrics, and optimization routines). Most requirements varied in complexity across different tool levels: for example, operational sensors specifications are required at all levels while the ability to specify arbitrary sensors is only required for Levels I and II.

Additional considerations applicable to all levels include issues of trust and user interface. The requirements for each level of tool must originate from the users who are in the best position to understand their specific role and the questions they are trying to answer. A tool that does not work well may result in it not being used, leading to ineffective operational employment of multistatic sonar based on monostatic or passive approaches and general dissatisfaction with multistatic sonar. Users also generally do not appreciate algorithms that they do not understand and may not employ the results effectively or consistently. The user interface for any tool must be carefully designed around the requirements of the actual users, including such considerations as outputs, units of measurement, displays, and customization. Linkages between multiple levels of tools would confer some advantages such as potentially allowing research-level ideas to be operationalized more easily (Levels I and II), and would facilitate transitions and sharing of ideas among tactics development, mission planning, and tactical decision-making roles (Levels II, III, and IV).

The few existing multistatic sonar performance prediction models available to the CAF were categorized according to the new taxonomy: PATS (Level I), ODIN (Level II), MSTPA (Levels II and III), TacTool (Levels II and III), and ASPECT (Levels III and IV). None of the multistatic sonar performance prediction tools currently in use fulfills all the requirements at its particular level though it may be possible to upgrade some of them. Before committing to a tool and expending time and resources on upgrading, the level of the tool must be identified, and the potential user community must be polled to determine their current and future requirements. In fact the usual process of selecting a sonar performance prediction tool should be reversed: not ‘Should we expend resources to upgrade Tool A or Tool B?’ but ‘What question are we trying to answer, which tool is correct for the job, and does it need to be upgraded to fulfill our requirements?’.

This report was not intended to provide an exhaustive list of requirements but instead lays the groundwork for improving requirements definition by introducing a taxonomy of multistatic sonar performance models used for different purposes by different user groups. The general requirements and considerations outlined in this report should not be overlooked when determining specific requirements for each of the four levels. Going forward, each level of tool requires its own separate, focused survey to augment the anecdotal comments contained in this report. The survey should define the user’s role within the CAF, the question that is being asked, the required functionality, and both the necessary and desired outputs. Although it is likely that there will be general consensus on some requirements and dissent on others, working closely with user groups and their scientific advisors is the only way to ensure that the tools provided will enable the CAF to maximally exploit multistatic sonar capabilities.

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List of symbols / abbreviations / acronyms / intialisms

1 CAD HQ	1 Canadian Air Division Headquarters
ADAC	Acoustic Data Analysis Centre
AESS	Allied Environmental Support System
AMOC	Advancing Multistatic Operational Capabilities
ARP	Acoustic Range Prediction
ARTEMIS	Adiabatic Reverberation and Target Echo Mode Incoherent Sum
ASW	Anti-Submarine Warfare
ASPECT	Active System Performance Estimate Computer Tool
CASS	Comprehensive Acoustic Simulation System
CAF	Canadian Armed Forces
CFAWC	Canadian Forces Air Warfare Centre
CFMWC	Canadian Forces Maritime Warfare Centre
CMRE	Centre for Maritime Research and Experimentation
CW	Continuous Wave
DICASS	Directional Command Active Sonobuoy System
DIFAR	Directional Low Frequency Analysis and Recording
DQI	Data Quality Index
DRDC	Defence Research and Development Canada
EMM	Environmental Model Manager
FM	Frequency Modulation
HOTEF	Helicopter Operational Test and Evaluation Facility
MAD	Magnetic Anomaly Detection
MAPS	Maritime Acoustic Processing System
MPACT	Multistatic Planning Acoustics Toolkit
MPEU	Maritime Proving and Evaluation Unit
MSTPA	Multistatic Tactical Planning Aid
NATO	North Atlantic Treaty Organization
NITES2R	Navy Integrated Tactical Environmental System, 2nd Revision
OFD	Operational Force Development
PATS	Performance Assessment for Tactical Systems
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
ROD	Range of the Day
ROTD	Range of the Day
SE	Signal Excess
TDA	Tactical Decision Aid
TDPM	Threat Density Probability Map
VME	Versa Module Europa

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The effective employment of multistatic active sonar by the Royal Canadian Navy (RCN) and Royal Canadian Air Force (RCAF) will require the development of new thinking, new doctrine, and new tactics, activities for which multistatic sonar performance prediction tools will be a key enabler. In order to guide the development of new tools, a four-level taxonomy of sonar performance prediction tools was developed, with each level differing in purpose, user group, and requirements: research (Level I), tactics development (Level II), mission planning (Level III), and tactical decision-making (Level IV). A comprehensive list of requirements was specified for each tool level, and organized to allow for comparison and evolution of specific capabilities across levels. Additional considerations including trust and user interface were discussed. Existing monostatic and multistatic sonar performance prediction tools were categorized according to the new taxonomy. It was concluded that no one tool will be able to provide the functionality required at all levels, and it is recommended that this report be used to foster critical discussions within user communities at each level regarding their unique requirements before specific tools are provided for general operational use.

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multistatics; anti-submarine warfare (ASW); mission planning; tactical decision aid; sonar performance