FFI RAPPORT

SYSTEM REQUIREMENTS ANALYSIS FOR A TORPEDO DEFENCE TACTICAL MODEL

KARLSEN Marcus, NORDØ Erik, LANGSET Frode

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Vidar S. Andersen
Director of Research

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b) Torpedo defence	b) Torpedoforsvar
c) Torpedo countermeasure	c) Torpedomottiltak
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8) ABSTRACT

During the coming years FFI will assist the Royal Norwegian Navy's Material Command in the testing and verification process of their new frigates. A part of this consists of developing reaction rules against attacking torpedoes. For this work a torpedo defence tactical model will be essential. This report addresses the context and the most important requirements for such a model.

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CONTENTS

SYSTEM REQUIREMENTS ANALYSIS FOR A TORPEDO DEFENCE TACTICAL MODEL

1 INTRODUCTION

During the coming years FFI will assist the Royal Norwegian Navy's Material Command (NAVMATCOMNOR) in the testing and verification process of their new frigates. A part of this consists of developing reaction rules against attacking torpedoes. The extent of assistance is specified in project agreement 795-E/161.4 – Nye fregatter.

The aim of this document is to define a set of user requirements for a torpedo defence tactical model. It is written as a support in our evaluation of different existing models (2) and as a start for a specification of a model if we decide to develop our own.

The next two chapters describes the use and need for a torpedo defence tactical model. Chapter four addresses the context of the model such as goals, scenarios, boundaries, input and output and potential users. The user requirements are stated in chapter five in a structured and prioritised manner. The last chapter includes some concluding remarks.

2 PROBLEM IDENTIFICATION AND DEFINITION

The defence of ships against torpedo attack has historically been limited to evasive manoeuvres and the towing of decoys and noisemakers, and the action of an individual ship once an attacking torpedo has been detected. The performance of modern torpedoes and the potential of modern torpedo defence systems designed to counter torpedo attacks makes this strategy inadequate. The potential of modern torpedoes and the possibility of launched decoys deployed before, as well as during a torpedo attack imply the need for more pre-planning and co-ordination of efforts in torpedo defence.

The New Norwegian Frigates (NF) will be delivered with a dedicated torpedo defence system that detects, classifies and tracks incoming torpedoes. The countermeasure reaction rules to be included in the system will be delivered by RNoN. The reaction rules consist of both manoeuvres and decoy deployment rules. The outcome of a torpedo attack may vary significantly depending on the chosen countermeasure reaction rules. The best reaction rules will depend on a great number of variables related to the threat, own ship acoustic signature, torpedo detection capabilities, decoys and environment. Basically, we need to:

1. Evaluate the effectiveness of different manoeuvres and decoy deployment rules against different types of torpedoes and scenarios and come up with an efficient solution for a given scenario.
2. Assist in the development of test and verification procedures (SAT2 test) for the torpedo defence system.

3 SYSTEM DESCRIPTION

The existing Norwegian frigates, the Oslo-class, do not have any decoys on board and rely completely on manoeuvres to avoid an attacking torpedo. The Oslo-class frigates are equipped with an active hull mounted sonar system with no dedicated torpedo detection capabilities.

The NF will have a significantly more advanced torpedo defence system. It will use a hull mounted and a low frequency towed array sonar, both capable of operating in active and passive mode for torpedo detection. NF will also be equipped with expendable acoustic decoys. This makes it possible to use more complex torpedo countermeasure reaction rules consisting of a combination of manoeuvres and acoustic decoys. To make the best use of the new system and its possibilities, one has to establish new torpedo countermeasure reaction rules for the NF. The torpedo countermeasure reaction rules need to be developed especially for the system onboard the NF while taking into account the official NATO tactics and reaction rules. A torpedo defence tactical model will be essential in the development of the reaction rules as well as in the planning of the test and verification procedures.

4 MODEL CONTEXT

4.1 The Goals of the Torpedo Defence Tactical Model

The primary purpose of the torpedo defence tactical model is to evaluate sets of torpedo countermeasure reaction rules for avoiding different kinds of attacking torpedoes in different scenarios. This can be refined by stating that the system shall be used to optimise decoy deployment and own ship manoeuvres with respect to different MOEs on system and subsystem level.

The secondary purpose of the torpedo defence tactical model is to plan, analyse, compare and evaluate scenarios and exercises, including the SAT2.

4.2 Scenarios

The scenarios in which the torpedo countermeasure rules are to be evaluated are operations with one or multiple platforms, some equipped with active and passive acoustic sensors, against a torpedo and submarine threat. The scenarios should include range independent- and range dependent environments in both littoral and open waters.

A scenario should at least include the following main elements:

1. One torpedo, straight running, wake homing, acoustic homing and wire-guided acoustic homing capability.
2. One surface ship.
3. Several stationary acoustic decoys.
4. Surface ship tactics for manoeuvres and decoy deployment.
5. Torpedo homing tactics.
6. Environmental parameters, sound speed profile, bottom depth, sea state, background noise, range independent open water.

4.3 Model Boundaries

The torpedo defence tactical model will be a stand alone unit with an acoustic model included. It will deliver input for statistical analysis of different tactics.

4.4 Input and Output

The environment of the torpedo defence tactical model, which consists of the input and the output can be found in Table 4.1.

Input	**Output**
Number and types of assets Area Environmental parameters Threat parameters Start points Tactics (Manoeuvres etc.) Operator time consumption	MOE Plots for detailed analysis Data files containing results from Monte Carlo simulations.

Table 4.1. Environment of the torpedo defence tactical model. See also chapter 5.2.4.

4.5 User Groups

The following potential users of a torpedo defence tactical model can be identified:

- FFIs Frigate Project 795
- FFIs Submarine Project
- NAVMATCOMNOR
- KNM Tordenskjold

According to the project agreement a torpedo defence tactical model shall be used to:

- evaluate and refine torpedo countermeasure reaction rules.
- assist in the development of test and verification procedures (SAT2 test) for the torpedo defence system.

Other areas where the torpedo defence tactical model might be used, depending on the complexity of the model and self development or acquisition of an existing model, are:

- plan, analyse, compare and evaluate the effectiveness of assets, sensors and tactics in exercises.
- to evaluate different types of decoys and their effect.
- to evaluate the effectiveness of different types of torpedoes, torpedo homing heads and tracking algorithms. One way this can be done is by linking the torpedo defence tactical model up to the different manufacturers own highly classified torpedo models. In this way the scenario is simulated in the torpedo defence tactical model using the torpedoes actual software for DCL.
- as a trainer for ASW operations, if a real time console is integrated into the model.

Extensions of the model in order to cover these areas will probably require considerably additional work, in particular if we have to develop our own model.

5 USER REQUIREMENTS

5.1 Definition of the Requirement Notation

The notation used for the requirements contains an identification of the requirement, the requirement itself, the priority of the requirement, a description of the requirement, additional comments and a description of what we see as the basic solution for a self developed model.

ID:	Requirement:	Priority:
Description:		
Comment:		
Basic solution:		

Table 5.1. The notation standard used for the user requirements.

The fields in Table 5.1 are read as follows:

1. *ID* – A unique identification of the requirement used for reference purposes in other requirements. The format is XY.
   X may be:
   E: environmental requirements
   A: asset requirements
   T: threat requirements
   I : input/output requirements
   O: other user requirements
   Y is a serial number running from 01.
2. *Requirement* – A text field giving a brief description of the requirement.
3. *Priority* – A number describing the priority of the requirement, given an ideal solution.
   1: Essential
   2: Important
   3: Desirable
4. *Description* - A text field giving a detailed description of the requirement.
5. *Comment* – additional information, e.g. relations to other requirements.
6. *Basic solution* – A text field giving a description of what we see as the basic solution for a self-developed model.

5.2 Requirements for a Torpedo Defence Tactical Model

5.2.1 Environmental requirements

ID:	Requirement:	Priority:
E01	Area	1
Description:		
The simulations are performed in a three dimensional underwater environment.		
Comment:		
This imply corresponding modelling of sonar (e.g. both vertical and horizontal beam patterns)		
Basic solution:		
The acoustic model will be a quasi 3D or N2D model e.g. Lybin.		

ID:	Requirement:	Priority:
E02	Area characteristics	1
Description:		
An area shall be characterised by: • Size, boundaries • Bottom type • Sound speed profile • Sea-state • Rain • Shipping density		
Comment:		
See also requirement E04 and E06.		
Basic solution:		
As described but the area boundaries will be very simple, e.g. a straight line to one or both sides of the ship. The sound speed profile will not be taken into account when 20log(r) is used for calculating the transmission loss.		

ID:	Requirement:	Priority:
E03	Acoustical model	1
Description:		
The performance of the sensors will be calculated by an acoustic model. This model shall take into account: • Signal level from the sound source. • Signal frequency • Transmission loss from source to receiver. • Background noise level • Own ship noise level. • Reverberation levels, surface-, volume- and bottom reverberation. • Target echo strength or radiated noise.		
Comment:		
• The model simulates both active and passive sonar • An extended Lybin version is preferred. See also requirement A04.		
Basic solution:		
As a minimum 20log(r) is used to calculate the transmission loss. The possibility to enter the transmission loss as a table will also be included. Most likely the acoustic model Lybin will be included if it is easily integrated. The background noise level and volume reverberation will be given as a constant value (as in Lybin).		

ID:	Requirement:	Priority:
E04	Modelling of wake	1
Description:		
The model should be able to model the wake of the platforms.		
Comment:		
To simulate wake homing torpedo homing head a model of the ship wake must be present.		
Basic solution:		
Extremely simple solution. The wake is modelled as the track of the surface ship, degraded as a function of time since the wake was produced and surface ship speed.		

ID:	Requirement:	Priority:
E05	Variable bottom topography	2
Description:		
The acoustical model should take into account variable bottom topography.		
Comment:		
This is especially important in shallow and littoral waters due to reverberation.		
Basic solution:		
Not included. If Lybin is integrated simple topography might be included.		

ID:	Requirement:	Priority:
E06	Link to a map database	3
Description:		
The model should be able to extract bottom topography from a map database.		
Comment:		
Implies requirement E05 fulfilled.		
Basic solution:		
Not included.		

5.2.2 Assets requirements

ID:	Requirement:	Priority:
A01	Platform	1
Description:		
A platform has a position, course and speed. A platform can have a depth. A platform can contain a number of sensors and weapons. A platform is assigned a radiated noise signature, broad- and narrow-band. A platform has a distributed echo strength (extended, high lights). A platform has a search and attack tactic. A platform has a countermeasure tactic. A platform can have a limited operating time. A platform can be own, friendly, neutral, hostile or unknown.		
Comment:		
A platform can be a surface vessel, submarine, decoy or torpedo.		
Basic solution:		
Only the torpedo and one surface ship will have sensors and weapons. Except for the torpedo, the other platforms will have very simple search and attack tactic. The echo strength will be constant and uniform.		

ID:	Requirement:	Priority:
A02	Number of platforms	1
Description:		
A scenario shall include • Several surface vessels • Several decoys • Several torpedoes • One submarine		
Comment:		
The submarine might be modelled with a very simple approach, e.g. constant depth. See also T05.		
Basic solution:		
One torpedo against one surface ship with several decoys. Acoustic noise from other ships will be allowed for, these ships will have no detection capabilities or weapons.		

ID:	Requirement:	Priority:
A03	Sensors	1
Description:		
A sensor can be active, passive narrowband or passive broadband. An acoustic model calculates the performance of a sensor. The sensor is modelled with horizontal and vertical beamforming.		
Comment:		
See also requirement E03 and A04.		
Basic solution:		
Included, level of detail must be investigated.		

ID:	Requirement:	Priority:
A04	Acoustic sensors	1
Description:		
The following acoustic sensors shall be modelled: 1. Hull Mounted Sonar (HMS), active and passive. 2. Active towed array sonar (ATAS), active and passive. 3. Torpedo sonar, active and passive. 4. Acoustic decoy, transponder and echo repeater.		
Comment:		
See also requirement A03 and I04.		
Basic solution:		
Own ship sonar performance is calculated with an external acoustic model. Torpedo sonar decoys included. Even if calculations of own ship sonar performance are included in the model the possibility to enter pre-calculated detection ranges is desirable, see requirement I04.		

ID:	Requirement:	Priority:
A05	Platform search tactics	1
Description:		
The platform executes a search tactic to detect a threat or target. A search tactic consists of: • Start-points in the area of operation. • Way-points in the area of operation. • Speed. • Sensor policy.		
Comment:		
See also requirement A01.		
Basic solution:		
The torpedo will have a detailed search tactic, for the surface ship the search or predefined tactic will be very simple.		

ID:	Requirement:	Priority:
A06	Platform countermeasure tactic	1
Description:		
A platform executes a countermeasure tactic when attacked by a weapon. A countermeasure tactic may consist of: • Manoeuvres • Decoy deployments • Counter attack		
Comment:		
See also requirement A01.		
Basic solution:		
The surface ship will have a countermeasure tactic, consisting of manoeuvres and decoy deployments, against torpedoes.		

ID:	Requirement:	Priority:
A07	Decoys	1
Description:		
The decoys will be both static and mobile.		
Comment:		
The decoy can have an echo structure with highlights, simulated extension, simulated speed and simulated acceleration.		
Basic solution:		
Both static and mobile decoys implemented. They will have similar acoustic properties.		

ID:	Requirement:	Priority:
A08	Transmission and reception of signals between objects	1
Description:		
Transmission and reception of signals between objects and interference on the sensors shall be taken into account.		
Comment:		
Simulate each ping to handle time delay of signals.		
Basic solution:		
Only applicable for multiple platform scenarios, will not be implemented in basic solution.		

ID:	Requirement:	Priority:
A09	Platform shape modelling	1
Description:		
The shape of the platform is modelled		
Comment:		
One solution is a point target, more sophisticated solutions can be used e.g. sphere trees.		
Basic solution:		
The platform will be simulated as a point target.		

ID:	Requirement:	Priority:
A10	Impact modelling	1
Description:		
The impact between two platforms are modelled and the consequences analysed.		
Comment:		
Basic solution:		
The impact is defined successful if the weapon comes within a specified boundary around the target.		

ID:	Requirement:	Priority:
A11	Jammers	1
Description:		
Both launched and towed torpedo and submarine jammers.		
Comment:		
Since torpedo and submarine jammers will not be onboard the new Norwegian frigates the modelling of these are not of high priority.		
Basic solution:		
Torpedo jammer, but no submarine jammer will be included in basic solution.		

ID:	Requirement:	Priority:
A12	Communication between ships	3
Description:		
The ability to broadcast messages, with time delay, to other surface ships, e.g. torpedo alarm.		
Comment:		
Only applicable for scenarios including several surface ships.		
Basic solution:		
Not included, only one surface ship.		

5.2.3 Threat requirements

ID:	Requirement:	Priority:
T01	Threat	1
Description:		
The threat is a torpedo fired from a submarine. The torpedo can be: • straight running torpedo. • independent acoustical homing torpedo. • wire-guided acoustical homing torpedo. • Wake homing torpedo.		
Comment:		
See also requirement T05. Concerning wake homing torpedo see chapter 6 and requirement E05. For threat distribution see Nato working group PG37 documents (1).		
Basic solution:		
The wire-guided torpedo is modelled in a very simple manner, e.g. no modelling of the submarine sonar. The torpedo receives true bearing added noise. The wake homer is modelled in a very simple manner. The wake homing torpedo is following the track of the surface ship. It will loose this track with a certain probability, which is a function of the time since the wake was created and the ship speed at that time. This way we can obtain valuable information on the detection of wake homers, and the time aspect of evasive manoeuvres against them.		

ID:	Requirement:	Priority:
T02	Threat sensors	1
Description:		
The following threat sensors shall be modelled, and their performance calculated by an acoustic model: • Active torpedo sonar • Passive torpedo sonar		
Comment:		
See also requirement A04.		
Basic solution:		
Included.		

ID:	Requirement:	Priority:
T03	Torpedo firing	1
Description:		
• The submarine can fire a torpedo against a target. • The platform (submarine) is firing on the basis of predefined rules when a target is detected.		
Comment:		
Basic solution:		
The torpedo is entering the simulation at a pre-set range, bearing, depth, time and with initial settings for the torpedo.		

ID:	Requirement:	Priority:
T04	Torpedo salvo	1
Description:		
The submarine can fire a salvo of torpedoes against one or more targets.		
Comment:		
See also requirement A02. For a threat distribution see the Nato working group PG37 documents.		
Basic solution:		
Not included.		

ID:	Requirement:	Priority:
T05	Additional threat sensors	3
Description:		
The performance of the submarine sonar is modelled by an acoustic model and used for detecting the surface ships and to guide the torpedo.		
Comment:		
See also requirement A04 and T01.		
Basic solution:		
Not included.		

5.2.4 Input/output requirements

ID:	Requirement:	Priority:
I01	Input	1
Description:		
The input of the torpedo defence tactical model consists of: • Number and types of assets and threats • Environmental parameters • Asset and threat parameters • Start points • Tactics (Manoeuvres etc.)		
Comment:		
Classification is not modelled. The tactic is pre-defined when setting up a scenario.The time consumption for classification is modelled see requirement O03.		
Basic solution:		
All included.		

ID:	Requirement:	Priority:
I02	Output	1
Description:		
The output of the torpedo defence tactical model consists of: • MOE values. • Data for detailed analysis of each simulated torpedo attack. An analysis tool shall be available. • Data to determine critical phases in TCM. An analysis tool shall be available. • Data files containing results from Monte Carlo simulations.		
Comment:		
MOE values according to I03		
Basic solution:		
All included.		

ID:	Requirement:	Priority:
I03	MOE	1
Description:		
The MOEs that can be used are: • Probability of escaping a torpedo, given a torpedo countermeasure reaction rule. • Probability of escaping torpedo with no manoeuvres and no decoys. • Probability of escaping torpedo by use of evasive manoeuvres. • Probability of escaping torpedo by use of evasive manoeuvres and decoys.		
Comment:		
Other MOEs can be included later.		
Basic solution:		
All included.		

ID:	Requirement:	Priority:
I04	Pre-set detection ranges	1
Description:		
It should be possible to give a pre-set value or a distribution for the detection range.		
Comment:		
Basic solution:		
Included.		

ID:	Requirement:	Priority:
I05	Measured input data	2
Description:		
Measured data should be used as input to the torpedo defence tactical model. Measure data comprise as a *minimum*: • MSI-90U recording of movement of torpedoes. • submarine, torpedo status (transit, search, homing, reattack). • selected guidance info (search startpoint, guidance mode).		
Comment:		
Can be used to validate accuracy of acoustic sonar modelling. Basic solution will include simpler methods for validation.		
Basic solution:		
Not included, but can be partly accomplished by entering input manually.		

5.2.5 Other requirements

ID:	Requirement:	Priority:
O01	PC performance	1
Description:		
• The torpedo defence tactical model shall be used as a stand alone unit. • The torpedo defence tactical model shall be capable of running both single simulations and Monte Carlo simulations. • The torpedo defence tactical model shall be capable of batch run processing of several different scenarios.		
Comment:		
The program will have a mode where time demanding simulation will be simplified.		
Basic solution:		
Included.		

ID:	Requirement:	Priority:
O02	Graphical User Interface	1
Description:		
The GUI shall consists of the following: • Operation area. • Assets and threats (by symbols). • Route of the assets and threats. • Plots for detailed analysis of single runs. • Tools for analysing critical phases in TCM.		
Comment:		
The GUI will be restricted to the needs of the analysis and of FFI project 795.		

ID:	Requirement:	Priority:
O03	Operator decision making	1
Description:		
The ASW operators performing the TCM function shall be modelled, as a minimum with regard to time consumption.		
Comment:		
Basic solution:		
Included as a constant time from detection to decision		

ID:	Requirement:	Priority:
O04	Repeatability	1
Description:		
It shall be possible to repeat a single simulation from a previous batch/single simulation and obtain identical results as before.		
Comment:		
This require storage of random seeds etc. 100% repeatability not possible in current version of Lybin.		
Basic solution:		
Included with the limitations described above in comments.		

ID:	Requirement:	Priority:
O05	HLA	2
Description:		
If a distributed simulator is designed, HLA shall be used as the architectural model.		
Comment:		
Basic solution:		
Not a distributed simulator.		

ID:	Requirement:	Priority:
O06	Change scenario during simulation	3
Description:		
It shall be possible to stop the simulation at any moment in time to change the scenario. After this the simulation will go on taking into account the changes made.		
Comment:		
Basic solution:		
Not included.		

ID:	Requirement:	Priority:
O07	Interactive simulation	3
Description:		
It shall be possible to run the simulation interactively where the user among other things can initiate manoeuvres and countermeasures.		
Comment:		
Basic solution:		
Not included.		

6 CONCLUDING REMARKS

This document describes the context, the need and the most important requirements for a torpedo defence tactical model. A model developed by FFI will not fulfil all the requirements because of lack of time and resources. At best we have five man years available for the torpedo defence activity in FFI project 795 comprising modelling, input data specification and analysis. With this manpower we believe we will be able to develop a torpedo defence model according to the specified basic solution described in chapter 5.2. This model will be limited to the needs of FFI project 795.

The sufficient detailed modelling of wake homing torpedoes and ship wake is regarded as too demanding considering the resources allocated to this activity. The availability of data is also limited. A detailed wake homing torpedo will therefore not be included in the basic solution. Valuable information on the detection of wake homers, and the time aspect of evasive manoeuvres against them, can however be studied by following the approach described in chapter 5.2, requirement E05 and T01. We feel however confident that we will be able to develop a model that handles scenarios which include straight running, independent and wire-guided torpedoes in such detail that it will give useful and reliable results.

The proposed basic solution is our current best estimate of what can be achieved in FFI project 795. However, due to the complexity and the uncertainty we expect that it will be necessary to redefine the contents of the basic solution during the development in order to obtain a reasonably balanced level of detail and ensure focus on the most critical issues that can be analysed with such a model.

APPENDIX

A ABBREVIATIONS

ASWCS	Anti Submarine Warfare Control System
ATAS	Active Towed Array Sonar
CW	Continuous Wave
DCL	Detection, Classification and Localisation
FM	Frequency Modulated
GUI	Graphical User Interface
HLA	High Level Architecture
HMS	Hull Mounted Sonar
NATO	North Atlantic Treaty Organization
NAVMATCOMNOR	Naval Material Command Norway
NF	New Norwegian Frigate
MOE	Measure Of Effectiveness
PC	Personal Computer
PG37	Project Group 37
RNoN	Royal Norwegian Navy
SAT2	Sea Acceptance Test 2
TCM	Torpedo Counter Measure

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(1) TNO (1996): NATO Surface Ship Torpedo Defence Study PG37. Final report SSTDS Governmental simulation contract ref 96/13, Confidential

(2) KARLSEN Marcus, NORDØ Erik, LANGSET Frode, Ljøgodt Håkon (2000): Selection of a tactical model of torpeo defence. An evaluation of three alternatives., FFI/RAPPORT-2000/05489, In Confidence

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