Risk Informed Inspection and Maintenance Management (RIIMM) for HALIFAX Class Ships - Scoping Study

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EXECUTIVE SUMMARY

Recent Royal Canadian Navy (RCN) experience has shown how structural defects can accrue near a vessel's end of life, resulting in higher than normal rates of damage, significant maintenance costs, and sometimes earlier than planned retirement of the ship. One way to offset those effects is to improve inspection routines so that defects are identified and repaired earlier on, avoiding the high-impact accumulation of damage near end of life. The challenge is to develop new inspection regimes that are cost-effective compared to existing methods, while at the same time are optimized to ensure that the most critical types of damage are identified in the most critical areas of the vessel. In order to address these challenges, DRDC Atlantic has initiated a multi-year study to develop and apply risk based approaches for the HALIFAX class ships. These approaches have the advantage to rationally treat uncertainties and risks associated with inspection and maintenance activities, and are well suited for optimizing these activities.

The main objective of the overall project is to develop Risk-Informed Inspection and Maintenance Management (RIIMM) strategies for the HALIFAX class ships. The current task is a scoping study aimed at investigating the feasibility and plan for undertaking a RIIMM methodology for the HALIFAX class. The scope of the current task includes: (a) review of the existing HALIFAX class defect, inspection and maintenance database and assessing its suitability for use in a RIIMM assessment; (b) developing a research plan for implementing a RIIMM approach for the HALIFAX class, including how to make use of the existing defect database; (c) performance of a case study to demonstrate the feasibility and benefits of the RIIMM methodology; and (d) development of an implementation plan for applying a RIIMM approach to the HALIFAX class.

The review of the HALIFAX class inspection database and analysis of the data provided a good insight into the nature of data collected and how the data could be applied in a risk-based framework. The features of the database that make it suitable for use in a risk-based framework include: (a) clear indication of the system breakdown, highlighting the compartments/components that are inspected and repaired; (b) specification of damage modes (corrosion, cracking, deformation, paint preservation, fabrication and other) that are inspected and how the damages are assessed; and (c) provision of inspection and repair frequencies and how these are carried out. A number of limitations/gaps were also identified that need to be addressed to enhance its use in the RIIMM framework. These include inconsistencies in the reporting of inspection data, such as damage sizes, and "Other" failure mode entries. Clarifications are also required on the subsets of components inspected and repaired at any given inspection/repair period; handling of difficult-to-inspect components; status of components listed in the database; and repair process, all of which will help to determine damage growth rates, and to establish maintenance costs of the current practice.

A preliminary RIIMM framework has been formulated in the current task. A methodology is developed that does not deviate much from current practice; makes use of available data as much as possible; does not have significant data collection requirements beyond current practice; is well structured, rigorous and repeatable; is easy to use and comprehend; enhances safety and mission readiness; and cost effective compared to current practice. It comprises of a six step process including:

(i) System boundary definition involving the definition of the scope of study (vessel, components, degradation modes being considered);

(ii) Qualitative risk assessment, based on a risk matrix that categorizes risk as "Low", "Medium", "High", or "Extreme", with input from historical incident database and subject matter expert opinion;

(iii) Risk based screening, based on the component criticality levels as assessed in the qualitative risk assessment step;

(iv) Quantitative risk assessment, focusing of select "High" and "Extreme" risk criticality components. This involves the performance of structural reliability analysis to refine the results of qualitative risk assessment;

(v) Inspection and maintenance plan based on component criticality levels; and

(vi) Updating of the inspection and maintenance plan following inspection and repair actions.

The main highlights/features of the proposed methodology are summarized below:

- Compartments/components ranked as "Low" or "Medium" risk do not require quantitative risk assessment.
- Compartments ranked as "High" or "Extreme" risks may require quantitative risk assessment (QRA) if there is reasonable doubt about the probability of failure and consequences assessed in the qualitative assessments.
- For compartments ranked as "Low" risk, it is proposed to increase the inspection interval from current five years to seven years, over which these compartments have to be completely inspected.
- For compartments ranked as "Medium" risk, it is proposed to maintain the current inspection cycle of five years. However, the RIIMM process suggests postponement of repairs to the next inspection cycle.
- For compartments ranked as "High" risk, the RIIMM approach suggests an increased inspection frequency, (i.e. every two years, instead of the current five years) with possibility to delay repairs until it is practicable to do so, before the end of current maintenance cycle.
- For compartments ranked as "Extreme" risk, it is proposed to immediately repair before the next mission. Repair methods are typically by replacement of the damaged component or some other advanced repair method, which will bring the damage component or structure back to an "as-good-as-new" condition.
- Optimization algorithms will be provided for making optimum inspection and repair plans during the full implementation.

A case study was performed to demonstrate the technical feasibility of applying RIIMM methodology to the HALIFAX class ships, and to demonstrate the potential benefits that can be gained through implementation of the RIIMM methodology. One ship from the East Coast fleet (HMCS Halifax) and one ship from West Coast fleet (HMCS Vancouver) were chosen for the case study. Approximately 180 compartments and structures were selected for each ship, for illustration purposes. The inspection and repair of corrosion and cracking damage modes were considered. The study was designed to demonstrate the following aspects of the RIIMM approach: (a) criticality (risk) assessment and the ranking of the compartments; (b) inspection and maintenance plan over a 10 year period; and (c) benefits (cost savings) of RIIMM, compared to current inspection and maintenance practice.

In order to facilitate the RIIMM assessments, some assumptions have been made in this case study. Therefore, the results presented are for illustration purposes only, until the assumptions have been refined during the full implementation. The main highlights of the case study are summarized below.

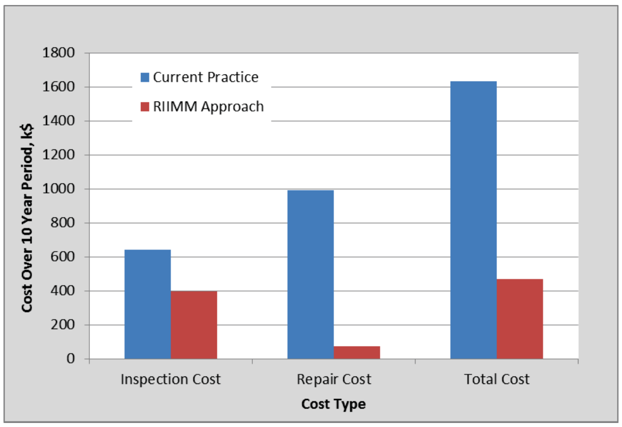
A summary of the numbers of compartments of HMCS Halifax and HMCS Vancouver falling into each of the risk criticality categories is shown in the table below for the case of corrosion damage. For this demonstration example, it is seen that 99% of the compartments of HMCS Halifax have a risk ranking of "Medium" or "Low", whereas only 1% of the compartments are ranked as "High" risk. For HMCS Vancouver, 72% are ranked as "Medium" or "Low" risk, whereas 28% are ranked as "High" or "Extreme" risk. Therefore, in this example, HMCS Vancouver will be regarded as having a higher risk profile than HMCS Halifax. A closer look of HMCS Vancouver results indicates that the "High" and "Extreme" risk values are influenced by the uncertainty in the corrosion depth and extents. Therefore, efforts would be made during the implementation phase to clarify the corrosion sizes as logged in the defects database.

Risk Level	No. of Compartments with Corrosion Damage	
	HMCS Halifax	HMCS Vancouver
Low	152	88
Medium	29	44
High	2	42
Extreme	0	9

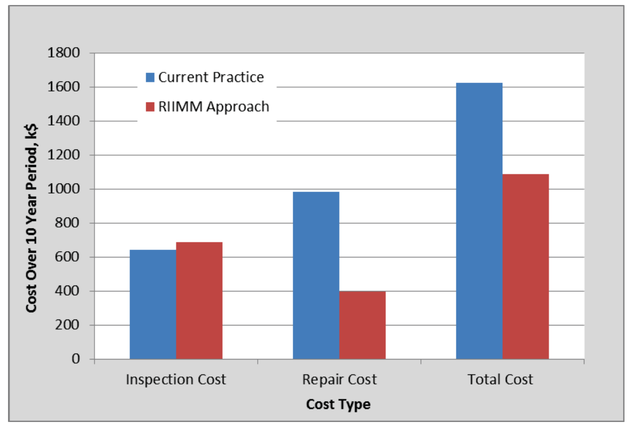
The numbers of inspections and repairs undertaken over the 10 year planning period are summarized in the table below for the current practice and proposed RIIMM process. In general, the RIIMM process suggests fewer numbers of inspections and repairs over the planning period, compared to the current practice. Also, due to the lower risk profile of HMCS Halifax, the RIIMM process requires fewer numbers of inspection and repairs than for HMCS Vancouver.

Description	**Current Practice***	**RIIMM Approach**	
	HMCS Halifax & Vancouver	**HMCS Halifax**	**HMCS Vancouver**
Number of Inspections Performed	366	231	356
Number of Repairs by Cleaning and Paint Preservation	184	0	0
Number of Repairs by Grinding and Filling with Weld Metal	112	0	0
Number of Repairs by Metal Replacement	70	17	78
Total Number of Repairs Required	366	17	78
* Assumes all defects are repaired in current RCN practice			

The inspection, repair and total costs for the planning period are summarized in the figure below. It is seen that the costs under the RIIMM regime are generally lower than those under the current practice. For this case study, the application of the RIIMM process provides 71% and 33% reductions in inspection and repair costs for HMCS Halifax and HMCS Vancouver, respectively. The greater savings are for HMCS Halifax, which has a lower risk profile than HMCS Vancouver. The RIIMM process allocates more resources to high risk compartments, rather than allocating resources equally to all compartments, as generally done in current practice.



HMCS Halifax



HMCS Vancouver

The results of the study have shown the feasibility of developing a RIIMM process for the HALIFAX class ships, and demonstrated potential benefits in terms of savings in inspection and maintenance costs, and enhancement of safety and mission readiness. It is recommended to undertake future studies to refine and implement the RIIMM methodology for the RCN. It is suggested to undertake the RIIMM implementation in three work packages (WP) as shown in the table below.

WP #	Tasks Included
1	Task 1: Stakeholder Engagement Task 2: Refinement of RIIMM Methodology Task 3: Assessment of Risk Profile of All Vessels of HALIFAX Class Task 4: RIIMM Software Architecture Development
2	Task 5: Implementation of RIIMM Methodology and Software Task 6: Case Studies
3	Task 7: Documentation Task 8: Training of RCN Fleet Maintenance Personnel

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GLOSSARY

COMPASS	Computational Methods for Probabilistic Analysis of Structures and Systems
CPF	Canadian Patrol Frigate
DA	Design Authority
DE	Depth Extent Corrosion Weighting Factors
DL	Depth Length Cracking Weighting Factors
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FEA	Finite Element Analysis
FMF	Fleet Maintenance Facilities
FTA	Formation Technical Authority
HMCS	Her Majesty's Canadian Ship
IR	Incident Rate
NDE	Non-destructive Evaluation
NAVORD	Naval Materiel Risk Management Process
NT	Nominal Thickness
PDF	Probability Distribution Function
QRA	Quantitative Risk Assessment
RA	Risk Assessment
RCN	Royal Canadian Navy
RIIMM	Risk-Informed Inspection and Maintenance Management
SME	Subject Matter Experts
UTG	Ultrasonic Thickness Gauging

1.0 INTRODUCTION

1.1 BACKGROUND

Recent Royal Canadian Navy (RCN) experience has shown how structural defects can accrue near a vessel's end of life, resulting in higher than normal rates of damage, significant maintenance costs, and sometimes earlier than planned retirement of the ship. One way to offset those effects is to improve inspection routines so that defects are identified and repaired earlier on, avoiding the high-impact accumulation of damage near end of life. The challenge is to develop new inspection regimes that are cost-effective compared to existing methods, while at the same time are optimized to ensure that the most critical types of damage are identified in the most critical areas of the vessel. The end goal is to develop a new inspection regime for the HALIFAX class frigate that will mitigate the impact of an increasing rate of defect development as the ships age, without increasing inspection and maintenance costs or timelines.

The current task is to study how a risk-based approach could be applied to improving vessel longevity through systematic and rational treatment of uncertainties and risks associated with inspection and maintenance activities. This could involve the enhancement of inspection and maintenance practices with a combination of advanced probabilistic methods; optimization algorithms; comparative risk, maintenance cost and decision models; and various corrective and preventive maintenance strategies. In particular, this task will establish the feasibility of a Risk-Informed Inspection and Maintenance Management (RIIMM) system for the HALIFAX class. A key component of the RIIMM system is the computation of time dependent reliability of vessel systems, sub-systems and components due to defects such as corrosion and cracking. This task will use the results of a recently developed inspection, defect and maintenance database for the HALIFAX class in order to determine the feasibility of undertaking such computations and to identify any gaps in the available data. The data will then be used in a proof-of-concept demonstration of the feasibility and benefits of the RIIMM system. The final outcome of the task will be recommendations for improving the HALIFAX class database and a plan for the development and implementation of the RIIMM system for the class.

1.2 OBJECTIVES AND SCOPE

The objective of the overall project is to develop Risk-Informed Inspection and Maintenance Management (RIIMM) strategies for RCN fleet vessels. The current task is a scoping study aimed at investigating the feasibility and plan for undertaking the RIIMM methodology for the RCN. The scope of the current task includes the following:

- Reviewing the existing HALIFAX class defect, inspection and maintenance database and assessing its suitability for use in the RIIMM assessment, as well as any recommendations for augmenting the available data;
- Developing a research plan for implementing the RIIMM approach for the HALIFAX class, including how to make use of the existing defect database, what risk assessment methods should be applied to each degradation mode considered, and how the risk-based approach could be used to improve the maintenance and inspection regime for the class;

- Description of the demonstration case, including the degradation mode considered, the risk assessment and other analytical methods used, and how the HALIFAX class defect database was leveraged to show how a RIIMM approach can improve maintainability; and
- Development of an implementation plan for applying a RIIMM approach to the HALIFAX class, including the technical strategy, detailed work plan, and estimated costs and schedule.

In order for the proposed RIIMM methodology to be successful and gain acceptance by the RCN maintenance community, it is desirable that the methodology makes use of the RCN inspection and maintenance and embraces current practices as much as possible. To this end a review of the HALIFAX class inspection and repair database and practices was undertaken to gain understanding of the RCN inspection and maintenance practices, as input to the RIIMM methodology.

1.3 ORGANIZATION OF REPORT

This report is organized as follows:

- Chapter 2 presents the review of the RCN maintenance policy and the defects database of the HALIFAX class ships. Analysis of the defects data for selected ships are presented and the suitability of the data for development of risk based methods is discussed along with limitations/gaps in the data.
- Chapter 3 provides details of the RIIMM methodology developed in this task.
- Chapter 4 discusses the case study undertaken to demonstrate the feasibility and benefits of the RIIMM process.
- The plan for full implementation of the RIIMM process for HALIFAX class ships is provided in Chapter 5.
- Chapter 6 provides the summary, conclusions and recommendations reached in this task.

2.0 REVIEW OF HALIFAX CLASS INSPECTION DATABASE

2.1 INTRODUCTION

A review of HALIFAX class inspection, defects and maintenance database was undertaken in this task to gain insights into the current inspection and maintenance management practices. The main goal of the review includes the following:

1) To gain an understanding of RCN inspection and maintenance management practices, degradation modes, inspection methods and frequency, and maintenance and repair strategies;
2) To assess how well the database accounts for the effects of time dependent degradation, inspection and repairs; and
3) To identify the any gaps in the HALIFAX class database that could prohibit or inhibit the RIIMM approach for the class.

2.2 CANADIAN NAVAL FLEET STRUCTURAL SURVEY (INSPECTION) AND MAINTENANCE MANAGEMENT PHILOSOPHY

The Department of National Defence (DND) maintenance policy document, C-03-015-003/AM-001 (“Requirements for the Survey and Repair of Steel Ships”) [1] was developed as guidance for Fleet Maintenance Facilities (FMF) hull surveyors to perform structural inspections and provide repair instructions as required. The document describes the survey procedures and repair criteria to maintain the fleet within the required naval standards. The following sub-sections summarize key elements of the document considering their relevance to risk-informed inspection and maintenance management.

2.2.1 Scope of Inspection and Maintenance Activities

The inspection (survey) is conducted under a progressive survey regime, and approximately 440 compartments are inspected in a five year inspection cycle. Five key damage/failure modes, namely corrosion, cracking, deformation, paint preservation, fabrication error, are focused on during inspection activities. Damages found during inspection that do not belong to any of above mentioned damage categories are considered as “Other” and suitable repair actions will be taken accordingly. Inspections are primarily performed by means of visual inspection and advanced methods such as Ultrasonic Thickness Gauging (UTG) are used if thickness loss is suspected to be more than 15% for critical structure, greater than 20% for primary structure, or greater than 25% for secondary structure.

Repairs recommended are planned to be completed within the same five year maintenance cycle. The requirement for repair is established as a result of survey data and at the direction of Formation Technical Authority (FTA) and Design Authority (DA). Repair methods also depend on the damage modes, severity of the damage and ship operations.

2.2.2 System Breakdown and Components

For the purposes of hull inspection and repair, a typical HALIFAX class ship is divided into approximately 440 compartments and structures. Inspection data are logged against the compartment names, and the locations of the damages are identified by the frame number and deck.

2.2.3 Damage/Failure Modes

Table 2-1 lists common failure modes which are considered for the HALIFAX class ships, based on the information from the survey data and guidance document.

Table 2-1: Summary of Failure Modes Associated with Structural Components

Damage Mode	Description
Corrosion	• Corrosion manifests itself in several forms, including general corrosion, pitting, and grooving (can be treated as pitting) • Common corrosion-susceptible areas include those that are inaccessible, always wet or oily areas such as bilge, shower stalls, galleys, areas where dissimilar metals are close or in contact
Cracking	• Two types of cracking are possible: ductile and brittle. Brittle cracks are rare in HALIFAX class ships • Ductile cracks are generally caused by fatigue and likely to occur in areas with high stress concentrations • Most cracks occur at junctions where the side shell longitudinals are connected to transverse bulkheads or web frames • Cracks are also found to occur in the deck and bulkhead openings, weld defects, abrupt changes in sections.
Paint Preservation	• Coating/ paint could fail due to improper selection, inappropriate application, aging, cracking or chipping • Common types of coating damages recorded in HALIFAX class survey reports are chip/peel, deck coating breakdown, blisters, erosion, and physical damages
Deformation	• Deformation of structure occur due to application of sudden excessive loading such as collision or rough sea • Common types of deformation recorded in HALIFAX class survey reports are dished in, wrinkled, tripped, and bent • Common deformation-susceptible areas include flight decks, bow plating due to slamming, plate at the quarter point in the form of diagonal wrinkling, and waterline and bottom
Fabrication	• Common fabrication damages recorded in HALIFAX class survey reports are misalignment, piece or part missing, and weld damage or missing
Other	• Other damages are damages that do not belong to any of above mentioned damage modes • Other damages are categorised into two different types: structural or general.

It is noted that surveys examine the coating breakdown (paint preservation) as a separate damage mechanism though it is a strong indication of susceptibility for corrosion.

2.2.4 Inspection/Survey Method and Frequency

2.2.4.1 Inspection Frequency

The surveys are usually conducted under progressive survey regime. The time between subsequent surveys of a particular compartment is not be more than five years. The sequences of compartments inspected in each year are listed in the guidance document Hull Structure (Progressive Survey) Part 1 to 4 ([2] to [6]). Pre-refit inspection is required to be completed as close to the refit date as possible. Within a five year cycle, surveyors are to cover all compartments and accessible structural elements within the ship.

2.2.4.2 Inspection Methods/Techniques

Visual inspection is primarily conducted to identify the damage modes and their extents. Non-destructive Evaluation (NDE) tests such as UTG are carried out if thickness loss is suspected to be more than 15% for critical structure, greater than 20% for primary structure, or greater than 25% for secondary structure. The most appropriate NDE tools are selected based on failure mechanism and the location. The Survey and Repair Guideline for Steel Ships [1] defines the survey best practices which describes where defects are likely to be found and how inspections are to be carried out. There are certain pre-inspection tasks that are required to be carried to ensure an accurate and effective survey. Some of the early preparation tasks are summarized below.

- Removal of fittings and equipment which prevent accessibility
- Cleaning of tanks and compartments to ensure they are debris free
- Tanks and void spaces are to be certified gas-free before entry
- Insulation and deck coverings may be removed as necessary
- Drainage holes of compartments are required to be cleaned to make sure they are not blocked

The inspection/survey results are recorded in a database and the following minimum information shall be included.

- Name, location (deck and frame) and survey name of all compartments and structures
- Full details of structural condition of the compartment with NDE results
- Full identification of all individual defects
- Full details of required repairs
- Confirmation that planned repairs have been completed

2.2.5 Repair Methods and Policy

2.2.5.1 Repair Policy

The requirement for repair is established as a result of survey data and at the direction of FTA and DA. Repair policy/methods vary according to damage mode as well as their severity at the point in time. The repair policy for cracking, corrosion and deformation is summarized below.

- Cracks that show no sign of growing and do not affect vessel effectiveness may not require immediate repair if the DA deems that full repair is not cost effective. However, these types of cracks need to be well documented and routinely monitored to make sure that they do not grow to unacceptable levels. Other cracks require full repair. Temporary repair will be performed with the approval by the FTA and DA if the crack is found when the ship is at sea or on a mission.
- The requirement of repair for corrosion depends on the size of the corrosion identified during the survey. If thickness loss is suspected to be more than 15% for critical structure, greater than 20% for primary structure, or greater than 25% for secondary structure, repairs are required. If thickness loss is below the criteria above mentioned, full repair may not require, instead the structure is to be cleaned and preserved in accordance with guidance for Maintenance Painting Specification for HMCS (D-23-003-005/SF-002) [7].
- The repair requirement for deformation damage depends on its size, depth and location in the ship. The minimum allowable deformation depth for plating and stiffeners are provided in guidance (C-03-015-003/AM-001) [2]. Plates and stiffeners deformed beyond their allowable depth require repairs. All tripped and torn stiffeners are to be replaced. If the distortion extends over more than one frame spacing or two longitudinals, but is less than the allowable values defined in guidance [1], repair is to be considered.

It should be mentioned that the above mentioned repair policies are generally consistent with risk based maintenance principles. However, as currently practiced by the RCN the decision making process is not clearly formalized and generally left to the direction of FTA and DA. A risk-informed approach, as being advocated in this project will provide a more formal approach to making repair decisions.

2.2.5.2 Repair Methods

Repair methods also depend on the damage modes, severity of the damage and ship operation. In general, repairs may involve monitoring, preservation, modification to design, rectification of previous work, or replacement of structure according to original design.

Table 2-2 summarizes the repair methods for cracking, corrosion and deformation as described in the Survey and Repair Guideline for Steel Ships guidance document [1].

Table 2-2: Repair Strategies for Corrosion, Cracking and Deformation

Damage Mode	Structure	Repair Method
Cracking	Primary and secondary structure	Defective plate is to be removed and replaced with an insert piece as the same strength and thickness as the defective plate when new
	Minor structure	Required to be gouged out, re-welded and ground smooth
	Welds	Completely removed and replaced in accordance with the welding specification
	Longitudinal stiffeners	All of the affected area removed and replaced with a new length of stiffener of the same dimensions
Corrosion	Critical structure, < 15% NT, Primary structure, < 20% NT Secondary structure, <25% NT	Cleaned and preserved in accordance with guidance for Maintenance Painting Specification for HMC Ships (D-23-003-005/SF-002) [8]
	Critical structure, > 15% NT, Primary structure, > 20% NT Secondary structure, > 25% NT; and pits of less than 50% NT	Ground out, filled with weld metal, and ground smooth
	Critical structure, > 15% NT, Primary structure, > 20% NT Secondary structure, > 25% NT; and pits of greater than 50% NT	Removed and an insert fitted in accordance with the welding specification in D-49-003-003/SF-001 (Welding Specification for HMC ships [9])
Deformation	Plate and stiffeners that have deformation above the allowable criteria	Remove and replace with new part

2.3 Summary of Canadian Naval Fleet Inspection Database

The existing HALIFAX class inspection, defect, and maintenance database was analyzed to determine the suitability of the inspection and maintenance data for RIIMM. The East Coast and West Coast ships were separately assessed, and the results for the overall fleet and selected individual ships are presented in the sections below.

In general, defects of individual ships were assessed in terms of compartments, the locations (decks and frames) where damages were found, and the year the damages were found. Repairs/ maintenance of damaged components were also assessed to gain an understanding of the fleet repair/maintenance patterns. Additionally, each damage mode was further investigated to identify any trends that can be used for risk-based inspection and maintenance.

2.3.1 Overall Fleet Summary

Inspection and maintenance data are collected separately on the East Coast and West Coast and the databases for the two coasts were made available to the study. Each of these databases contained five ships and summaries of the damage distributions are provided in Table 2-3, Figure 2-1, and Figure 2-2.

Table 2-3: Summary of Damages for East Coast and West Coast Fleet

Fleet	Ship	Pennant Number	Year Commissio	Damage Modes						Total
				Corrosion	Cracking	Deformation	Paint_Preservation	Fabrication	Other	
East Coast	HFX	FFH 330	29/06/1992	254	52	22	626	18	867	1839
	VDQ	FFH 332	14/08/1994	172	59	25	652	9	677	1594
	FRED	FFH 337	10/09/1994	206	31	15	535	8	617	1412
	CHAR	FFH 339	09/09/1995	143	39	16	630	8	759	1595
	STJ	FFH 340	26/06/1996	141	27	20	515	10	654	1367
West Coast	VAN	FFH 331	23/08/1993	722	64	12	100	0	36	934
	REG	FFH 334	29/12/1993	83	33	13	52	3	30	214
	CAL	FFH 335	12/05/1995	80	11	20	116	0	23	250
	WIN	FFH 338	23/06/1996	300	21	9	113	11	38	492
	OTT	FFH 341	28/09/1996	119	47	11	157	3	10	347

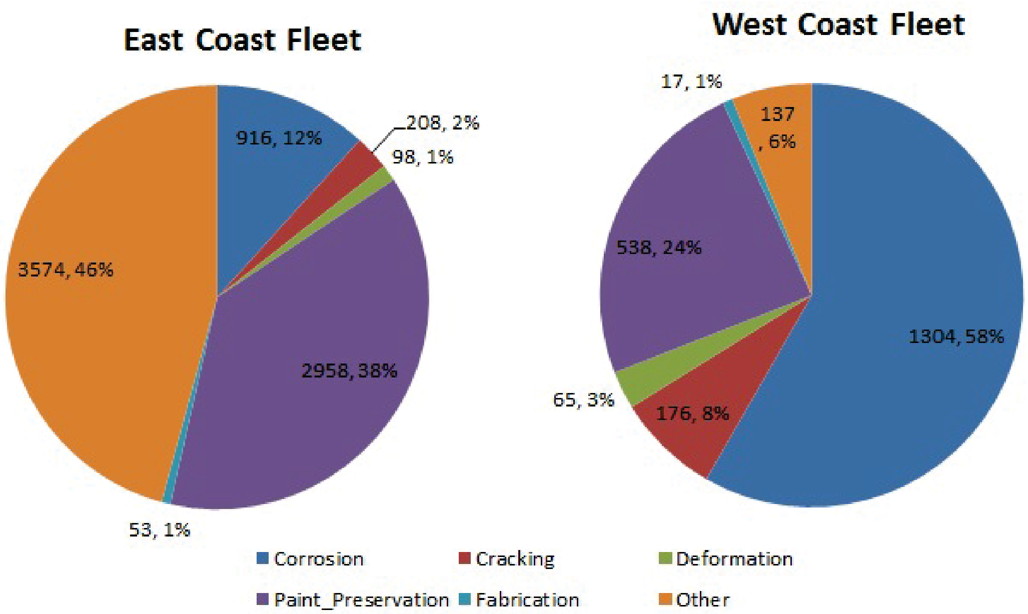
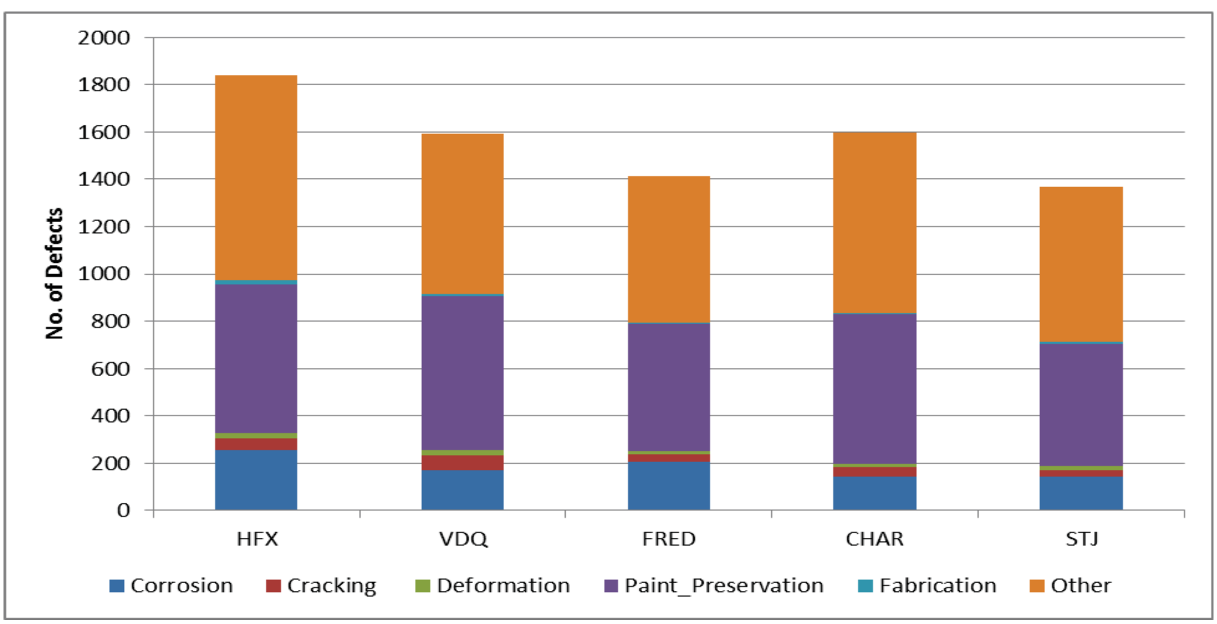
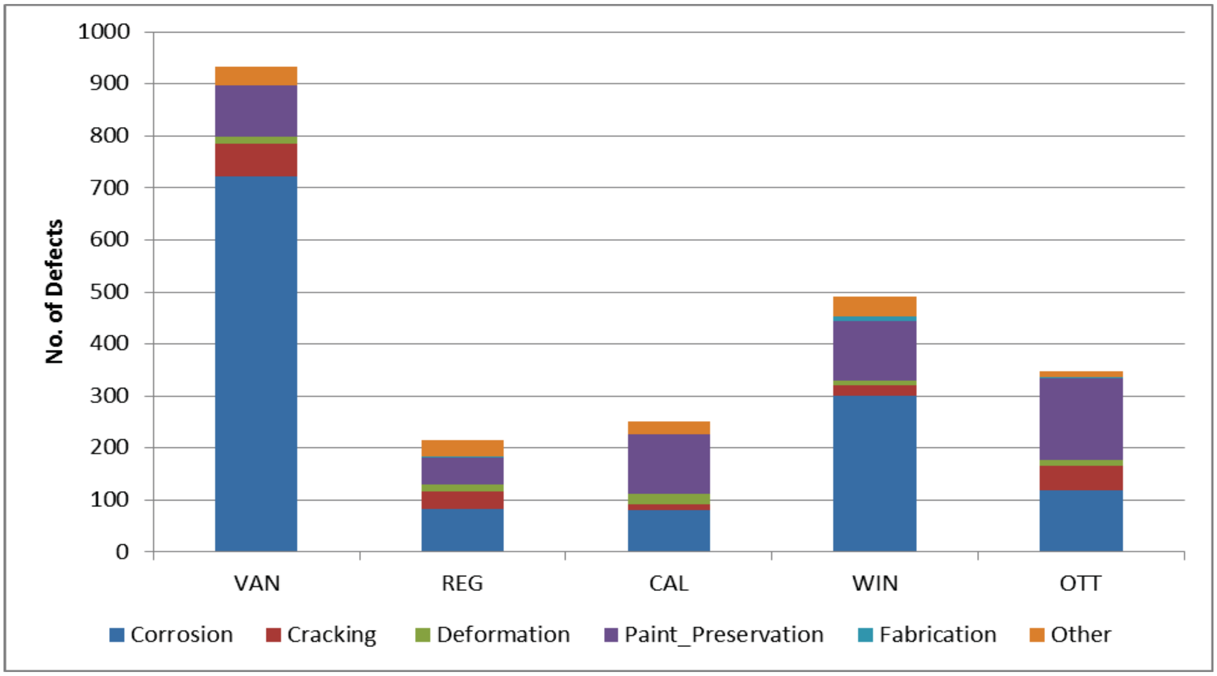


Figure 2-1: Overall Damage Summary for East Coast and West Coast Fleets



(a)



(b)

Figure 2-2: Damage Summary by Ship: (a) East Coast and (b) West Coast

The following observations can be made.

- The East Coast ships generally have more damage incidents recorded than West Coast ships
- The East Coast database contained large number of entries for the damage category "Other". It is not clear what damage modes these actually are.
- The East Coast database also contains large number of entries for the "Paint Preservation" damage mode compared to the West Coast database. Given the larger number of corrosion incidents in West Coast ships than in East Coast ships, it is possible that some of these entries could be categorized as "Corrosion" damage. Clarification will be sought from RCN fleet maintenance personnel during full implementation of the RIIMM methodology.
- Considering the damage modes that could affect structural integrity, i.e. corrosion, cracking, deformation and fabrication errors, it is seen that all ships generally have more incidents of corrosion damage, followed by cracking, deformation and fabrication errors, in that order.
- Individual ships exhibit different level of damage for each of the damage modes.

2.3.2 Individual Ship Summaries

In-depth reviews of the incidents data for individual ships were carried out to gain insight into how the various forms of damage are distributed on individual ships. In the following sub sections, the results for HMCS Halifax (East Coast) and HMCS Vancouver (West Coast) are discussed. The summaries for other ships reviewed in this task, including HMCS Ville de Quebec, Regina, Calgary, Winnipeg, and Ottawa, are provided in Appendix A.

2.3.2.1 HMCS Halifax (East Coast)

The results for HMCS Halifax are shown in this section as a representative ship of the East Coast fleet. Figure 2-3 shows the number of defects by type.

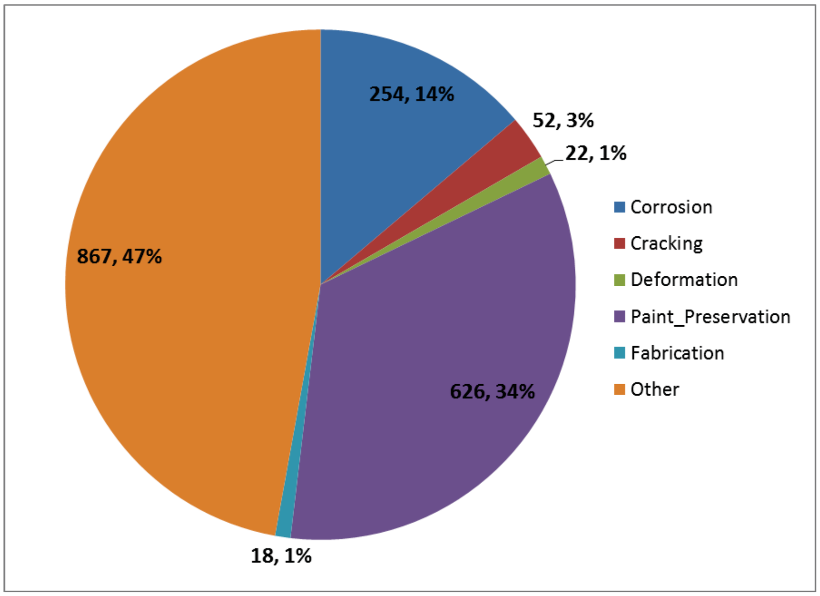
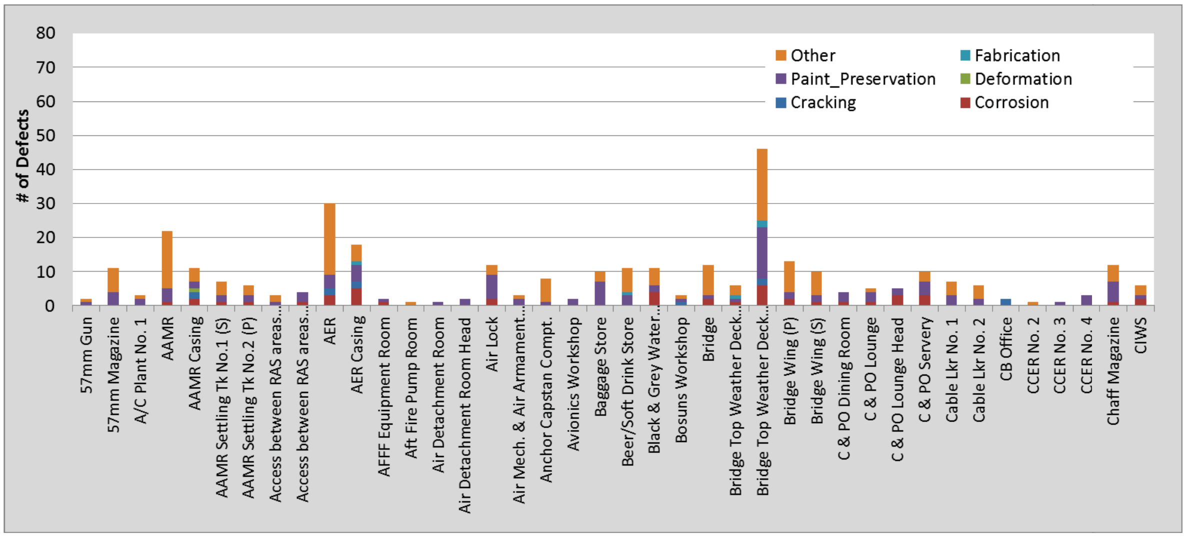


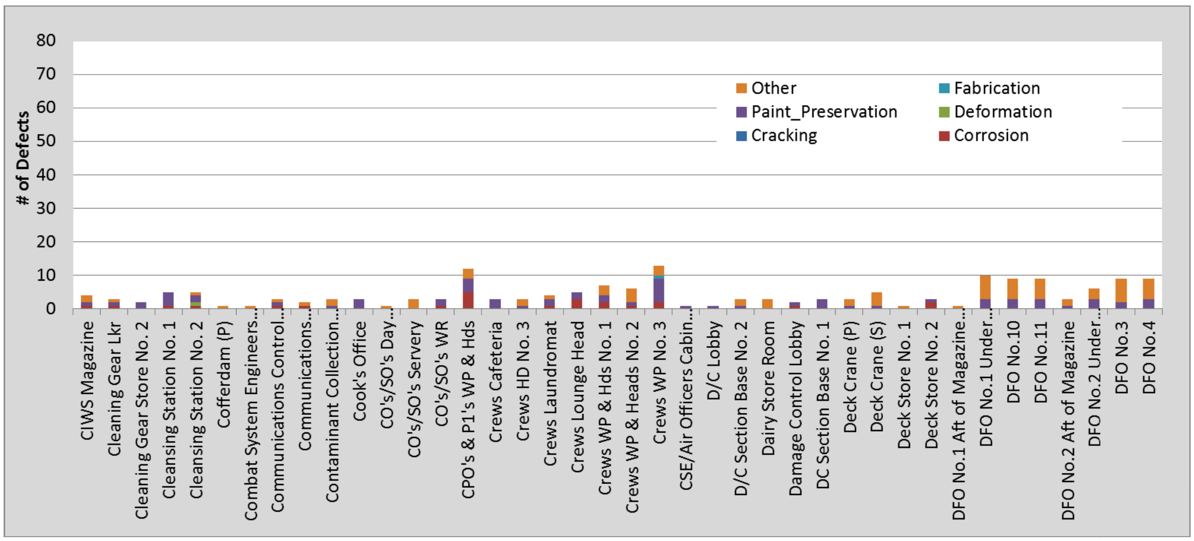
Figure 2-3: Total Numbers of Defects by Type for HMCS Halifax

As is typical of East Coast fleet, the HMCS Halifax inspection data is dominated by “Paint Preservation” and “Other” damage modes. Considering only the damage modes that could affect structural integrity (i.e. corrosion, cracking, deformation and fabrication), corrosion is seen to be the most prevalent damage mode, followed by cracking, deformation, and fabrication, in that order.

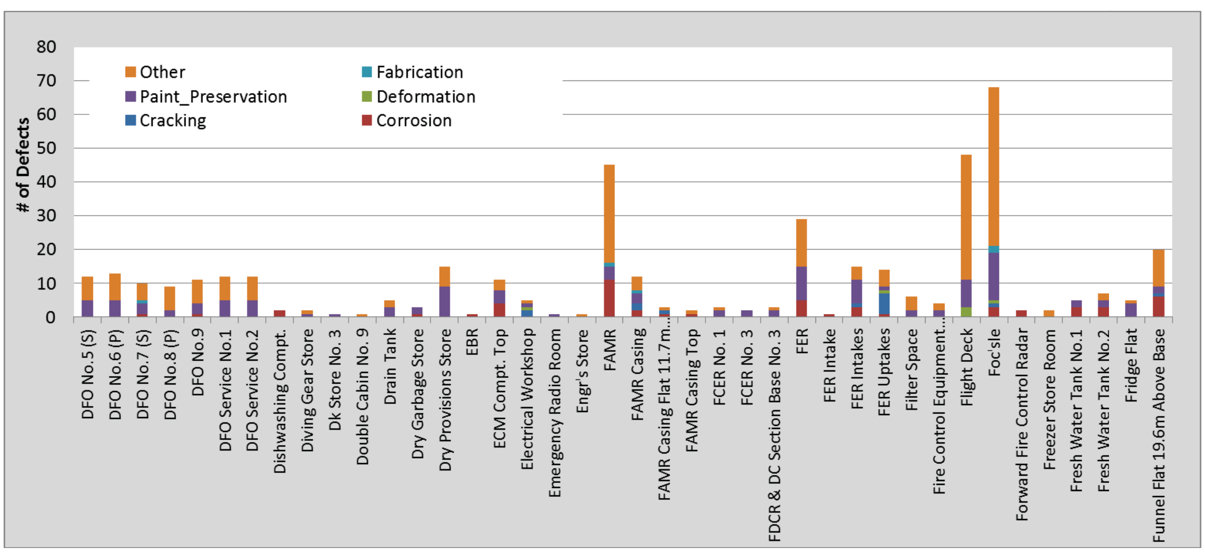
Figure 2-4 shows the distribution of damage by compartments for those compartments where at least one damage incident have been recorded in the database. The compartments are listed in alphabetical order. It is seen that damage incidents have been reported for 241 of 440 compartments of the ship.



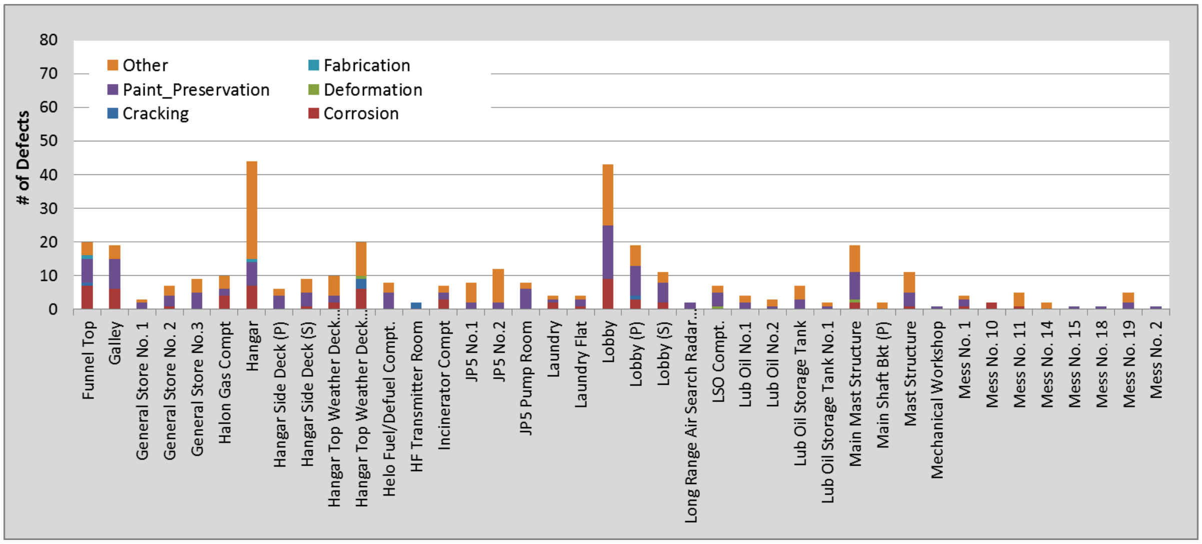
80
70
60
50
40
30
20
10
0
# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
57mm Gun
57mm Magazine
A/C Plant No. 1
AAMR
AAMR Casing
AAMR Settling Tk No.1 (S)
AAMR Settling Tk No.2 (P)
Access between RAS areas…
Access between RAS areas…
AER
AER Casing
AFFF Equipment Room
Aft Fire Pump Room
Air Detachment Room
Air Detachment Room Head
Air Lock
Air Mech. & Air Armament…
Anchor Capstan Compt.
Avionics Workshop
Baggage Store
Beer/Soft Drink Store
Black & Grey Water…
Bosuns Workshop
Bridge
Bridge Top Weather Deck…
Bridge Top Weather Deck…
Bridge Wing (P)
Bridge Wing (S)
C & PO Dining Room
C & PO Lounge
C & PO Lounge Head
C & PO Servery
Cable Lkr No. 1
Cable Lkr No. 2
CB Office
CCER No. 2
CCER No. 3
CCER No. 4
Chaff Magazine
CIWS



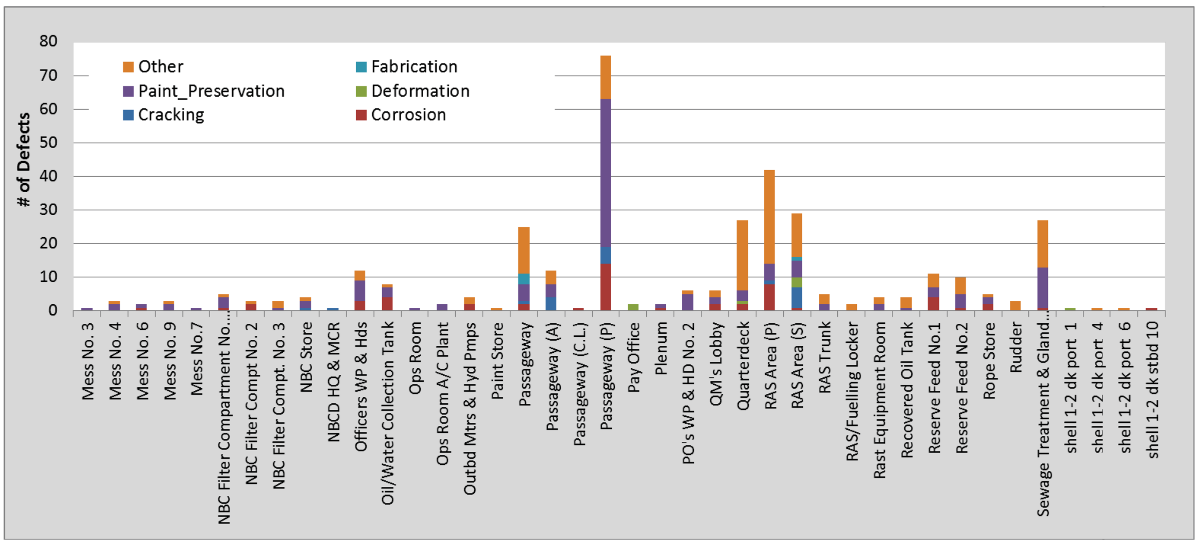
80
70
60
50
40
30
20
10
0
# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
CIWS Magazine
Cleaning Gear Lkr
Cleaning Gear Store No. 2
Cleansing Station No. 1
Cleansing Station No. 2
Cofferdam (P)
Combat System Engineers…
Communications Control…
Communications…
Contaminant Collection…
Cook's Office
CO's/SO's Day…
CO's/SO's Servery
CO's/SO's WR
CPO's & P1's WP & Hds
Crews Cafeteria
Crews HD No. 3
Crews Laundromat
Crews Lounge Head
Crews WP & Hds No. 1
Crews WP & Heads No. 2
Crews WP No. 3
CSE/Air Officers Cabin…
D/C Lobby
D/C Section Base No. 2
Dairy Store Room
Damage Control Lobby
DC Section Base No. 1
Deck Crane (P)
Deck Crane (S)
Deck Store No. 1
Deck Store No. 2
DFO No.1 Aft of Magazine…
DFO No.1 Under…
DFO No.10
DFO No.11
DFO No.2 Aft of Magazine
DFO No.2 Under…
DFO No.3
DFO No.4



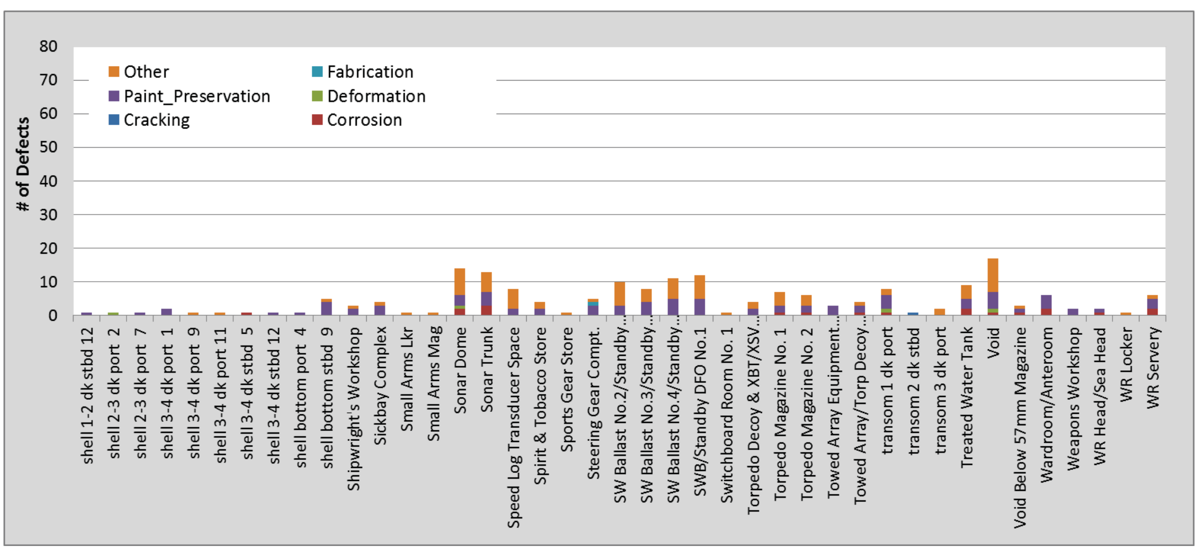
80
70
60
50
40
30
20
10
0
# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
DFO No.5 (S)
DFO No.6 (P)
DFO No.7 (S)
DFO No.8 (P)
DFO No.9
DFO Service No.1
DFO Service No.2
Dishwashing Compt.
Diving Gear Store
Dk Store No. 3
Double Cabin No. 9
Drain Tank
Dry Garbage Store
Dry Provisions Store
EBR
ECM Compt. Top
Electrical Workshop
Emergency Radio Room
Engr's Store
FAMR
FAMR Casing
FAMR Casing Flat 11.7m…
FAMR Casing Top
FCER No. 1
FCER No. 3
FDCR & DC Section Base No. 3
FER
FER Intake
FER Intakes
FER Uptakes
Filter Space
Fire Control Equipment…
Flight Deck
Foc'sle
Forward Fire Control Radar
Freezer Store Room
Fresh Water Tank No.1
Fresh Water Tank No.2
Fridge Flat
Funnel Flat 19.6m Above Base



# of Defects
0
10
20
30
40
50
60
70
80
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
Funnel Top
Galley
General Store No. 1
General Store No. 2
General Store No.3
Halon Gas Compt
Hangar
Hangar Side Deck (P)
Hangar Side Deck (S)
Hangar Top Weather Deck...
Hangar Top Weather Deck...
Helo Fuel/Defuel Compt.
HF Transmitter Room
Incinerator Compt
JP5 No.1
JP5 No.2
JP5 Pump Room
Laundry
Laundry Flat
Lobby
Lobby (P)
Lobby (S)
Long Range Air Search Radar...
LSO Compt.
Lub Oil No.1
Lub Oil No.2
Lub Oil Storage Tank
Lub Oil Storage Tank No.1
Main Mast Structure
Main Shaft Bkt (P)
Mast Structure
Mechanical Workshop
Mess No. 1
Mess No. 10
Mess No. 11
Mess No. 14
Mess No. 15
Mess No. 18
Mess No. 19
Mess No. 2



# of Defects
0
10
20
30
40
50
60
70
80
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
Mess No. 3
Mess No. 4
Mess No. 6
Mess No. 9
Mess No.7
NBC Filter Compartment No....
NBC Filter Compt No. 2
NBC Filter Compt. No. 3
NBC Store
NBCD HQ & MCR
Officers WP & Hds
Oil/Water Collection Tank
Ops Room
Ops Room A/C Plant
Outbd Mtrs & Hyd Pmps
Paint Store
Passageway
Passageway (A)
Passageway (C.L.)
Passageway (P)
Pay Office
Plenum
PO's WP & HD No. 2
QM's Lobby
Quarterdeck
RAS Area (P)
RAS Area (S)
RAS Trunk
RAS/Fuelling Locker
Rast Equipment Room
Recovered Oil Tank
Reserve Feed No.1
Reserve Feed No.2
Rope Store
Rudder
Sewage Treatment & Gland...
shell 1-2 dk port 1
shell 1-2 dk port 4
shell 1-2 dk port 6
shell 1-2 dk stbd 10



# of Defects
0
10
20
30
40
50
60
70
80
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
shell 1-2 dk stbd 12
shell 2-3 dk port 2
shell 2-3 dk port 7
shell 3-4 dk port 1
shell 3-4 dk port 9
shell 3-4 dk port 11
shell 3-4 dk stbd 5
shell 3-4 dk stbd 12
shell bottom port 4
shell bottom stbd 9
Shipwright's Workshop
Sickbay Complex
Small Arms Lkr
Small Arms Mag
Sonar Dome
Sonar Trunk
Speed Log Transducer Space
Spirit & Tobacco Store
Sports Gear Store
Steering Gear Compt.
SW Ballast No.2/Standby...
SW Ballast No.3/Standby...
SW Ballast No.4/Standby...
SWB/Standby DFO No.1
Switchboard Room No. 1
Torpedo Decoy & XBT/XSV...
Torpedo Magazine No. 1
Torpedo Magazine No. 2
Towed Array Equipment...
Towed Array/Torp Decoy...
transom 1 dk port
transom 2 dk stbd
transom 3 dk port
Treated Water Tank
Void
Void Below 57mm Magazine
Wardroom/Anteroom
Weapons Workshop
WR Head/Sea Head
WR Locker
WR Servery

Figure 2-4: Defects Summary by Compartments for HMCS Halifax

For the compartment not listed, it is not clear if they have not experienced any damage during the reporting period (from 1993 to 2014) or if these compartments were just not inspected over this period. Table 2-4 lists the compartments of HMCS Halifax that do not appear in the incident data base. Clarification of the status of these compartments will be required in order to determine the complete risk profile of the vessel. It is also observed that there is inconsistency of using compartment names in the database compared to the list in the guidance documents. These clarifications will be sought during the development stage of the RIIMM process.

Table 2-4: Compartments not Seen in Incident Database of HMCS Halifax

Compartment Name (As listed at Guidance Documents [3] to [7])			
AAMR Air Lock	Electronic Warfare Equipment Room	Shell 1 - 2 dk port 8	Shell 3 - 4 dk stbd 7
A/C Plant No. 2	EMR	Shell 1 - 2 dk port 9	Shell 3 - 4 dk stbd 8
Admin Office	FAMR Air Lock	Shell 1 - 2 dk port 10	Shell 3 - 4 dk stbd 9
AER Air Lock	FER Air Lock	Shell 1 - 2 dk port 11	Shell 3 - 4 dk stbd 10
Aft Fire Control Radar	FER Uptake Fan Plenum	Shell 1 - 2 dk port 12	Shell 3 - 4 dk stbd 11
Aft Sonar Instrument Space (No. 1)	Fire Fighting Equipment Store	Shell 1 - 2 dk stbd 1	Shell bottom port 2
Air Lock (Fr 8)	Flour Store	Shell 1 - 2 dk stbd 2	Shell bottom port 3
Air Lock (Fr 34)	Forward Sonar Instrument Space (No. 2)	Shell 1 - 2 dk stbd 3	Shell bottom port 5
Air Lock (Fr 54)	Fruit and Vegetable Store Room	Shell 1 - 2 dk stbd 4	Shell bottom port 6
Air Lock (Fr 57)	Galley A/C Plant	Shell 1 - 2 dk stbd 5	Shell bottom port 7
Air Maintenance Control Office	General Store 1C	Shell 1 - 2 dk stbd 6	Shell bottom port 8
Aviation Store	General Store No. 1A	Shell 1 - 2 dk stbd 7	Shell bottom port 9
Bilge Keel (P)	General Store No. 1A	Shell 1 - 2 dk stbd 8	Shell bottom port 10
Bilge Keel (S)	General Store 1B	Shell 1 - 2 dk stbd 9	Shell bottom port 11
Canteen	Gunners Store	Shell 1 - 2 dk stbd 11	Shell bottom port 12
Canteen Store	Gyro Room No. 1	Shell 2 - 3 dk port 1	Shell bottom stbd 2
CBRN Filter Compartment No. 1	Gyro Room No. 2	Shell 2 - 3 dk port 3	Shell bottom stbd 3
CBRN Filter Comp. No.2	Helo Power Compt.	Shell 2 - 3 dk port 4	Shell bottom stbd 4
CBRN Filter Comp. No.3	Helo Ru Lub Lk	Shell 2 - 3 dk port 5	Shell bottom stbd 5
CBRN Filter Comp. No.4	Mess No. 8	Shell 2 - 3 dk port 6	Shell bottom stbd 6
CBRN Store	Int Shaft Bkt (P)	Shell 2 - 3 dk port 8	Shell bottom stbd 7
CBRND HQ and MCR	Int Shaft Bkt (S)	Shell 2 - 3 dk port 9	Shell bottom stbd 8
CCER No. 1	Loan Clothing Store	Shell 2 - 3 dk port 10	Shell bottom stbd 10
Chaff Launcher (P, fwd)	Lub Oil Storage Tank No.2	Shell 2 - 3 dk port 11	Shell bottom stbd 11
Chaff Launcher (P, aft)	Maint. Co-ord/Mar. System Eng. Off.	Shell 2 - 3 dk port 12	Shell bottom stbd 12
Chaff Launcher (S, fwd)	Main Shaft Bkt (S)	Shell 2 - 3 dk stbd 1	SMI - E
Chaff Launcher (S, aft)	MEO Cabin No. 10	Shell 2 - 3 dk stbd 2	SO's Cabin
Chart Room	Medical Store	Shell 2 - 3 dk stbd 3	Sonobuoy Store No. 1
Cleaning Gear Store No.1	Mess No. 5	Shell 2 - 3 dk stbd 4	Sonobuoy's Store No. 2
CO's Cabin	Mess No. 8	Shell 2 - 3 dk stbd 6	SPS 49 Cooling Equipment Room

Compartment Name (As listed at Guidance Documents [3] to [7])			
Cofferdam (S)	Mess No. 12	Shell 2 - 3 dk stbd 7	Stores Office
Combat Officer Cabin No. 12	Mess No. 16	Shell 2 - 3 dk stbd 8	Supply Officers Cabin No. 14
Common Locker	Mess No. 17	Shell 2 - 3 dk stbd 9	Switchboard Room No. 2
Control System Workshop	Ops Room Admin	Shell 2 - 3 dk stbd 10	TAU Compt.
Coxswain Office	Paint Locker	Shell 2 - 3 dk stbd 11	Tool Crib
Coxswain Single Cabin	Plenum (S)	Shell 2 - 3 dk stbd 12	Transom 1 dk stbd
C and PO Dining Room	Plenum (P)	Shell 3 - 4 dk port 2	Transom 2 dk port
C and PO Lounge	Potato Locker	Shell 3 - 4 dk port 3	Transom 3 dk stbd
C and PO Lounge Head	Radar Room No. 1	Shell 3 - 4 dk port 4	UHF Antenna
C and PO Survey	Radar Room No. 2	Shell 3 - 4 dk port 5	Void (Aft)
Crews Lounge	Rope Store (Fr 58-60.5)	Shell 3 - 4 dk port 6	Void (Forepeak)
Damage Control Store	Rope Store (Fr 60.5-6.26)	Shell 3 - 4 dk port 7	XBT/XSV Store
Degaussing Equipment Room	Satcom Antenna (P)	Shell 3 - 4 dk port 8	XO Cabin No. 2
Double Cabin No. 1	Satcom Antenna (S)	Shell 3 - 4 dk port 10	
Double Cabin No. 3	Sea Head	Shell 3 - 4 dk port 12	
Double Cabin No. 4	SHINCOM Equipment Room	Shell 3 - 4 dk stbd 1	
Double Cabin No. 5	Shell 1 - 2 dk port 2	Shell 3 - 4 dk stbd 2	
Double Cabin No. 6	Shell 1 - 2 dk port 3	Shell 3 - 4 dk stbd 3	
Double Cabin No. 7	Shell 1 - 2 dk port 5	Shell 3 - 4 dk stbd 4	
Double Cabin No. 8	Shell 1 - 2 dk port 7	Shell 3 - 4 dk stbd 6	

The 25 most damage prone compartments of HMCS Halifax are shown in Figure 2-5. These would represent the compartments most likely to experience the various damage modes, and would require frequent attention to ensure ship safety. However, decision on allocation of inspection and maintenance resources should also take into consideration the consequence of failure due to these damage modes. This is what the RIIMM process seeks to address.

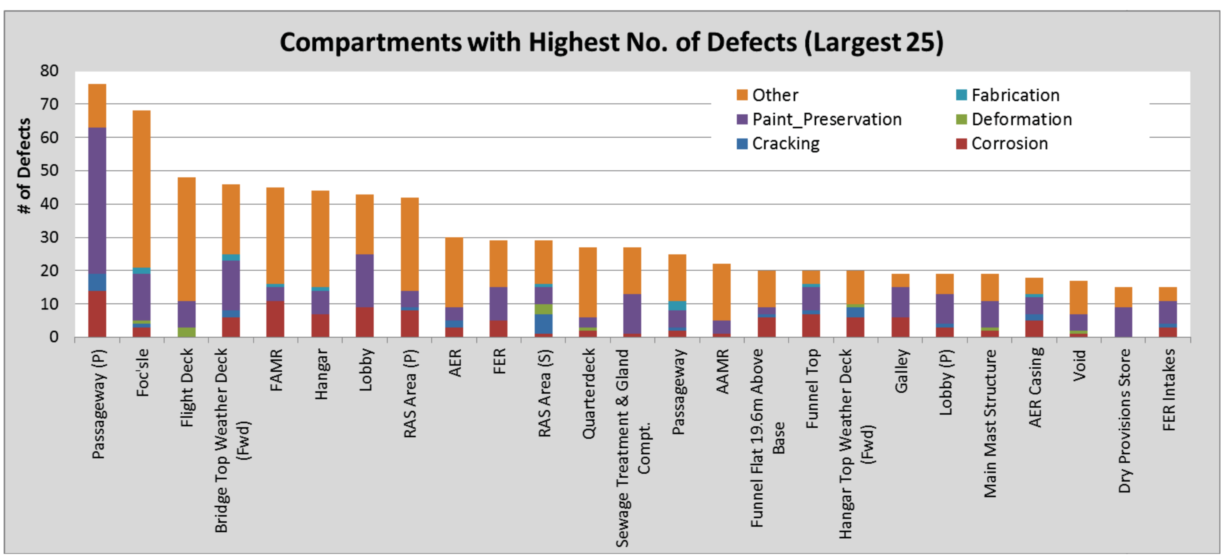


Figure 2-5: Most Damage Prone Compartments for HMCS Halifax

Figure 2-6 and Figure 2-7 show the distribution of damage on HMCS Halifax by frame number and deck, respectively. The larger number of damage incidents have been found around the frame numbers 12,13,21,22,26,39,44,45,48; and on decks 1, 2 and 5.

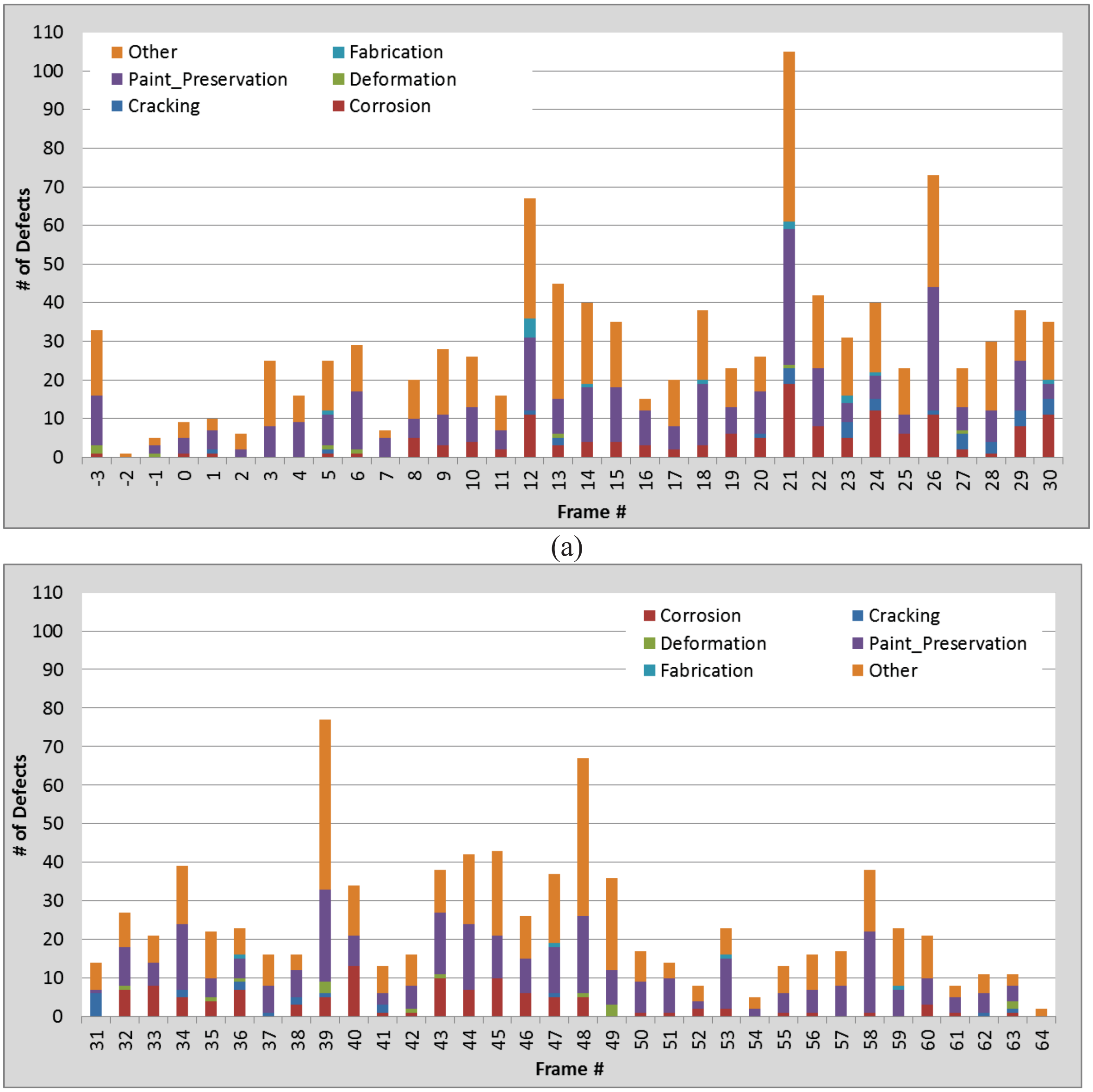


Figure 2-6: Damage by Frame for HMCS Halifax: (a) Frame # -3 to 30 and (b) Frame # 31-64

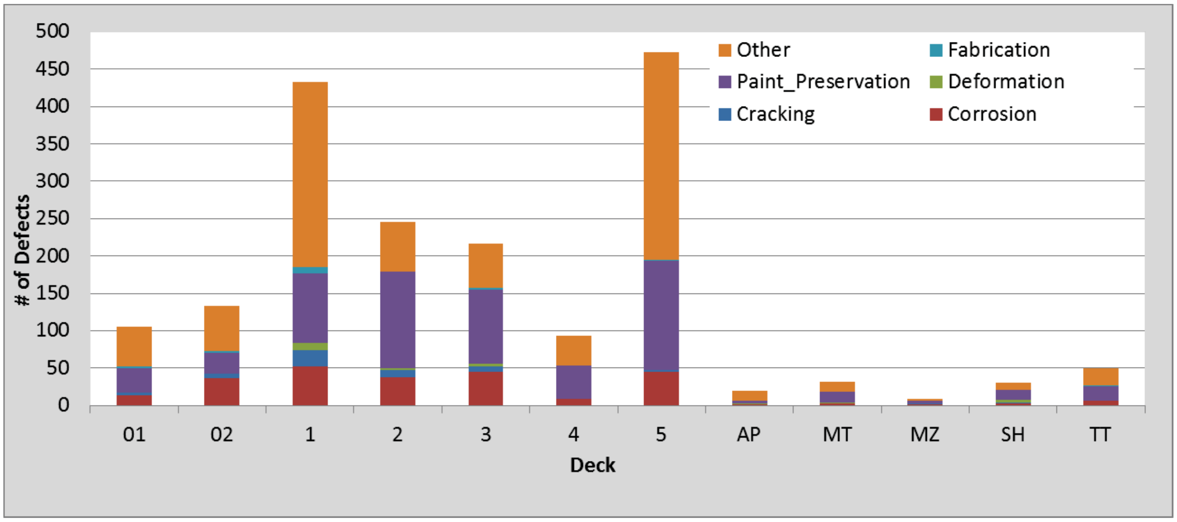
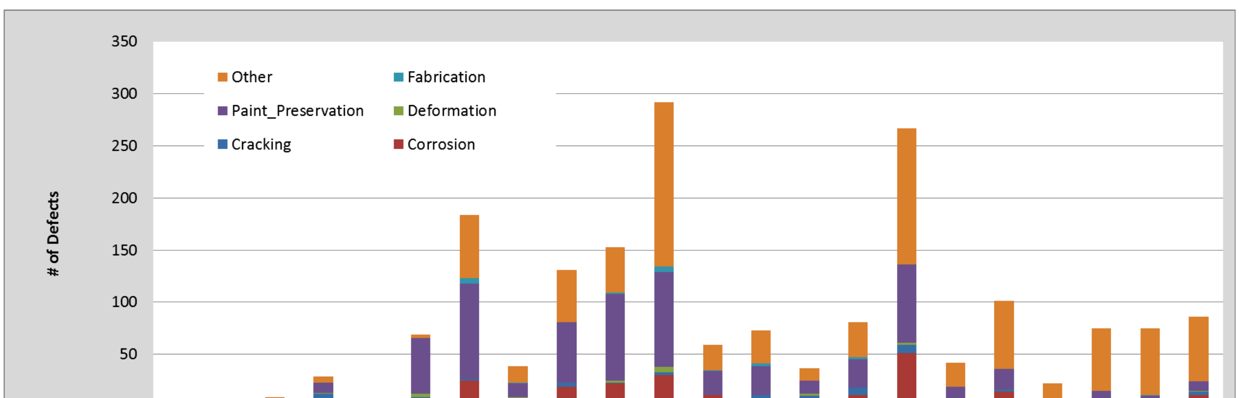


Figure 2-7: Damage by Deck for HMCS Halifax

The damage history from vessel commissioning in 1993 to 2014 is presented graphically in Figure 2-8. The figure clearly shows the progressive inspection regime followed in the East Coast, whereby the first inspection cycle started in 1993 and progressed every year until it was completed in 1999 (a 6-year cycle). The second inspection cycle started in 2000 and was completed in 2003 (a 4-year cycle), and the next cycle started in 2004 and was completed in 2008 (a 5-year cycle), etc.

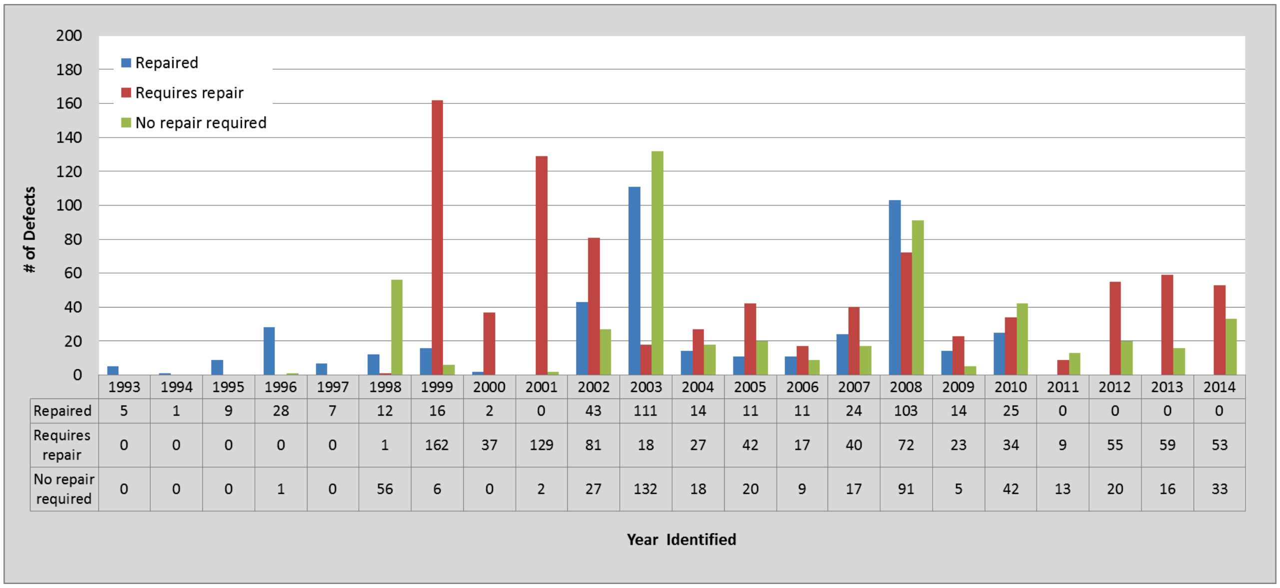


	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	0	0	3	6	2	3	61	16	50	44	158	24	32	12	34	131	23	65	15	60	64	62
Fabrication	0	0	0	0	0	0	5	1	0	1	5	1	2	0	2	0	0	0	0	0	1	0
Paint_Preservation	0	0	3	10	2	54	92	13	58	83	91	23	28	13	27	75	11	20	2	7	5	9
Deformation	2	0	1	1	0	3	0	1	0	2	5	0	0	2	0	2	0	0	0	2	0	1
Cracking	2	1	1	5	1	2	1	0	4	1	3	0	6	4	7	8	0	2	0	1	0	3
Corrosion	1	0	1	7	2	7	25	8	19	22	30	11	5	6	11	51	8	14	5	5	5	11

Year Identified

Figure 2-8: Damages According to Year Identified (HMCS Halifax)

The repair history from vessel commissioning in 1993 to 2014 is also presented graphically in Figure 2-9. The figure demonstrates the intended repair regime, in that any damages found were repaired or tagged for the repairs. However, it was not possible to determine from the data reviewed if the policy was followed in all cases. For instance, it can be seen that in the year 1996, approximately 30 defects were found (see Figure 2-8) and most of these (28) were repaired. However, in 1999, approximately 184 defects were found, but only 16 were repaired, and the majority (162) were tagged for repairs and it is not clear if they were repaired at any point in time. Similar trends were also noticed for several other years after 1999. It is possible that a number of these defects are those under the categories of "Other" or "Paint Preservation" and were deliberately left un-repaired. Clarification of this will be required in order to properly determine the benefits of the RIIMM approach verses current practices. This clarification will be sought in the next phase of the project when the project team will have face-to-face meetings with various stake holders.



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	5	1	9	28	7	12	16	2	0	43	111	14	11	11	24	103	14	25	0	0	0	0
Requires repair	0	0	0	0	0	1	162	37	129	81	18	27	42	17	40	72	23	34	9	55	59	53
No repair required	0	0	0	1	0	56	6	0	2	27	132	18	20	9	17	91	5	42	13	20	16	33

Figure 2-9: Damages According to Repair Status for HMCS Halifax

2.3.2.2 HMCS Vancouver (West Coast)

The results for HMCS Vancouver are shown in this section. Figure 2-10 shows the number of defects by type.

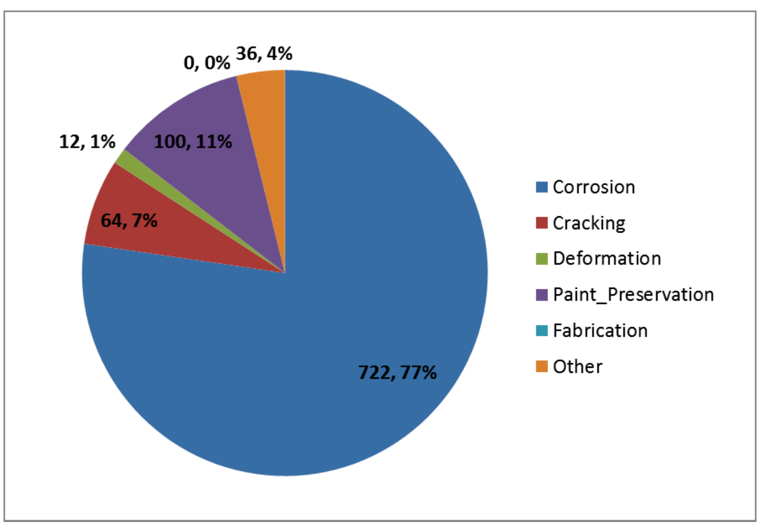
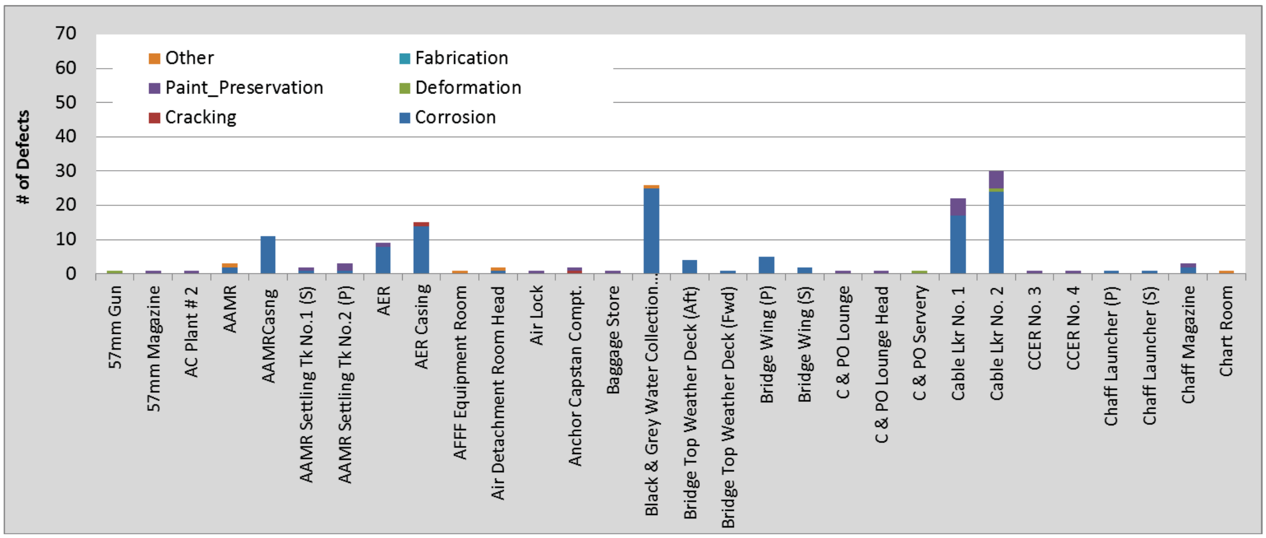
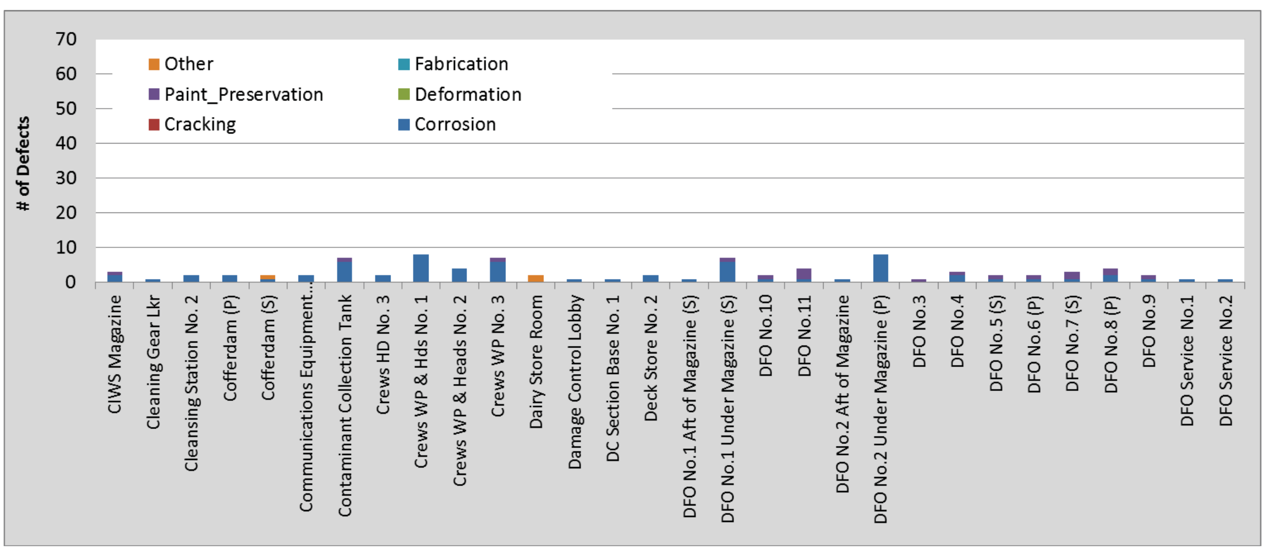


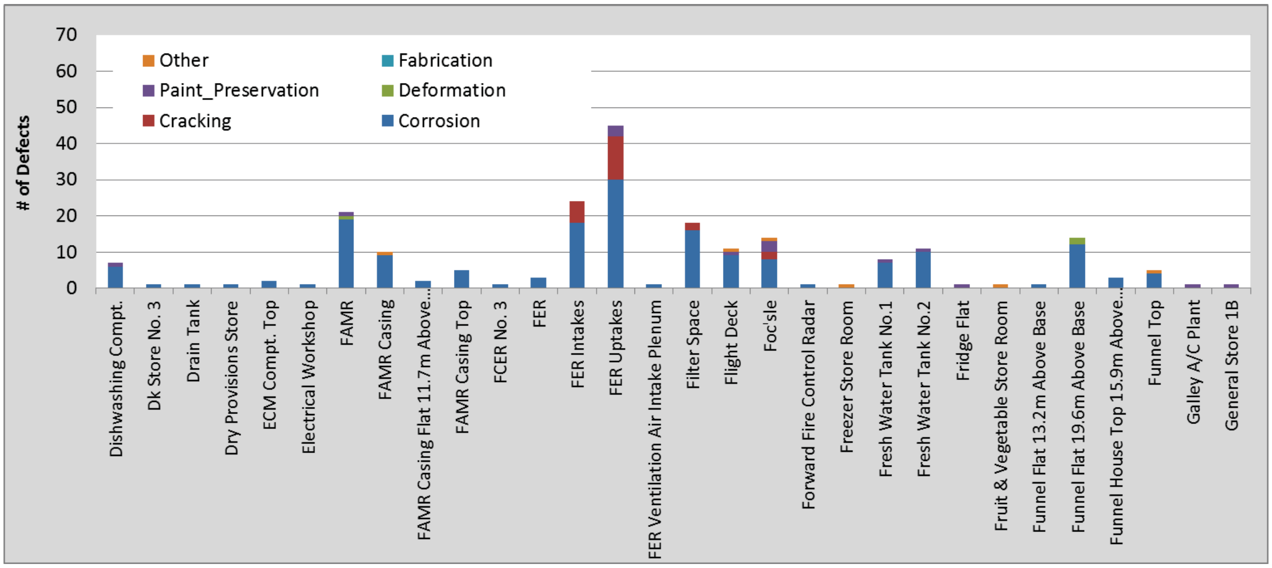
Figure 2-10: Total Number of Defects by Type for HMCS Vancouver

Considering the damage modes that affect structural integrity, it is seen that corrosion is the most dominant defect type followed by cracking and deformation. There are much fewer defects of the "Paint Preservation" and "Other" categories than observed in HMCS Halifax.

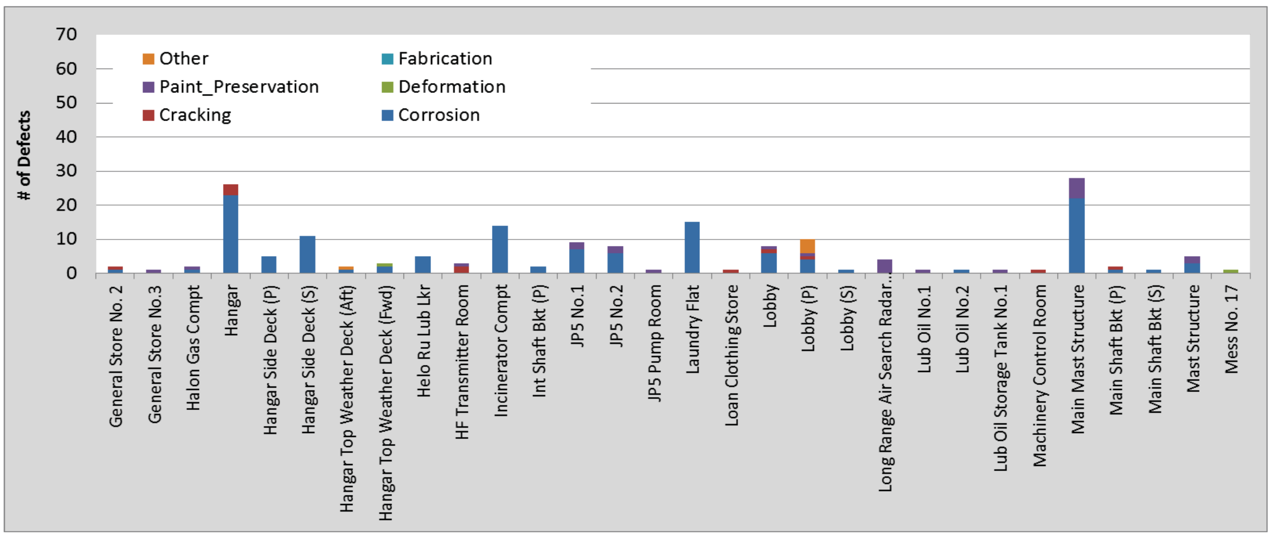
Figure 2-11 shows the distribution of damage by compartments, for those compartments with at least one damage incident observed in the database. The compartments are listed in alphabetical order. It is seen that damage incidents have been reported for 186 of 440 compartments of the ship.



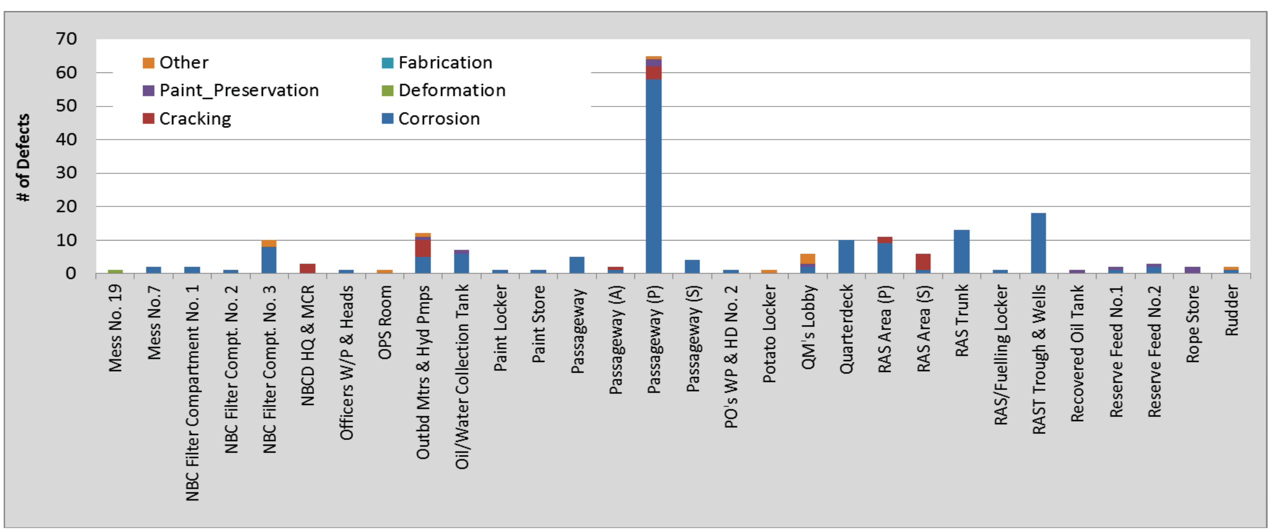




# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
Dishwashing Compt.
Dk Store No. 3
Drain Tank
Dry Provisions Store
ECM Compt. Top
Electrical Workshop
FAMR
FAMR Casing
FAMR Casing Flat 11.7m Above...
FAMR Casing Top
FCER No. 3
FER
FER Intakes
FER Uptakes
FER Ventilation Air Intake Plenum
Filter Space
Flight Deck
Foc'sle
Forward Fire Control Radar
Freezer Store Room
Fresh Water Tank No.1
Fresh Water Tank No.2
Fridge Flat
Fruit & Vegetable Store Room
Funnel Flat 13.2m Above Base
Funnel Flat 19.6m Above Base
Funnel House Top 15.9m Above...
Funnel Top
Galley A/C Plant
General Store 1B



# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
General Store No. 2
General Store No.3
Halon Gas Compt
Hangar
Hangar Side Deck (P)
Hangar Side Deck (S)
Hangar Top Weather Deck (Aft)
Hangar Top Weather Deck (Fwd)
Helo Ru Lub Lkr
HF Transmitter Room
Incinerator Compt
Int Shaft Bkt (P)
JP5 No.1
JP5 No.2
JP5 Pump Room
Laundry Flat
Loan Clothing Store
Lobby
Lobby (P)
Lobby (S)
Long Range Air Search Radar...
Lub Oil No.1
Lub Oil No.2
Lub Oil Storage Tank No.1
Machinery Control Room
Main Mast Structure
Main Shaft Bkt (P)
Main Shaft Bkt (S)
Mast Structure
Mess No. 17



# of Defects
Other
Fabrication
Paint_Preservation
Deformation
Cracking
Corrosion
Mess No. 19
Mess No.7
NBC Filter Compartment No. 1
NBC Filter Compt. No. 2
NBC Filter Compt. No. 3
NBCD HQ & MCR
Officers W/P & Heads
OPS Room
Outbd Mtrs & Hyd Pmps
Oil/Water Collection Tank
Paint Locker
Paint Store
Passageway
Passageway (A)
Passageway (P)
Passageway (S)
PO's WP & HD No. 2
Potato Locker
QM's Lobby
Quarterdeck
RAS Area (P)
RAS Area (S)
RAS Trunk
RAS/Fuelling Locker
RAST Trough & Wells
Recovered Oil Tank
Reserve Feed No.1
Reserve Feed No.2
Rope Store
Rudder

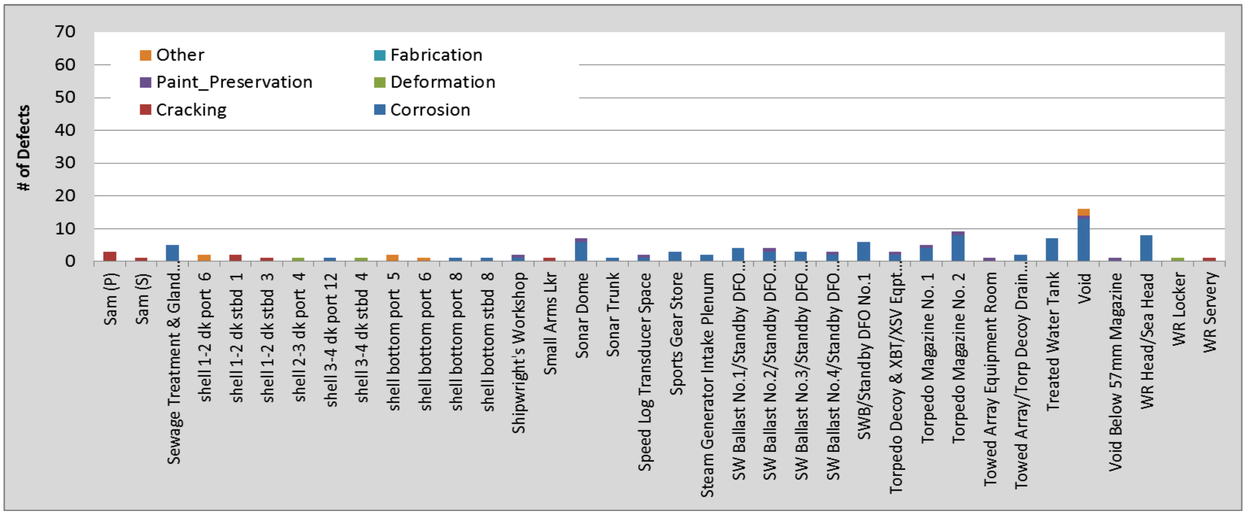


Figure 2-11: Defects Summary by Compartments for HMCS Vancouver

For the compartments not listed, it is again not clear if they have not experienced any damage during the reporting period (1993 – 2014) or if these compartments have not been inspected over this period. The list of compartments with no record of defects is provided in Table 2-5. It is also observed that there are inconsistencies in the compartment names in the database compared to list in the guidance documents. These clarifications will be sought during the development stage of the RIIMM process.

Table 2-5: Compartments of HMCS Vancouver not Seen in Incident Database of HMCS Vancouver

Compartment Name (As listed at Guidance Document [3] to [7])			
AAMR Air Lock	Double Cabin No. 1	Radar Room No. 1	Shell 3 - 4 dk port 9
Access between RAS areas Fr. 36-37.5	Double Cabin No. 3	Radar Room No. 2	Shell 3 - 4 dk port 10
A/C Plant No. 1	Double Cabin No. 4	RAST Equipment Room	Shell 3 - 4 dk port 11
Admin Office	Double Cabin No. 5	Rope Store (Fr 58-60.5)	Shell 3 - 4 dk stbd 1
AER Air Lock	Double Cabin No. 6	Rope Store (Fr 60.5-6.26)	Shell 3 - 4 dk stbd 2
Aft Fire Control Radar	Double Cabin No. 7	Satcom Antenna (P)	Shell 3 - 4 dk stbd 3
Aft Fire Pump Room	Double Cabin No. 8	Satcom Antenna (S)	Shell 3 - 4 dk stbd 5
Aft Sonar Instrument Space (No. 1)	Double Cabin No. 9	Sea Head	Shell 3 - 4 dk stbd 6
Air Detachment Room	Dry Garbage Store	SHINCOM Equipment Room	Shell 3 - 4 dk stbd 7
Air Lock (Fr 8)	EBR	Shell 1 - 2 dk port 1	Shell 3 - 4 dk stbd 8
Air Lock (Fr 34)	Electronic Warfare Equipment Room	Shell 1 - 2 dk port 2	Shell 3 - 4 dk stbd 9
Air Lock (Fr 54)	EMR	Shell 1 - 2 dk port 3	Shell 3 - 4 dk stbd 10
Air Lock (Fr 57)	Emergency Radio Room	Shell 1 - 2 dk port 4	Shell 3 - 4 dk stbd 11
Air Maintenance Control Office	Engris Store	Shell 1 - 2 dk port 5	Shell 3 - 4 dk stbd 12
Air Mech. and Air Armament Workshop	FAMR Air Lock	Shell 1 - 2 dk port 7	Shell bottom port 2

Compartment Name (As listed at Guidance Document [3] to [7])			
Aviation Store	FCER No. 1	Shell 1 - 2 dk port 8	Shell bottom port 3
Avionics Workshop	FDCR and DC Section Base No. 3	Shell 1 - 2 dk port 9	Shell bottom port 4
Beer/Soft Drink Store	FER Air Lock	Shell 1 - 2 dk port 10	Shell bottom port 7
Bilge Keel (P)	FER Uptake Fan Plenum	Shell 1 - 2 dk port 11	Shell bottom port 9
Bilge Keel (S)	Fire Control Equipment Room No. 2	Shell 1 - 2 dk port 12	Shell bottom port 10
Bosuns Workshop	Fire Fighting Equipment Store	Shell 1 - 2 dk stbd 2	Shell bottom port 11
Bridge	Flour Store	Shell 1 - 2 dk stbd 4	Shell bottom port 12
Canteen	Fwd Sonar Instrument Space (No. 2)	Shell 1 - 2 dk stbd 5	Shell bottom stbd 2
Canteen Store	Galley	Shell 1 - 2 dk stbd 6	Shell bottom stbd 3
CB Office	General Store 1C	Shell 1 - 2 dk stbd 7	Shell bottom stbd 4
CBRN Filter Compartment No. 1	General Store No. 1	Shell 1 - 2 dk stbd 8	Shell bottom stbd 5
CBRN Filter Compt. No. 2	General Store No. 1A	Shell 1 - 2 dk stbd 9	Shell bottom stbd 6
CBRN Filter Compt. No. 3	Gunners Store	Shell 1 - 2 dk stbd 10	Shell bottom stbd 7
CBRN Filter Compt. No. 4	Gyro Room No. 1	Shell 1 - 2 dk stbd 11	Shell bottom stbd 9
CBRN Store	Gyro Room No. 2	Shell 1 - 2 dk stbd 12	Shell bottom stbd 10
CBRND HQ and MCR	Helo Power Compt.	Shell 2 - 3 dk port 1	Shell bottom stbd 11
CCER No. 1	Helo Fuel/Defuel Compt.	Shell 2 - 3 dk port 2	Shell bottom stbd 12
CCER No. 2	Int Shaft Bkt (S)	Shell 2 - 3 dk port 3	Sickbay Complex
CIWS	Laundry	Shell 2 - 3 dk port 5	Small Arms Mag
Cleaning Gear Store No. 1	LSO Compt.	Shell 2 - 3 dk port 6	SMI - E
Cleaning Gear Store No. 2	Lub Oil Storage Tank No. 2	Shell 2 - 3 dk port 7	SO's Cabin
Cleansing Station No. 1	Maint. Co-ord/Mar. System Eng. Off.	Shell 2 - 3 dk port 8	Sonobuoy Store No. 1
CO's Cabin	MEO Cabin No. 10	Shell 2 - 3 dk port 9	Sonobuoy's Store No. 2
CO's/SO's Day Room/Dining Room	Mechanical Workshop	Shell 2 - 3 dk port 10	Spirit and Tobacco Store
CO's/SO's Servery	Medical Store	Shell 2 - 3 dk port 11	SPS 49 Cooling Equipment Room
Combat Officer Cabin No. 12	Mess No. 1	Shell 2 - 3 dk port 12	Steering Gear Compt.
Combat System Engineers Office	Mess No. 2	Shell 2 - 3 dk stbd 1	Stores Office
Comm Lkr	Mess No. 3	Shell 2 - 3 dk stbd 2	Supply Officers Cabin No. 14
Communications Control Room	Mess No. 4	Shell 2 - 3 dk stbd 3	Switchboard Room No. 1
Control System Workshop	Mess No. 5	Shell 2 - 3 dk stbd 4	Switchboard Room No. 2
Cook's Office	Mess No. 6	Shell 2 - 3 dk stbd 6	TAU Compt.
Coxn' Office	Mess No. 8	Shell 2 - 3 dk stbd 7	Tool Crib
Coxwain Single Cabin	Mess No. 9	Shell 2 - 3 dk stbd 8	Transom 1 dk port
C and PO Dining Room	Mess No. 10	Shell 2 - 3 dk stbd 9	Transom 1 dk stbd
CPO's & P1's WP & Hds	Mess No. 11	Shell 2 - 3 dk stbd 10	Transom 2 dk port
Crews Cafeteria	Mess No. 12	Shell 2 - 3 dk stbd 11	Transom 2 dk stbd
Crews Lounge	Mess No. 14	Shell 2 - 3 dk stbd 12	Transom 3 dk port

Compartment Name (As listed at Guidance Document [3] to [7])			
Crews Lounge Head	Mess No. 15	Shell 3 - 4 dk port 1	Transom 3 dk stbd
Crews Laundromat	Mess No. 16	Shell 3 - 4 dk port 2	UHF Antenna
CSE/Air Officers Cabin No. 11	Mess No. 18	Shell 3 - 4 dk port 3	Void (Aft)
Damage Control Store	Ops Room A/C Plant	Shell 3 - 4 dk port 4	Void (Forepeak)
D/C Section Base No. 2	Ops Room Admin	Shell 3 - 4 dk port 5	Wardroom/Anteroom
Deck Store No. 1	Pay Office	Shell 3 - 4 dk port 6	Weapons Workshop
Degaussing Equipment Room	Plenum (S)	Shell 3 - 4 dk port 7	XBT/XSV Store
Diving Gear Store	Plenum (P)	Shell 3 - 4 dk port 8	XO Cabin No. 2

The 25 most damage prone compartments of HMCS Vancouver are shown in Figure 2-12. This represents the compartments most likely to experience various damage modes based on historical evidence. As mentioned in section 2.3.2.1, this likelihood of damage occurrence should be combined with the severity of the consequences of the damage in risk-based inspection and maintenance regimes.

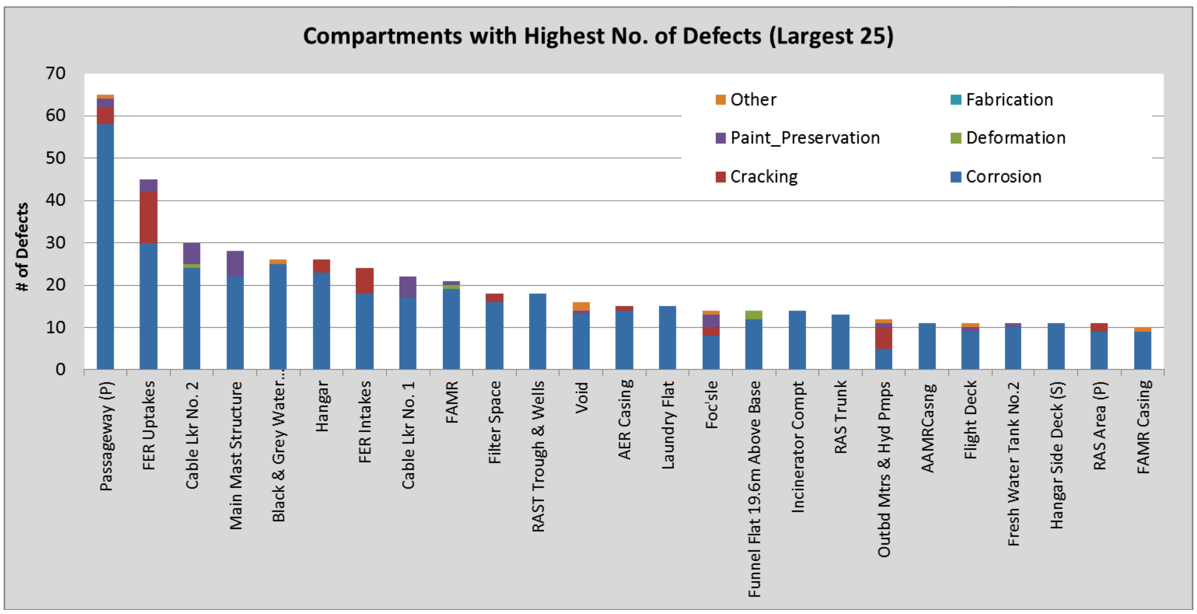
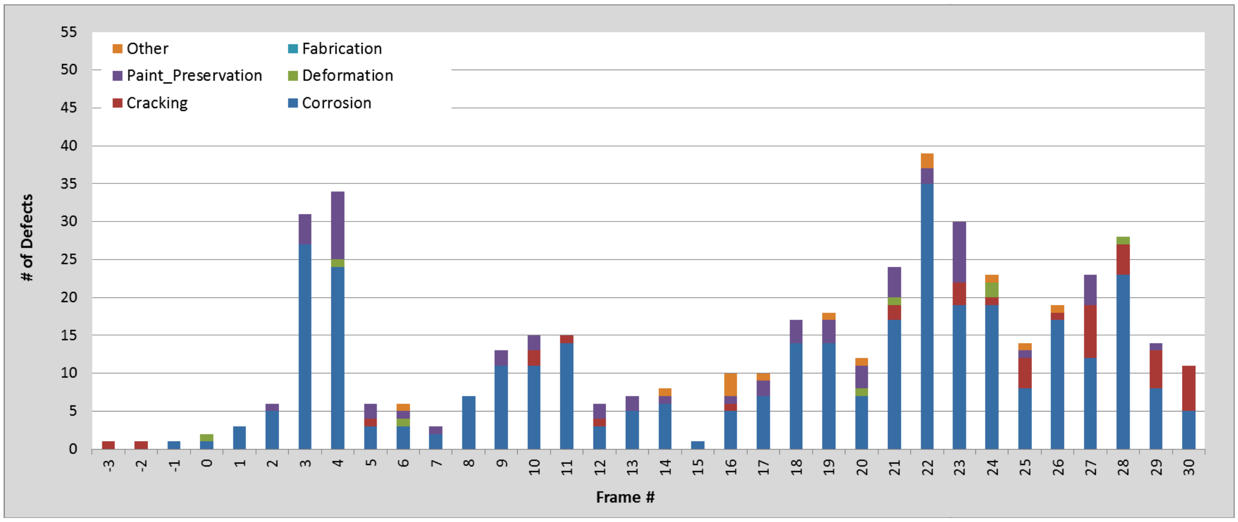
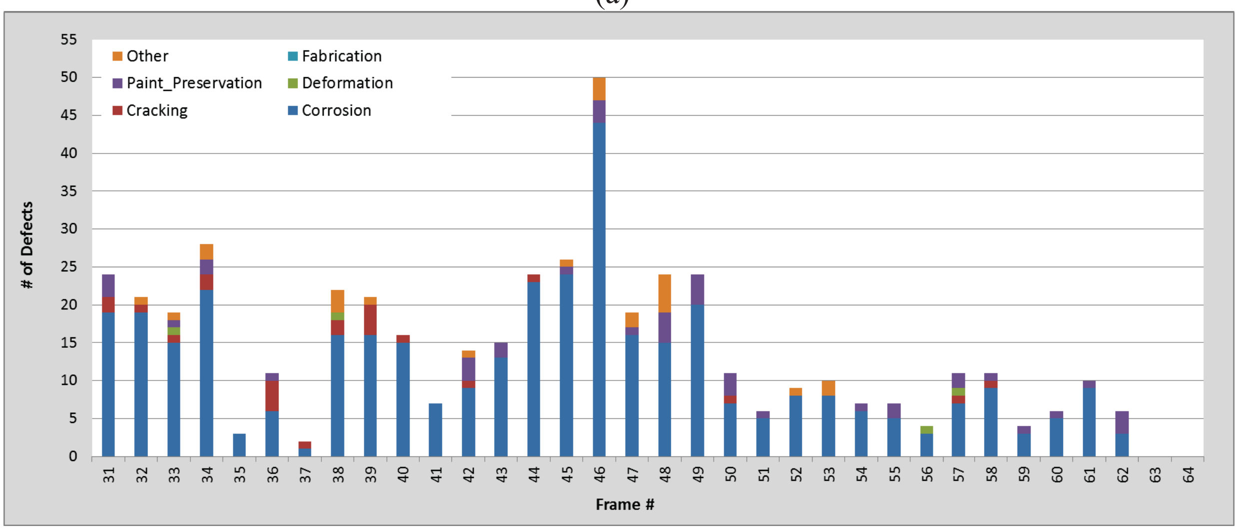


Figure 2-12: Most Damage Prone Compartments for HMCS Vancouver

Figure 2-13 and Figure 2-14 show the distribution of damage on HMCS Vancouver by frame number and deck, respectively. The larger number of damage incidents have been found around the frame numbers 3,4,22,23,26,31,34,45,46,48,49; and on decks 1 and 5.



(a)



(b)

Figure 2-13: Damage by Frame for HMCS Vancouver: (a) Frame # -3 to 30 and (b) Frame # 31-64

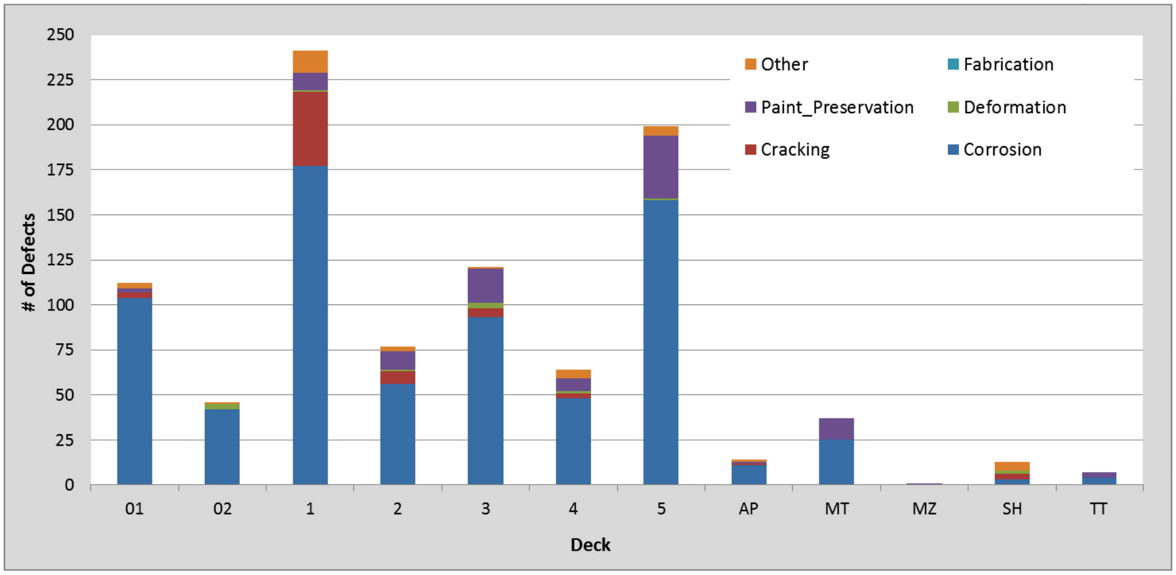
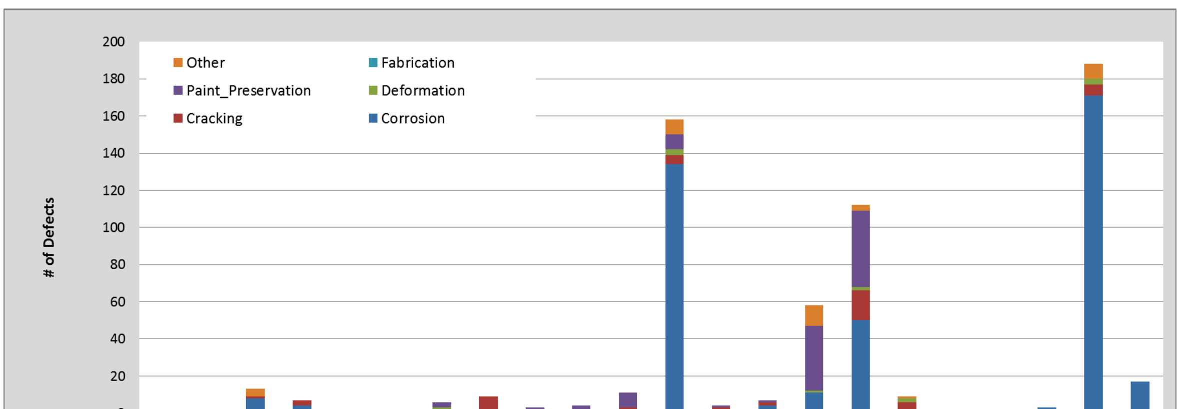


Figure 2-14: Damage by Deck for HMCS Vancouver

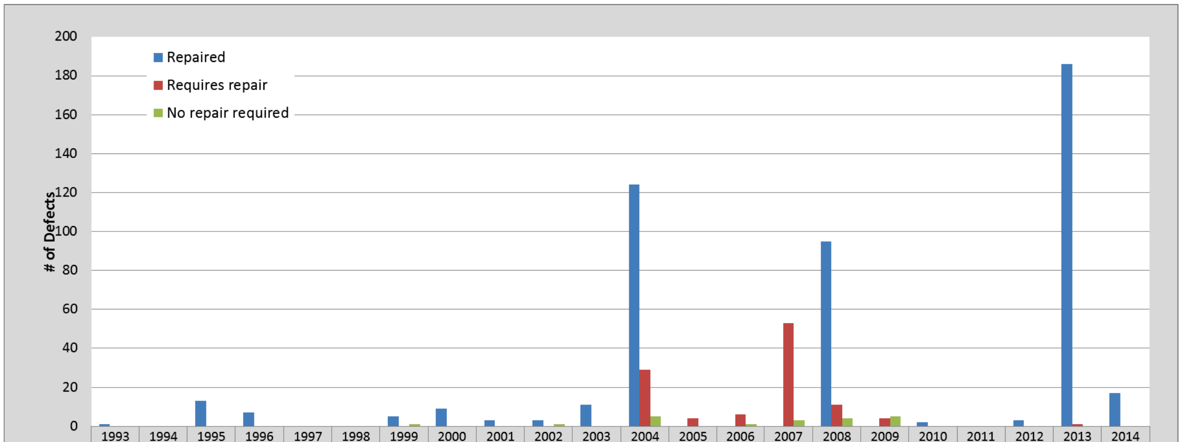
The damage and repair histories from vessel commissioning in 1993 to 2014 are also presented graphically in Figure 2-15 and Figure 2-16, respectively. Figure 2-15 illustrates the progressive inspection regime, although it appears that most of the inspections were carried out in the final years of the inspection cycles 2004, 2008 and 2013. The inspection cycle appears to be four or five years, assuming first cycle was completed in 1999. Figure 2-16 demonstrates the actual repair regime is largely in line with the fleet repair policy, in that most of the defects found were repaired or tagged for repairs during the four or five year cycle. This wasn't very clear for the HMCS Halifax data as discussed above (Section 2.3.2.1).



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	1	0	4	0	0	0	0	0	0	0	0	8	0	0	11	3	1	0	0	0	8	0
Fabrication	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paint_Preservation	0	0	0	0	0	0	3	0	1	2	8	8	1	1	35	41	0	0	0	0	0	0
Deformation	0	0	0	0	0	0	1	0	0	0	0	3	0	0	1	2	2	0	0	0	3	0
Cracking	0	0	1	3	0	0	1	7	2	1	3	5	3	2	0	16	5	0	0	0	6	0
Corrosion	0	0	8	4	0	0	1	2	0	1	0	134	0	4	11	50	1	2	0	3	171	17

Year of Identified

Figure 2-15: Damages According to Year Identified for HMCS Vancouver



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	1	0	13	7	0	0	5	9	3	3	11	124	0	0	0	95	0	2	0	3	186	17
Requires repair	0	0	0	0	0	0	0	0	0	0	0	29	4	6	53	11	4	0	0	0	1	0
No repair required	0	0	0	0	0	0	1	0	0	1	0	5	0	1	3	4	5	0	0	0	0	0

Figure 2-16: Damages According to Repair Status for HMCS Vancouver

2.4 Suitability of Inspection Database for use in RIIMM

The review of the RCN fleet inspection database and analysis of the data provided a good insight into the nature of data collected and how the data could be applied in a risk-based framework. The features of the database that make it suitable for use in a risk-based framework include the following:

- The database provides a clear indication of the system breakdown, highlighting the components that are inspected and repaired.
- It specifies the damage modes that are inspected and how the damages were assessed
- The database provides understanding of the inspection frequency and how inspection are carried out
- It provides understanding of the repair frequency and how repairs are carried out

In spite of the above desirable features of the database, there are some limitations/gaps that need to be addressed to enhance its use in the RIIMM framework. There are summarized below:

- There are some inconsistencies in the reporting of inspection data. For instance, as discussed earlier the East Coast database (and to some extent the West Coast database) contains several entries of “Other” failure mode. Clarification of these entries would be required to ensure the data used in RIIMM is of good quality. There is also inconsistency in the reporting of damage sizes (e.g. corrosion depth and crack length), with some of the entries not recording the sizes. Again, clarification of the recordings of these would be required in the RIIMM process.

- Clarification of repair process will be required to help determine damage growth rates, if possible, and to establish maintenance costs of the current practice.
- Clarification is also needed on the scope of inspections during any given inspection period within the 5 year inspection cycle. This would be helpful in establishing damage progression rates and maintenance costs.
- Clarification is required on the inspection and maintenance requirement for difficult to inspect areas or areas not listed in the database.
- Clarification is required on the current repair practice and recording.
- Clarification is required on how to handle the "Other", as well as the "Paint Preservation" damage modes.

3.0 METHODOLOGY FOR RISK-INFORMED INSPECTION AND MAINTENANCE MANAGEMENT (RIIMM)

3.1 INTRODUCTION

As stated in Chapter 1, a requirement of this project includes the formulation of a research plan for applying a RIIMM approach to the HALIFAX class inspection and maintenance management process. The research plan shall include the following elements.

a) Identification of the most suitable risk assessment technique for each degradation mode captured in the HALIFAX class database, including at a minimum, coating breakdown, corrosion, and cracking. Consideration shall be given to structural reliability and other probabilistic methods. The suitability of the HALIFAX class defect database shall also be considered, including how the availability of data for each degradation mode limits the analysis and how the data could be augmented with additional or assumed data, if necessary.

b) Identification of analytical methods to build upon the risk assessment in order to mitigate the impact of defects on the HALIFAX class while having a minimum impact on maintenance costs and timelines. Existing HALIFAX class maintenance and inspection standards and practices shall be used as the baseline. Consideration shall be given to optimization algorithms for the frequency and area of inspections and repair; comparative risk, maintenance cost and decision models; and corrective and preventative maintenance strategies.

With the above requirements in mind, a preliminary RIIMM framework has been formulated in the current task to demonstrate the feasibility of the RIIMM approach for the RCN fleet inspection and maintenance management. The methodology is developed with the following goals in mind:

- The methodology shall be acceptable to RCN fleet inspection and maintenance management and other stakeholders. To achieve this goal, the methodology seeks to obtain input from various stakeholders throughout the development process. Furthermore, the methodology does not deviate much from current practice; makes use of available data as much as possible; does not have significant data collection requirements beyond current practice; and is easy to use and comprehend;
- It is well structured, rigourous and repeatable;
- It enhances safety and mission readiness; and
- It is cost effective compared to current practice.

3.2 OVERALL APPROACH

Figure 3-1 illustrates the basic elements of the RIIMM method. The methodology consists of six main steps and subsequent sub-sections are structured to describe these steps in detail.

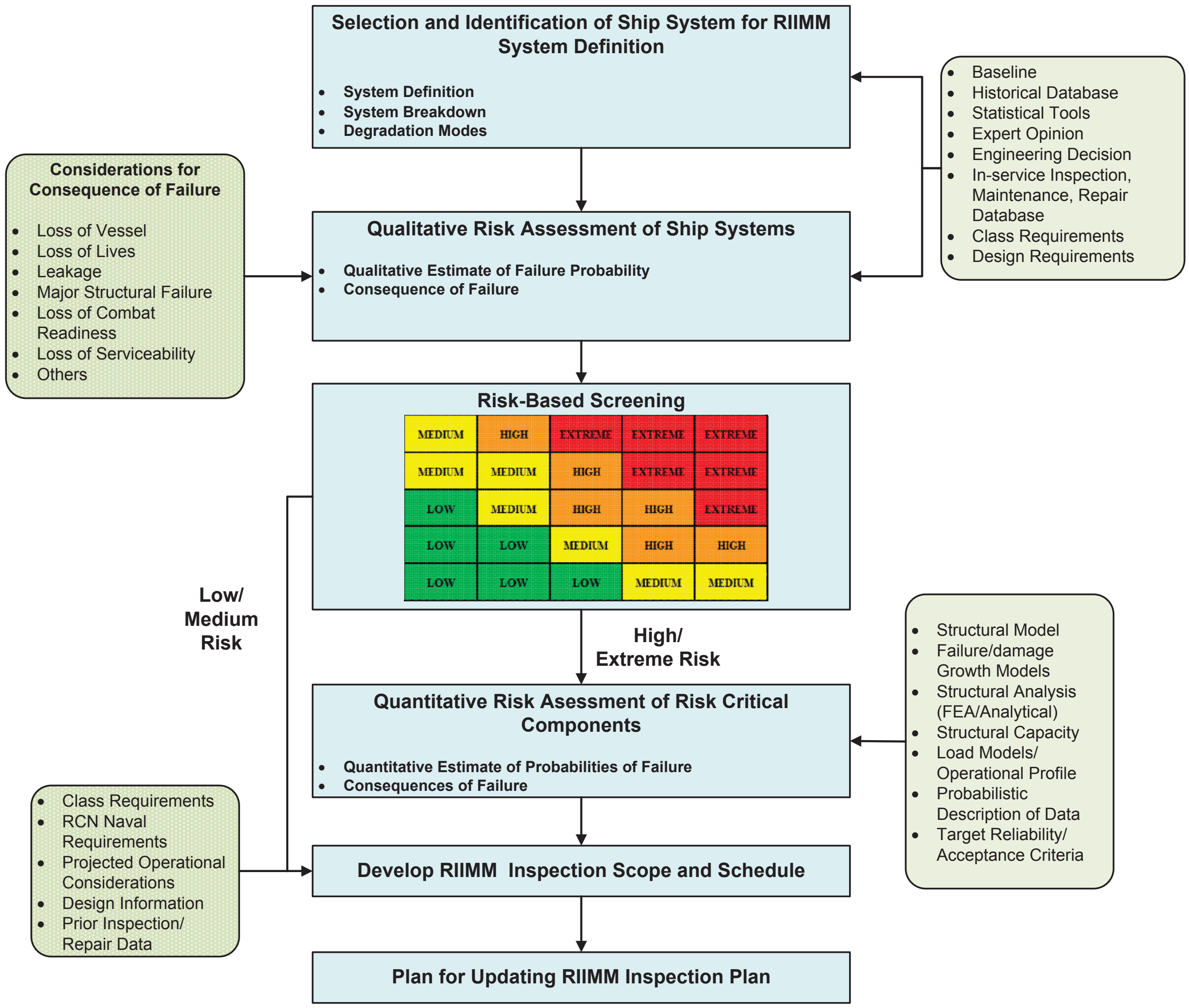


Figure 3-1: Proposed RIIMM Framework

3.3 SYSTEM DEFINITION

The first step of the RIIMM methodology is to define the objectives and systems or components of interest. For the RCN fleet, the system comprises the vessels in the East and West Coast fleets. As discussed in Chapter 2, for the hull structural integrity management process, the HALIFAX class ships are sub-divided into approximately 440 compartments, which are identified by unique names and location (using frame and deck numbers). The goal/ scope of the RIIMM exercise has to be first established. This could be for:

- The whole fleet
- Selected ship (s) of the fleet
- Selected compartments of selected ship (s)

Once the ships and compartments are identified, the scope of the RIIMM study is established. The damage modes to be considered have to be established. For the RCN fleet, the following are the possible damage modes of interest:

- Corrosion
- Cracking
- Deformation
- Paint preservation
- Fabrication

Input data collection will be performed during this stage. Appropriate and sufficient information (input data) is required for carrying out an effective RIIMM program. The types of data to be collected and reviewed for the components within the scope of the RIIMM program for HALIFAX class ships in operation include design analysis, operation history analysis, and inspection and repair data analysis. For new build ships, operation history and inspection data will not be readily available. In such cases, the historical data from similar ships will be utilized. In the case of scarce or incomplete data or for newly built ships, opinion from subject matter experts (SME) would be considered as potential input data.

The data quality or uncertainty associated with data has a direct relation to the relative accuracy or usefulness of the RIIMM analysis. It is important to assure that the data are up to date and validated by subject matter experts or any other validation method to enhance the integrity of RIIMM analysis.

3.4 QUALITATIVE RISK ASSESSMENT

The next step of the RIIMM process is to undertake a qualitative risk assessment. The objective of qualitative risk assessment is to provide an idea about the risks associated with components/compartments to be inspected, should they be affected by the various damage modes. The risk information will be later utilized for the purpose of screening components based on the criticality to develop the inspection plan. Components or systems prone to the various damage modes are identified during the system definition phase.

Qualitative risk assessment requires estimates of the failure likelihood (or damage probability) and severity of consequences of a damage scenario that can be identified through inspection. These are described in the following sub-sections.

3.4.1 Likelihood Definitions

Table 3-1 shows typical likelihood definitions for use in risk assessment adopted from DND In-Service Naval Materiel Risk Management Process (NAVORD 3001-1) [10].

Table 3-1: Likelihood (Probability of Failure) Definitions

Likelihood	Description	Probability of Failure	
		Frequency (/year)	Indicative Scale
Improbable	Not expected to occur, but may occur in rare or exceptional circumstances	$<10^{-4}$	1
Remote	Unlikely but could possibly occur during the life of the asset	10^{-4} - 10^{-3}	2
Occasional	Unlikely, but can be reasonably expected to occur during the life of the asset	10^{-3} - 10^{-2}	3

Likelihood	Description	Probability of Failure	
		Frequency (/year)	Indicative Scale
Probable	Will occur several times during the life of the asset	10^{-2} - 10^{-1}	4
Frequent	Likely to occur regularly	>10^{-1}	5

In this study, the damage incidents observed in the inspection database are used to determine the probability of failure for each damage modes. The method for corrosion and cracking damage modes are presented below. Methodology for other damage, such as Paint Preservation, Deformation and Fabrication errors will be developed in future phases of the work.

3.4.2 Qualitative Assessment of Probability of Failure Due to Corrosion Damage

The probability of failure due to corrosion damage is computed using the historical corrosion incident data in conjunction with engineering judgement. The average annual corrosion incident rate as observed from the inspection database is first determined and categorised as shown in Table 3-2.

Table 3-2: Categorization of Corrosion Incident Rates

Incident Rate (IR1) (Incidents/year)	Indicative Scale
<0.25	1
0.25-0.50	2
0.50-0.75	3
0.75-1.00	4
>1.00	5

These values alone provide an indication of likelihood of corrosion occurrence in a given compartment per year. As an example, a compartment in a more corrosive environment, such as black water tank, may be more likely to experience corrosion defects than another compartment in a less corrosive environment, such as portable water tank or void.

In order to determine the probability of failure due to corrosion, the corrosion extent and corrosion depth, which are recorded in the inspection database are used as weighting factors to the corrosion incident rate (IR1). The corrosion weighting matrix shown in Table 3-3 is used to obtain the weighting factors (DE) for each depth and extent combination. For instance, a corrosion incident that is recorded as having a depth of $<$ 50% (metal thickness) and extensive in size ($>$ 25%) will be given a weighting factor of 9, and so on.

Table 3-3: General/Pitting Corrosion Weighting Matrix (DE)

Extent	Depth				
	Surface (<10%)	Moderate (<25%)	Deep (<50%)	Excessive (>50%)	Unspecified/ Unknown
Localized (<5%)	1	2	3	4	5
Scattered (<25%)	2	4	6	8	10
Extensive (>25%)	3	6	9	12	15
Unspecified/ Unknown	4	8	12	14	20

The weighting factors (DE) are multiplied with the corrosion incident rates (IR1) to obtain the probability of failure index and corresponding indicative scale as shown in Table 3-4.

Table 3-4: Probability of Failure Due to Corrosion Damage and Indicative Scale

Probability of Failure Index (IR1 x DE)	Indicative Scale
0-5	1
6-10	2
11-20	3
21-50	4
51-100	5

3.4.3 Qualitative Assessment of Probability of Failure Due to Cracking Damage

The probability of failure due to cracking damage is also computed using the historical cracking incident data in conjunction with engineering judgement. The average annual cracking incidents rates (IR2) as observed from the inspection database are first determined and categorized as shown in Table 3-5.

Table 3-5: Categorization of Cracking Incident Rates (IR2)

Incident Rate (IR2) (Incidents/year)	Indicative Scale
<0.25	1
0.25-0.50	2
0.50-0.75	3
0.75-1.00	4
>1.00	5

These values provide an indication of areas that are prone to cracking. In order to determine the probability of failure due to cracking, the crack length and crack depth are used as weighting factors to the cracking incident rate (IR2). The cracking damage weighting matrix shown in Table 3-6 is used to obtain the weighting factors (DL) for each depth and length combination.

Table 3-6: Cracking Damage Weighting Matrix (DL)

Depth	Crack Length (cm)				
	0 – 5	5 – 10	10 – 25	25 – 50	>50 or Unspecified
Surface	1	2	3	4	5
Moderate	2	4	6	8	10
Deep	3	6	9	12	15
Through Crack	4	8	12	14	20

The weighting factors (DL) are used to multiply the cracking incident rates (IR2) to obtain the probability of failure index and corresponding indicative scale as shown in Table 3-7.

Table 3-7: Probability of Failure Due to Cracking Damage and Indicative Scale

Probability of Failure Index (IR2 x DL)	Indicative Scale
0-5	1
6-10	2
11-20	3
21-50	4
51-100	5

It should be noted that in the database, cracking defects are indicated by their length, but crack depths are generally not recorded. In this study, when the crack depth is not provided, it will be assumed to be a through-crack.

3.4.4 Consequence Definitions

Table 3-8 shows typical consequence definitions for use in the risk assessment, adopted from the DND In-Service Naval Materiel Risk Management Process (NAVORD 3001-1) [10]. Four categories of consequences, namely People, Environmental, Asset and Mission are considered.

Table 3-8: Consequence Definitions

Consequence Definitions				
Level	**People**	**Environmental**	**Asset**	**Mission**
Negligible (1)	Minor injury treatable by First Aid	Localised, transient, ecological disruption; no regulatory violation; spill < 1 m^3; environmental and clean-up costs on the order of $3,000	Minimal effect ; no immediate repair required; safety & integrity (S&I) remains intact; loss between $2K to $10K	No impact on operations; mission continues minor capability degradation
Marginal (2)	Single minor injury or temporary disability, Injury requiring emergency medical treatment, or injury eligible for compensation.	Mostly localized and damage ecological system; no regulatory violation; spill 1 to 10 m^3; environmental and clean-up costs on the order of $30,000	Minor damage; some at sea repair required; S&I compromised temporally but be easily controlled and restored loss between $10K to $100K	Temporary loss of service/equipment; mission element failure(s); mission continues with minor degradation.
Significant (3)	Single severe injury, multiple minor injuries, single permanent disability, or multiple temporary disabilities	Impact may be extensive or localized and damage ecological system; no regulatory violation; spill 10 to 100 m^3; environmental and clean-up costs on the order of $300,000	Major damage; at sea or local base repairs; S&I compromised but controlled and restored in few weeks or less; withdraw from operation; loss between $100K to $500K	Temporary loss of service/equipment; Single significant mission element failure; May be unsuitable to continue.
Critical (4)	Single death, multiple severe injuries, or multiple permanent disabilities.	Impact extensive or nationally significant degradation and damage ecological system; regulatory violation; spill 100 to 1000m^3; environmental and clean-up costs on the order of $3M	Severe damage; repairs in dockyard or naval base; S&I compromised and difficult to control and can be restored in a few months; loss between $500K to $1M	Equipment lost for extended period of time; multiple significant mission element failures; unsuitable to continue of operation
Catastrophic (5)	Multiple deaths	Impact extensive or internationally significant degradation and damage ecological system; regulatory violation; spill > 1000m^3; environmental and clean-up costs on the order of $30M	Massive loss which may lead to sink or loss of platform; repairs may be significant and may not be worthwhile; S&I compromised and uncontrollable and restoration could take more than 6 months or early decommissioning loss > $1M.	Damage beyond repair within mission timeline; total mission failure inability to continue.

3.4.5 Risk Matrix

Risk is presented in terms of risk matrix by combining the probability/likelihood of failure and the consequences as shown in Figure 3-2. The risk matrix used here is similar to that in NAVORD 3001-1 except for the color scheme, which is considered to be more intuitive than that in in NAVORD 3001-1 [9].

Probability/Likelihood of failure						
	5. Frequent	MEDIUM	HIGH	EXTREME	EXTREME	EXTREME
	4. Probable	MEDIUM	MEDIUM	HIGH	EXTREME	EXTREME
	3. Occasional	LOW	MEDIUM	HIGH	HIGH	EXTREME
	2. Remote	LOW	LOW	MEDIUM	HIGH	HIGH
	1. Improbable	LOW	LOW	LOW	MEDIUM	MEDIUM
		1. Negligible	2. Marginal	3. Significant	4.Critical	5. Catastrophic
		Consequences				

Figure 3-2: Risk Matrix Adopted from NAVORD [9]

3.5 RISK-BASED SCREENING

In this step the risk ranking (or criticality) of compartments is used to determine if detailed quantitative risk assessment is required to refine the probability of failure and/or consequences of damage. The proposed approach is as follows:

- Compartments ranked as "Low" or "Medium" risks do not require quantitative risk assessment. It is assumed that the qualitative risk assessment is adequate for these compartments.
- Compartments ranked as "High" or "Extreme" risks may require quantitative risk assessment (QRA) if there is reasonable doubt about the probability of failure and consequences assessed in the qualitative assessments.

3.6 QUANTITATIVE RISK ASSESSMENT (QRA)

In order to gain a better picture of risks associated with "High" and "Extreme" risk compartments, QRA is performed where the probability of failure and severity of consequence associated with damage modes are represented in terms of quantitative values rather than qualitative terms. Such assessment will seek to account for inherent uncertainties such as those associated with measurements of the damage, material properties, models and data used for the risk assessment. Appropriate limit states (or performance functions) are developed and the probability of failure is computed as the probability of violating these limit states. Typical limit states for yield or ultimate strength, corrosion damage, and crack growth based on the crack size are shown in Table 3-9.

Table 3-9: Typical Limit States

Limit State	Description
Yield (or Ultimate Strength)	$g_Y = C_Y - L_{vm}$ g_Y = Yield limit state C_Y = Yield capacity of component L_{vm} = Von misses stress on component
Corrosion	$g_{cor} = d_{limit} - d_{cur}$ g_{cor} = Scantling limit state function d_{limit} = Acceptable scantling limit d_{cur}= Current scantling due to reduction from damage (corrosion)
Crack Growth based on the Crack Size	$g_{crack_1} = a_{limit} - a_N$ g_{crack_1} = Crack limit state function based on crack length a_{limit}= Critical crack size a_N= Crack size from damage

Figure 3-3 shows the probability distribution function (PDF) for a typical limit state ($g_s(X) = Strength - Load$).

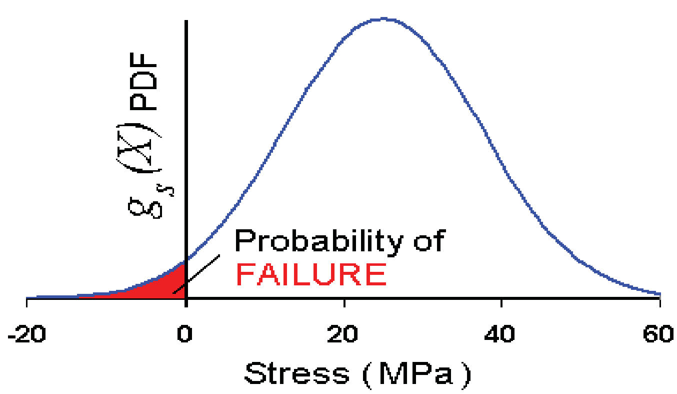


Figure 3-3: Probability Distribution Function (PDF) for a Typical Limit State

The probability of the failure is given by the area under the PDF curve ($g_s(X)$) less than zero. If both the load and resistance are normally distributed, then the probability of failure is given by the following equation.

$$P_f = \Phi\left[\frac{\mu_{Strength} - \mu_{Load}}{\sqrt{\sigma^2_{Strength} + \sigma^2_{Load}}}\right]$$

Where $\mu_{Strength}$ and μ_{Load} are the mean values of the strength and load, respectively; $\sigma_{Strength}$ and σ_{Load} are the standard deviations of the strength and load, respectively; and Φ is the cumulative distribution function of the standard normal variate.

In general, the variable can assume any probability distribution other than normal distribution and the P_f has to be obtained numerically. Several tools are available (e.g. COMPASS software) for performing the computations for the most generic cases. Because of the complexity and computational intensities of these computations, it is proposed to undertake these computations offline using other existing tools such as finite element software (Trident-FEA) and reliability software (COMPASS) and the probability of failure results fed in from external systems into RIIMM system.

Figure 3-4 shows graphically how such a system could be developed. Finite element software such as DND's Trident FEA system could be used to generate a library of responses of the CPF to selected load profiles/cases. Top-down analysis capability will be used to zero in on selected high or extreme risk components such as the stiffened shell structures shown in Figure 3-4.

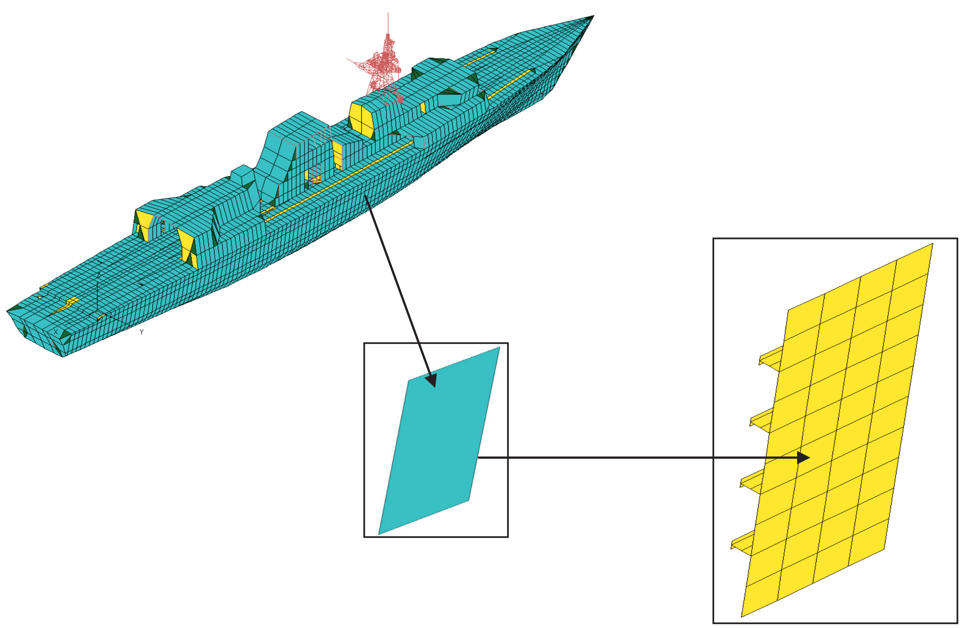


Figure 3-4: Conceptual Illustration of How Available Tools used to Compute the Reliability of a Component

Reliability analysis, taking account of uncertainties in loads, structural variables, and damage and model parameters can be undertaken using Martec's COMPASS system. Results will be stored in a database for retrieval by the RIIMM system. Details of these interactions will be worked out in the development phase of the project.

Based on the QRA results the criticality ranking of the components will be reassessed.

3.7 DEVELOPMENT AND EXECUTION OF RIIMM PLAN

The objective of this step is to develop an effective and efficient inspection and maintenance plan for the compartments based on their criticality as assessed by qualitatively and/or quantitatively risk assessments in the previous steps.

Table 3-10 shows the proposed inspection and repair actions based on the compartment risk level. As this represents a modest change from current RCN inspection and maintenance philosophy, consultations with stakeholders will be carried out during the implementation phase, to ensure that the proposed changes are acceptable/tolerable to stakeholders. Such consultations, as well as targeted numerical simulations and/or in-service experience will be used to refine the proposed inspection and repair intervals.

Table 3-10: Proposed Inspection and Repair Actions

Risk Level	Action to be Performed
Low	Possibility to reduce inspection frequency (e.g.: 7 years, i.e. 5 year inspection time interval push back by another 2 years)
Medium	Maintain current inspection interval. Possibility to postpone repair
High	Possibility to monitor, with increased inspection frequency (e.g.: 2 years i.e. inspection interval reduced by three years). Repair as soon as practicable
Extreme	Must repair before next mission.

As stated in Section 3.1, two main goals of the RIIMM approach are: (a) to provide a cost effective inspection and maintenance process compared to current practice; and (b) enhance safety and mission readiness of the RCN fleet. The proposed provisions of Table 3-10 fulfill these goals as summarized below.

- For the compartments that have been ranked as "Low" risk, it is proposed to increase the inspection interval from 5 to 7 years, over which these compartments have to be completely inspected. This has the possibility of reducing inspection and repair costs, without compromising safety.
- For compartments ranked as "Medium" risk, it is proposed to maintain the current inspection cycle: that is, these compartments have to be completely inspected within a five year cycle. However, unlike current maintenance practice, the RIIMM process suggests postponement of repairs to the next inspection cycle. This has the potential to provide savings in repair costs. It should be mentioned that current RCN fleet maintenance policy has similar provisions, with the FTA and DA given the latitude to delay repairs. The RIIMM process formalizes the process based on assessed risk levels of the compartments.
- For compartments ranked as "High" risk, the RIIMM approach suggests an increased inspection frequency, (i.e. every two years, instead of the current five year period) with possibility to delay repairs until it is practicable to do so, before the end of current maintenance cycle. This has the potential to increase safety and mission readiness. Inspection cost for the components may be higher under the current practice, but the

RIIMM approach ensures that such costs are directed at these safety critical compartments, rather than being spread evenly across the all compartments which may or may not be safety critical. Given that for well managed systems, “High” risk compartments are much fewer than “Low” or “Medium” risk compartments, the RIIMM approach may still be the more cost effective solution. To ensure this is the case, optimization algorithms will be built into RIIMM methodology (in the implementation phase) to allow maintenance personnel make optimal inspection and repair plans.

- For compartments ranked as “Extreme” risk, it is proposed to immediately repair the compartment before the next mission. Repair methods will typically be by replacement of the damaged component or some other advanced repair method, which will bring the damaged component or structure back to an “as-good-as-new” condition. This feature ensures safety and mission readiness, but may have similar repair costs as current practice. Again, optimization algorithms will be provided for making optimum inspection and repair plans during the full implementation.

3.8 UPDATING AND FOLLOW UP OF INSPECTION AND REPAIR PLAN

The RIIMM program shall include a structured and documented process to incorporate new evidence and information generated from components subjected to the RIIMM process. Following implementation of any of the inspection and repair actions defined in the previous section, the risk profile of the affected compartment will be updated and new inspection and repair plans made for the compartments based on their residual risks. For example, if a compartment was assessed as “Extreme” it would have to be repaired immediately, as per RIIMM philosophy. If the residual risk following implementation of the repair plan, (e.g. replace the part) is “Medium”, then this compartment needs to be inspected within the next five years. If the risk is assessed to be “Low”, a seven year inspection cycle is required.

Another type of information that needs to be updated includes the overall fleet incident rates that are used in developing the probability of failure estimates. As more data is collected over the remaining life of the vessels, the information has to be updated in order to capture any potential changes in defects incident trends.

3.9 OPTIMAL INSPECTION AND REPAIR PLAN

A major advantage of the RIIMM method is its suitability for undertaking optimal maintenance management and planning. The main elements considered in developing optimal maintenance strategies include the maintenance costs (inspection and repair costs) and the level of risk reduction, as summarized below.

3.9.1 Inspection Cost

The inspection cost for a compartment depends on (a) the surface area or length of the compartment inspected; (b) the type of inspection method employed; and (c) the unit cost (labour and materials) for the inspection method. The inspection cost is estimated using the following equation:

$$C_I = Ac_1\alpha_i \quad \text{... 3-1}$$

where, A is the area or length inspected, c_1 is the unit inspection cost for visual inspection and α_i is the weighting factor dependent on the inspection method *i.*

The areas of surfaces to be inspected for each of the compartments will have to be developed during the full implementations as these are not clearly stated in the fleet defects databases. The unit cost for visual inspection, c_1, and weighting factors for various advanced inspection methods will be obtained from their maintenance personnel through consultations.

3.9.2 Repair Costs

Similar to inspection cost, the repair cost of a compartment depends on (a) defect size; (b) the type of the repair method; and (c) the unit cost (labour and materials) for the repair method, as expressed in the following equation:

$$C_R = Bc_2\beta_i \text{ for corrosion damage repair; and............. 3-2}$$

$$C_R = Bc_3\lambda_i \text{ for cracking damage repair .... 3-3}$$

where, B is the size of the defect being repaired, c_2 is the unit repair cost for the repair method of grinding and filling with weld metal, and β_i is the weighting factor for corrosion repair method *i.* c_3 is the unit repair cost for the cracking repair method of gouging out, rewelding and grinding smooth, and λ_i weighting factor for crack damage repair method *i.*

The various repair cost components will be determined based on the consultations with East and West Coasts fleet maintenance management personnel during the implementation phase.

3.9.3 Risk Reduction

The benefit of inspection and repair actions will be measured in terms of risk reduction or risk averted due to the inspection and maintenance actions. Table 3-11 shows a possible risk reduction matrix that can be used to measure risk reduction benefits of inspection and repair actions. For instance, consider a component that is assessed to be "Extreme" risk. If after repair actions the risk is assessed to have been reduced to "Medium" risk level, then the risk is assumed to have reduced by 2 basis points; and 3 basis points if the risk level was reduced to "Low"; and so on for other possible pre- and post-repair risk level combinations. The risk reduction for all compartments of the ship will be aggregated to obtain the risk reduction benefit for the vessel; and those for the vessels aggregated to obtain the risk reduction for the fleet.

Table 3-11: Possible Risk Reduction Matrix

Risk Level		Risk Reduction Index
Initial Risk Estimate	Risk after inspection and Repair actions	
EXTREME	LOW	3
EXTREME	MEDIUM	2
EXTREME	HIGH	1
EXTREME	EXTREME	0
HIGH	LOW	2
HIGH	MEDIUM	1
HIGH	HIGH	0
MEDIUM	LOW	1
MEDIUM	MEDIUM	0
LOW	LOW	0

3.9.4 Inspection and Maintenance Optimization Scenarios

Typical inspection and repair optimization problems that would be developed in the implementation phase shall include the following:

1. Given a fixed maintenance budget over a five year maintenance cycle, what is the optimal inspection and repair plan that ensures that the risk level of all compartments is no higher than medium risk?
2. Comparison of alternative maintenance plans based on compartment risk levels and/ or maintenance costs
3. The most effective way to allocate resources to maximize safety and mission readiness.

4.0 DEMONSTRATION OF RIIMM METHODOLOGY

A demonstration of the application of the RIIMM approach to the HALIFAX class ships is provided in this section. The objectives of this case study are to demonstrate the technical feasibility of applying RIIMM methodology to the HALIFAX class ships, and to demonstrate the potential benefits that can be gained through implementation of the RIIMM methodology.

4.1 PROBLEM DEFINITIONS

One ship from the East Coast fleet (HMCS Halifax) and one ship from West Coast fleet (HMCS Vancouver) are chosen for the case study. Approximately 180 compartments and structures are selected for each ship, for illustration purposes. The inspection and repair of corrosion and cracking damage modes are considered. The study is designed to demonstrate the following aspects of the RIIMM approach.

1. Criticality (risk) assessment and the ranking of the compartments;
2. Inspection and maintenance plan over a 10 year period;
3. Benefits (cost savings) of RIIMM, compared to current inspection and maintenance practice.

4.2 ASSUMPTIONS AND METHODOLOGY

The followings assumptions are made in the case study:

- Data from the RCN defects database is used to estimate the probability of component failure due to the pressure of given damage mode (corrosion and cracking) as discussed in Chapter 3.
- Assignment of severity of consequences is approximate, based on one engineer's opinion. In the full implementation, the severity scores will be obtained from a panel of subject matter experts and aggregated.
- For estimates under the current RCN inspection and maintenance practices, it is assumed that all 180 compartments are inspected over every five year cycle in a progressive manner, and all damages identified are repaired within the five year cycle.
- For estimates under the RIIMM approach, inspection and maintenance actions for the various compartments are based on their criticality levels as described in Section 3.7.
- Table 4-1 shows the assumptions made for estimating the cost of inspection and repairs for purposes of illustration. These assumptions will be refined based on the actual cost data and consultations with fleet maintenance management personnel. Highlights of the cost elements are summarized below.
    - It is assumed that on the average, it takes 2 man days to inspect a compartment by visual inspection. In a real situation, this would depend on the surface area or length inspected and the nature of the environment. In the full implementation, these would be accounted for by applying an inspection area and or length factor to this base values for each compartment. Inspections by other, more advanced inspection methods (e.g. UTG) are accounted for by

applying a factor (e.g. 1.5 in the Table 4-1). It is further assumed that visual inspection is utilized for 80% of the compartments, and that 20% of the compartments require advanced inspection methods. This distribution will be refined during the implementation phase, based on the input from stakeholders.

- It is assumed that on the average, it takes 2 man days to repair a damaged compartment by a repair method such as grinding and filling with weld metal. Other repair methods such as clean and preservation (for corrosion damage) and inserting a new plate (for corrosion and/or cracking damage) are accounted for by appropriate cost factors (e.g. 0.67 and 4.0, respectively as shown in the Table 4-1). It is also assumed that for corrosion damages 50% are repaired by cleaning and paint preservation; 30% by grinding and welding; and 20% by part replacement. Again, refinement of these allocation and factors will be undertaken during the full implementation.
- The hourly inspection and repair costs include average labour, overhead and material costs.

Table 4-1: Summary of Cost Estimation

Base Cost Estimation		
Base time to perform visual inspection on one compartment (hrs)	16	
Base time to repair by grinding and filling with weld metal (hrs)	16	
Cost for visual inspection ($/hr)	100	
Cost for repair by grinding and filling with weld metal ($/hr)	120	
Base cost to perform visual inspection on one compartment ($)	1,600	
Base cost to repair one compartment ($)	1,920	
Inspection Method and Cost Allocation		
	% of Comp.	Cost Factor
Compartments that require visual inspection	0.8	1
Compartments that require advanced inspection (e.g. UTG)	0.2	1.5
Repair Method and Cost Allocation		
	% of Comp.	Cost Factor
Cleaning and preserve with coating	0.5	0.67
Grinding out, filling with weld metal, and grind smooth	0.3	1
Remove and insert new plate	0.2	4

4.3 QUALITATIVE RISK ASSESSMENT FOR COMPARTMENTS AND RISK RANKINGS

Qualitative risk assessment for the compartments will be undertaken in a workshop setting that utilizes the collective knowledge and experience of subject matter experts (SMEs) from various stakeholders. In this study, a preliminary assessment has been undertaken by the project team for illustration purposes. Actual assessment will be carried out during the full implementation phase.

4.3.1 HMCS Halifax Criticality Summary

A summary of the numbers of compartments falling into each of the risk criticality categories is shown in Table 4-2. Considering corrosion damage, it is observed that out of the 183 compartments assessed, 152 were ranked as “Low” risk; 29 as “Medium” risk and two as “High”. For cracking damage, 158 compartments were ranked as “Low” risk, 17 as “Medium” risk and eight as “High” risk. For both damage modes, none of the compartments was ranked as “Extreme” risk.

Table 4-2: Criticality Summary for HMCS Halifax Ship

Risk Level	No. of Compartments	
	Corrosion	Cracking
Low	152	158
Medium	29	17
High	2	8
Extreme	0	0

The distributions of the numbers of compartments in each cell of the risk matrix are shown in Figure 4-1. The detailed risk ranking of all compartments for corrosion and cracking damage are shown in Table 4-3.

(a)

Probability of Damage	1	2	3	4	5
5	0	0	0	0	0
4	0	0	0	0	0
3	0	0	0	0	0
2	30	27	21	2	0
1	29	39	27	8	0
	Consequences				

(b)

Probability of Damage	1	2	3	4	5
5	0	0	0	0	0
4	0	1	1	0	0
3	8	7	5	2	0
2	0	0	1	0	0
1	54	55	41	8	0
	Consequences				

Figure 4-1: Criticality Distribution for HMCS Halifax: (a) Corrosion Damage and (b) Cracking Damage

Table 4-3: Criticality of HMCS Halifax Compartments: (a) Corrosion and (b) Cracking

(a) Corrosion

Compartment	Risk Level
AER	HIGH (8)
AER Casing	HIGH (8)
AAMR	MEDIUM (6)
AAMR Casing	MEDIUM (6)
AAMR Settling Tk No.2 (P)	MEDIUM (6)
Bridge	MEDIUM (6)
Bridge Top Weather Deck (Fwd)	MEDIUM (6)
Bridge Wing (P)	MEDIUM (6)
Bridge Wing (S)	MEDIUM (6)
CIWS	MEDIUM (6)
ECM Compt. Top	MEDIUM (6)
FAMR	MEDIUM (6)
FAMR Casing	MEDIUM (6)
FER	MEDIUM (6)
FER Intakes	MEDIUM (6)
FER Uptakes	MEDIUM (6)
Main Mast Structure	MEDIUM (6)
Mess No. 1	MEDIUM (6)
Mess No. 6	MEDIUM (6)
Mess No. 10	MEDIUM (6)
shell 3-4 dk stbd 5	MEDIUM (6)
Sonar Dome	MEDIUM (6)
Sonar Trunk	MEDIUM (6)
DFO No.10	MEDIUM (4)
DFO No.11	MEDIUM (4)
DFO No.7 (S)	MEDIUM (4)
DFO No.8 (P)	MEDIUM (4)
DFO Service No.1	MEDIUM (4)
DFO Service No.2	MEDIUM (4)
JP5 No.1	MEDIUM (4)
JP5 No.2	MEDIUM (4)
Black & Grey Water Collection Tank	LOW (4)
Cleaning Gear Lkr	LOW (4)
D/C Lobby	LOW (4)
FAMR Casing Top	LOW (4)
Foc'sle	LOW (4)
Forward Fire Control Radar	LOW (4)
Fresh Water Tank No.2	LOW (4)
Galley	LOW (4)
Hangar	LOW (4)
Lobby	LOW (4)
Lobby (P)	LOW (4)
Lobby (S)	LOW (4)
Mess No. 11	LOW (4)
Officers WP & Hds	LOW (4)
Outbd Mtrs & Hyd Pmps	LOW (4)

(b) Cracking

Compartment	Risk Level
AER	HIGH (12)
AER Casing	HIGH (12)
FER Uptakes	HIGH (12)
AAMR Casing	HIGH (9)
Bridge Top Weather Deck (Fwd)	HIGH (9)
FAMR Casing	HIGH (9)
FER Intakes	HIGH (9)
HF Transmitter Room	HIGH (9)
RAS Area (S)	MEDIUM (8)
Foc'sle	MEDIUM (6)
Lobby (P)	MEDIUM (6)
NBCD HQ & MCR	MEDIUM (6)
Passageway	MEDIUM (6)
Passageway (A)	MEDIUM (6)
Passageway (P)	MEDIUM (6)
RAS Area (P)	MEDIUM (6)
transom 2 dk stbd	MEDIUM (6)
DFO No.10	MEDIUM (4)
DFO No.11	MEDIUM (4)
DFO No.7 (S)	MEDIUM (4)
DFO No.8 (P)	MEDIUM (4)
DFO Service No.1	MEDIUM (4)
DFO Service No.2	MEDIUM (4)
JP5 No.1	MEDIUM (4)
JP5 No.2	MEDIUM (4)
AAMR	LOW (3)
AAMR Settling Tk No.1 (S)	LOW (3)
AAMR Settling Tk No.2 (P)	LOW (3)
Air Detachment Room Head	LOW (3)
Bosuns Workshop	LOW (3)
Bridge	LOW (3)
Bridge Wing (P)	LOW (3)
Bridge Wing (S)	LOW (3)
CB Office	LOW (3)
Chaff Magazine	LOW (3)
CIWS	LOW (3)
CIWS Magazine	LOW (3)
Communications Control Room	LOW (3)
Communications Equipment Room	LOW (3)
DFO No.1 Under Magazine (S)	LOW (3)
DFO No.2 Aft of Magazine	LOW (3)
DFO No.2 Under Magazine (P)	LOW (3)
DFO No.4	LOW (3)
DFO No.5 (S)	LOW (3)
DFO No.6 (P)	LOW (3)
DFO No.9	LOW (3)

(a) Corrosion

Compartment	Risk Level
Oil/Water Collection Tank	LOW (4)
Passageway	LOW (4)
Passageway (C.L.)	LOW (4)
Passageway (P)	LOW (4)
Quarterdeck	LOW (4)
RAS Area (P)	LOW (4)
RAS Area (S)	LOW (4)
Rope Store	LOW (4)
Sewage Treatment & Gland Compt.	LOW (4)
shell 1-2 dk stbd 10	LOW (4)
transom 1 dk port	LOW (4)
Treated Water Tank	LOW (4)
AAMR Settling Tk No.1 (S)	LOW (3)
Air Detachment Room Head	LOW (3)
Chaff Magazine	LOW (3)
CIWS Magazine	LOW (3)
Communications Control Room	LOW (3)
Communications Equipment Room	LOW (3)
DFO No.1 Under Magazine (S)	LOW (3)
DFO No.2 Aft of Magazine	LOW (3)
DFO No.2 Under Magazine (P)	LOW (3)
DFO No.4	LOW (3)
DFO No.5 (S)	LOW (3)
DFO No.6 (P)	LOW (3)
DFO No.9	LOW (3)
HF Transmitter Room	LOW (3)
Machinery Control Room	LOW (3)
Main Shaft Bkt (P)	LOW (3)
Main Shaft Bkt (S)	LOW (3)
Mast Structure	LOW (3)
Mess No.7	LOW (3)
NBCD HQ & MCR	LOW (3)
Rudder	LOW (3)
shell bottom port 8	LOW (3)
shell bottom stbd 8	LOW (3)
Speed Log Transducer Space	LOW (3)
Torpedo Decoy & XBT/XSV Eqpt Room	LOW (3)
Torpedo Magazine No. 1	LOW (3)
Torpedo Magazine No. 2	LOW (3)
Access between RAS areas Fr.36-37.5	LOW (2)
Air Lock	LOW (2)
Anchor Capstan Compt.	LOW (2)
Bridge Top Weather Deck (Aft)	LOW (2)
C & PO Lounge	LOW (2)
C & PO Lounge Head	LOW (2)
Cable Lkr No. 1	LOW (2)
Cable Lkr No. 2	LOW (2)
Chaff Launcher (P)	LOW (2)
Chaff Launcher (S)	LOW (2)

(b) Cracking

Compartment	Risk Level
ECM Compt. Top	LOW (3)
Electrical Workshop	LOW (3)
FAMR	LOW (3)
FAMR Casing Flat 11.7m Above Base	LOW (3)
FER	LOW (3)
Funnel Flat 19.6m Above Base	LOW (3)
Funnel Top	LOW (3)
Hangar Top Weather Deck (Fwd)	LOW (3)
Machinery Control Room	LOW (3)
Main Mast Structure	LOW (3)
Main Shaft Bkt (P)	LOW (3)
Main Shaft Bkt (S)	LOW (3)
Mast Structure	LOW (3)
Mess No. 1	LOW (3)
Mess No. 6	LOW (3)
Mess No.7	LOW (3)
Mess No. 10	LOW (3)
NBC Store	LOW (3)
Rudder	LOW (3)
shell 3-4 dk stbd 5	LOW (3)
shell bottom port 8	LOW (3)
shell bottom stbd 8	LOW (3)
Sonar Dome	LOW (3)
Sonar Trunk	LOW (3)
Speed Log Transducer Space	LOW (3)
Torpedo Decoy & XBT/XSV Eqpt Room	LOW (3)
Torpedo Magazine No. 1	LOW (3)
Torpedo Magazine No. 2	LOW (3)
Anchor Capstan Compt.	LOW (2)
Black & Grey Water Collection Tank	LOW (2)
Cable Lkr No. 1	LOW (2)
Cable Lkr No. 2	LOW (2)
Chaff Launcher (P)	LOW (2)
Chaff Launcher (S)	LOW (2)
Cleaning Gear Lkr	LOW (2)
Cofferdam (P)	LOW (2)
Cofferdam (S)	LOW (2)
Contaminant Collection Tank	LOW (2)
D/C Lobby	LOW (2)
DC Section Base No. 1	LOW (2)
Dk Store No. 3	LOW (2)
Drain Tank	LOW (2)
ECM Compt. Top	LOW (3)
Electrical Workshop	LOW (3)
FAMR	LOW (3)
FAMR Casing Flat 11.7m Above Base	LOW (3)
FER	LOW (3)
Funnel Flat 19.6m Above Base	LOW (3)
Funnel Top	LOW (3)

(a) Corrosion

Compartment	Risk Level
Cleansing Station No. 2	LOW (2)
Cofferdam (P)	LOW (2)
Cofferdam (S)	LOW (2)
Contaminant Collection Tank	LOW (2)
CO's/SO's WR	LOW (2)
CPO's & P1's WP & Hds	LOW (2)
Crews HD No. 3	LOW (2)
Crews WP & Hds No. 1	LOW (2)
Crews WP & Heads No. 2	LOW (2)
Crews WP No. 3	LOW (2)
Crews Laundromat	LOW (2)
Crews Lounge Head	LOW (2)
DC Section Base No. 1	LOW (2)
Deck Store No. 2	LOW (2)
Dishwashing Compt.	LOW (2)
Dk Store No. 3	LOW (2)
Drain Tank	LOW (2)
Dry Garbage Store	LOW (2)
EBR	LOW (2)
Filter Space	LOW (2)
Flight Deck	LOW (2)
Fresh Water Tank No.1	LOW (2)
Funnel Flat 19.6m Above Base	LOW (2)
Funnel Top	LOW (2)
Halon Gas Compt	LOW (2)
Hangar Side Deck (P)	LOW (2)
Hangar Side Deck (S)	LOW (2)
Hangar Top Weather Deck (Aft)	LOW (2)
Hangar Top Weather Deck (Fwd)	LOW (2)
Incinerator Compt	LOW (2)
Laundry	LOW (2)
Loan Clothing Store	LOW (2)
Lub Oil No.2	LOW (2)
NBC Filter Compartment No. 1	LOW (2)
NBC Filter Compt No. 2	LOW (2)
Passageway (A)	LOW (2)
Passageway (S)	LOW (2)
Plenum	LOW (2)
PO's WP & HD No. 2	LOW (2)
RAS Trunk	LOW (2)
RAS/Fuelling Locker	LOW (2)
RAST Trough & Wells	LOW (2)
Reserve Feed No.1	LOW (2)
Reserve Feed No.2	LOW (2)
shell 1-2 dk stbd 1	LOW (2)
shell 1-2 dk stbd 3	LOW (2)
shell 3-4 dk port 12	LOW (2)
Small Arms Lkr	LOW (2)
SW Ballast No.1/Standby DFO No.1	LOW (2)

(b) Cracking

Compartment	Risk Level
FAMR Casing Top	LOW (2)
Filter Space	LOW (2)
Flight Deck	LOW (2)
Forward Fire Control Radar	LOW (2)
Fresh Water Tank No.1	LOW (2)
Fresh Water Tank No.2	LOW (2)
Hangar	LOW (2)
Hangar Side Deck (P)	LOW (2)
Hangar Side Deck (S)	LOW (2)
Incinerator Compt	LOW (2)
Loan Clothing Store	LOW (2)
Lobby	LOW (2)
Lobby (S)	LOW (2)
Lub Oil No.2	LOW (2)
Mess No. 11	LOW (2)
Officers WP & Hds	LOW (2)
Outbd Mtrs & Hyd Pmps	LOW (2)
Oil/Water Collection Tank	LOW (2)
Passageway (C.L.)	LOW (2)
Passageway (S)	LOW (2)
PO's WP & HD No. 2	LOW (2)
Quarterdeck	LOW (2)
RAS Trunk	LOW (2)
RAS/Fuelling Locker	LOW (2)
RAST Trough & Wells	LOW (2)
Rope Store	LOW (2)
Sewage Treatment & Gland Compt.	LOW (2)
shell 1-2 dk stbd 1	LOW (2)
shell 1-2 dk stbd 3	LOW (2)
shell 1-2 dk stbd 10	LOW (2)
shell 3-4 dk port 12	LOW (2)
Small Arms Lkr	LOW (2)
SW Ballast No.1/Standby DFO No.1	LOW (2)
SW Ballast No.2/Standby DFO No.2	LOW (2)
SW Ballast No.3/Standby DFO No.3	LOW (2)
SW Ballast No.4/Standby DFO No.4	LOW (2)
SWB/Standby DFO No.1	LOW (2)
Towed Array/Torp Decoy Drain Tank	LOW (2)
transom 1 dk port	LOW (2)
Treated Water Tank	LOW (2)
WR Head/Sea Head	LOW (2)
Access between RAS areas Fr.36-37.5	LOW (1)
FAMR Casing Top	LOW (2)
Filter Space	LOW (2)
Flight Deck	LOW (2)
Forward Fire Control Radar	LOW (2)
Fresh Water Tank No.1	LOW (2)
Fresh Water Tank No.2	LOW (2)
Hangar	LOW (2)

(a) Corrosion

Compartment	Risk Level
SW Ballast No.2/Standby DFO No.2	LOW (2)
SW Ballast No.3/Standby DFO No.3	LOW (2)
SW Ballast No.4/Standby DFO No.4	LOW (2)
SWB/Standby DFO No.1	LOW (2)
Towed Array/Torp Decoy Drain Tank	LOW (2)
transom 2 dk stbd	LOW (2)
Void Below 57mm Magazine	LOW (2)
Wardroom/Anteroom	LOW (2)
WR Head/Sea Head	LOW (2)
WR Servery	LOW (2)
AFFF Equipment Room	LOW (1)
Bosuns Workshop	LOW (1)
C & PO Dining Room	LOW (1)
C & PO Servery	LOW (1)
CB Office	LOW (1)
Cleansing Station No. 1	LOW (1)
DFO No.1 Aft of Magazine (S)	LOW (1)
Dry Provisions Store	LOW (1)
Electrical Workshop	LOW (1)
FAMR Casing Flat 11.7m Above Base	LOW (1)
FCER No. 3	LOW (1)
FER Ventilation Air Intake Plenum	LOW (1)
Funnel Flat 13.2m Above Base	LOW (1)
Funnel House Top 15.9m Above Base	LOW (1)
General Store No. 2	LOW (1)
Helo Ru Lub Lkr	LOW (1)
Int Shaft Bkt (P)	LOW (1)
Laundry Flat	LOW (1)
NBC Filter Compt. No. 3	LOW (1)
NBC Store	LOW (1)
Paint Locker	LOW (1)
Paint Store	LOW (1)
QM's Lobby	LOW (1)
Sam (P)	LOW (1)
Sam (S)	LOW (1)
Shipwright's Workshop	LOW (1)
Sports Gear Store	LOW (1)
Steam Generator Intake Plenum	LOW (1)
Void	LOW (1)
SW Ballast No.2/Standby DFO No.2	LOW (2)
SW Ballast No.3/Standby DFO No.3	LOW (2)
SW Ballast No.4/Standby DFO No.4	LOW (2)
SWB/Standby DFO No.1	LOW (2)
Towed Array/Torp Decoy Drain Tank	LOW (2)
transom 2 dk stbd	LOW (2)
Void Below 57mm Magazine	LOW (2)
Wardroom/Anteroom	LOW (2)
WR Head/Sea Head	LOW (2)
WR Servery	LOW (2)

(b) Cracking

Compartment	Risk Level
AFFF Equipment Room	LOW (1)
Air Lock	LOW (1)
Bridge Top Weather Deck (Aft)	LOW (1)
C & PO Dining Room	LOW (1)
C & PO Lounge	LOW (1)
C & PO Lounge Head	LOW (1)
C & PO Servery	LOW (1)
Cleansing Station No. 1	LOW (1)
Cleansing Station No. 2	LOW (1)
CO's/SO's WR	LOW (1)
CPO's & P1's WP & Hds	LOW (1)
Crews HD No. 3	LOW (1)
Crews WP & Hds No. 1	LOW (1)
Crews WP & Heads No. 2	LOW (1)
Crews WP No. 3	LOW (1)
Crews Laundromat	LOW (1)
Crews Lounge Head	LOW (1)
Deck Store No. 2	LOW (1)
DFO No.1 Aft of Magazine (S)	LOW (1)
Dishwashing Compt.	LOW (1)
Dry Garbage Store	LOW (1)
Dry Provisions Store	LOW (1)
EBR	LOW (1)
FCER No. 3	LOW (1)
FER Ventilation Air Intake Plenum	LOW (1)
Funnel Flat 13.2m Above Base	LOW (1)
Funnel House Top 15.9m Above Base	LOW (1)
Galley	LOW (1)
General Store No. 2	LOW (1)
Halon Gas Compt	LOW (1)
Hangar Top Weather Deck (Aft)	LOW (1)
Helo Ru Lub Lkr	LOW (1)
Int Shaft Bkt (P)	LOW (1)
Laundry	LOW (1)
Laundry Flat	LOW (1)
NBC Filter Compartment No. 1	LOW (1)
NBC Filter Compt No. 2	LOW (1)
NBC Filter Compt. No. 3	LOW (1)
Paint Locker	LOW (1)
Paint Store	LOW (1)
Plenum	LOW (1)
QM's Lobby	LOW (1)
Reserve Feed No.1	LOW (1)
Reserve Feed No.2	LOW (1)
Sam (P)	LOW (1)
Sam (S)	LOW (1)
Shipwright's Workshop	LOW (1)
Sports Gear Store	LOW (1)
Steam Generator Intake Plenum	LOW (1)

4.3.2 HMCS Vancouver Criticality Summary

A summary of the numbers of compartments falling into each of the risk criticality categories for HMCS Vancouver is shown in Table 4-4. Considering corrosion damage, out of the 183 compartments assessed, 88 were ranked as “Low” risk; 44 as “Medium” risk; 42 as “High” risk; and nine as “Extreme” risk. As opposed to HMCS Halifax corrosion criticality, a number of compartments are assessed to be “High” and “Extreme” risk. A closer look indicates that these “High” and “Extreme” risk values are influenced by the uncertainty in the corrosion depth and extents. Therefore, efforts would have to be made to clarify the corrosion sizes when logging the inspection details.

For cracking damage, 158 compartments were ranked as “Low” risk; 20 as “Medium” risk; four as “High” risk; and one as “Extreme” risk.

Table 4-4: Criticality Summary for HMCS Vancouver

Risk Level	No. of Compartments	
	Corrosion	Cracking
Low	88	158
Medium	44	20
High	42	4
Extreme	9	1

Figure 4-2 shows the compartment criticality distributions for corrosion and cracking damage modes. The detailed risk ranking of all compartments assessed for corrosion and cracking damage are shown in Table 4-5.

(a)

Probability of Damage	Consequences 1	2	3	4	5
5	3	9	5	1	0
4	4	12	5	3	0
3	21	25	22	6	0
2	2	3	0	0	0
1	30	16	16	0	0

(b)

Probability of Damage	Consequences 1	2	3	4	5
5	0	0	1	0	0
4	0	0	1	0	0
3	1	11	2	1	0
2	1	0	0	0	0
1	58	56	42	9	0

Figure 4-2: Criticality Distribution for HMCS Vancouver: (a) Corrosion Damage and (b) Cracking Damage

Table 4-5: Criticality of HMCS Vancouver Compartments: (a) Corrosion, and (b) Cracking

(a) Corrosion

Compartment	Risk Level
AER Casing	EXTREME (20)
AER	EXTREME (16)
JP5 No.1	EXTREME (16)
JP5 No.2	EXTREME (16)
AAMR Casing	EXTREME (15)
FAMR	EXTREME (15)
FER Intakes	EXTREME (15)
FER Uptakes	EXTREME (15)
Main Mast Structure	EXTREME (15)
DFO No.1 Under Magazine (S)	HIGH (12)
DFO No.10	HIGH (12)
DFO No.11	HIGH (12)
DFO No.2 Under Magazine (P)	HIGH (12)
DFO No.7 (S)	HIGH (12)
DFO No.8 (P)	HIGH (12)
DFO Service No.1	HIGH (12)
DFO Service No.2	HIGH (12)
FAMR Casing	HIGH (12)
Sonar Dome	HIGH (12)
Torpedo Magazine No. 2	HIGH (12)
Black & Grey Water Collection Tank	HIGH (10)
Cable Lkr No. 1	HIGH (10)
Cable Lkr No. 2	HIGH (10)
Filter Space	HIGH (10)
Hangar	HIGH (10)
Hangar Side Deck (S)	HIGH (10)
Incinerator Compt	HIGH (10)
Passageway (P)	HIGH (10)
RAS Trunk	HIGH (10)
AAMR	HIGH (9)
Air Detachment Room Head	HIGH (9)
Bridge Top Weather Deck (Fwd)	HIGH (9)
Bridge Wing (P)	HIGH (9)
Bridge Wing (S)	HIGH (9)
Chaff Magazine	HIGH (9)
CIWS Magazine	HIGH (9)
Communications Equipment Room	HIGH (9)
DFO No.5 (S)	HIGH (9)
DFO No.6 (P)	HIGH (9)
DFO No.9	HIGH (9)
ECM Compt. Top	HIGH (9)
FER	HIGH (9)
Main Shaft Bkt (P)	HIGH (9)
Main Shaft Bkt (S)	HIGH (9)
Mast Structure	HIGH (9)
Mess No.7	HIGH (9)

(b) Cracking

Compartment	Risk Level
FER Uptakes	EXTREME (15)
AER Casing	HIGH (12)
FER Intakes	HIGH (12)
HF Transmitter Room	HIGH (9)
NBCD HQ & MCR	HIGH (9)
Anchor Capstan Compt.	MEDIUM (6)
Filter Space	MEDIUM (6)
Foc'sle	MEDIUM (6)
Hangar	MEDIUM (6)
Lobby (P)	MEDIUM (6)
Outbd Mtrs & Hyd Pmps	MEDIUM (6)
Passageway (P)	MEDIUM (6)
RAS Area (P)	MEDIUM (6)
RAS Area (S)	MEDIUM (6)
shell 1-2 dk stbd 1	MEDIUM (6)
shell 1-2 dk stbd 3	MEDIUM (6)
AER	MEDIUM (4)
DFO No.10	MEDIUM (4)
DFO No.11	MEDIUM (4)
DFO No.7 (S)	MEDIUM (4)
DFO No.8 (P)	MEDIUM (4)
DFO Service No.1	MEDIUM (4)
DFO Service No.2	MEDIUM (4)
JP5 No.1	MEDIUM (4)
JP5 No.2	MEDIUM (4)
AAMR	LOW (3)
AAMR Casing	LOW (3)
AAMR Settling Tk No.1 (S)	LOW (3)
AAMR Settling Tk No.2 (P)	LOW (3)
Air Detachment Room Head	LOW (3)
Bridge	LOW (3)
Bridge Top Weather Deck (Fwd)	LOW (3)
Bridge Wing (P)	LOW (3)
Bridge Wing (S)	LOW (3)
Chaff Magazine	LOW (3)
CIWS	LOW (3)
CIWS Magazine	LOW (3)
Communications Control Room	LOW (3)
Communications Equipment Room	LOW (3)
DFO No.1 Under Magazine (S)	LOW (3)
DFO No.2 Aft of Magazine	LOW (3)
DFO No.2 Under Magazine (P)	LOW (3)
DFO No.4	LOW (3)
DFO No.5 (S)	LOW (3)
DFO No.6 (P)	LOW (3)

(a) Corrosion

Compartment	Risk Level
Rudder	HIGH (9)
Sonar Trunk	HIGH (9)
Speed Log Transducer Space	HIGH (9)
Torpedo Decoy & XBT/XSV Eqpt Room	HIGH (9)
Torpedo Magazine No. 1	HIGH (9)
Contaminant Collection Tank	MEDIUM (8)
Flight Deck	MEDIUM (8)
Foc'sle	MEDIUM (8)
Fresh Water Tank No.1	MEDIUM (8)
Fresh Water Tank No.2	MEDIUM (8)
Lobby	MEDIUM (8)
Oil/Water Collection Tank	MEDIUM (8)
Quarterdeck	MEDIUM (8)
RAS Area (P)	MEDIUM (8)
SWB/Standby DFO No.1	MEDIUM (8)
Treated Water Tank	MEDIUM (8)
WR Head/Sea Head	MEDIUM (8)
Chaff Launcher (P)	MEDIUM (6)
Chaff Launcher (S)	MEDIUM (6)
Cleaning Gear Lkr	MEDIUM (6)
Cofferdam (P)	MEDIUM (6)
Cofferdam (S)	MEDIUM (6)
D/C Lobby	MEDIUM (6)
Dk Store No. 3	MEDIUM (6)
Drain Tank	MEDIUM (6)
FAMR Casing Top	MEDIUM (6)
Forward Fire Control Radar	MEDIUM (6)
Hangar Side Deck (P)	MEDIUM (6)
Lobby (P)	MEDIUM (6)
Lobby (S)	MEDIUM (6)
Lub Oil No.2	MEDIUM (6)
Officers WP & Hds	MEDIUM (6)
Outbd Mtrs & Hyd Pmps	MEDIUM (6)
Passageway	MEDIUM (6)
Passageway (A)	MEDIUM (6)
Passageway (S)	MEDIUM (6)
Sewage Treatment & Gland Compt.	MEDIUM (6)
SW Ballast No.1/Standby DFO No.1	MEDIUM (6)
SW Ballast No.2/Standby DFO No.2	MEDIUM (6)
SW Ballast No.3/Standby DFO No.3	MEDIUM (6)
SW Ballast No.4/Standby DFO No.4	MEDIUM (6)
Towed Array/Torp Decoy Drain Tank	MEDIUM (6)
Funnel Flat 19.6m Above Base	MEDIUM (5)
Laundry Flat	MEDIUM (5)
Void	MEDIUM (5)
Crews WP & Hds No. 1	MEDIUM (4)
Crews WP No. 3	MEDIUM (4)
Dishwashing Compt.	MEDIUM (4)
NBC Filter Compt. No. 3	MEDIUM (4)
Towed Array/Torp Decoy Drain Tank	MEDIUM (6)

(b) Cracking

Compartment	Risk Level
DFO No.9	LOW (3)
ECM Compt. Top	LOW (3)
FAMR	LOW (3)
FAMR Casing	LOW (3)
FER	LOW (3)
Machinery Control Room	LOW (3)
Main Mast Structure	LOW (3)
Main Shaft Bkt (P)	LOW (3)
Main Shaft Bkt (S)	LOW (3)
Mast Structure	LOW (3)
Mess No. 1	LOW (3)
Mess No. 6	LOW (3)
Mess No.7	LOW (3)
Rudder	LOW (3)
Sam (P)	LOW (3)
shell bottom port 8	LOW (3)
shell bottom stbd 8	LOW (3)
Sonar Dome	LOW (3)
Sonar Trunk	LOW (3)
Speed Log Transducer Space	LOW (3)
Torpedo Decoy & XBT/XSV Eqpt Room	LOW (3)
Torpedo Magazine No. 1	LOW (3)
Torpedo Magazine No. 2	LOW (3)
Black & Grey Water Collection Tank	LOW (2)
Cable Lkr No. 1	LOW (2)
Cable Lkr No. 2	LOW (2)
Chaff Launcher (P)	LOW (2)
Chaff Launcher (S)	LOW (2)
Cleaning Gear Lkr	LOW (2)
Cofferdam (P)	LOW (2)
Cofferdam (S)	LOW (2)
Contaminant Collection Tank	LOW (2)
D/C Lobby	LOW (2)
DC Section Base No. 1	LOW (2)
Dk Store No. 3	LOW (2)
Drain Tank	LOW (2)
FAMR Casing Top	LOW (2)
Flight Deck	LOW (2)
Forward Fire Control Radar	LOW (2)
Fresh Water Tank No.1	LOW (2)
Fresh Water Tank No.2	LOW (2)
Hangar Side Deck (P)	LOW (2)
Hangar Side Deck (S)	LOW (2)
DFO No.9	LOW (3)
ECM Compt. Top	LOW (3)
FAMR	LOW (3)
FAMR Casing	LOW (3)
FER	LOW (3)
Machinery Control Room	LOW (3)

(a) Corrosion

Compartment	Risk Level
PO's WP & HD No. 2	LOW (4)
RAS/Fuelling Locker	LOW (4)
RAST Trough & Wells	LOW (4)
AAMR Settling Tk No.1 (S)	LOW (3)
AAMR Settling Tk No.2 (P)	LOW (3)
Bridge	LOW (3)
Bridge Top Weather Deck (Aft)	LOW (3)
CIWS	LOW (3)
Cleansing Station No. 2	LOW (3)
Communications Control Room	LOW (3)
Crews HD No. 3	LOW (3)
Crews WP & Heads No. 2	LOW (3)
DFO No.2 Aft of Magazine	LOW (3)
DFO No.4	LOW (3)
Dry Provisions Store	LOW (3)
FAMR Casing Flat 11.7m Above Base	LOW (3)
FCER No. 3	LOW (3)
FER Ventilation Air Intake Plenum	LOW (3)
Funnel Top	LOW (3)
Halon Gas Compt	LOW (3)
Hangar Top Weather Deck (Aft)	LOW (3)
Hangar Top Weather Deck (Fwd)	LOW (3)
Helo Ru Lub Lkr	LOW (3)
HF Transmitter Room	LOW (3)
Int Shaft Bkt (P)	LOW (3)
Machinery Control Room	LOW (3)
Mess No. 1	LOW (3)
Mess No. 6	LOW (3)
Mess No. 10	LOW (3)
Mess No. 11	LOW (3)
NBCD HQ & MCR	LOW (3)
NBC Filter Compartment No. 1	LOW (3)
NBC Filter Compt No. 2	LOW (3)
Paint Locker	LOW (3)
Paint Store	LOW (3)
Reserve Feed No.2	LOW (3)
shell bottom port 8	LOW (3)
shell bottom stbd 8	LOW (3)
Shipwright's Workshop	LOW (3)
Sports Gear Store	LOW (3)
Anchor Capstan Compt.	LOW (2)
DC Section Base No. 1	LOW (2)
Funnel House Top 15.9m Above Base	LOW (2)
Galley	LOW (2)
Loan Clothing Store	LOW (2)
QM's Lobby	LOW (2)
RAS Area (S)	LOW (2)
Rope Store	LOW (2)

(b) Cracking

Compartment	Risk Level
Incinerator Compt	LOW (2)
Loan Clothing Store	LOW (2)
Lobby	LOW (2)
Lobby (S)	LOW (2)
Lub Oil No.2	LOW (2)
Mess No. 10	LOW (2)
Mess No. 11	LOW (2)
Officers WP & Hds	LOW (2)
Oil/Water Collection Tank	LOW (2)
Passageway	LOW (2)
Passageway (A)	LOW (2)
Passageway (C.L.)	LOW (2)
Passageway (S)	LOW (2)
PO's WP & HD No. 2	LOW (2)
Quarterdeck	LOW (2)
RAS Trunk	LOW (2)
RAS/Fuelling Locker	LOW (2)
RAST Trough & Wells	LOW (2)
Rope Store	LOW (2)
Sam (S)	LOW (2)
Sewage Treatment & Gland Compt.	LOW (2)
shell 1-2 dk stbd 10	LOW (2)
shell 3-4 dk stbd 5	LOW (2)
shell 3-4 dk port 12	LOW (2)
Small Arms Lkr	LOW (2)
SW Ballast No.1/Standby DFO No.1	LOW (2)
SW Ballast No.2/Standby DFO No.2	LOW (2)
SW Ballast No.3/Standby DFO No.3	LOW (2)
SW Ballast No.4/Standby DFO No.4	LOW (2)
SWB/Standby DFO No.1	LOW (2)
Towed Array/Torp Decoy Drain Tank	LOW (2)
transom 1 dk port	LOW (2)
transom 2 dk stbd	LOW (2)
Treated Water Tank	LOW (2)
Void Below 57mm Magazine	LOW (2)
Wardroom/Anteroom	LOW (2)
WR Head/Sea Head	LOW (2)
Access between RAS areas Fr.36-37.5	LOW (1)
AFFF Equipment Room	LOW (1)
Air Lock	LOW (1)
Bosuns Workshop	LOW (1)
Bridge Top Weather Deck (Aft)	LOW (1)
C & PO Dining Room	LOW (1)
C & PO Lounge	LOW (1)
C & PO Lounge Head	LOW (1)
C & PO Servery	LOW (1)
CB Office	LOW (1)
Cleansing Station No. 1	LOW (1)
Cleansing Station No. 2	LOW (1)

(a) Corrosion

Compartment	Risk Level
shell 1-2 dk stbd 1	LOW (2)
shell 1-2 dk stbd 3	LOW (2)
shell 1-2 dk stbd 10	LOW (2)
shell 3-4 dk stbd 5	LOW (2)
shell 3-4 dk port 12	LOW (2)
Small Arms Lkr	LOW (2)
transom 1 dk port	LOW (2)
transom 2 dk stbd	LOW (2)
Void Below 57mm Magazine	LOW (2)
Wardroom/Anteroom	LOW (2)
Access between RAS areas Fr.36-37.5	LOW (1)
AFFF Equipment Room	LOW (1)
Air Lock	LOW (1)
Bosuns Workshop	LOW (1)
C & PO Dining Room	LOW (1)
C & PO Lounge	LOW (1)
C & PO Lounge Head	LOW (1)
C & PO Servery	LOW (1)
CB Office	LOW (1)
Cleansing Station No. 1	LOW (1)
CO's/SO's WR	LOW (1)
CPO's & P1's WP & Hds	LOW (1)
Crews Laundromat	LOW (1)
Crews Lounge Head	LOW (1)
Deck Store No. 2	LOW (1)
DFO No.1 Aft of Magazine (S)	LOW (1)
Dry Garbage Store	LOW (1)
EBR	LOW (1)
Electrical Workshop	LOW (1)
Funnel Flat 13.2m Above Base	LOW (1)
General Store No. 2	LOW (1)
Laundry	LOW (1)
NBC Store	LOW (1)
Passageway (C.L.)	LOW (1)
Plenum	LOW (1)
Reserve Feed No.1	LOW (1)
Sam (P)	LOW (1)
Sam (S)	LOW (1)
Steam Generator Intake Plenum	LOW (1)
WR Servery	LOW (1)

(b) Cracking

Compartment	Risk Level
CO's/SO's WR	LOW (1)
CPO's & P1's WP & Hds	LOW (1)
Crews HD No. 3	LOW (1)
Crews WP & Hds No. 1	LOW (1)
Crews WP & Heads No. 2	LOW (1)
Crews WP No. 3	LOW (1)
Crews Laundromat	LOW (1)
Crews Lounge Head	LOW (1)
Deck Store No. 2	LOW (1)
DFO No.1 Aft of Magazine (S)	LOW (1)
Dishwashing Compt.	LOW (1)
Dry Garbage Store	LOW (1)
Dry Provisions Store	LOW (1)
EBR	LOW (1)
Electrical Workshop	LOW (1)
FAMR Casing Flat 11.7m Above Base	LOW (1)
FCER No. 3	LOW (1)
FER Ventilation Air Intake Plenum	LOW (1)
Funnel Flat 13.2m Above Base	LOW (1)
Funnel Flat 19.6m Above Base	LOW (1)
Funnel House Top 15.9m Above Base	LOW (1)
Funnel Top	LOW (1)
Galley	LOW (1)
General Store No. 2	LOW (1)
Halon Gas Compt	LOW (1)
Hangar Top Weather Deck (Aft)	LOW (1)
Hangar Top Weather Deck (Fwd)	LOW (1)
Helo Ru Lub Lkr	LOW (1)
Int Shaft Bkt (P)	LOW (1)
Laundry	LOW (1)
Laundry Flat	LOW (1)
NBC Filter Compartment No. 1	LOW (1)
NBC Filter Compt No. 2	LOW (1)
NBC Filter Compt. No. 3	LOW (1)
NBC Store	LOW (1)
Paint Locker	LOW (1)
Paint Store	LOW (1)
Plenum	LOW (1)
QM's Lobby	LOW (1)
Reserve Feed No.1	LOW (1)
Reserve Feed No.2	LOW (1)
Shipwright's Workshop	LOW (1)
Sports Gear Store	LOW (1)
Steam Generator Intake Plenum	LOW (1)
Void	LOW (1)
WR Servery	LOW (1)

At this stage, it may be necessary to undertake a quantitative risk assessment to refine the probability of failure and/or consequence severity levels for the compartments with "High" or

"Extreme" risk criticality. For this pilot study this step is not undertaken, for simplicity, and we go directly to demonstrate the inspection and maintenance plan.

4.4 INSPECTION AND REPAIR PLAN

The inspection and repair plans according to the current RCN practice and the proposed RIIMM approach are presented in this section. The planning period is 10 years, which represents two inspection and maintenance cycles under current practices.

4.4.1 HMCS Halifax Inspection and Repair Plan

Table 4-6 shows the inspection and maintenance plan for HMCS Halifax as per current progressive inspection regime. The focus is on corrosion damage. It is assumed that all of the 183 compartments are inspected within a five year cycle with approximately 20% inspected every year. Therefore, at the end of the 10 year period, each compartment would have been inspected twice. Additionally, for costing purposes it is assumed that in each year 80% of the inspections are by visual inspection, while 20% of the inspections are by advanced NDE inspection methods. All damages found are repaired according to the following scheme: 50% by cleaning and preserving with coating; 30% of grinding and filling with weld metals; and 20% by metal replacement.

Table 4-6: Inspection and Repair Plans for HMCS Halifax According to Current Practice

(a) Inspection Plan

	No. of Components Inspected in Year										Total
	1	2	3	4	5	6	7	8	9	10	
Inspection Plan	36	36	36	36	39	36	36	36	36	39	366
Compartments Inspected by Visual Inspection	29	29	29	29	31	29	29	29	29	31	294
Compartment Inspected by Advanced Methods	7	7	7	7	8	7	7	7	7	8	72

(b) Repair Plan

	No. of Components Repaired in Year										Total
	1	2	3	4	5	6	7	8	9	10	
Repair Plan	36	36	36	36	39	36	36	36	36	39	366
Compartments Repaired by Cleaning and Paint Preservation	18	18	18	18	20	18	18	18	18	20	184
Compartments Repaired by Grinding and Filling with Weld Metal	11	11	11	11	12	11	11	11	11	12	112
Compartments Repaired by Metal Replacement	7	7	7	7	7	7	7	7	7	7	70

Table 4-7 shows the inspection and repair plans according to the RIIMM approach. Compartments to be inspected are determined by their risk criticality. Recall that for corrosion damage on HMCS Halifax, 152 components were assessed at "Low" risk, 29 at "Medium" risk and two at “High” risk criticality and none at “Extreme” risk criticality. The two compartments at “High” risk criticality are planned to be monitored and inspected again in two years. Twenty nine compartments had a “Medium” risk criticality and are planned to be inspected by Year 5. The inspection of compartments ranked as “Low” risk is delayed till Year 7. Therefore, according to the initial inspection plan all 152 “Low” risk compartments are inspected by Year 7. After inspection or/ and repair actions have been carried out in each year, a reassessment of the risk of inspected or repaired compartments is carried out and the risk profile and inspection plan updated. In the table RA stands for risk assessment.

Table 4-7: Inspection and Repair Plans for HMCS Halifax According to RIIMM

(a) Inspection Plan

	No. of Components Inspected in Year										Total
	1	2	3	4	5	6	7	8	9	10	
Initial Inspection Plan	0	2	0	0	29	0	152	0	0	0	
Inspection Plan After Year 2 RA	0	0	0	2	0	0	0	0	0	2	
Inspection Plan After Year 5 RA	0	0	0	0	0	0	15	0	0	14	
Inspection Plan After Year 7 RA	0	0	0	0	0	0	0	0	15	0	
Total	**0**	**2**	**0**	**2**	**29**	**0**	**167**	**0**	**15**	**16**	**231**

(b) Repair Plan

	No. of Components Repaired in Year										Total
	1	2	3	4	5	6	7	8	9	10	
Initial Repair Plan	0	0	0	0	2	0	0	0	0	0	
Repair Plan After Year 2 RA	0	0	0	0	0	0	0	0	0	0	
Repair Plan After Year 5 RA	0	0	0	0	0	0	0	0	0	15	
Repair Plan After Year 7 RA	0	0	0	0	0	0	0	0	0	0	
Total	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**15**	**17**

Consider the two “High” risk compartments, after inspection at Year 2 the risk level is still assessed to be “High”, therefore, they are planned to be monitored and inspected again in Year 4. At Year 4, the risk level is still assessed as “High”, so these compartments will continue to be monitored. However, at the next dry dock opportunity in Year 5, these two compartments are repaired. At this time, risk criticality of these two compartments are reassessed and determined to be “Medium” risk, and are then stipulated to be inspected again in five years’ time (i.e. at Year 10).

Consider the 29 compartments initially assessed to have a “Medium” risk criticality level. As per the RIIMM approach these compartments are selected to be inspected in Year 5, but not repaired at that time. It is assumed that during this inspection it is confirmed that approximately half (15) of the compartments have gotten worse and their criticality assessed to have increased to “High” risk level. These 15 compartments will now have to be monitored and inspected in 2 years’ time (i.e. in Year 7). The remaining 14 compartments are still assessed to be at “Medium” risk criticality and scheduled for inspection again at Year 10.

Consider the 152 compartments initially assessed to have “Low” risk criticality. As per RIIMM approach these compartments are scheduled to be inspected in Year 7. Furthermore, based on the inspection, 80% (122) of these compartments are assessed to continue to be at "Low" risk criticality level, while 20% (30) of them are now assessed to be "Medium" risk criticality level. Hence the next scheduled inspection for the 122 "Low" risk compartments will be in seven years (Year 14) and for the 30 "Medium" risk compartments will be in five years (Year 12). Both of these time frames are outside of the 10 years planning period.

In summary, over the 10 years planning period, the RIIMM process requires 231 inspections compared to 366 inspections performed as per current practice. In terms of repairs, the RIIMM process requires a total of 17 compartments to be repaired over the 10 year period. Such repairs will be by advanced repair methods such as metal replacements or grinding and filling with weld metal. In comparison, for this case study, it is assumed that according to the current maintenance practice, 366 repairs are required: 184 by simple cleaning and coating preservation, 122 by grinding and welding, and 70 by metal replacement. It should be mentioned that in real situations under the current practice, some repairs are not implemented depending on the level of damage and with the approval of the FTA and/or DA, although the repair philosophy is to repair any defects that are found. The number of deferred repairs under the current practice is not clear. The uncertainty in the number of repairs deferred under the current practice is accounted for by the assumed distribution of compartments repaired by various methods: 50% by cleaning and preservation, 30% by grinding and welding, and 20% by metal replacement.

Table 4-8 summarizes the total numbers of inspections and repairs over 10 years planning period. However, during the implementation phase, the project team will seek clarification of the actual numbers of repairs from East and West Coasts inspection and maintenance personnel. This will ensure a more accurate cost comparison with proposed RIIMM process.

Table 4-8: Number of Inspections and Repairs for HMCS Halifax over 10 Year Period

Description	Current Practice*	RIIMM Approach
Number of Inspections Performed	366	231
Number of Repairs by Cleaning and Paint Preservation	184	0
Number of Repairs by Grinding and Filling with Weld Metal	112	0
Number of Repairs by Metal Replacement	70	17
Total Number of Repairs Required	366	17
* Assumes all defects are repaired in current RCN practice		

4.4.2 HMCS Vancouver Inspection and Repair Plan

The inspection and maintenance plan for HMCS Vancouver based on current practice is identical to HMCS Halifax assuming both ships follow the progressive inspection regime. The project team will discuss with the inspection and maintenance personnel during the full implementation phase, if there are any differences.

The inspection and repair plans according to the RIIMM approach were developed using the qualitative risk assessment results and are shown in Table 4-9. The compartments to be inspected or repaired are determined by their risk criticality levels. Considering corrosion damage, 88 compartments were assessed as "Low" risk, 44 as "Medium" risk, 42 as "High" risk and nine as "Extreme" risk criticality. The nine compartments at "Extreme" risk require immediate full repair. The forty-two compartments at "High" risk criticality are planned to be monitored and inspected again in two years. Forty-four compartments had a "Medium" risk criticality and are planned to be inspected by Year 5. The inspection of the 88 compartments ranked as "Low" risk is delayed till Year 7. As discussed above, after inspection and repair actions have been carried out in each year, a reassessment of the risk of inspected or repaired compartments is carried out and the risk profile and inspection plan updated.

Table 4-9: Inspection and Repair Plans for HMCS Vancouver According to RIIMM

(a) Inspection Plan

	No. of Components Inspected in Year										Total
	1	2	3	4	5	6	7	8	9	10	
Initial Inspection Plan	9	42	0	0	44	0	88	0	0	0	
Inspection Plan After Year 1 RA	0	0	0	0	9	0	0	0	0	0	
Inspection Plan After Year 2 RA	0	0	0	42	0	0	0	0	0	42	
Inspection Plan After Year 5 RA	0	0	0	0	0	0	27	0	0	26	
Inspection Plan After Year 7 RA	0	0	0	0	0	0	0	0	27	0	
Total	**9**	**42**	**0**	**42**	**53**	**0**	**115**	**0**	**27**	**68**	**356**

(b) Repair Plan

	No. of Components Repaired in Year										
	1	2	3	4	5	6	7	8	9	10	Total
Initial Repair Plan	9	0	0	0	42	0	0	0	0	0	51
Repair Plan After Year 1 RA	0	0	0	0	0	0	0	0	0	0	
Repair Plan After Year 2 RA	0	0	0	0	0	0	0	0	0	0	
Repair Plan After Year 5 RA	0	0	0	0	0	0	0	0	0	27	27
Repair Plan After Year 7 RA	0	0	0	0	0	0	0	0	0	0	
Total	**9**	**0**	**0**	**0**	**42**	**0**	**0**	**0**	**0**	**27**	**78**

The nine compartments at "Extreme" risk are repaired immediately. After performing a full repair, the risk level of these compartments is reassessed to be "Medium". Therefore, they are scheduled to be inspected again in Year 5. Consider the 42 "High" risk compartments. After inspection at Year 2 the risk level is still assessed to be "High", therefore, they are planned to be monitored and inspected again in Year 4. At Year 4, the risk level is still assessed as "High", so these compartments will continue to be monitored. However, at the next dry dock opportunity in Year 5, these 42 compartments are repaired. At this time, the risk criticality of these 42 compartments are reassessed and determined to be "Medium" risk, and are scheduled to be inspected again in five year time (i.e. at Year 10).

Consider the 44 compartments initially assessed to have a "Medium" risk criticality level. As per the RIIMM approach these compartments are selected to be inspected in Year 5, but not repaired at that time. In addition, there are nine compartments at "Medium" risk that are required to be inspected in Year 5. Therefore, in Year 5, a total of 53 compartments are inspected. It is assumed that during this inspection it is confirmed that approximately half (27) of the compartments have gotten worse and their criticality assessed to have increased to “High” risk level. These 27 compartments will now have to be monitored and inspected in 2 years’ time (i.e. in Year 7). The remaining 26 compartments are still assessed to be at “Medium” risk criticality and scheduled for inspection again at Year 10.

Consider the 88 compartments initially assessed to have “Low” risk criticality. As per RIIMM approach these compartments are scheduled to be inspected in Year 7. As discussed above, after Year 7 inspection, 80% (70) of these compartments are assessed to continue to be at “Low” risk criticality level, while 20% (18) of them are now assessed to be at “Medium” risk criticality level. Hence the next scheduled inspection for the 70 “Low” risk compartments will be in seven years (Year 14), and for the 18 “Medium” risk compartments will be in five years (Year 12). Both of these time frames are outside of the 10 years planning period.

In summary, over the 10 years planning period, the RIIMM process requires 356 inspections compared to 366 inspections performed as per current practice. In terms of repairs, the RIIMM process requires a total of 78 compartments to be repaired over the 10 year period using advanced repair methods. Table 4-8 summarizes the total number of inspections and repairs over 10 years planning period. Again, during the implementation phase, the project team will seek clarification of the actual numbers of repairs from East and West Coasts inspection and maintenance personnel.

Table 4-10: Number of Inspections and Repairs for HMCS Vancouver Over 10 Year Period

Description	Current Practice*	RIIMM Approach
Number of Inspections Performed	366	356
Number of Repairs by Cleaning and Paint Preservation	184	0
Number of Repairs by Grinding and Filling with Weld Metal	112	0
Number of Repairs by Metal Replacement	70	78
Total Number of Repairs Required	366	78
* Assume all defects are repaired in current RCN practice		

4.5 COST ESTIMATION

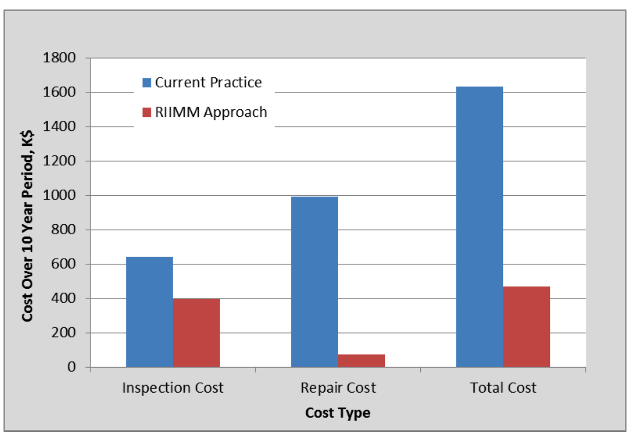
In this section, the estimation of inspection and repair costs is demonstrated to illustrate potential benefits of RIIMM approach in terms of savings in inspection and maintenance costs. The inspection and repair plans presented in Section 4.4 are used in conjunction with the cost assumptions in Table 4-1, using Equations 3-1 and 3-2.

4.5.1 Cost Estimation for HMCS Halifax

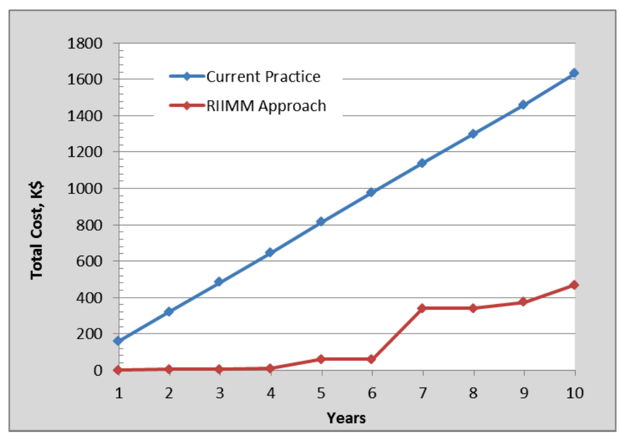
Table 4-11 summarizes the estimated annual inspection, repair and total costs for HMCS Halifax according to current practice and RIIMM approach. The total costs over the 10 year period are also presented in Figure 4-3, along with the cumulative cost for inspection, repair and total costs. As stated earlier these results should be treated as qualitative rough order of magnitude values, since actual costs have not been used. However, the table clearly illustrates that, in general, there is potentially a cost benefit to be gained by the use of the RIIMM process, as both inspection and repair costs under RIIMM process are lower than under current practice. In this illustrative example, the total inspection and maintenance costs using the RIIMM process are approximately on 30% of the total costs based on the current practice.

Table 4-11: Summary of Inspection and Repair Costs for HMCS Halifax

Year	Inspection Cost* (k$)		Repair Cost* (k$)		Total Cost* (k$)	
	Current Practice	RIIMM	Current Practice	RIIMM	Current Practice	RIIMM
Year 1	63	0	98	0	161	0
Year 2	63	5	98	0	161	5
Year 3	63	0	98	0	161	0
Year 4	63	5	98	0	161	5
Year 5	69	46	103	4	172	50
Year 6	63	0	98	0	161	0
Year 7	63	279	98	0	161	279
Year 8	63	0	98	0	161	0
Year 9	63	36	98	0	161	36
Year 10	69	26	103	69	172	95
Total	**643**	**397**	**989**	**73**	**1632**	**470**
*For illustration purposes only						



(a)



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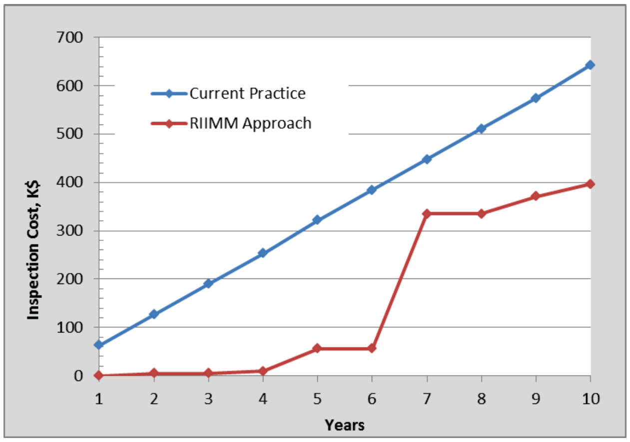

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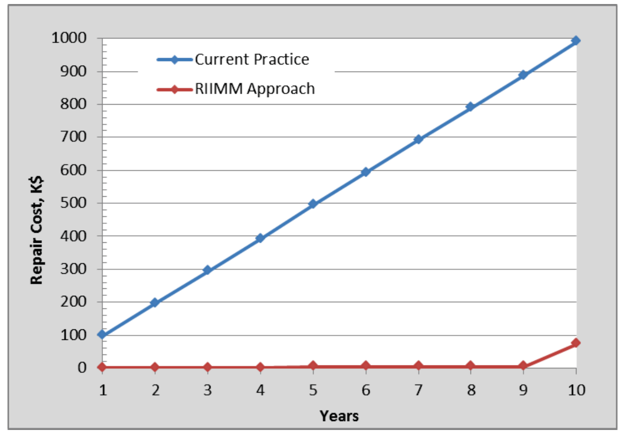


(d)

Figure 4-3: Cost Distribution for HMCS Halifax: (a) Cost Over 10 Year Period, (b) Cumulative Total Cost, (c) Cumulative Inspection Cost, and (d) Cumulative Repair Cost

4.5.2 Cost Estimation for HMCS Vancouver

A summary of annual inspection, repair and total costs for the HMCS Vancouver is shown in Table 4-12. The total costs over the 10 year period are also presented in Figure 4-4, along with the cumulative inspection, repair and total costs. Again, these results should be treated as qualitative rough order of magnitude values, since actual costs have not been used. In this example, the total inspection and repair costs using under the RIIMM regime are approximately 67% of the total costs under the current practice.

Table 4-12: Summary of Inspection and Repair Costs for HMCS Vancouver

Year	Inspection Cost* (k$)		Repair Cost* (k$)		Total Cost* (k$)	
	Current Practice	RIIMM	Current Practice	RIIMM	Current Practice	RIIMM
Year 1	63	22	98	69	161	91
Year 2	63	101	98	0	161	101
Year 3	63	0	98	0	161	0
Year 4	63	101	98	0	161	101
Year 5	69	85	103	202	172	287
Year 6	63	0	98	0	161	0
Year 7	63	206	98	0	161	206
Year 8	63	0	98	0	161	0
Year 9	63	65	98	0	161	65
Year 10	69	109	103	127	172	236
Total	**643**	**689**	**989**	**398**	**1632**	**1087**
*For illustration purposes only						

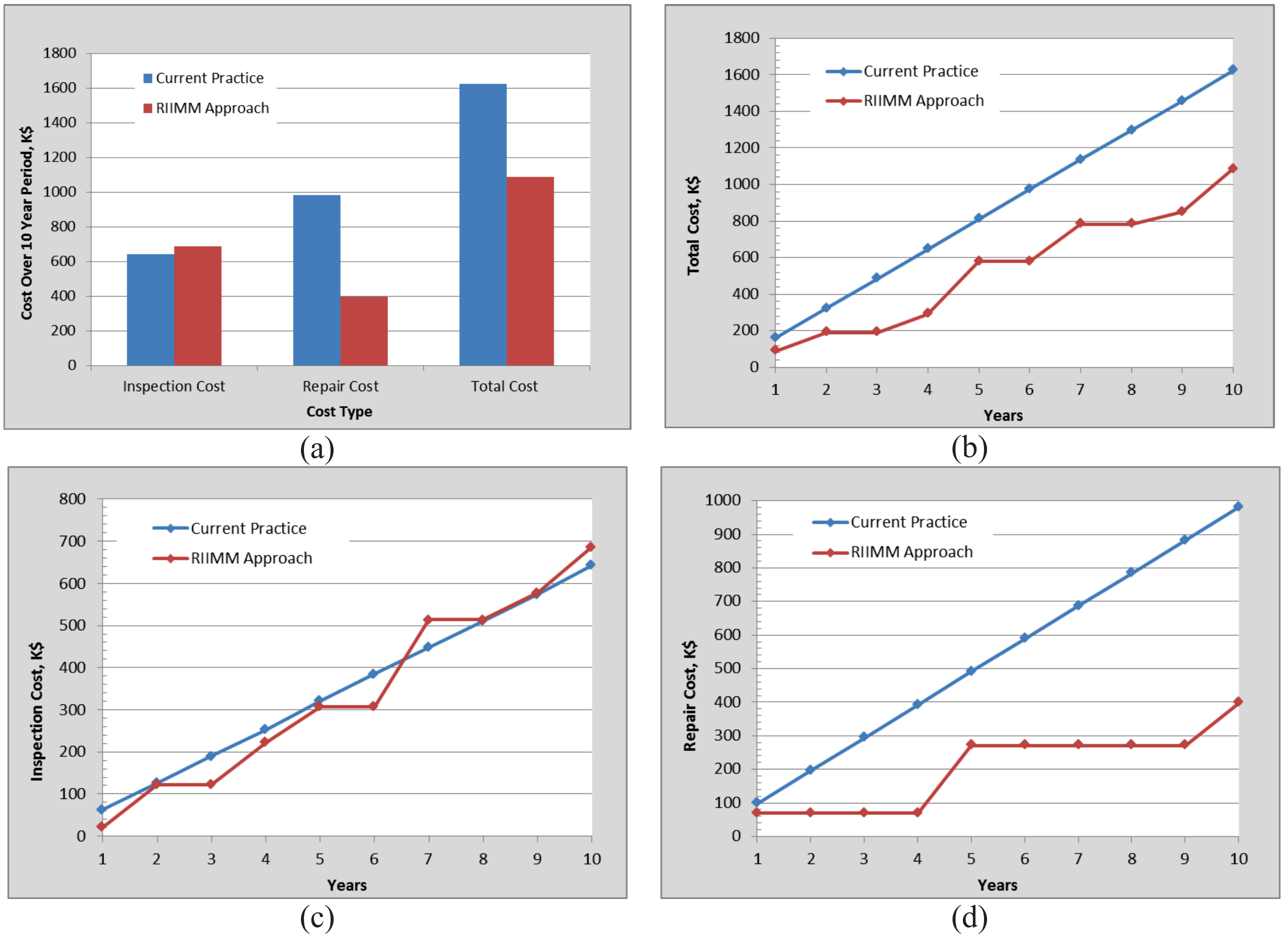


Figure 4-4: Cost Distribution for HMCS Vancouver: (a) Cost Over 10 Year Period, (b) Cumulative Total Cost, (c) Cumulative Inspection Cost, and (d) Cumulative Repair Cost

It is seen that the cost savings are higher for HMCS Halifax than for HMCS Vancouver. This is because there are fewer compartments ranked as “High” or “Extreme” risk criticality for HMCS Halifax than HMCS Vancouver. The RIIMM process allocates more resources to high risk compartments, rather than allocating resources equally to all compartments, as generally done in current practice.

5.0 RIIMM IMPLEMENTATION PLAN

5.1 INTRODUCTION

The preceding chapters have shown the feasibility of developing a RIIMM process for the RCN fleet, and demonstrated potential benefits in terms of savings in inspection and repair costs, and enhancement of safety and mission readiness. In this chapter a plan for the full implementation of the RIIMM process for the HALIFAX class ships is presented. The main tasks to be carried out in the RIIMM implementation are listed below:

- Task 1: Stakeholder Engagement
- Task 2: Refinement of RIIMM Methodology
- Task 3: Assessment of Risk Profile of All Vessels of RCN Fleet
- Task 4: RIIMM Software Architecture Development
- Task 5: Implementation of RIIMM Methodology and Software
- Task 6: Case Studies
- Task 7: Documentation
- Task 8: Training of RCN Fleet Maintenance Personnel

Details of the activities in each of the tasks are provided in the following section.

5.2 DESCRIPTION OF RIIMM IMPLEMENTATION TASKS

5.2.1 Task 1: Stakeholder Engagement

In this task the project team will engage various stakeholders on the East and West Coasts, as well as Headquarters to explain the RIIMM philosophy and methodology. The project team will also seek clarification on various issues/gaps identified in this study, such as uncertainties/inconsistencies in the defects database; how difficult-to-inspect components are treated; inspection and repair scopes at any given time/cycle; inspection and repair costs; risk matrix and risk tolerance criteria; etc. This will be carried out through administration of questionnaires and face-to-face meetings with inspection and maintenance personnel. Discussions will be held with the stakeholders to gain agreement on the RIIMM concepts, such as delaying inspections of Low risk components by two years; delaying repairs of Medium risk components; increasing the frequency of inspection of High and Extreme risk components; etc. It is anticipated that SME (Subject Matter Expert) opinion, historical experience, and results from targeted computational studies will be used to gain confidence in the provisions of the RIIMM inspection and repair strategies, and to facilitate agreement.

5.2.2 Task 2: Refinement of RIIMM Methodology

The results of Task 1 will be used to refine the RIIMM methodology. It is anticipated that stakeholder engagement will enable refinement of the following aspects of the methodology:

- Clarification of uncertainties and inconsistencies in the defects database, enabling the project team to make better use of the database
- Refinement of the damage incident rates

- Refinement of definition/estimation of damage frequencies and probability of failure due to defects
- Risk tolerance criteria and potential changes in inspection and repair frequencies
- Inspection/repair techniques for various types and level of defects
- Inspection and repair costs

5.2.3 Task 3: Assessment of Risk Profiles of All Vessels of HALIFAX Class

A major aspect of the RIIMM process requires determination of the risk profiles of the vessels of the fleet, as input to inspection and maintenance planning. To this end, the risk profiles of all vessels of the HALIFAX Class will be determined in this task, using the qualitative risk assessment approach described in this report. This would be held in workshop settings with various SMEs attending and contributing to the risk estimation. The project team will provide a Facilitator and Technical Scribe. It should be mentioned that the outcome of this task will be useful by itself to the RCN, even before the complete full implementation of the RIIMM methodology. This is because the risk profiles will enable RCN to know the inherent risks of their vessels, which can provide input to fleet operational decisions.

5.2.4 Task 4: RIIMM Software Architecture Development

In this task, the RIIMM software framework will be developed. Consideration will be given to the following:

- Database management framework that utilizes the HALIFAX Class defects database
- Framework for managing (reviewing and updating) the vessels risk profiles
- Framework for the RIIMM process and inspection and repair activity planning and optimization
- User interaction with RIIMM system

The vessels' risk profiles, initially assessed using Excel worksheets will be transferred to the RIIMM software framework so developed as a demo. This will be a functional tool to review and update the vessels' risk profiles.

5.2.5 Task 5: RIIMM Software Implementation

In this task, full implementation of the RIIMM software will be undertaken. This would include the following:

- Development of RIIMM algorithms, including the inspection and maintenance plan optimization
- Development of structural reliability analysis databases, and input to the RIIMM system
- Full implementation of database management processes that interacts with the RCN defects database, ensuring that ways of capturing future updates to the defects database are in place
- Full implementation of managing the vessels' risk profiles
- Full implementation of the Graphical User Interface (GUI) for the RIIMM system.

5.2.6 *Task 6: Case Studies*

In this task, several case studies will be performed to demonstrate various aspects of the RIIMM methodology. The case studies will be carefully selected by the project team, in collaboration with RCN maintenance personnel to illustrate benefits/advantages of the RIIMM approach over the current practice, as well as to demonstrate any potential limitations of the RIIMM approach. As a minimum, the following cases will be considered:

(a) Inspection and maintenance planning for select individual vessels of the East Coast Fleet
(b) Inspection and maintenance planning for select individual vessels of the West Coast Fleet
(c) Inspection and maintenance planning for East Coast Fleet
(d) Inspection and maintenance planning for West Coast Fleet

5.2.7 *Task 7: Documentation*

This task involves the preparation of RIIMM documentation, including the following:

(a) Reports on the RIIMM methodology and results obtained for all case studies
(b) RIIMM software user’s and examples manuals
(c) Training material

5.2.8 *Task 8: Training of RCN Fleet Maintenance Personnel*

The project team will provide training to RCN personnel on the use of the RIIMM software system. It is planned to have training sessions in Halifax, Victoria and Ottawa, as may be required.

5.3 SCHEDULE

It is planned to undertake the RIIMM implementation in three work packages (WP) as shown in Table 5-1.

Table 5-1: RIIMM Work Packages

WP #	Tasks Included	Duration
1	Task 1: Stakeholder Engagement Task 2: Refinement of RIIMM Methodology Task 3: Assessment of Risk Profile of All Vessels of RCN Fleet Task 4: RIIMM Software Architecture Development	12 Months
2	Task 5: Implementation of RIIMM Methodology and Software Task 6: Case Studies	12 Months
3	Task 7: Documentation Task 8: Training of RCN Fleet Maintenance Personnel	3 months after WP #1; and 3 months after WP #2

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This report provides details of a multi-year study initiated by DRDC Atlantic to develop and apply risk based approaches for the HALIFAX class ships. The main objective of the overall project is to develop risk-informed inspection and maintenance management (RIIMM) strategies for the HALIFAX class vessels. The current task is a scoping study aimed at investigating the feasibility and plan for undertaking a RIIMM methodology for the HALIFAX Class, and includes: (a) review of the existing HALIFAX class defect, inspection and maintenance database and assessing its suitability for use in a RIIMM assessment; (b) developing a research plan for developing a RIIMM approach for the HALIFAX class; (c) performance of a case study to demonstrate the feasibility and benefits of the RIIMM methodology; and (d) development of an implementation plan for applying a RIIMM approach to the HALIFAX class.

The review of the HALIFAX class inspection database and analysis of the data provided a good insight into the nature of data collected and how the data could be applied in a risk-based framework. The features of the database that make it suitable for use in a risk-based framework include: (a) clear indication of the system breakdown, highlighting the compartments/components that are inspected and repaired; (b) specification of damage modes (corrosion, cracking, deformation, paint preservation, fabrication and other) that are inspected and how the damages are assessed; (c) provision of inspection and repair frequencies and how these are carried out. A number of limitations/gaps were also identified that need to be addressed to enhance its use in the RIIMM framework. These include inconsistencies in the reporting of inspection data, such as damage sizes, and "Other" failure mode entries. Clarifications are also required on the subsets of components inspected and repaired at any given inspection/repair period; handling of difficult-to-inspect components; status of components listed in the database; and repair process, all of which will be required to determine damage growth rates, and to establish maintenance costs of the current practice.

A preliminary RIIMM framework has been formulated in the current task. A methodology is developed that does not deviate much from current practice; makes use of available data as much as possible; does not have significant data collection requirements beyond current practice; is well structured, rigorous and repeatable; is easy to use and comprehend; enhances safety and mission readiness; and is cost effective compared to current practice. It comprises a six step process including: (i) system boundary definition; (ii) qualitative risk assessment, based on a risk matrix that categorizes risk as "Low", "Medium", "High", or "Extreme", with input from historical incident database and subject matter expert opinion; (iii) risk based screening; (iv) quantitative risk assessment; (v) inspection and maintenance plan; and (vi) updating of the inspection and maintenance plan following inspection and repair actions. The highlights of the proposed methodology are summarized below:

- Increased inspection interval for components ranked as "Low" risk;
- Delay of repairs for components ranked as "Medium" risk;
- Reduced inspection interval for components ranked as "High" risk. Possibility to delay repairs until it is practicable to do so;
- Immediate repairs of components ranked as "Extreme" risk before next mission.
- Optimization algorithms will be provided for making optimum inspection and repair plans during the full implementation.

A case study was performed to demonstrate the technical feasibility of applying RIIMM methodology to the HALIFAX class ships, and to demonstrate the potential benefits that can be gained through implementation of the RIIMM methodology. One ship from the East Coast fleet (HMCS Halifax) and one ship from West Coast fleet (HMCS Vancouver) were chosen for the case study. Approximately 180 compartments and structures were selected for each ship, for illustration purposes. The inspection and repair of corrosion and cracking damage modes were considered. The study was designed to demonstrate the following aspects of the RIIMM approach: (a) criticality (risk) assessment and the ranking of the compartments; (b) inspection and maintenance plan over a 10 year period; and (c) benefits (cost savings) of RIIMM, compared to current inspection and maintenance practice.

In order to facilitate the RIIMM assessments, some assumptions have been made in this case study. Therefore, the results presented are for illustration purposes only, until the assumptions have been refined during the full implementation. For this demonstration example, it is seen that 99% of the compartments of HMCS Halifax have a risk ranking of Medium or Low, whereas only 1% of the compartments are ranked as “High” risk. For HMCS Vancouver, 72% are ranked as “Medium” or “Low” risk, whereas 28% are ranked as “High” or “Extreme” risk. Therefore, in this example, HMCS Vancouver will be regarded as having a higher risk profile than HMCS Halifax. A closer look of HMCS Vancouver results indicates that the “High” and “Extreme” risk values are influenced by the uncertainty in the corrosion depth and extents. Therefore, efforts would be made during the implementation phase to clarify the corrosion sizes as logged in the defects database.

The numbers of inspections and repairs undertaken over the 10 year planning period were also calculated for the current practice and proposed RIIMM process. In general, the RIIMM process suggests fewer numbers of inspections and repairs over the planning period, compared to the current practice. Also, due to the lower risk profile of HMCS Halifax, the RIIMM process requires fewer numbers of inspections and repairs than for HMCS Vancouver. In terms of inspection, repair and total costs for the planning period, it is seen that the costs under the RIIMM regime are generally lower than those under the current practice. For this case study, the application of the RIIMM process provide 71% and 33% reductions in inspection and repair costs for HMCS Halifax and HMCS Vancouver, respectively. The greater savings are for HMCS Halifax, which has a lower risk profile than HMCS Vancouver. The RIIMM process allocates more resources to high risk compartments, rather than allocating resources equally to all compartments, as generally done in current practice.

The results of the study have shown the feasibility of developing a RIIMM process for the HALIFAX class ships, and demonstrated potential benefits in terms of savings in inspection and repair costs, and enhancement of safety and mission readiness. It is recommended to undertake future studies to refine and implement the RIIMM methodology for the RCN. It is suggested to undertake the RIIMM implementation in three work packages (WP) as shown in Table 5-1.

7.0 REFERENCES

[1] DND, "Maintenance Policy: Requirements for the Survey and Repair of Steel Ships (C-03-015-003/AM-001)," 2002.
[2] DND, "Hull Structure (Progressive Survey) Part 1 (C-28-402-000/NW-001)," 2015.
[3] DND, "Hull Structure (Progressive Survey) Part 2 (C-28-402-000/NW-002)," 2015.
[4] DND, "Hull Structure (Progressive Survey) Part 3 (C-28-402-000/NW-003)," 2015.
[5] DND, "Hull Structure (Progressive Survey) Part 4 (C-28-402-000/NW-004)," 2015.
[6] DND, "Hull Structure (Progressive Survey) Part 5 (C-28-402-000/NW-005)," 2015.
[7] DND, "Maintenance Painting Specification for HMC Ships - D-23-003-005/SF-002".
[8] DND, "Welding Specification for HMC Ships - D-49-003-003/SF-001".
[9] DND, NAVORD 3001-1: In-service Naval Material Risk Management Process, 2014

APPENDIX A

Summaries of Defects Analysis Results for

HMCS Ville de Quebec (East Coast)
HMCS Regina (West Coast)
HMCS Calgary (West Coast)
HMCS Winnipeg (West Coast)
HMCS Ottawa (West Coast)

A.1 Defects Summary for HMCS Ville de Québec (East Coast)

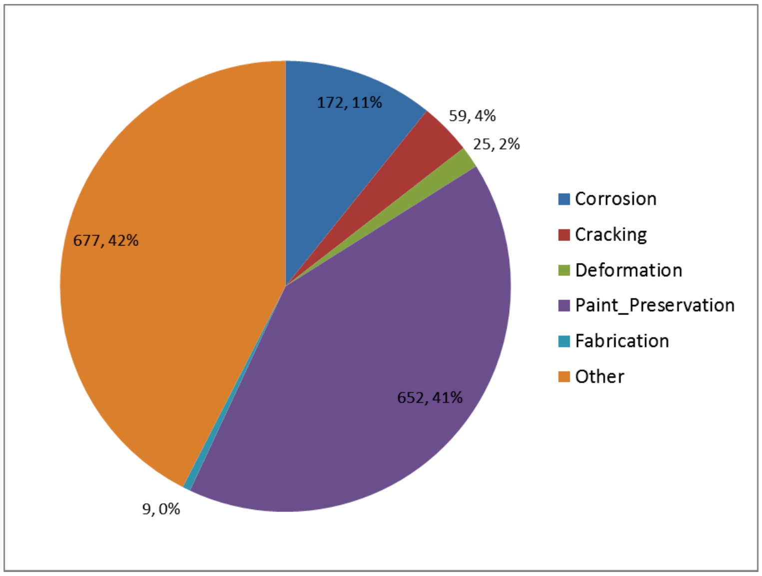
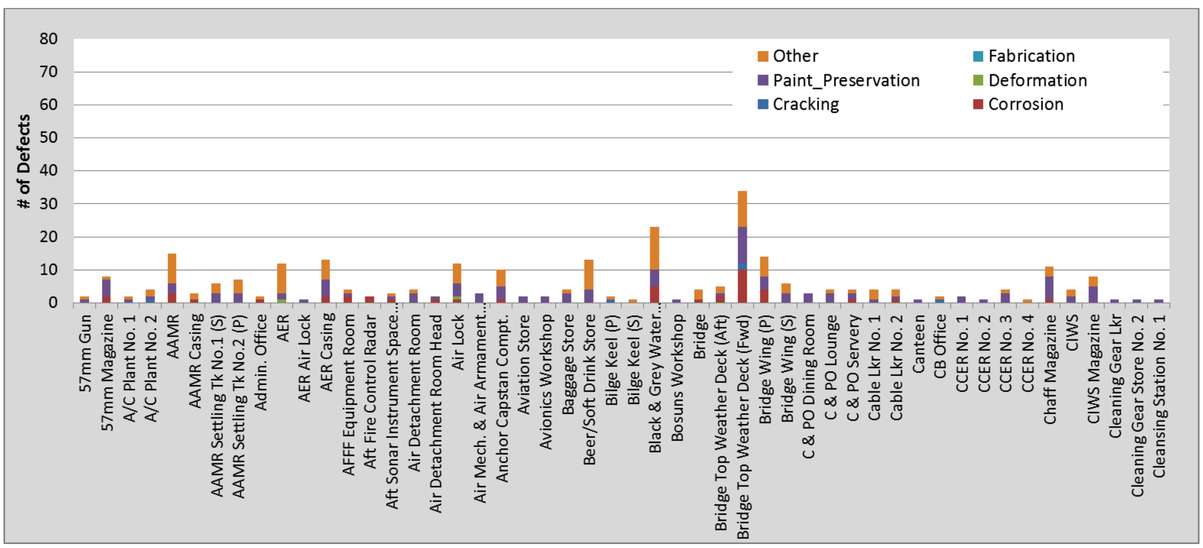
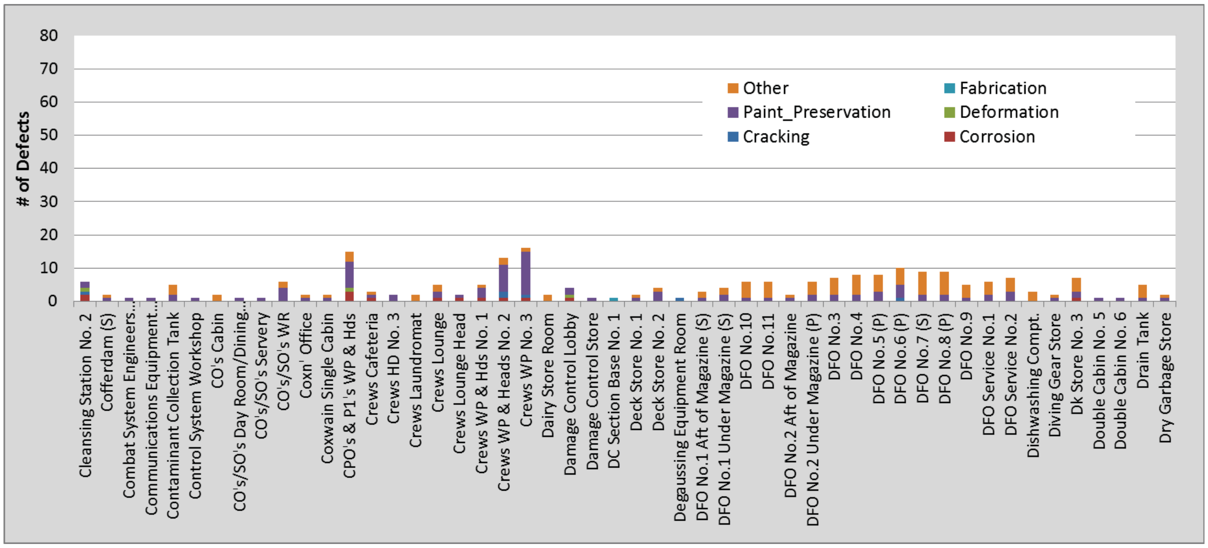
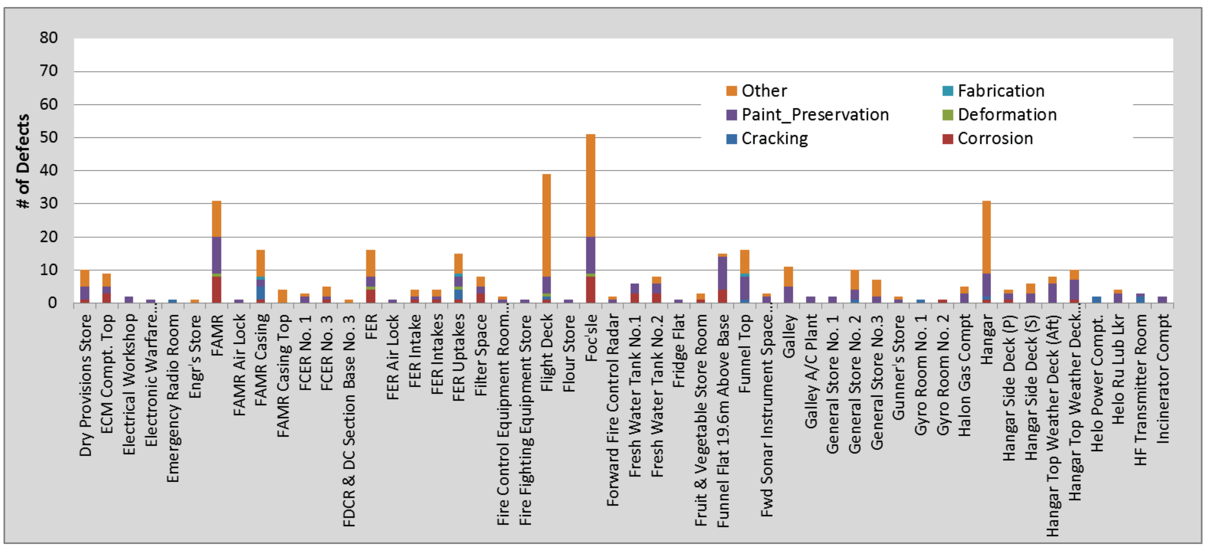


Figure A-1: Total Numbers of Defects by Type for HMCS Ville de Québec

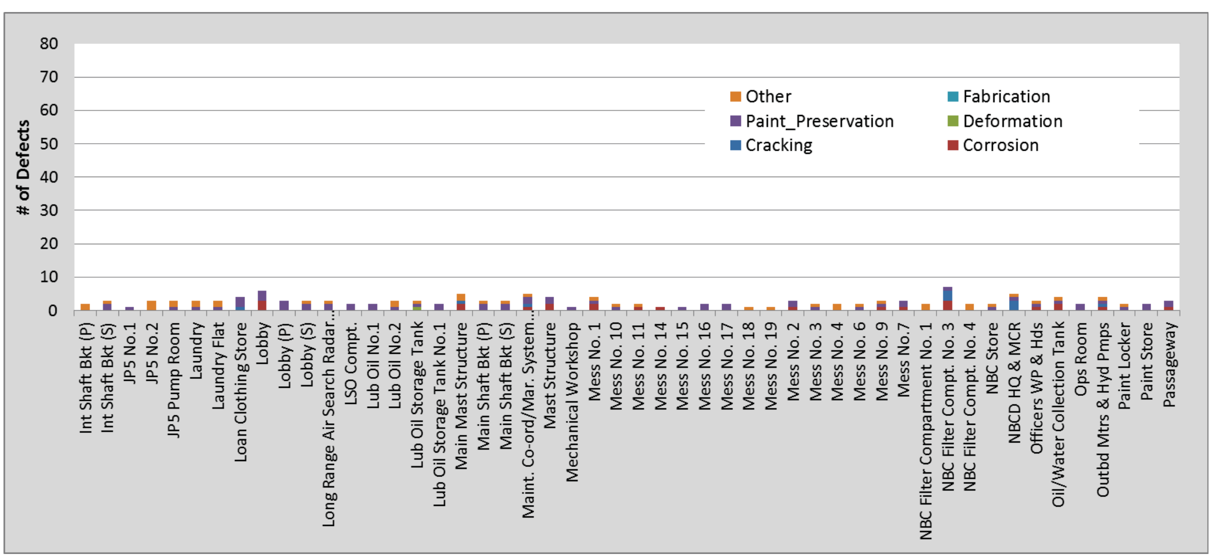




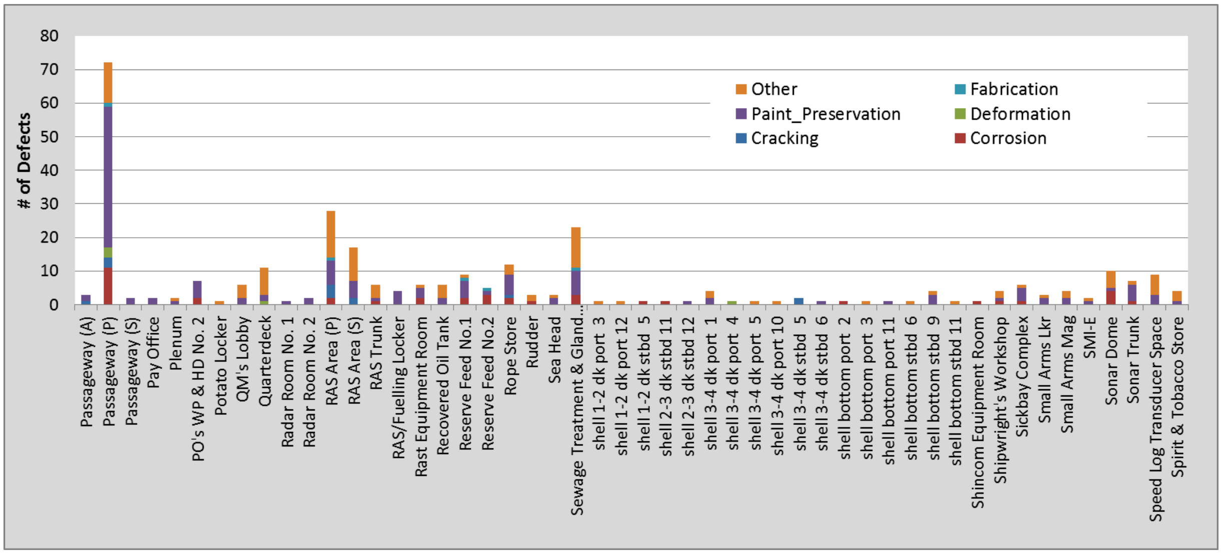
# of Defects
80
70
60
50
40
30
20
10
0
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
Cleansing Station No. 2
Cofferdam (S)
Combat System Engineers...
Communications Equipment...
Contaminant Collection Tank
Control System Workshop
CO's Cabin
CO's/SO's Day Room/Dining...
CO's/SO's Servery
CO's/SO's WR
Coxn' Office
Coxwain Single Cabin
CPO's & P1's WP & Hds
Crews Cafeteria
Crews HD No. 3
Crews Laundromat
Crews Lounge
Crews Lounge Head
Crews WP & Hds No. 1
Crews WP & Heads No. 2
Crews WP No. 3
Dairy Store Room
Damage Control Lobby
Damage Control Store
DC Section Base No. 1
Deck Store No. 1
Deck Store No. 2
Degaussing Equipment Room
DFO No.1 Aft of Magazine (S)
DFO No.1 Under Magazine (S)
DFO No.10
DFO No.11
DFO No.2 Aft of Magazine
DFO No.2 Under Magazine (P)
DFO No.3
DFO No.4
DFO No.5 (P)
DFO No.6 (P)
DFO No.7 (S)
DFO No.8 (P)
DFO No.9
DFO Service No.1
DFO Service No.2
Dishwashing Compt.
Diving Gear Store
Dk Store No. 3
Double Cabin No. 5
Double Cabin No. 6
Drain Tank
Dry Garbage Store



# of Defects
80
70
60
50
40
30
20
10
0
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
Dry Provisions Store
ECM Compt. Top
Electrical Workshop
Electronic Warfare...
Emergency Radio Room
Engr's Store
FAMR
FAMR Air Lock
FAMR Casing
FAMR Casing Top
FCER No. 1
FCER No. 3
FDCR & DC Section Base No. 3
FER
FER Air Lock
FER Intake
FER Intakes
FER Uptakes
Filter Space
Fire Control Equipment Room...
Fire Fighting Equipment Store
Flight Deck
Flour Store
Foc'sle
Forward Fire Control Radar
Fresh Water Tank No.1
Fresh Water Tank No.2
Fridge Flat
Fruit & Vegetable Store Room
Funnel Flat 19.6m Above Base
Funnel Top
Fwd Sonar Instrument Space...
Galley
Galley A/C Plant
General Store No. 1
General Store No. 2
General Store No.3
Gunner's Store
Gyro Room No. 1
Gyro Room No. 2
Halon Gas Compt
Hangar
Hangar Side Deck (P)
Hangar Side Deck (S)
Hangar Top Weather Deck (Aft)
Hangar Top Weather Deck...
Helo Power Compt.
Helo Ru Lub Lkr
HF Transmitter Room
Incinerator Compt



# of Defects
80
70
60
50
40
30
20
10
0
Other
Paint_Preservation
Cracking
Fabrication
Deformation
Corrosion
Int Shaft Bkt (P)
Int Shaft Bkt (S)
JP5 No.1
JP5 No.2
JP5 Pump Room
Laundry
Laundry Flat
Loan Clothing Store
Lobby
Lobby (P)
Lobby (S)
Long Range Air Search Radar...
LSO Compt.
Lub Oil No.1
Lub Oil No.2
Lub Oil Storage Tank
Lub Oil Storage Tank No.1
Main Mast Structure
Main Shaft Bkt (P)
Main Shaft Bkt (S)
Maint. Co-ord/Mar. System...
Mast Structure
Mechanical Workshop
Mess No. 1
Mess No. 10
Mess No. 11
Mess No. 14
Mess No. 15
Mess No. 16
Mess No. 17
Mess No. 18
Mess No. 19
Mess No. 2
Mess No. 3
Mess No. 4
Mess No. 6
Mess No. 9
Mess No.7
NBC Filter Compartment No. 1
NBC Filter Compt. No. 3
NBC Filter Compt. No. 4
NBC Store
NBCD HQ & MCR
Officers WP & Hds
Oil/Water Collection Tank
Ops Room
Outbd Mtrs & Hyd Pmps
Paint Locker
Paint Store
Passageway



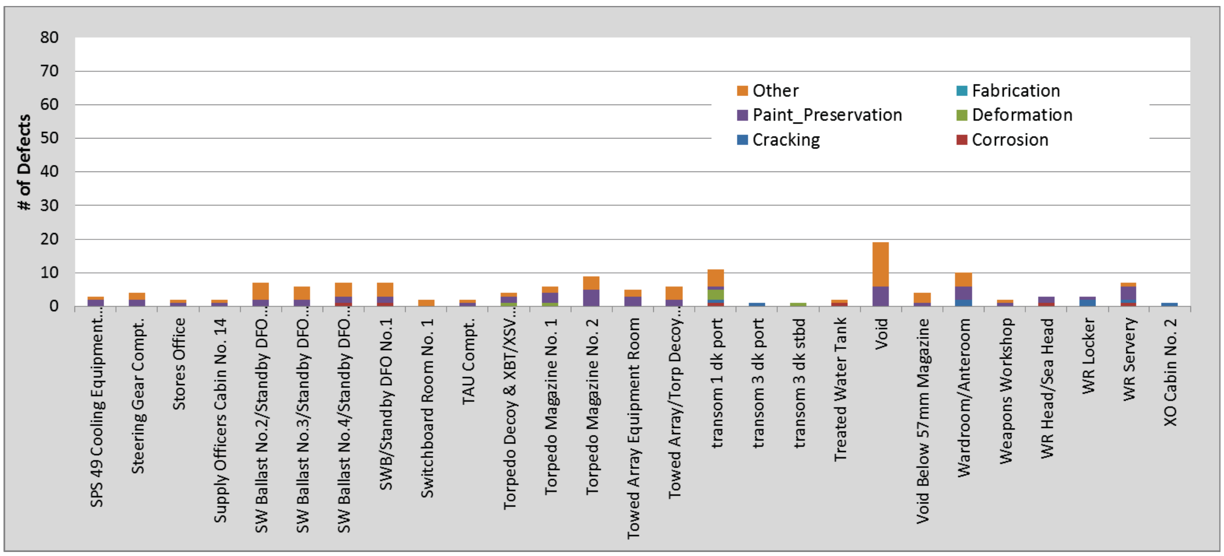


Figure A-2: Defects by Compartments for HMCS Ville de Québec

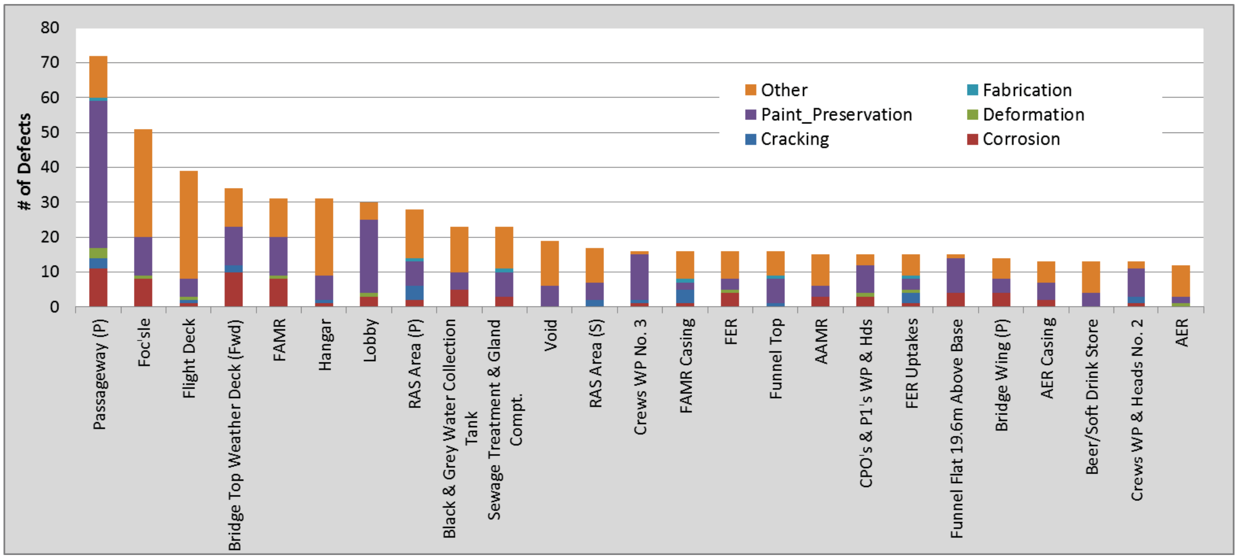
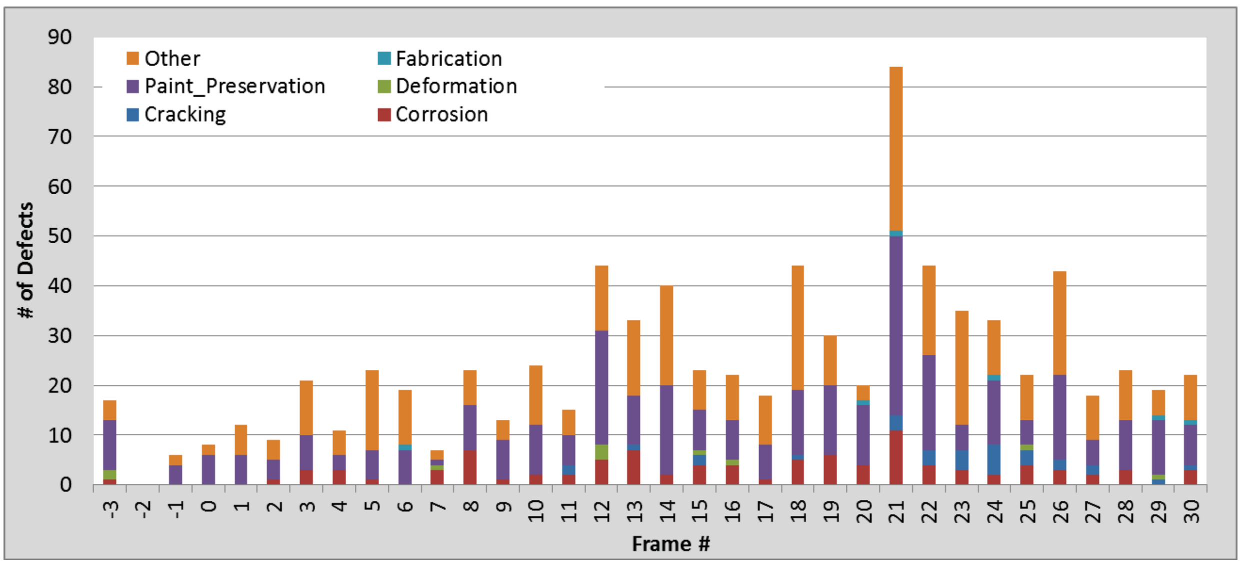
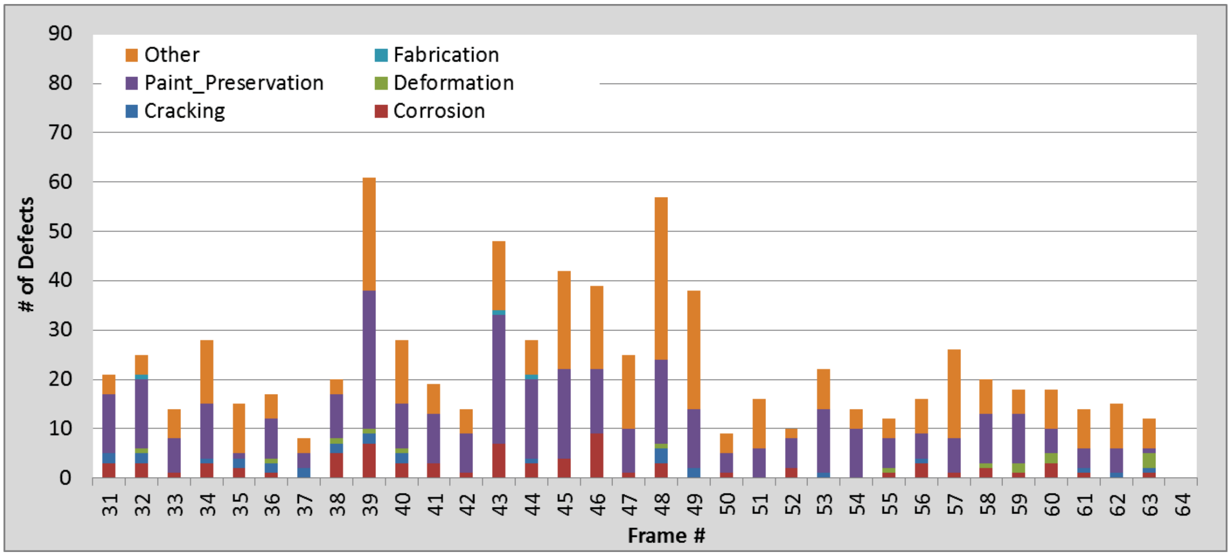


Figure A-3: Most Damage Prone Compartments for HMCS Ville de Québec



(a)



(b)

Figure A-4: Damage by Frame for HMCS Ville de Québec: (a) Frame # -3 to 30 and (b) Frame # 31-64

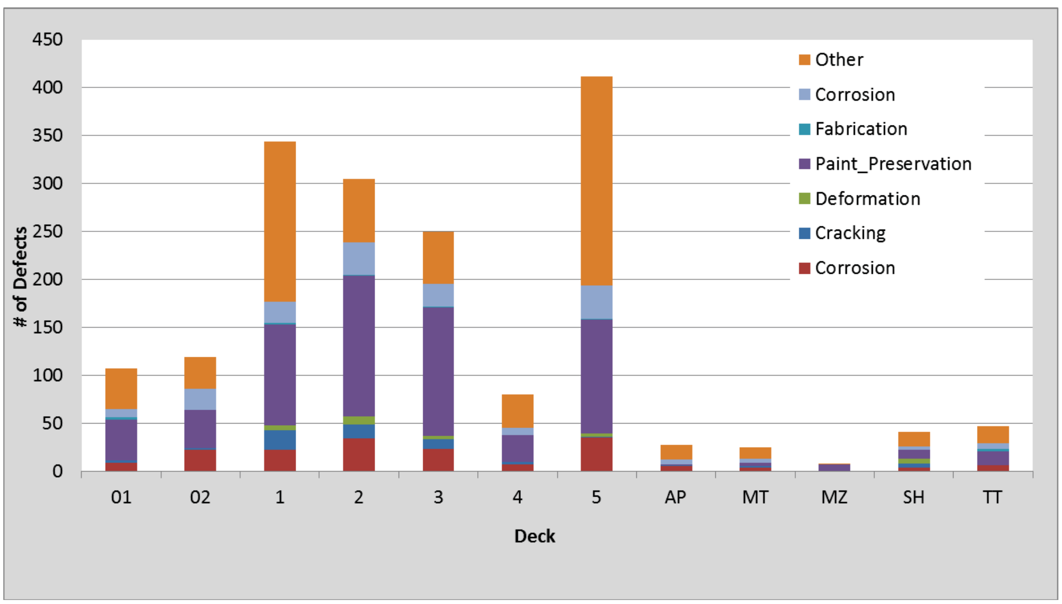
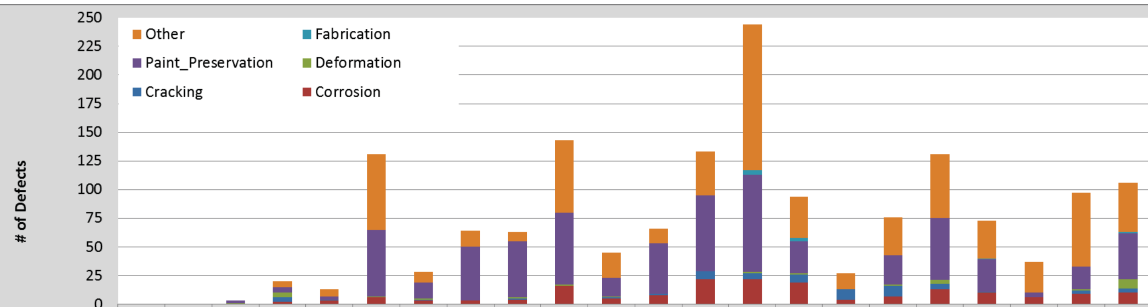


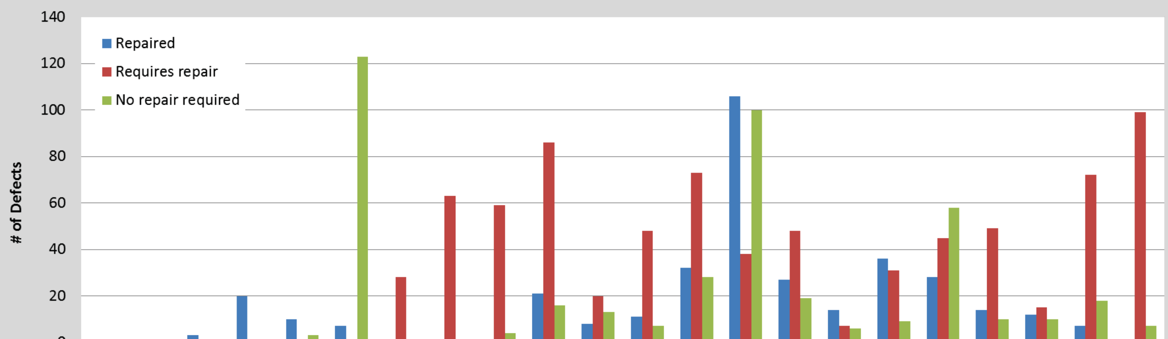
Figure A-5: Damages by Deck: HMCS Ville de Québec



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	0	0	0	5	6	66	9	14	8	63	22	13	38	127	36	14	33	56	33	27	64	43
Fabrication	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	1	0	0	1
Paint_Preservation	0	0	2	5	3	58	14	47	49	63	16	44	66	85	28	0	26	54	28	4	20	40
Deformation	0	0	1	4	0	1	1	0	1	1	1	0	0	1	1	0	1	3	0	0	1	8
Cracking	0	0	0	4	1	0	1	0	1	0	1	1	7	5	7	9	9	5	1	0	3	4
Corrosion	0	0	0	2	3	6	3	3	4	16	5	8	22	22	19	4	7	13	10	6	9	10

Year Identified

Figure A-6: Damages by Year Identified: HMCS Ville de Québec



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	0	0	3	20	10	7	0	1	0	21	8	11	32	106	27	14	36	28	14	12	7	0
Requires repair	0	0	0	0	0	1	28	63	59	86	20	48	73	38	48	7	31	45	49	15	72	99
No repair required	0	0	0	0	3	123	0	0	4	16	13	7	28	100	19	6	9	58	10	10	18	7

Year Identified

Figure A-7: Damages by Repair Status for HMCS Ville de Québec

A.2 DEFECTS SUMMARY FOR HMCS REGINA (WEST COAST)

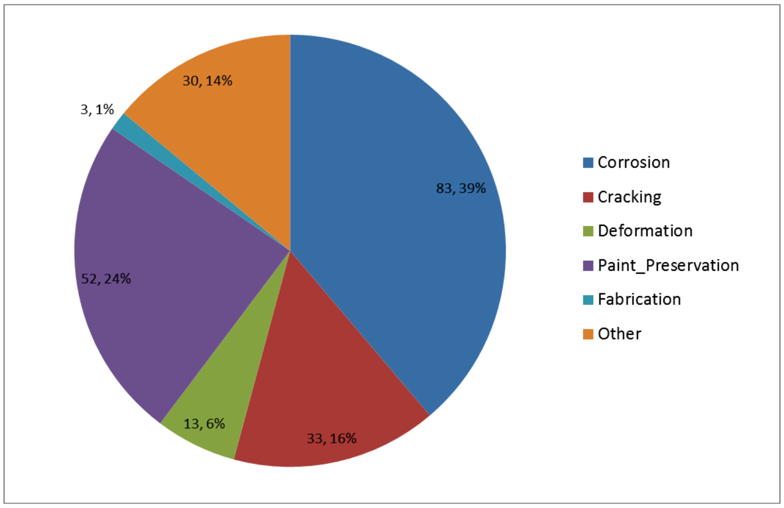
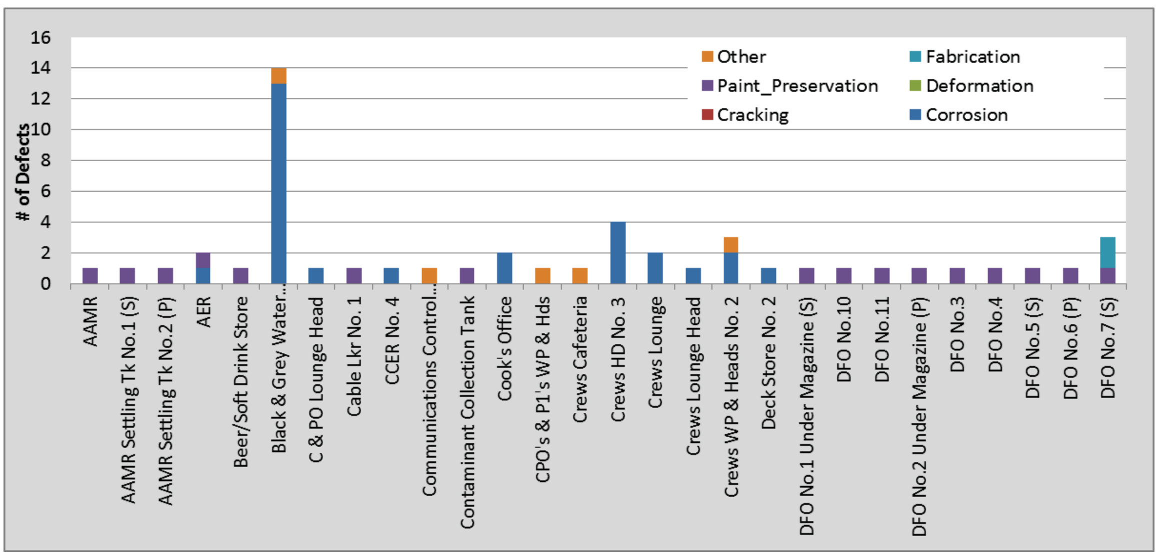


Figure A-8: Total Numbers of Defects by Type for HMCS Regina



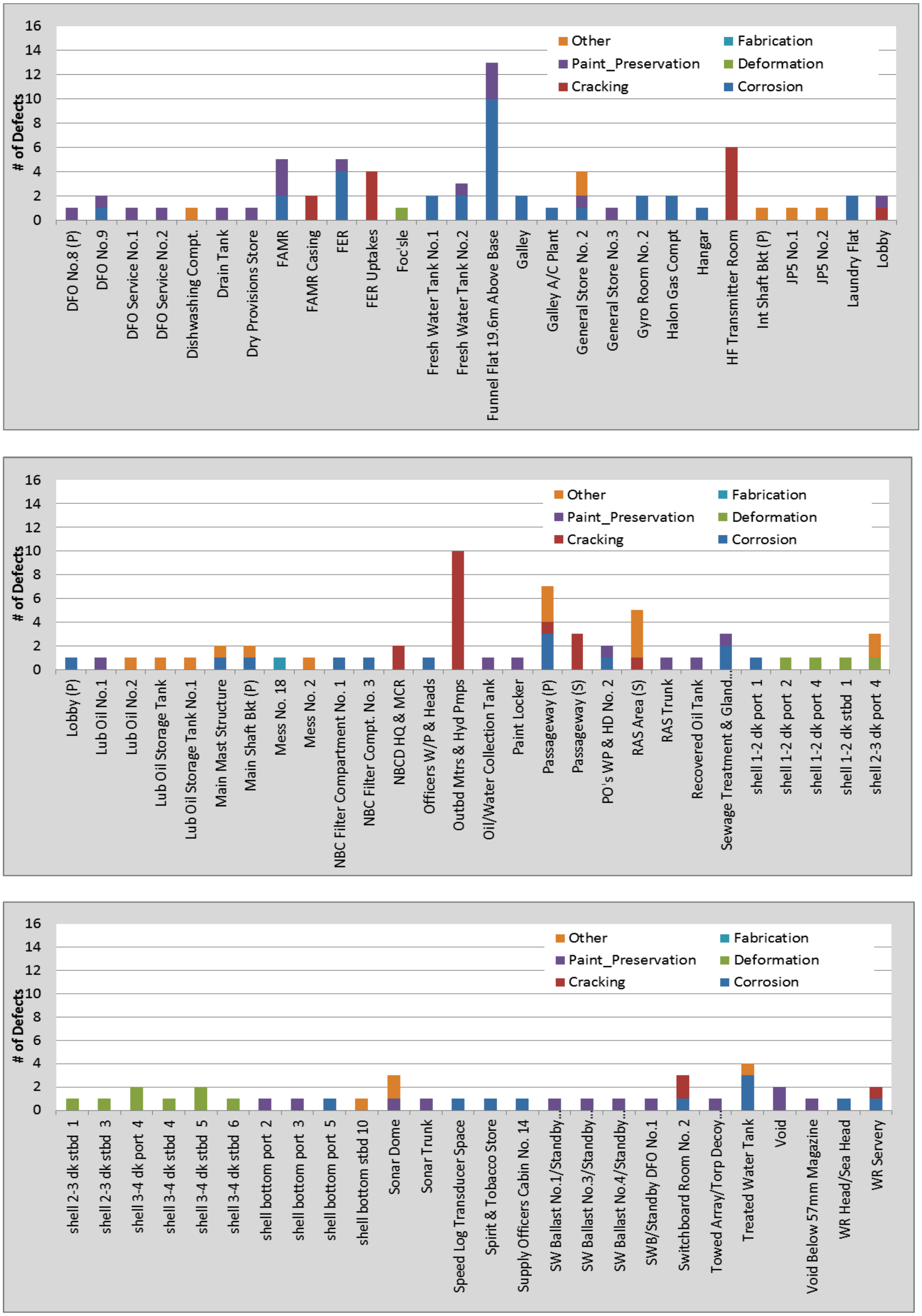


Figure A-9: Defects by Compartments for HMCS Regina

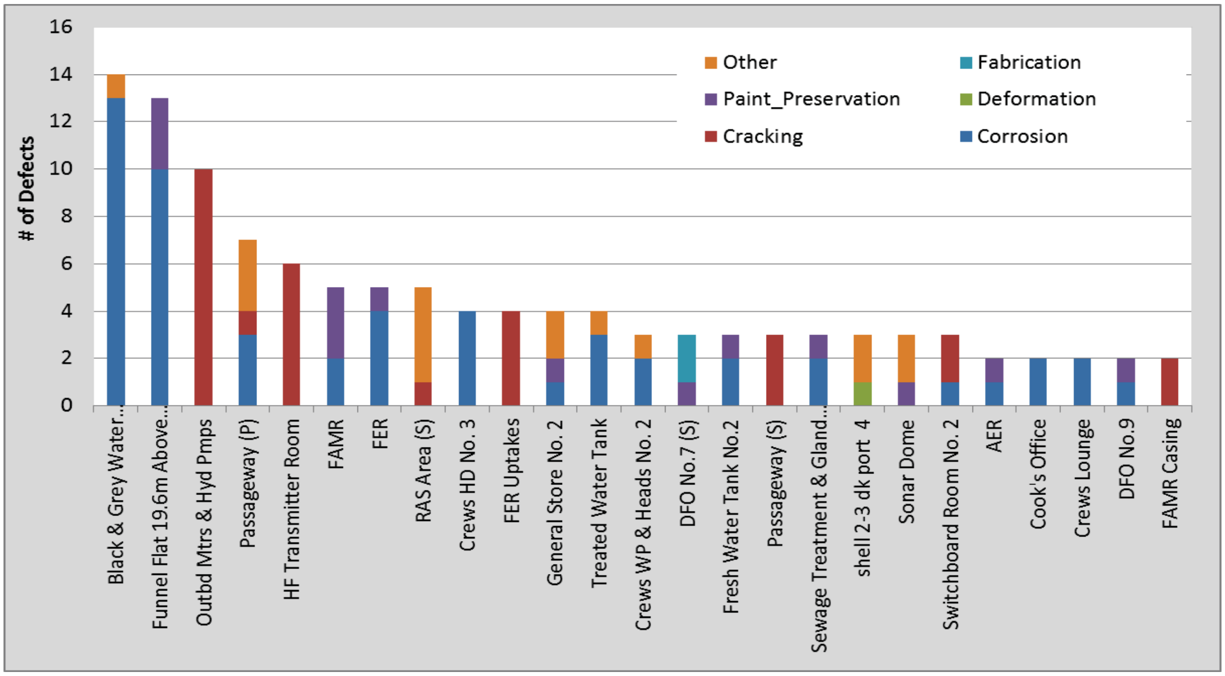
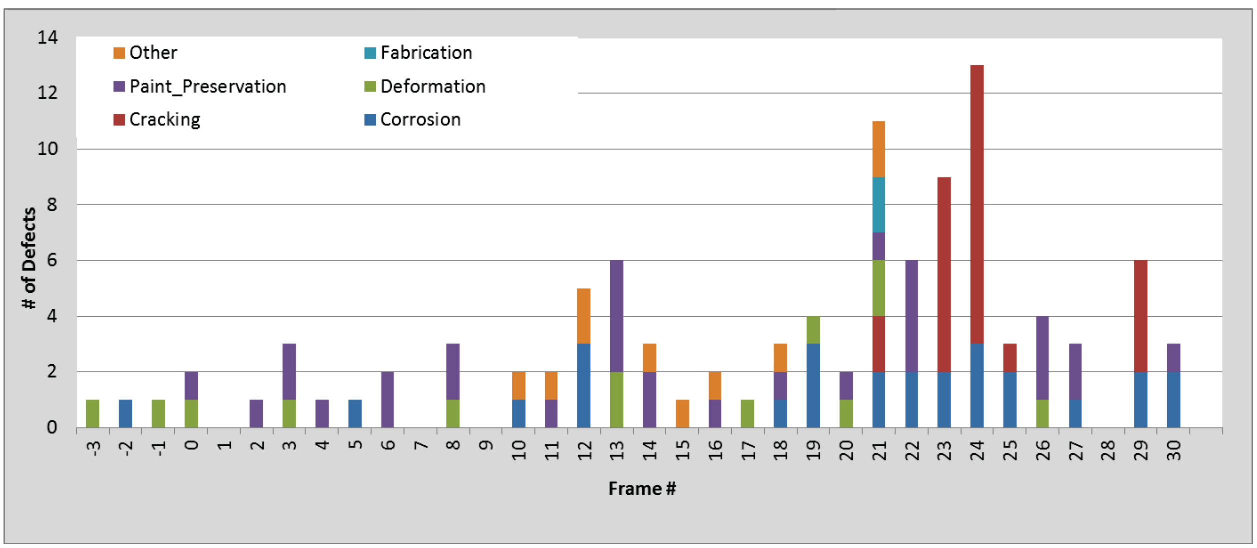
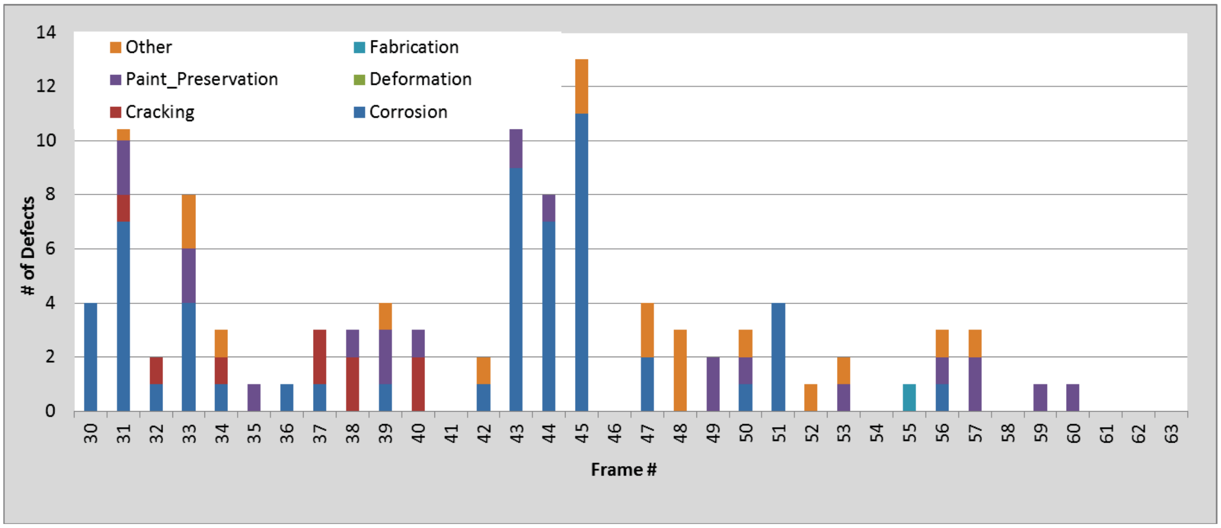


Figure A-10: Most Damage Prone Compartments for HMCS Regina



(a)



(b)

Figure A-11: Damage by Frame for HMCS Regina: (a) Frame # -3 to 30 and (b) Frame # 31-64

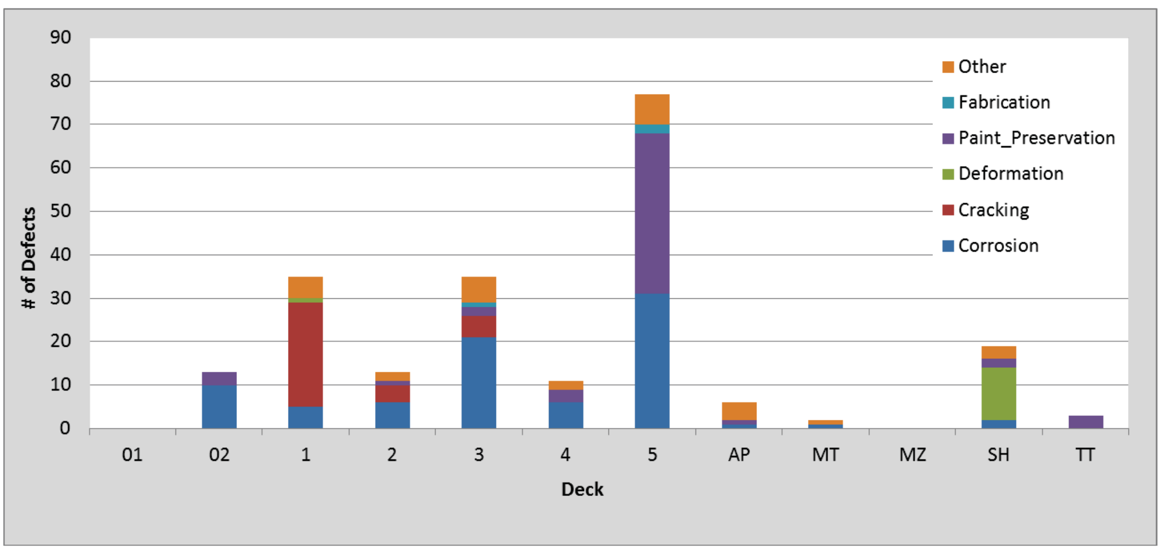
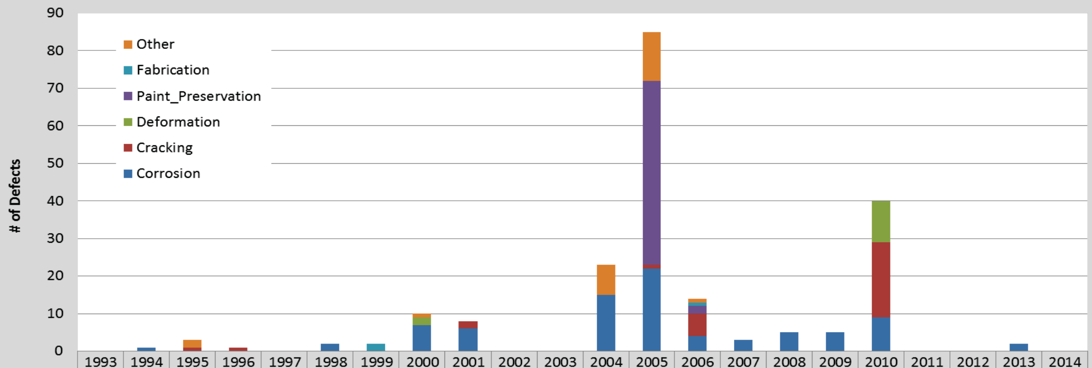


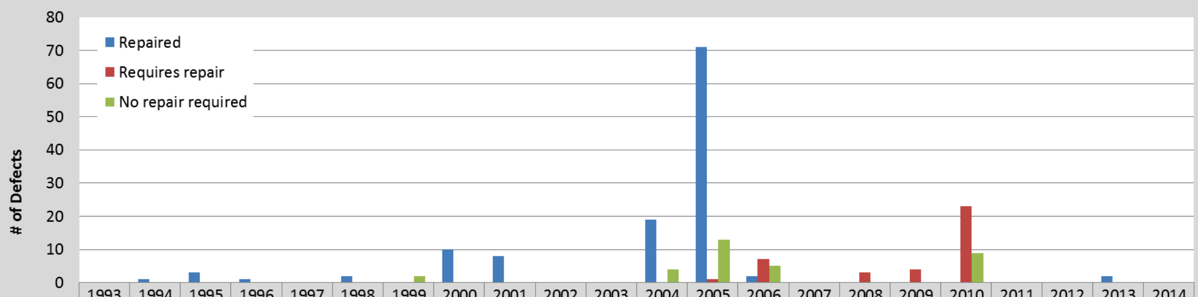
Figure A-12: Damage by Deck for HMCS Regina



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	0	0	2	0	0	0	0	1	0	0	0	8	13	1	0	0	0	0	0	0	0	0
Fabrication	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Paint_Preservation	0	0	0	0	0	0	0	0	0	0	0	0	49	2	0	0	0	0	0	0	0	0
Deformation	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	11	0	0	0	0
Cracking	0	0	1	1	0	0	0	0	2	0	0	0	1	6	0	0	0	20	0	0	0	0
Corrosion	0	1	0	0	0	2	0	7	6	0	0	15	22	4	3	5	5	9	0	0	2	0

Year of Identified

Figure A-13: Damages by Year Identified for HMCS Regina



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	0	1	3	1	0	2	0	10	8	0	0	19	71	2	0	0	0	0	0	0	2	0
Requires repair	0	0	0	0	0	0	0	0	0	0	0	0	1	7	0	3	4	23	0	0	0	0
No repair required	0	0	0	0	0	0	2	0	0	0	0	4	13	5	0	0	0	9	0	0	0	0

Year of Identified

Figure A-14: Damages by Repair Status for HMCS Regina

A.3 DEFECTS SUMMARY FOR HMCS CALGARY (WEST COAST)

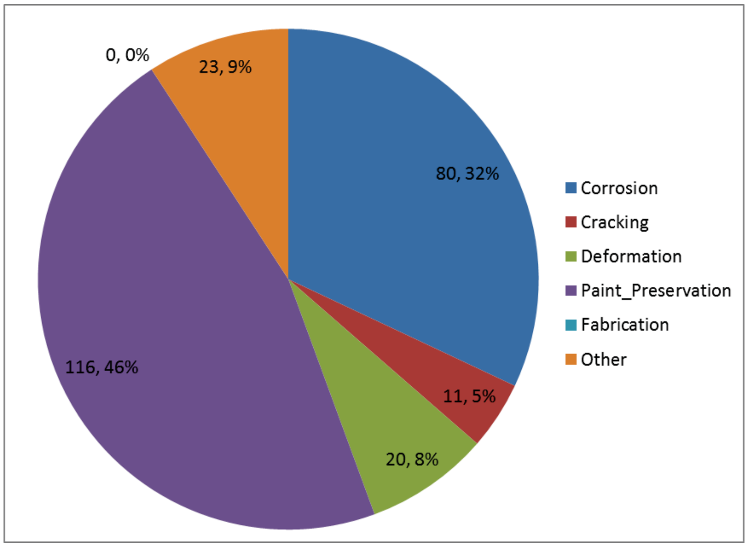
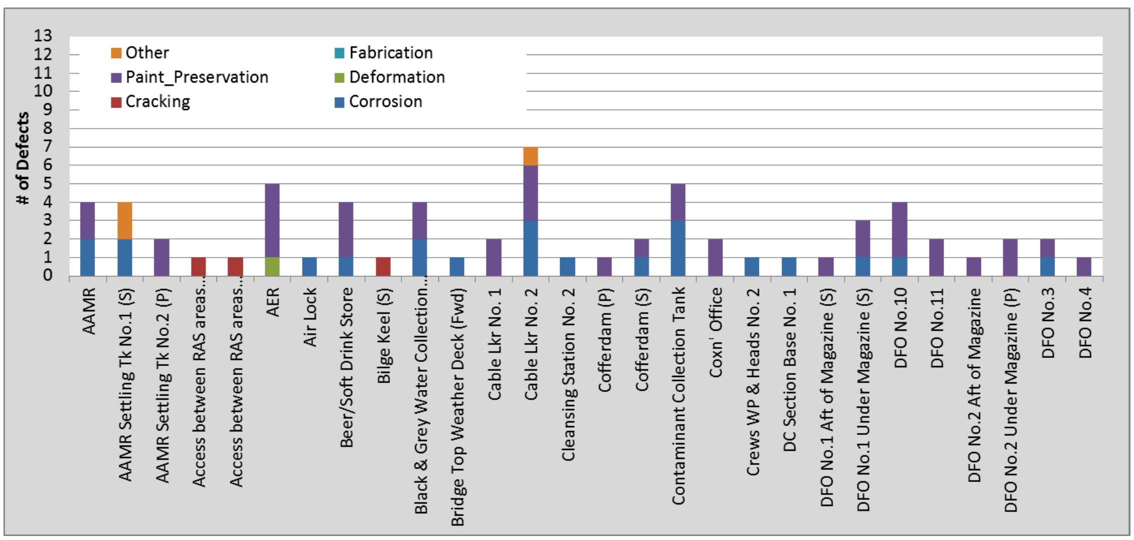
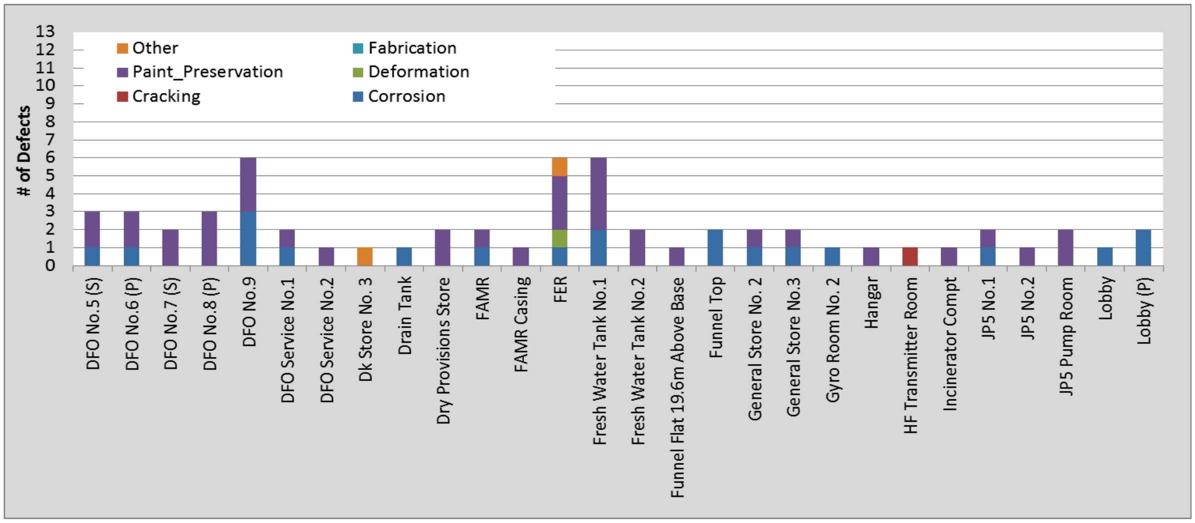
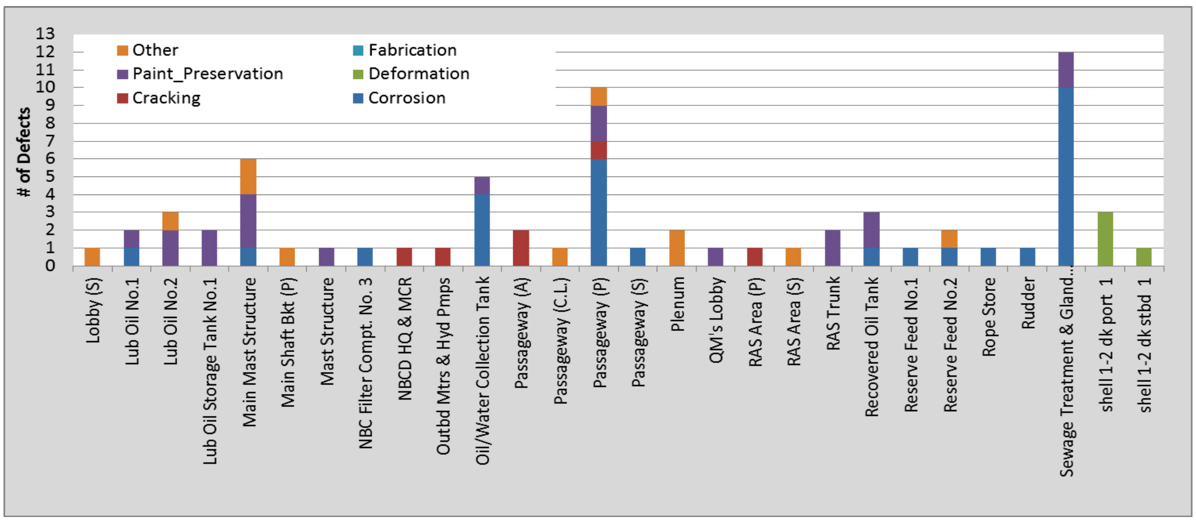


Figure A-15: Total Number of Defects by Type: HMCS Calgary







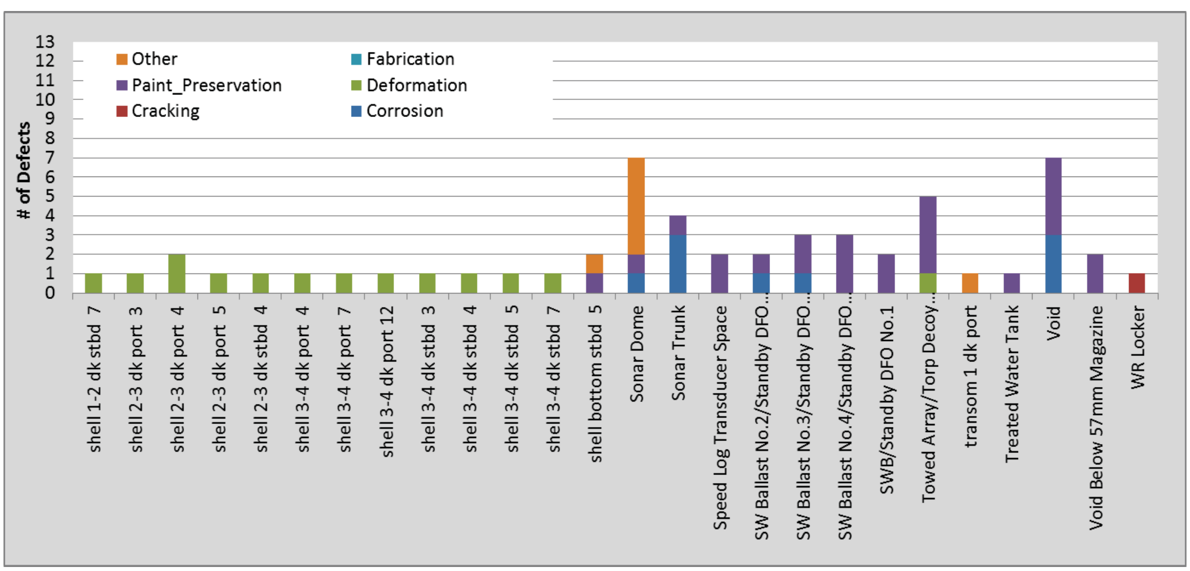


Figure A-16: Defects Summary by Compartments for HMCS Calgary

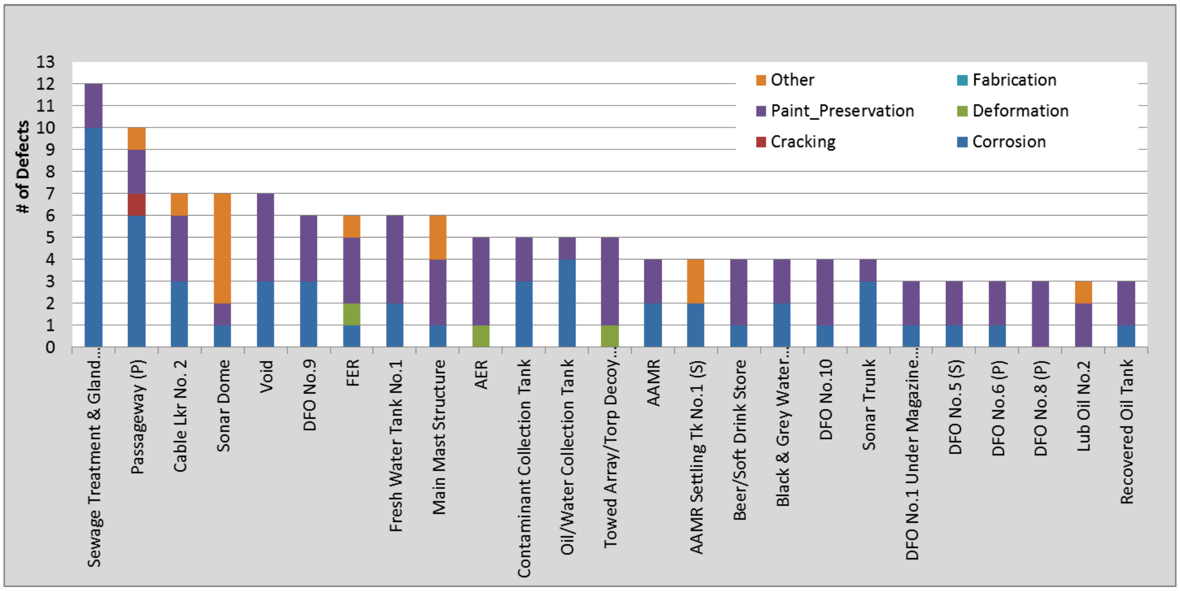
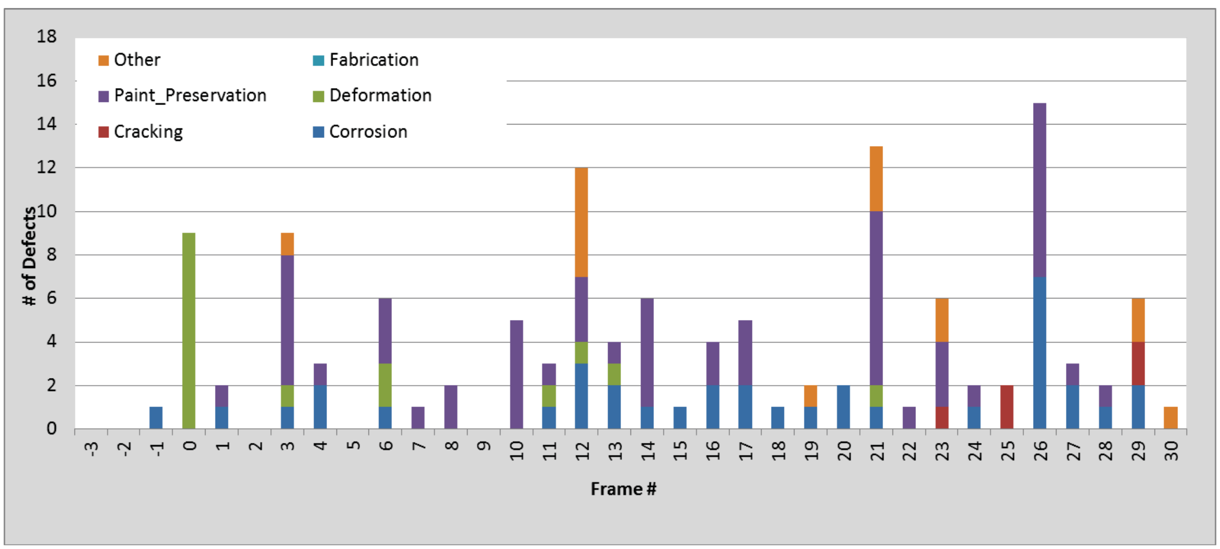
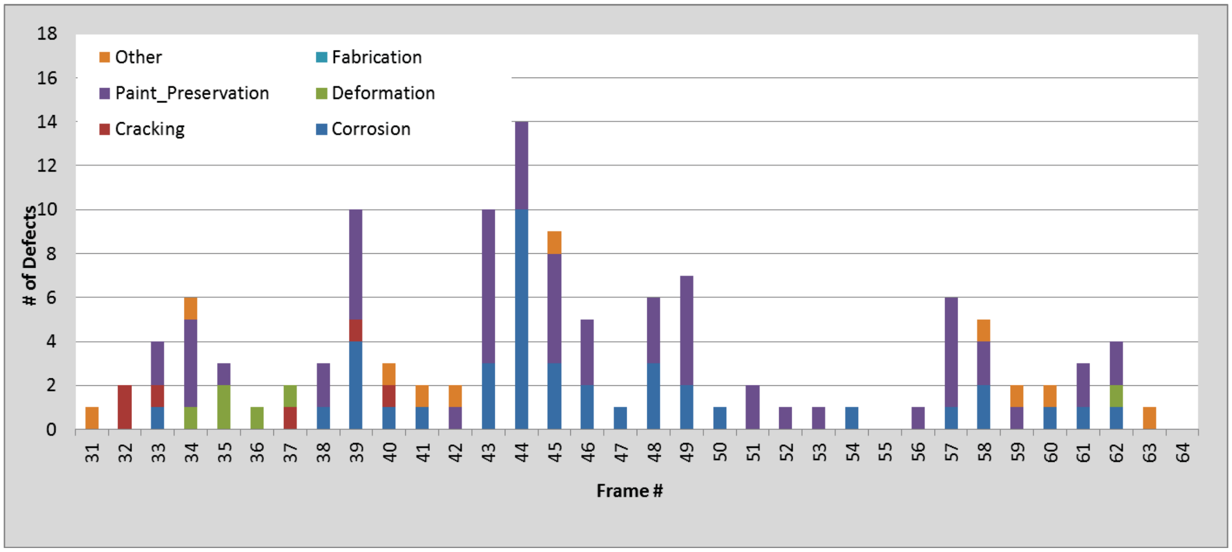


Figure A-17: Most Damage Prone Compartments for HMCS Calgary



(a)



(b)

Figure A-18: Damage by Frame for HMCS Calgary: (a) Frame # -3 to 30 and (b) Frame # 31-64

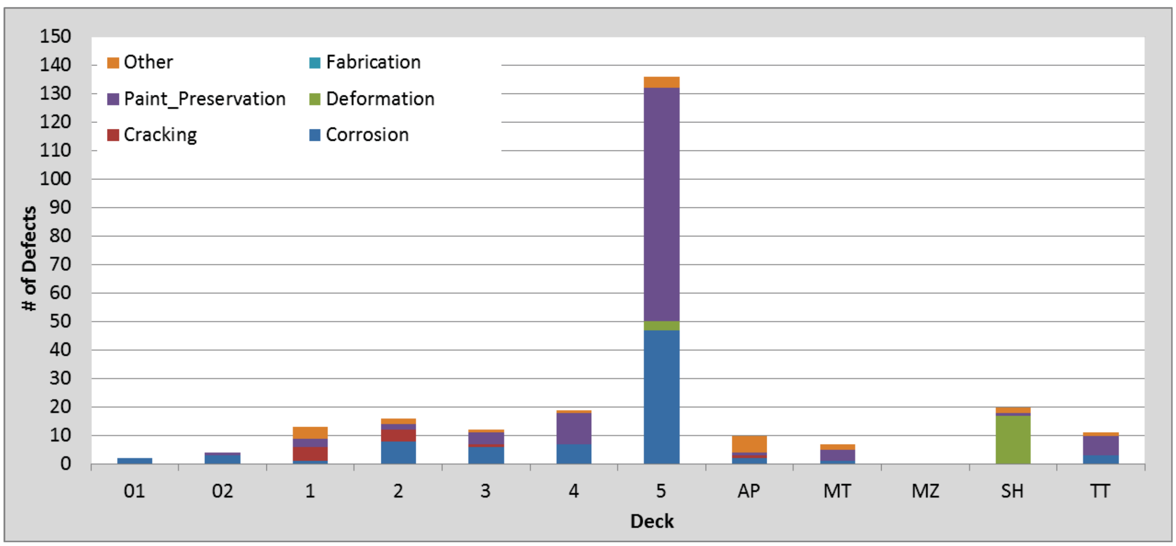
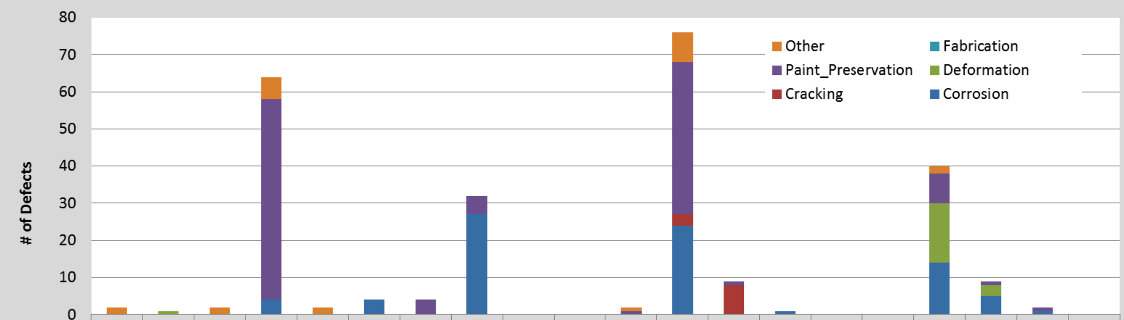


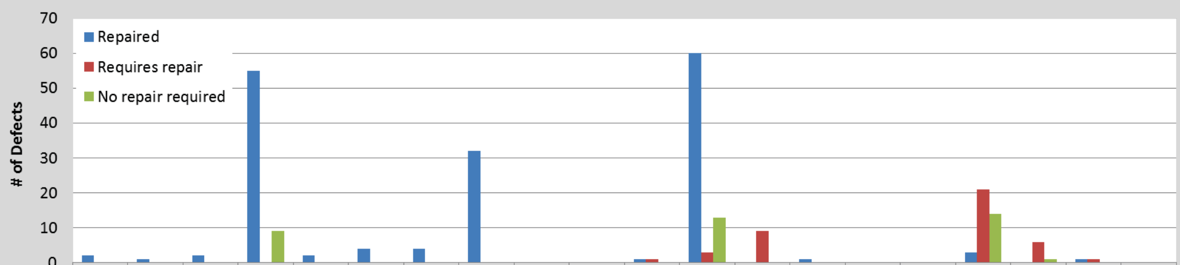
Figure A-19: Damage by Deck for HMCS Calgary



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	2	0	2	6	2	0	0	0	0	0	1	8	0	0	0	0	2	0	0	0
Fabrication	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paint_Preservation	0	0	0	54	0	0	4	5	0	0	1	41	1	0	0	0	8	1	1	0
Deformation	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	3	0	0
Cracking	0	0	0	0	0	0	0	0	0	0	0	3	8	0	0	0	0	0	0	0
Corrosion	0	0	0	4	0	4	0	27	0	0	0	24	0	1	0	0	14	5	1	0

Year of Identified

Figure A-20: Damages by Year Identified for HMCS Calgary



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	2	1	2	55	2	4	4	32	0	0	1	60	0	1	0	0	3	0	1	0
Requires repair	0	0	0	0	0	0	0	0	0	0	1	3	9	0	0	0	21	6	1	0
No repair required	0	0	0	9	0	0	0	0	0	0	0	13	0	0	0	0	14	1	0	0

Year of Identified

Figure A-21: Damages by Repair Status for HMCS Calgary

A.4 DEFECTS SUMMARY FOR HMCS WINNIPEG (WEST COAST)

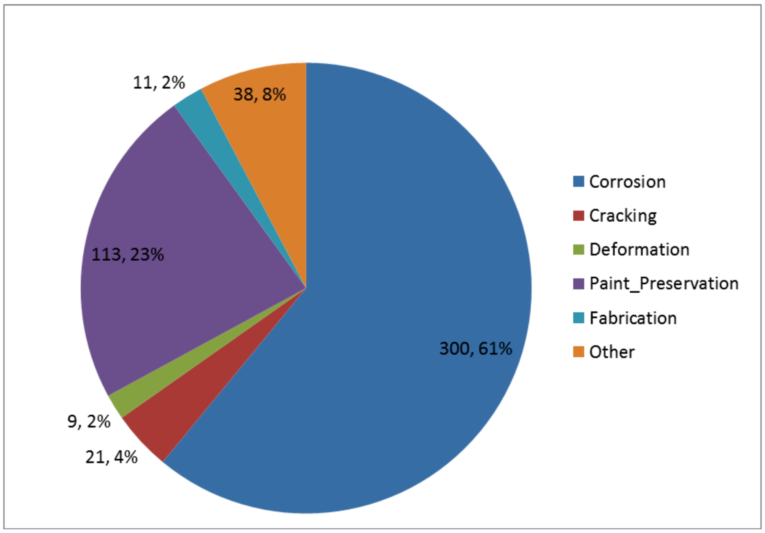
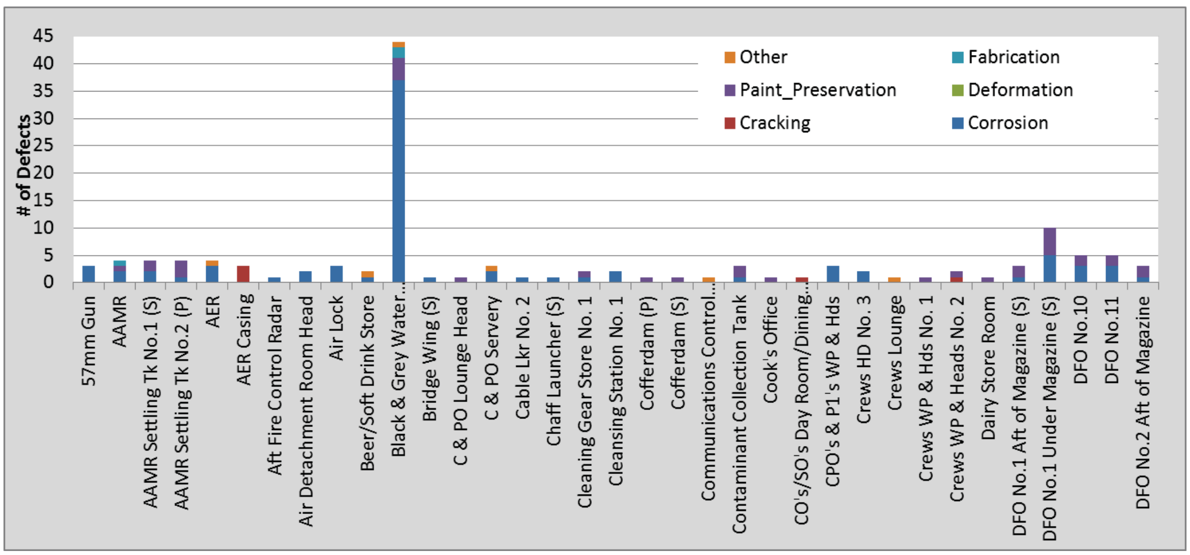


Figure A-22: Total Number of Defects by Type: HMCS Winnipeg



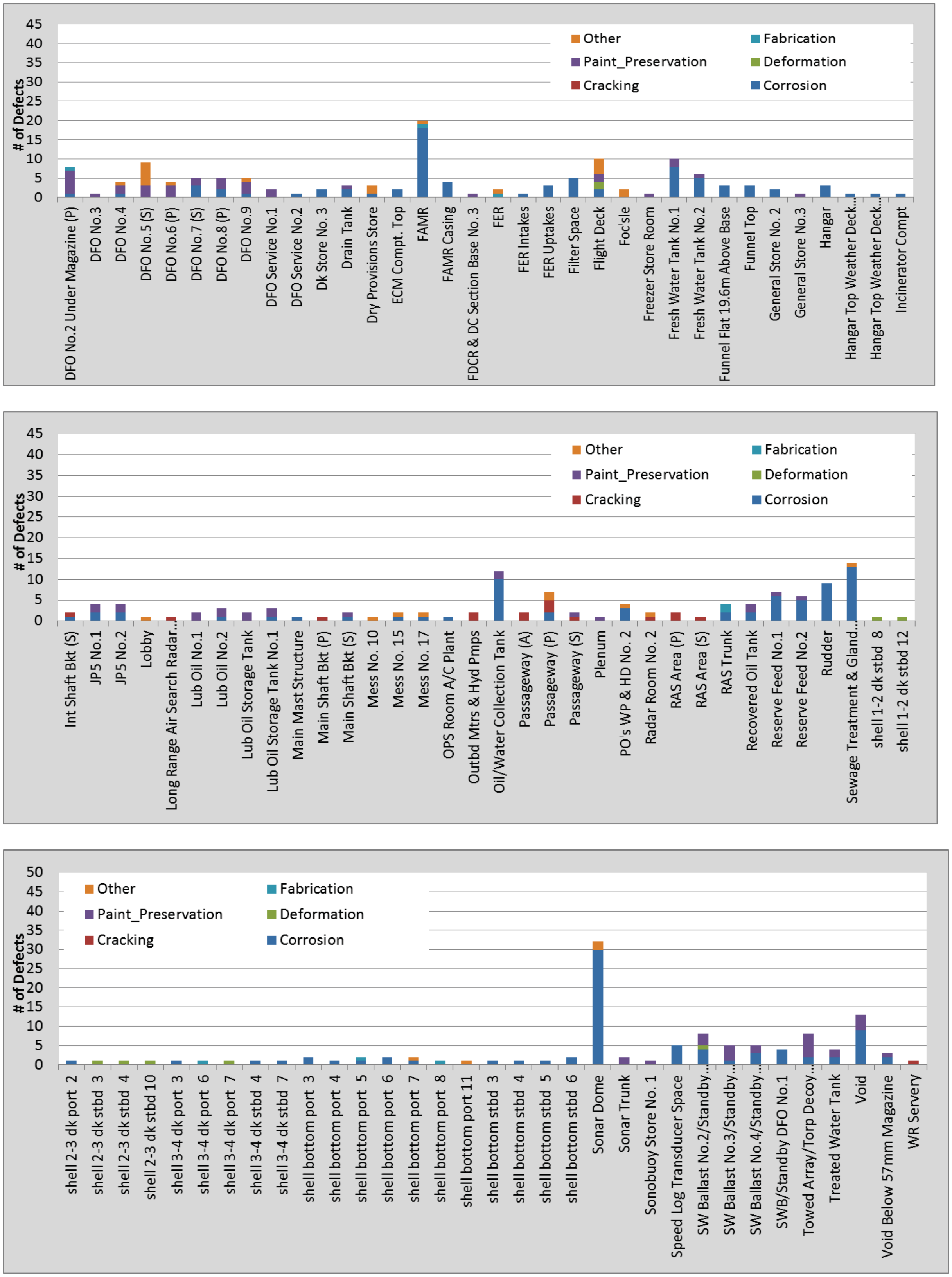


Figure A-23: Defects Summary by Compartments for HMCS Winnipeg

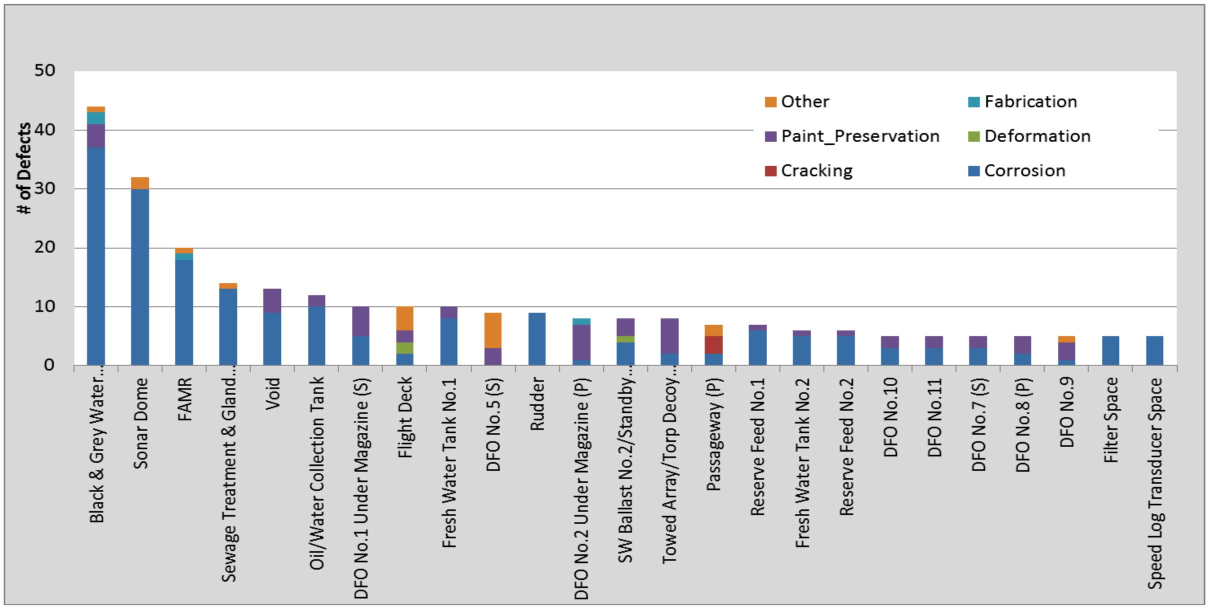
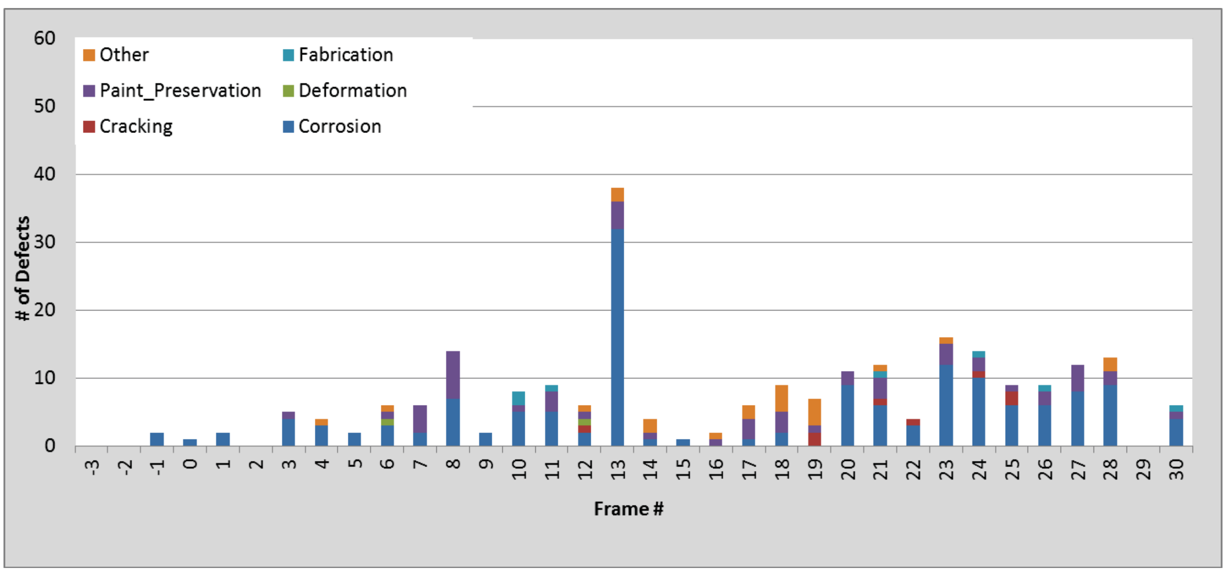
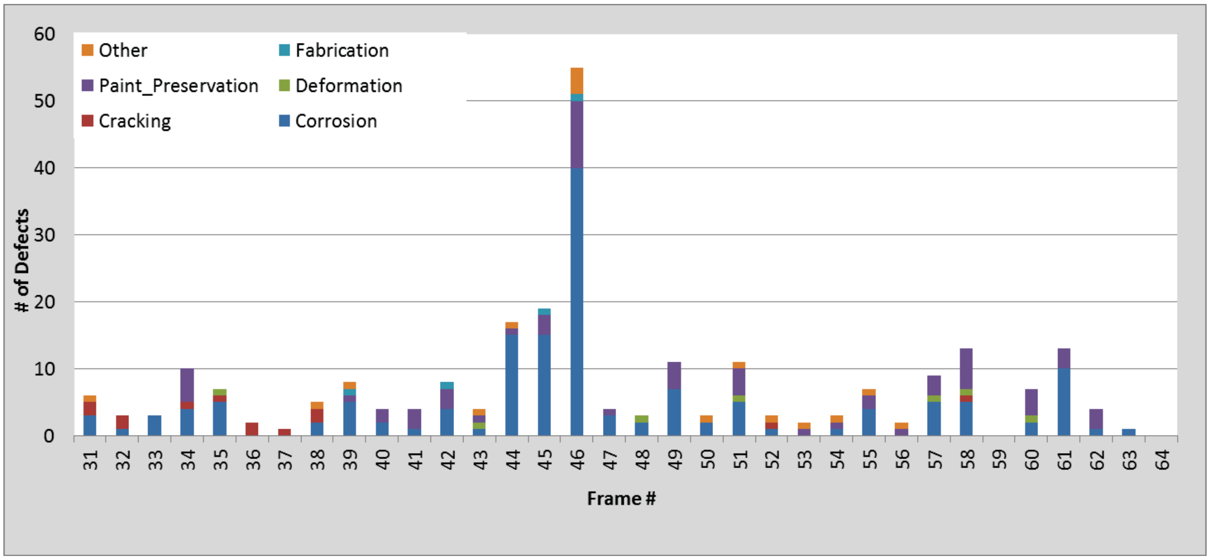


Figure A-24: Most Damage Prone Compartments for HMCS Winnipeg



(a)



(b)

Figure A-25: Damage by Frame for HMCS Winnipeg: (a) Frame # -3 to 30 and (b) Frame # 31-64

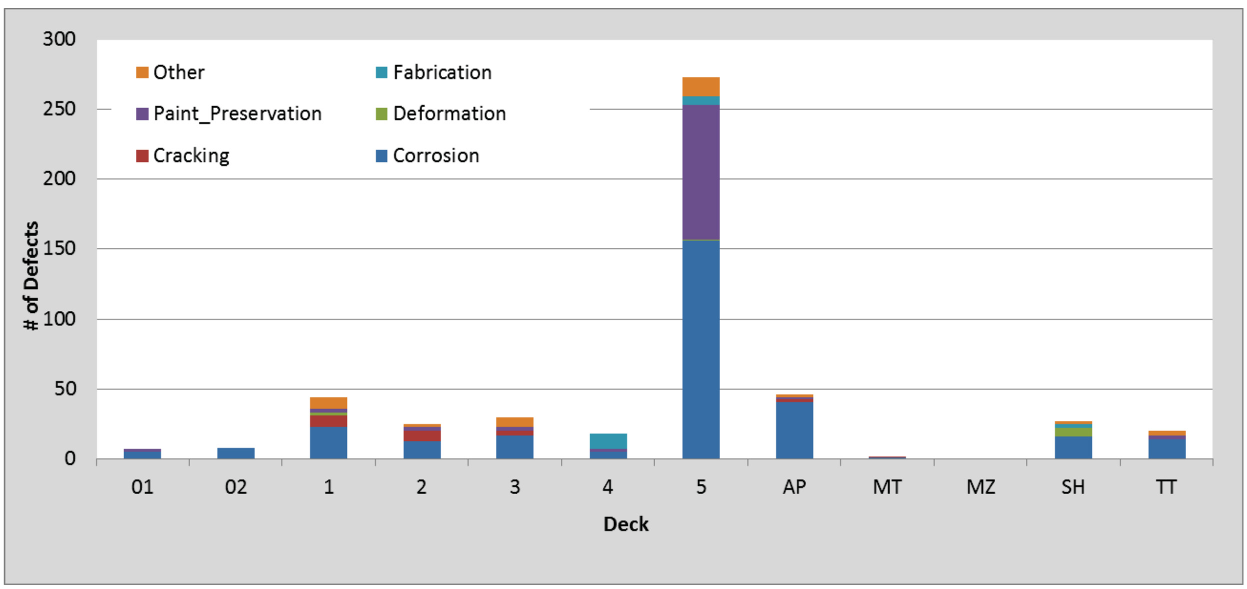
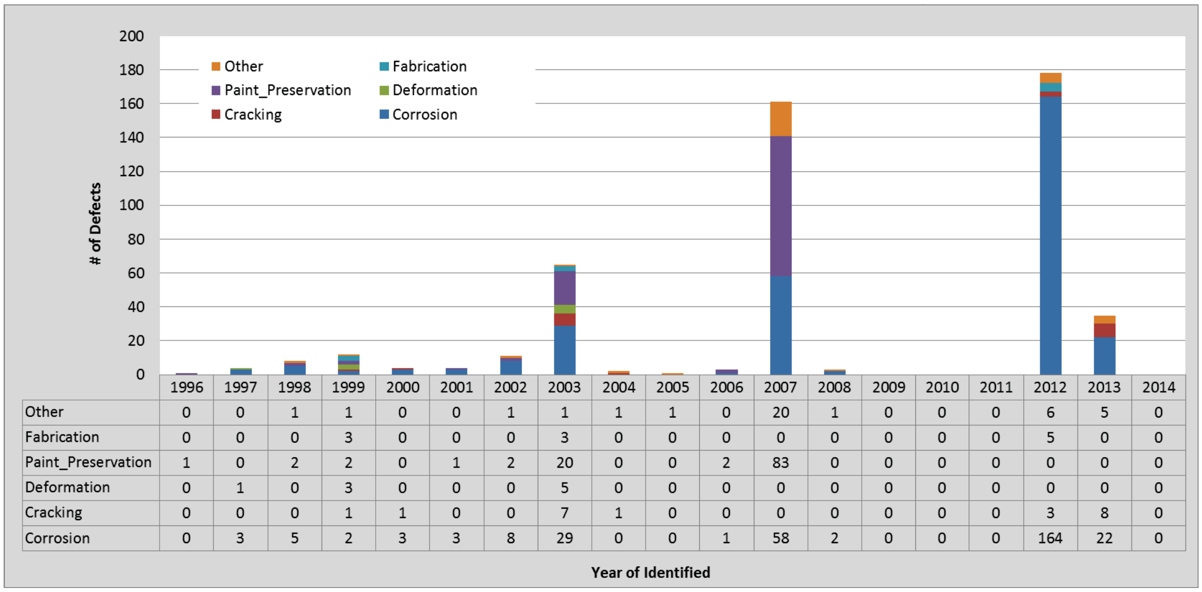
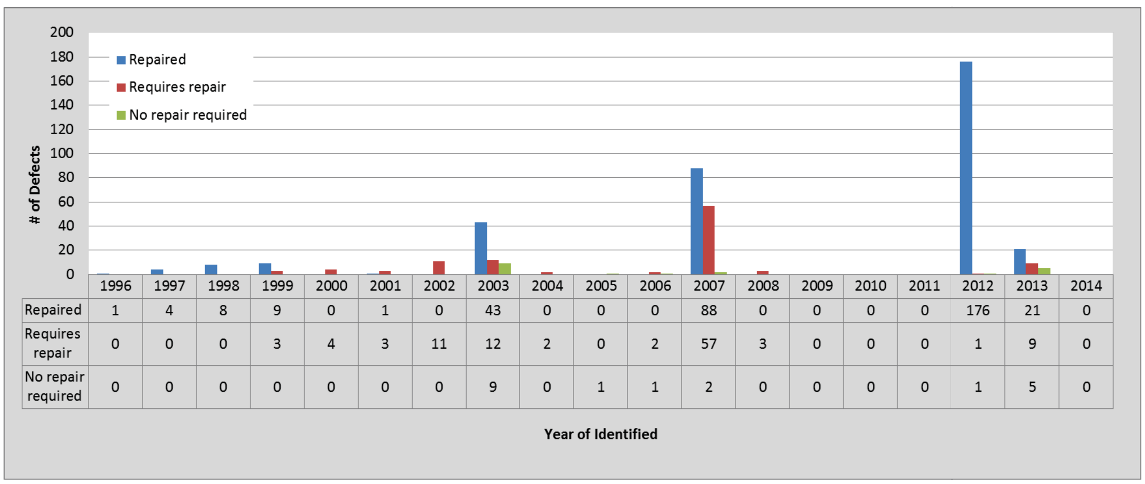


Figure A-26: Damage by Deck for HMCS Winnipeg



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	0	0	1	1	0	0	1	1	1	1	0	20	1	0	0	0	6	5	0
Fabrication	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	5	0	0
Paint_Preservation	1	0	2	2	0	1	2	20	0	0	2	83	0	0	0	0	0	0	0
Deformation	0	1	0	3	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
Cracking	0	0	0	1	1	0	0	7	1	0	0	0	0	0	0	0	3	8	0
Corrosion	0	3	5	2	3	3	8	29	0	0	1	58	2	0	0	0	164	22	0

Figure A-27: Damages by Year Identified for HMCS Winnipeg



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	1	4	8	9	0	1	0	43	0	0	0	88	0	0	0	0	176	21	0
Requires repair	0	0	0	3	4	3	11	12	2	0	2	57	3	0	0	0	1	9	0
No repair required	0	0	0	0	0	0	0	9	0	1	1	2	0	0	0	0	1	5	0

Figure A-28: Damages by Repair Status for HMCS Winnipeg

A.5 DEFECTS SUMMARY FOR HMCS OTTAWA (WEST COAST)

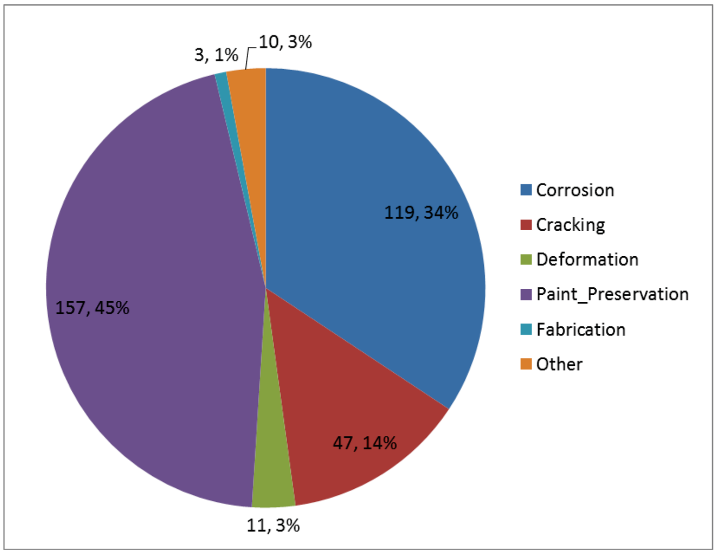
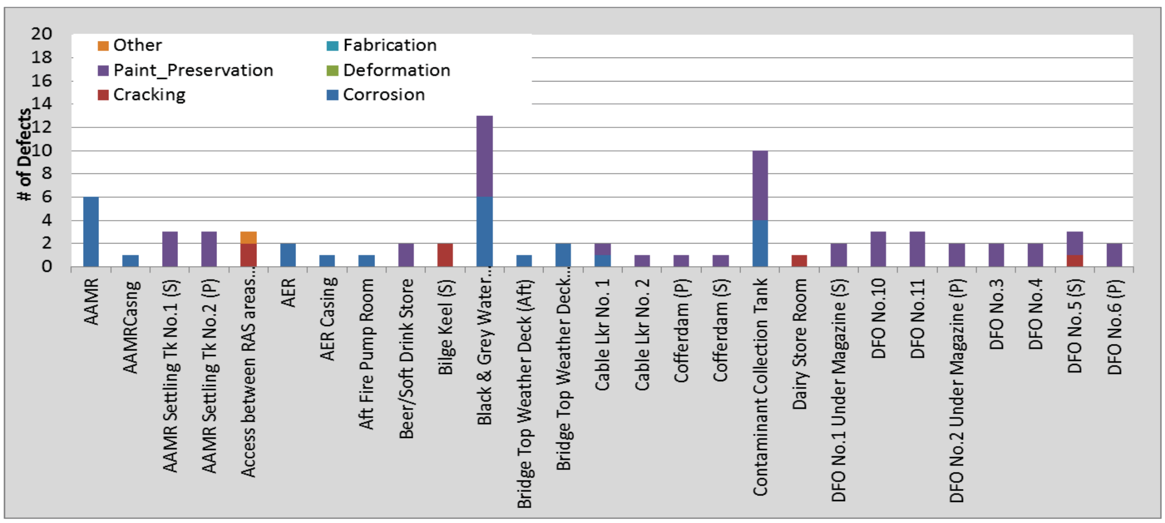


Figure A-29: Total Number of Defects by Type: HMCS Ottawa



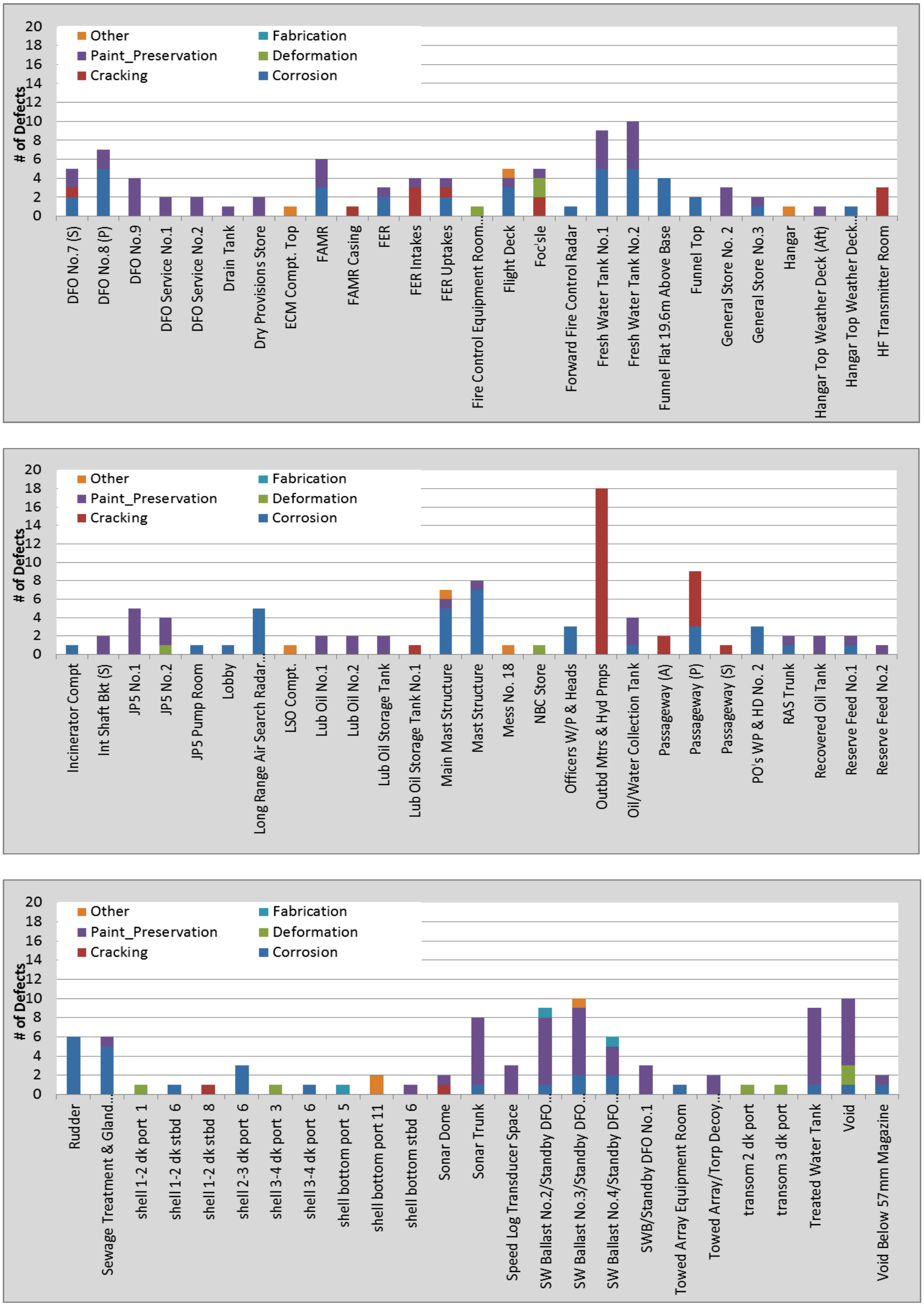


Figure A-30: Defects Summary by Compartments for HMCS Ottawa

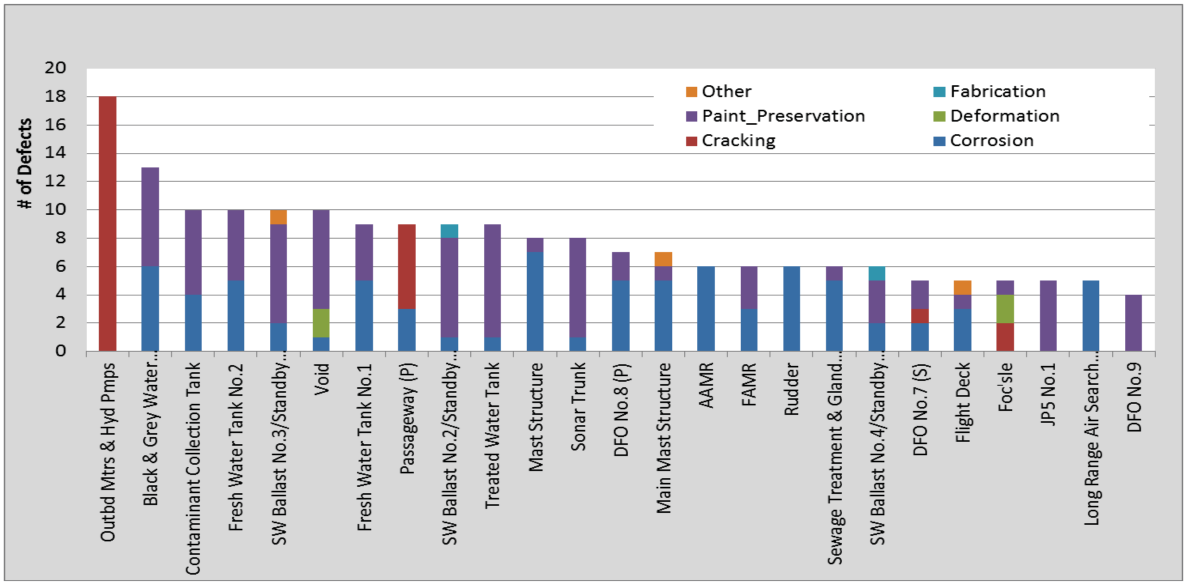
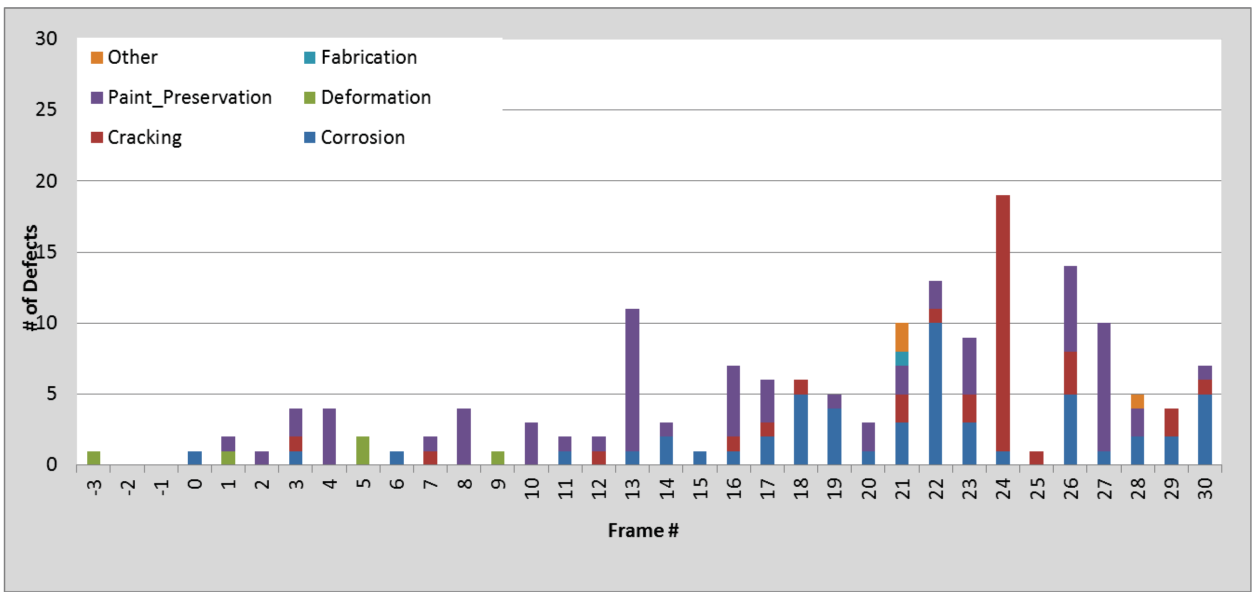
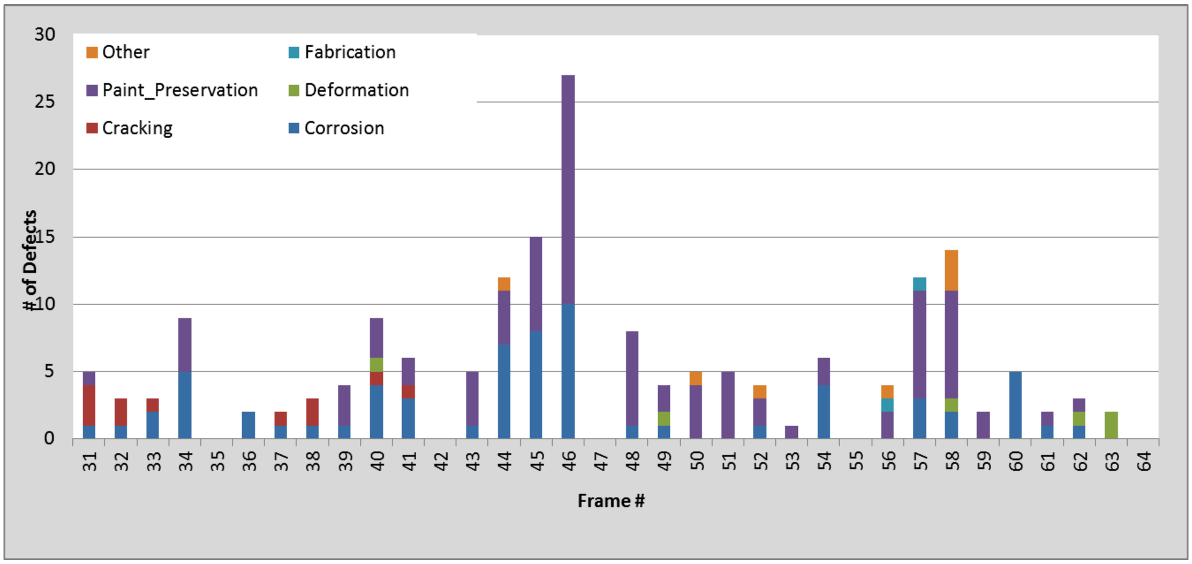


Figure A-31: Most Damage Prone Compartments for HMCS Ottawa



(a)



(b)

Figure A-32: Damage by Frame for HMCS Ottawa: (a) Frame # -3 to 30 and (b) Frame # 31-64

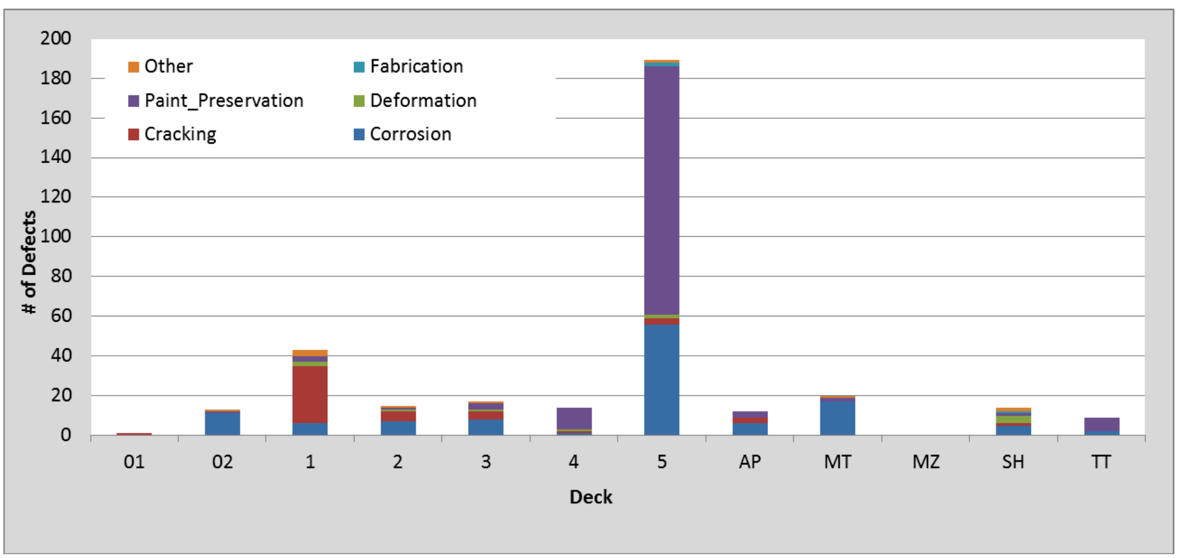
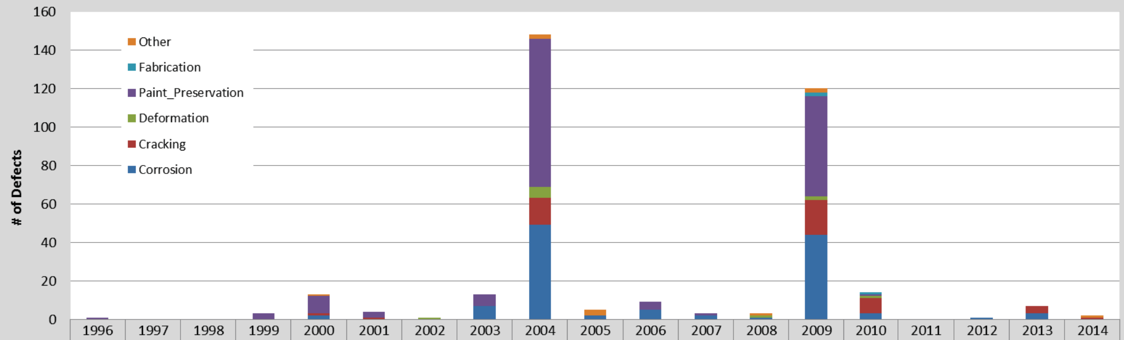


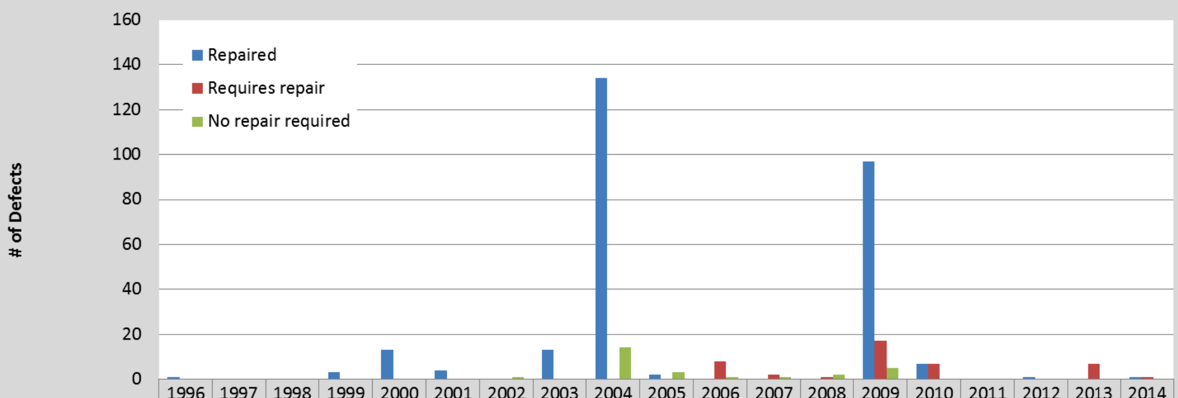
Figure A-33: Damage by Deck for HMCS Ottawa



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other	0	0	0	0	1	0	0	0	2	3	0	0	1	2	0	0	0	0	1
Fabrication	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
Paint_Preservation	1	0	0	3	9	3	0	6	77	0	4	1	0	52	1	0	0	0	0
Deformation	0	0	0	0	0	0	1	0	6	0	0	0	1	2	1	0	0	0	0
Cracking	0	0	0	0	1	1	0	0	14	0	0	0	0	18	8	0	0	4	1
Corrosion	0	0	0	0	2	0	0	7	49	2	5	2	1	44	3	0	1	3	0

Year of Identified

Figure A-34: Damages by Year Identified for HMCS Ottawa



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Repaired	1	0	0	3	13	4	0	13	134	2	0	0	0	97	7	0	1	0	1
Requires repair	0	0	0	0	0	0	0	0	0	0	8	2	1	17	7	0	0	7	1
No repair required	0	0	0	0	0	0	1	0	14	3	1	1	2	5	0	0	0	0	0

Year of Identified

Figure A-35: Damages by Repair Status for HMCS Ottawa