TP 15474E

Reducing Vessel Emissions through Machine Learning-based Routing

Prepared for
The Innovation Centre
of
Transport Canada

by
Fujitsu Intelligence Technology Limited

March 2021

TP 15474E

Reducing Vessel Emissions through Machine Learning-based Routing

by

Dr. Todd Law

Fujitsu Intelligence Technology Limited

March 2021

Notices

Project Team

Todd Law, Product Manager

Masahiko Sumida, Project Director

Joony Lee, Developer

Marco San Juan, Project Manager

Donal Armstrong, Software Engineer

Un sommaire français se trouve avant la table des matières

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 15474E	2. Project No. -	3. Catalogue No. T89-5/2021E-PDF	4. ISBN 978-0-660-38866-3

5. Title and Subtitle Reducing Vessel Emissions through Machine Learning-based Routing	6. Publication Date March 2021 7. Performing Organization Document No. --
8. Author(s) Todd Law	9. Transport Canada File No. --
10. Performing Organization Name and Address Fujitsu Intelligence Technology Limited One Bentall Centre 505 Burrard Street, Suite 500, Box 8 Vancouver, BC V7X 1M4	11. PWGSC File No. -- 12. PWGSC or Transport Canada Contract No. T8009-190192/005/XLV
13. Sponsoring Agency Name and Address Innovation Centre 330 Sparks Street Ottawa, Ontario K1A 0N5	14. Type of Publication and Period Covered Final 15. Project Officer J. O'Reilly

16. Supplementary Notes (Funding programs, titles of related publications, etc.)

17. Abstract

The purpose of this project was to advance the technical readiness level of the Vessel Fuel Optimization (VFO) technology by (a) improving the implementation, and (b) evaluating the performance and usability in operational settings. The project team improved the implementation by following agile software development methods for various aspects of the code, including automation of previously manual tasks and increasing the overall quality. The project team evaluated the performance and usability by conducting sea trials of the implementation in collaboration with sea trial partners on actual vessels. The results show that the VFO can reduce fuel consumption by as much as 8.1%, and CO_2 emissions by as much as 56,000 kg on a typical voyage, with potential for even more improvements with more accurate weather forecasts. The results also showed that the VFO application is reasonably usable, but could be improved with minor changes. The conclusion is that VFO is an effective and easy-to-deploy tool to reduce fuel consumption and emissions.

18. Key Words Optimization, routing, maritime	19. Distribution Statement Digital Copy

20. Security Classification (of this publication) Unclassified	21. Security Classification (of this page) Unclassified	22. Declassification (date) —	23. No. of Pages xv, 36, apps	24. Price --

CI/IC 79-005
Rev. 96

Canada

Transports Canada / Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. No de la publication de Transports Canada TP 15474E	2. Nº de l'étude	3. Nº de catalogue T89-5/2021E-PDF	4. No de catalogue du destinataire / ISBN 978-0-660-38866-3
5. Titre et sous-titre Réduction des émissions des navires grâce au routage basé sur l'apprentissage automatique			6. Date de la publication mars 2021 7. No de document de l'organisme exécutant
8. Auteur(s) Todd Law			9. No de dossier - Transports Canada --
10. Nom et adresse de l'organisme executant Fujitsu Intelligence Technology Limited One Bentall Centre 505 Burrard Street, Suite 500, Box 8 Vancouver, BC V7X 1M4			11. No de dossier - TPSGC -- 12. No de contrat - TPSGC ou Transports Canada T8009-190192/005/XLV
13. Nom et adresse de l'organisme parrain Centre d'Innovation 330, rue Sparks Ottawa (Ontario) K1A 0N5			14. Genre de publication et période visée Finale 15. Agent de projet J. O'Reilly
16. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)			

17. Résumé

Le but de ce projet était de faire progresser le niveau de maturité technologique de la technologie d'optimisation du carburant des navires (OCN) en (a) améliorant la mise en œuvre et (b) en évaluant les performances et la facilité d'utilisation dans les contextes opérationnels. L'équipe du projet a amélioré la mise en œuvre en suivant des méthodes de développement de logiciel agiles pour divers aspects du code, y compris l'automatisation de tâches auparavant manuelles et l'augmentation de la qualité globale. L'équipe du projet a évalué les performances et la facilité d'utilisation en menant des essais en mer en collaboration avec des partenaires d'essais en mer sur des navires existants. Les résultats montrent que l'OCN parvient à réduire la consommation de carburant de 8,1% et les émissions de CO_2 de 56,000 kg lors d'un voyage typique, avec un potentiel pour encore plus d'améliorations avec des prévisions météorologiques plus précises. Les résultats ont également montré que l'application d'OCN est raisonnablement utilisable, mais pourrait être améliorée avec des modifications mineures. La conclusion est que l'OCN est un outil efficace et facile à déployer pour réduire la consommation de carburant et les émissions.

18. Mots clés	19. Diffusion
Optimisation, itinéraire, maritime	Copie numérique

20. Classification de sécurité (de cette publication)	21. Classification de sécurité (de cette page)	22. Déclassification (date)	23. Nombre de pages	24. Prix
Non classifiée	Non classifiée	—	xv, 36, ann.	--

CI/IC 79-005

Canada

ACKNOWLEDGEMENTS

Fujitsu would like to thank:

- Metis Cybertechnologies for
  - being a long-distance sea trial partner
  - providing fuel consumption data
- Horizon Maritime for being a short-distance sea trial partner
- Blue Comet Seafoods for being a short-distance sea trial partner
- Transport Canada for the opportunity and being flexible with the interim milestone dates
- ExactEarth for providing historical AIS data

EXECUTIVE SUMMARY

Fujitsu's "Vessel Fuel Optimization" (VFO) technology provides AI-powered ship route optimization. Through its models, VFO is able to identify a fuel-efficient route for ships which helps reduce GHG and CAC emissions.

Through the Clean Marine initiative, Transport Canada and Fujitsu collaborated on a project to validate VFO's effectiveness in reducing fuel consumption and the emissions of GHGs and CACs. This involved elevating the technical readiness of Fujitsu's "Vessel Fuel Optimization" (VFO) technology to a state of reasonable completion so that VFO can be used in a real operational environment and validated.

The project had two key phases where were spread across 5 milestones:

- Software Development phase:
  - Milestones 1 and 2 focused on the development and implementation of technical enhancements to VFO so that it can function efficiently and optimally in a production environment.
  - This phase had to be completed before VFO could be used in a production environment.
- Sea Trials phase:
  - Milestones 3 and 4 focused on conducting sea trials with the appropriate partners.
  - A significant amount of time and effort was put into planning and preparing for sea trials. The activities included, but were not limited to, marketing, recruiting and research.
  - Transport Canada and Fujitsu worked closely together in this phase. This phase started at the same time as the software development phase to get a head start.
  - After sea trials were successfully completed, Fujitsu analyzed and shared the results of sea trials with Transport Canada.

The deliverable at the end of each milestone was a report of the activities that were conducted, progress updates and results / analysis (for sea trials). The final milestone was a compilation and summary of all the work that was completed, as well as overall findings and observations.

The project was not without its challenges. The most challenging activity was the recruitment of sea trials partners as the Fujitsu team spent more time and effort than originally anticipated. Overcoming the challenges took some creative problem solving by the Fujitsu team. Despite the challenges, the Fujitsu team completed both the Software Development and Sea Trials phases within the target dates.

In the Software Development phase:

- Fujitsu developed new features and components that did not exist previously that allowed for the project to proceed with the sea trials phase.
- Improvements and enhancements were made to code quality, hosting infrastructure and the cloud computing environment that increased the confidence of the technology being ready for sea trials.

In the Sea Trials phase:

- Fujitsu was able to establish key partnerships with the right sea trial partners who collaborated with Fujitsu in developing the right sea trial plan and procedures

- Fujitsu successfully completed both short-distance and long-distance sea trials
- Fujitsu demonstrated how VFO can help reduce consumption and the emissions of GHGs and CACs.

Overall, the project was a great learning experience for both Transport Canada and Fujitsu. Fujitsu welcomes the opportunity to work with Canada again in future projects.

RÉSUMÉ

La technologie de Fujitsu visant à optimiser la consommation de carburant par les navires permet d'optimiser par l'intelligence artificielle (IA) les itinéraires des navires. Grâce à ses modèles, cette technologie est en mesure de déterminer un itinéraire économique en carburant pour les navires, ce qui contribue à réduire les émissions de gaz à effet de serre (GES) et de principaux contaminants atmosphériques (PCA).

Dans le cadre de l'initiative pour le transport maritime propre, Transports Canada (TC) et Fujitsu ont collaboré à un projet visant à valider l'efficacité de la technologie d'optimisation du carburant des navires (OCN) en ce qui concerne la réduction de la consommation de carburant et des émissions de GES et des PCA. Cela nécessitait de faire progresser le niveau de maturité technologique de la technologie d'OCN de Fujitsu vers un état de maturité raisonnable afin qu'elle puisse être utilisée dans un environnement opérationnel réel et validé.

Le projet comportait deux phases clés réparties sur cinq jalons :

- Phase de développement des logiciels :
    - Les jalons 1 et 2 étaient axés sur l'élaboration et la mise en œuvre d'améliorations techniques à l'OCN afin que celle-ci puisse fonctionner de manière efficace et optimale dans un environnement de production.
    - Cette phase devait être terminée avant que l'OCN puisse être utilisée dans un environnement de production.
- Phase d'essais en mer :
    - Les jalons 3 et 4 étaient axés sur la réalisation d'essais en mer avec les partenaires appropriés.
    - Beaucoup de temps et d'efforts ont été consacrés à la planification et à la préparation des essais en mer. Les activités comprenaient, sans s'y limiter, le marketing, le recrutement et la recherche.
    - TC et Fujitsu ont travaillé en étroite collaboration au cours de cette phase. Celle-ci a démarré en même temps que la phase de développement des logiciels pour prendre une longueur d'avance.
    - Une fois les essais en mer terminés avec succès, Fujitsu a analysé et partagé les résultats des essais en mer avec TC.

À l'issue de chaque étape, un rapport répertoriant les activités qui ont été menées, les mises à jour des progrès effectués et les résultats/analyses (pour les essais en mer) a été présenté. L'étape finale était une compilation et un résumé de tout le travail qui a été accompli, ainsi que les conclusions et observations générales.

Le projet comportait son lot de difficultés. L'activité la plus difficile a été le recrutement de partenaires pour les essais en mer, car l'équipe de Fujitsu a consacré plus de temps et d'efforts que prévu initialement. Afin de relever les défis, l'équipe de Fujitsu a dû faire preuve de créativité. Malgré tout, elle a terminé les phases de développement des logiciels et de réalisation des essais en mer dans les délais impartis.

Durant la phase de développement des logiciels :

- Fujitsu a mis au point de nouvelles fonctionnalités et composantes qui n'existaient pas auparavant, ce qui a permis au projet de passer à la phase de réalisation des essais en mer.
- Des améliorations et des ajouts ont été apportés à la qualité des codes, à l'infrastructure d'hébergement et à l'environnement infonuagique, ce qui a renforcé la certitude que la technologie était prête pour les essais en mer.

Durant la phase d'essais en mer :

- Fujitsu a pu établir des partenariats clés avec les bons intervenants pour collaborer à l'élaboration d'un plan et de procédures appropriés pour les essais en mer.
- Fujitsu a réalisé avec succès des essais en mer à courte et à longue distance.
- Fujitsu a démontré en quoi l'OCN peut aider à réduire la consommation et les émissions de GES et des PCA.

Dans l'ensemble, le projet a été une excellente expérience d'apprentissage pour TC et Fujitsu. Fujitsu se réjouit de l'occasion de travailler à nouveau avec le Canada dans le cadre d'autres projets.

Table of Contents

APPENDICES

List of Figures

List of Tables

Glossary of Abbreviations, Acronyms and Special Terms

AIS – Automatic Identification System

API – Application Programming Interface

CAC – Criteria Air Contaminants

CI/CD – Continuous Integration/Continuous Delivery

CMAC – Canadian Maritime Advisory Council

DJSI – Dow Jones Sustainability Index

ECDIS – Electronic Chart Display and Information System

GCR – Great Circle Route

GHG – Green House Gasses

GT – Gross Tonnage, a nonlinear measure of a ship's overall internal volume

HFO – High-Sulphur Fuel Oil

IDE – Integrated Development Environment

IMO – International Maritime Organization

IoT – Internet of Things

Kbps – kilobits per second

kg – kilogram

KML – Keyhole Markup Language

MGO – Marine Gas Oil

MMSI – Maritime Mobile Service Identity

mt – metric tonnes

M/V – Maritime Vessel

REST – Representational State Transition

SMC – Ship Model Creation

UI – User Interface

VFO – Vessel Fuel Optimization

1. INTRODUCTION

1.1 Background/Objective of the Project Work

1.1.1 Background

Fujitsu as a company focuses on sustainability and has been recognized as such by inclusion in the World Dow Jones Sustainable Index (DJSI) for 21 consecutive years. The World DJSI chooses the top ~10% of 2,500 candidate companies. Fujitsu achieved high evaluations for its environmental initiatives such as climate strategy, environmental reporting, social efforts, including Social Reporting and Human Rights initiatives.

Additionally, Fujitsu has participated in numerous projects that benefit the environment, including:

- Owl habitat preservation project
- Wind turbine quality inspection projects
- Flood and tsunami prediction projects
- Australian bushland preservation project
- Alberta wildfire anticipation and Readiness Engine System (AWARE)

Fujitsu has also participated in numerous projects for maritime, including:

- Ship Collision Risk Prediction
- Fleet Connectivity and Performance
- Maritime Big Data Platform
- Autonomous Shipping
- Port Optimization

With the two themes of environment and maritime in mind, Fujitsu initiated background research into the core technology (i.e. of Vessel Fuel Optimization (VFO)) that was used in this project with the Tokyo University of Marine Science and Technology. Subsequently, based on this initial research, Fujitsu's Vancouver office embarked on furthering the development VFO as a commercial offering, as announced in a press release in 2019.

1.1.2 Objective

The objective of this project was to advance VFO's technical readiness level to Level 8, which Innovation Canada defines as *"Actual technology completed and qualified through tests and demonstrations"*, and *"Technology has been proven to work in its final form and under expected conditions. Activities include developmental testing and evaluation of whether it will meet operational requirements."*

Specifically, this means,

- Completing development work items as defined in the project plan
- Supporting sea trials with one or more vessel operators on ships making trans-oceanic voyages
- Evaluation of the performance under real-world conditions
- Evaluation of the user experience of the software

Table 1 articulates the goals, objectives and business outcomes in more detail.

Table 1 Project goals, objectives and business outcomes

No.	Goals	Objectives	Business Outcomes
1	Advance implementation to a reasonable state of completion and market-readiness	Perform the development tasks specified for each milestone.	Increase confidence in the implementation's robustness and scalability.
2	Evaluate the usability and performance of VFO	• Qualify the usability in an operational setting • Quantify the fuel savings • Quantify the CO_2 reduction performance • Quantify the CAC reduction performance	Increase confidence in the technology's value proposition
3	Communicate goals 1 & 2 effectively	Generate reports at the end of each milestone	Increase transparency to Transport Canada and future potential customers.

Specifically, the development work largely focused on automating tasks which originally needed to be done manually. Besides automation, the other major theme of the development work is testing, to improve the quality of the implementation.

1.1.3 Project Overview

The project was divided into 5 milestones. The first two milestones focused on software development to deliver technical enhancements to Fujitsu's Vessel Fuel Optimization (VFO) implementation. The second two milestones focused on the preparation and execution of sea trials to evaluate the usability in an operational setting, and the performance of the algorithm.

Table 2 provides descriptions for each milestone.

Table 2 Milestone descriptions

Milestone	Description
1	• Automate the gathering of historic AIS data, current, wave, and wind data • Automate and optimize data ingestion processes • Automate and optimize ship model creation processes • Write and submit interim report
2	• Provide a REST API to initialize vessel model creation and retrieve progress information • Improve all aspects of the service performance through testing, profiling, and re-factoring (re-work of code) • Write and submit interim report

3	• Train ship crew(s) • Provide support during sea trials • Write and submit interim report
4	• Analyze results from sea trials • Write and submit draft final report
5	• Create and deliver (remotely) presentation to Transport Canada • Integrate feedback • Submit final report

Of note, recruitment activities (for sea trial partners) which was not specifically mentioned in the milestones was an essential activity in the project which ran from Milestone 1 to Milestone 4.

1.2 Summary of the VFO Tool and its Capabilities

1.2.1 Overview

VFO provides AI-powered ship route optimization utilizing open data only. It achieves this through a model that learns from a ship captain's operation strategies and the ship's performance.

The implementation uses historical weather data such as wind, currents and wave heights, as well as ship historical trajectory data, to model ship performance in various environmental conditions. For upcoming voyages, models are then used to identify a fuel-efficient route for the vessel. Reductions in GHG and CAC emissions are achieved by reductions in fuel consumption.

Figure 1 shows a block diagram of VFO components.

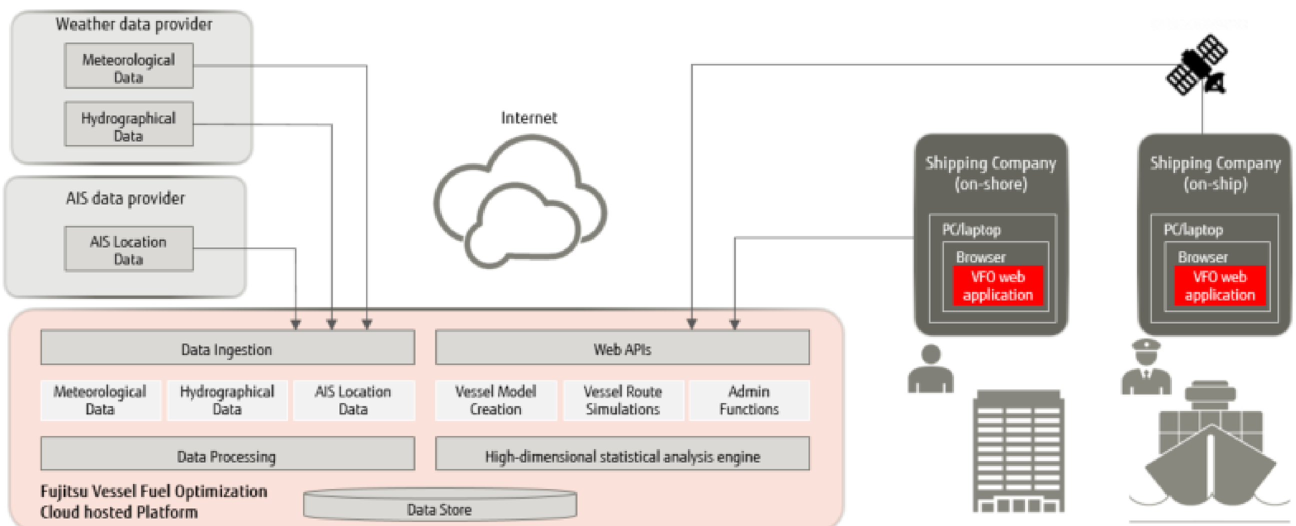


Figure 1 Block diagram of VFO components

Here is a description of each part of the implementation.

Weather data provider: This is a commercial data feed which provides historical and real-time weather data.

AIS data provider: This is a commercial data feed which provides the historical and current locations of large ships. AIS stands for Automatic Identification System, and is a standardized technology for locating ships.

Data ingestion: This part of our implementation accepts the weather and AIS data feeds as inputs, and creates local copies of these datasets.

Data processing: The data processing engine "cleans" and organizes the multiple datasets, e.g. to have a common time format to be consumed by the high-dimensional statistical analysis engine.

High-dimensional statistical analysis engine: This component performs the key functions of creating vessel models and calculating new routes for vessels.

Data store: The data store includes the ingested weather and vessel databases, as well as user data, previous route trajectories

Web APIs: API stands for Application Programming Interface. In our implementation, APIs are the mechanism by which key functionality is exposed.

Web application: The web application is used by the end user to access the implementation through a graphical user interface (GUI), using a common browser such as Chrome or similar. Figure 2 shows a screenshot of the web application in its current form.

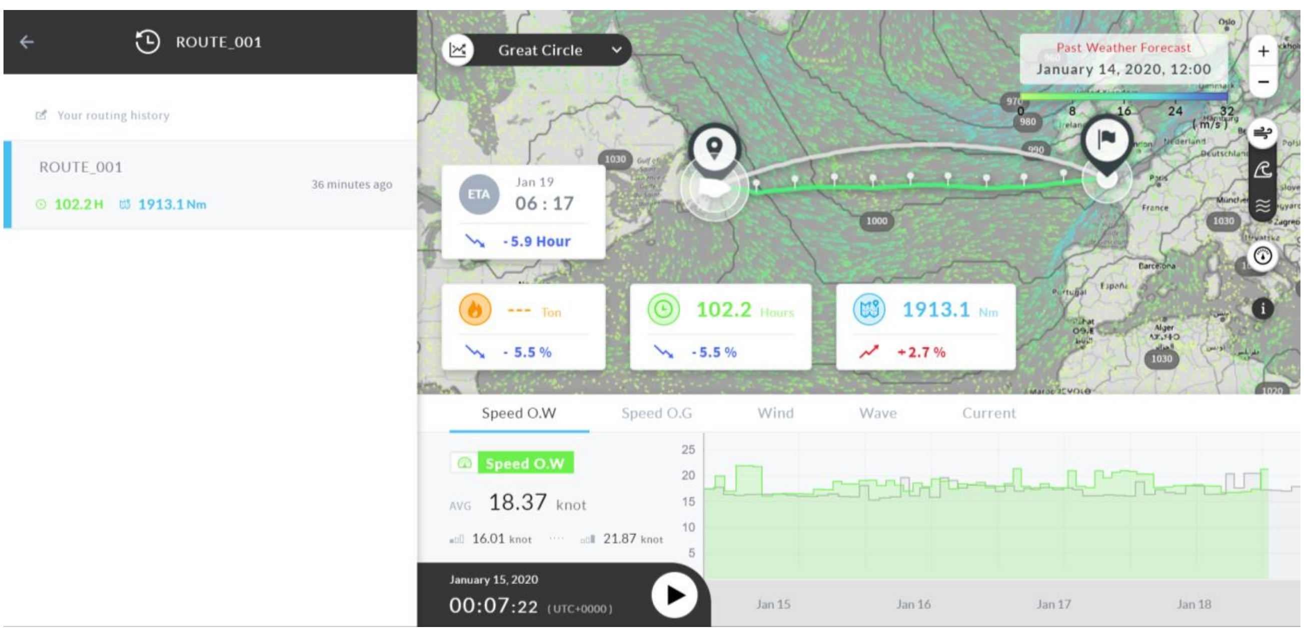


Figure 2 VFO screenshot

The VFO GUI shows various things, such as,

- Maps, showing oceans, land masses, and port locations. The user can zoom in/out, scroll up/down/left right on the maps, or right-click to add waypoint information.
- Weather information: including wind, current and wave data
- Route information, including departure/arrival points, departure/arrival times, route waypoints
- Route previews, showing an animation of wind, wave and current information throughout the voyage
- A comparison of fuel consumed versus the great-circle route.
    - *The screenshot shows a route from Newfoundland to the UK wherein the route reduced the fuel consumed by 5.5%*

VFO includes the following functionality

- ability to log on to the web application
- ability to add a ship to the system
- ability to set various ship parameters such as draught, etc
- ability to specify a voyage in terms of departure and arrival points
- ability to calculate an optimized route for the specified voyage
- ability to display that route on a map in the GUI
- ability to export the route as a flat text file, for input to the ship's navigation system
- ability to compare the fuel efficiency of the optimized route versus a great-circle route
- ability to see an animated preview of the voyage, showing currents, wave heights, and winds at each stage

1.2.2 Key Features and Benefits

Table 3 lists the key features of VFO and the benefits those features provide.

Table 3 VFO Key Features and Benefits

Features	Benefits
1. Each ship modeled individually for performance. 2. Uses only publicly available ship information (ship ID, i.e. IMO / MMSI number). 3. Uses publicly available metrological, hydrographical and tracking (AIS) information. 4. No sensor installation on vessel required. 5. No software installation required. 6. Secured via multiple mechanisms.	1. Fuel cost and emissions reduction (up to ~10 %). 2. Low initial investment on ship. 3. Service can be used immediately. 4. Applicable to a broad range of vessels.

2. SOFTWARE DEVELOPMENT

2.1 Goals and Objectives of the Software Development

Prior to this project, the onboarding of new ships into the VFO system was a manual and tedious process that required human intervention and could take up to 2 weeks. The process involved procuring a ship's AIS data, downloading and storing it, combining it with weather data and then performing detailed analysis on the combined data; all steps occurring manually.

Once the detailed analysis is completed and a ship model is created, it is then manually integrated into the VFO system so that it can be used to generate routes.

2.1.1 Goals

The goal of the software development activities was to advance the VFO implementation to a reasonable state of completion and market-readiness.

2.1.2 Objectives

To meet the software development goal, the following objectives needed to be met:

- Automating key processes that were manual, inefficient and time-consuming
- Optimizing code that prevented VFO from being used in real operational environment
- Enhancing and hardening VFO hosting environment to ensure VFO security and stability when used in a real operational environment

Milestone 1 focused on automating the ship model creation or SMC process (onboarding of new ships) so that the only thing required is simply a ship's IMO #.

When a ship's IMO # is submitted to the automated ship SMC process, a pipeline process would kick off that automatically downloads, retrieves and stores a ship's AIS data and then combines it with weather data to be processed and analyzed automatically to generate the appropriate ship model. The model is then automatically integrated into the VFO system.

Development work in Milestone 1 focused on foundational architectural components ("the internal workings" or "what's under the hood") that were required to efficiently and effectively automate VFO's ship model creation process.
While several components were developed, they were not immediately deployed to the new production cloud environment in which a lot of set up work was done in the milestone 1.

Milestone 2 development work focused on improving the user experience and workflow of the pipeline (SMC process). Another focus in the milestone was the deployment of the new automated pipeline from the previous milestone to the production cloud environment so that it can be used by admin users via the available interfaces (API and UI). Table 4 summarizes the milestone 2 tasks and results

Table 4 Milestone 2 tasks and results

Planned Task	Results of the Work	Actual Completion
Deployment of components developed in previous milestone to the cloud	All components that were developed in the previous phase were deployed to the new production cloud environment.	04-Sep-20
Testing, profiling and refactoring for components developed in previous milestone	This work involved: • Setting up continuous integration/continuous development (CI/CD) pipeline to support automated testing • Testing and performance profiling	

	• Optimizing and refactoring code • Setting up Domain / Domain Name Server (DNS) for the new production environment • Undergoing Fujitsu security review (e.g. vulnerability testing) • Deploying all components	
Model notification service (with testing, profiling and refactoring)	Developed APIs for new cloud services and connected the APIs to a newly developed user interface for ship model creation. After these newly developed components were tested and verified, they were deployed to the new production cloud environment.	28-Sep-20
Ship enrollment API (with testing, profiling and refactoring)		
Ship model creation API (with testing, profiling and refactoring)		
Ship model progress API (with testing, profiling and refactoring)		
UI interface for consuming REST APIs (with testing, profiling and refactoring)		

The Fujitsu team achieved this goal by developing a simple but elegant and straightforward user interface where a ship's IMO # can be submitted and where the status and progress of the process would be displayed. Also, in milestone 2, the development team worked on improving code quality through refactoring and testing.

2.2 Summary of the Software Development Work

2.2.1 Planning

Fujitsu planned this project in detail in its response to Transport Canada's RFP for Clean Marine. The contract with Transport Canada reflects that same plan.

Solution development planning and analysis was conducted upfront as part of Fujitsu's response to the RFP. The process involved 1) estimating the number of sprints we thought we would need, 2) what each sprint would focus on and 3) the sequence of the sprints.

For each sprint, we estimated that 2-weeks was required which is a standard practice followed by agile teams all over the world.

In each sprint, we followed standard SDLC (software development life cycle) steps (i.e. plan / analyze -> design -> develop -> test). This helped ensure that we were thorough.

For each sprint, we also had planning sessions before starting and recap / review sessions after. This helped us keep track of our work and helped us communicate effectively. In some sprints, we also had planning sessions mid-sprint.

The sequence of the sprints were determined according to priority: (Sprint 1) Setting up foundational and essential infrastructure, (Sprint 2) Automating and configuring Big Data processing components, (Sprint 3 & 4) Automating SMC components.

So in terms of planning, there was some detailed planning upfront and then more detailed and focused continuous planning and review by sprints.

2.2.2 Methodology

For the software development work, our approach was to use an Agile methodology. There are many forms of Agile; for this project, the development team primarily followed the Scrum variant of Agile, which has the following attributes:

- Daily, short, stand-up meetings where team members report on their recent work, upcoming work, and any reasons they might be blocked
- "Sprints" of work, which in this case are two weeks in duration, and contain user stories
- User stories which articulate a chunk of work, how large that work is, the purpose of that work, and acceptance criteria for that work

We chose an Agile/Scrum workflow because we wanted to split work into short, incremental development cycles (sprints) to provide flexibility.

We also used techniques from Extreme Programming (Test Driven Development), DevOps (Continuous Integration) and Kanban. Table 5 shows descriptions for each of the agile methodologies used in the project.

Table 5 Project Methodologies

Methodology	Description
Scrum	The formal ceremonies of scrum helped ensure that the development team maintained discipline, remained organized and worked on improving after each iteration. Scrum also helped the team to prioritize the most valuable tasks and adapt plans to deliver those tasks.
XP & DevOps	The use of XP and DevOps were critical in ensuring that software quality was built-in and accounted for throughout the development process, especially since Milestone 2 included the development of the API and user interfaces which required integration testing. Integration testing is a very important activity as it validates whether the end product works.
Kanban	The use of Kanban helped the team to track tasks efficiently and stay productive.

The development team used Microsoft's Azure DevOps Agile environment to organize and keep track of progress on user stories and sprints. Azure DevOps is an all-in-one project tracking and planning tool mixed with developer tools and many extensions for development purposes.

2.2.3 Development Environment

For Milestone 1, the development of this software project was entirely cloud based, using the Microsoft Azure cloud computing environment. The "experimental setup" consists of testing the VFO implementation in that cloud environment. The development team tested each piece of functionality.

Two environments were set up: a development environment and a production environment.

Both environments consist of virtual servers, databases, containers, streaming / event services and security infrastructure. Also, both environments were hosted on Microsoft Azure.

A CI / CD (Continuous Integration / Continuous Delivery) pipeline has also been set up to automatically test and check any new code before integrating and merging the code with the development and production environments.

With the use of short incremental development cycles, only components that were required were provisioned as required for each sprint. The environments were incrementally enhanced as sprints progressed.

For Milestone 2, the cloud environments that were initially set up in the previous milestone were expanded to support the new components (i.e., services). These environments were also enhanced further with added security configuration and cloud management services to further improve the security, automated configuration, coordination, and management of all cloud components required to support VFO and upcoming sea trial activities.

Testing was also a key activity throughout the duration of milestone 2. With the complexity of cloud environments, especially those that have automated pipelines and multiple cloud services that need to be flexible and scalable, it was very important to start testing activities earlier.

The development team also used new tools in milestone 2, specifically for version control of database development tasks. The new tools included

- Microsoft Azure DevOps – an agile workflow management environment
- Visual Studio, IntelliJ – integrated development environments (IDEs) for software development
- PostGres Admin – a database administration tool

As new cloud services were added, keeping track of changes by each developer was important.

2.3 Results of the Work

2.3.1 Milestone 1 Results

The result of Milestone 1 was that we had an automated pipeline that takes in a ship's IMO # and outputs a ship model. Models that previously took days to create could be created in hours.

From a schedule perspective. All of the user stories in Sprints 1, 2, 3, and 4 were completed. Table 6 summarizes the completion status of those tasks.

Table 6 Milestone 1 tasks and results

<table>
<tr><th>Planned Task</th><th>Results of the Work</th><th>Actual Completion</th></tr>
<tr><td>Set up and configure big data storage</td><td>Set up new cloud storage infrastructure on Azure. This replaced the previous storage infrastructure which was end-of-life.</td><td rowspan="4">22-Jun-20</td></tr>
<tr><td>Weather data loader</td><td rowspan="3">Replaced previous vendor software with a custom developed data ingestion / transformation module.</td></tr>
<tr><td>Set up automated data collection</td></tr>
<tr><td>Big data loading / streaming functionality</td></tr>
</table>

<table>
<tr><td>Big Data cleaning / transformation / processing functionality</td><td rowspan="2">This module ran against an FTP server where weather data from the data provider was dropped.

The previous vendor software was not set up and configured properly so therefore was unreliable. It was making key tasks such as logging of data drops, detecting failed data drops / transformations and reinitializing failed processes difficult.</td><td rowspan="2">13-Jul-20</td></tr>
<tr><td>Big Data ingestion into Application Database</td></tr>
<tr><td>AIS data loader</td><td rowspan="6">Developed a new automated pipeline (Ship Model Creation (SMC)) that takes in a ship’s IMO # and outputs a ship model. Models that previously took days to create could now be created in hours.

Each key step in the pipeline was developed as a cloud service, thereby taking advantage of cloud computing features. This also allows for the pipeline to be further scaled in the future, allows for parallel processing of multiple ship models and makes the code and overall system more optimal.

Prior to this feature existing, this entire process was done manually by a resource with specialized skills. The entire process could take up to two weeks.</td><td rowspan="5">28-Jul-20</td></tr>
<tr><td>AIS data acquisition</td></tr>
<tr><td>AIS data cleansing</td></tr>
<tr><td>Route selection</td></tr>
<tr><td>Combine AIS data with routes</td></tr>
<tr><td>Combine data with weather</td><td>12-Aug-20</td></tr>
</table>

2.3.2 Milestone 2 Results

Building off the foundational architectural components and initial automation code from the previous milestone, the Fujitsu development team accomplished the following:

- Deployed the foundational architectural components and automated SMC pipeline from the previous milestone to the cloud
- Developed individual cloud applications (“services”) for each component in the automated SMC pipeline
- Developed the backend code for the authentication (i.e. login) and administration (e.g. customer and ship creation) components for the SMC pipeline
- Developed the frontend user interfaces for the authentication, administration and ship model creation components
- Optimized code through refactoring and testing

Table 7 summarizes the results for Milestone 2.

Table 7 Milestone 2 results

Sprint	Description	No-later-than Date	Actual Completion Date
5	Deployment of components developed in previous milestone to the cloud	N/A	04-Sep-20
5	Testing, profiling and refactoring for components developed in previous milestone	N/A	04-Sep-20
6	Model notification service (with testing, profiling and refactoring)	28-Sep-20	28-Sep-20
6	Ship enrolment API (with testing, profiling and refactoring)	28-Sep-20	28-Sep-20
6	Ship model creation API (with testing, profiling and refactoring)	28-Sep-20	28-Sep-20
6	Ship model progress API (with testing, profiling and refactoring)	28-Sep-20	28-Sep-20
6	UI interface for consuming REST APIs (with testing, profiling and refactoring)	28-Sep-20	28-Sep-20

2.3.3 New features in VFO

The following new features are now available in VFO.

Customer (Company) enrollment feature: This feature allows admin users to add new customers. This is required for ship enrollment as each ship needs to be linked to a customer (company). Figure 3 shows a screenshot of the company enrollment feature.

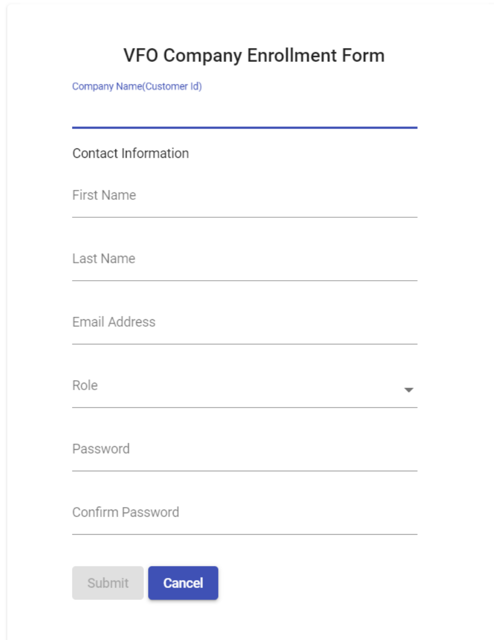


Figure 3 VFO company enrolment form

Ship enrollment feature: This feature allows admin users to onboard new ships for each customer. It has a simple user interface (UI) so that users do not need coding / programming skills to make use of this feature. This feature utilizes the new Ship enrolment API. Figure 4 shows a screenshot of the ship enrollment feature.

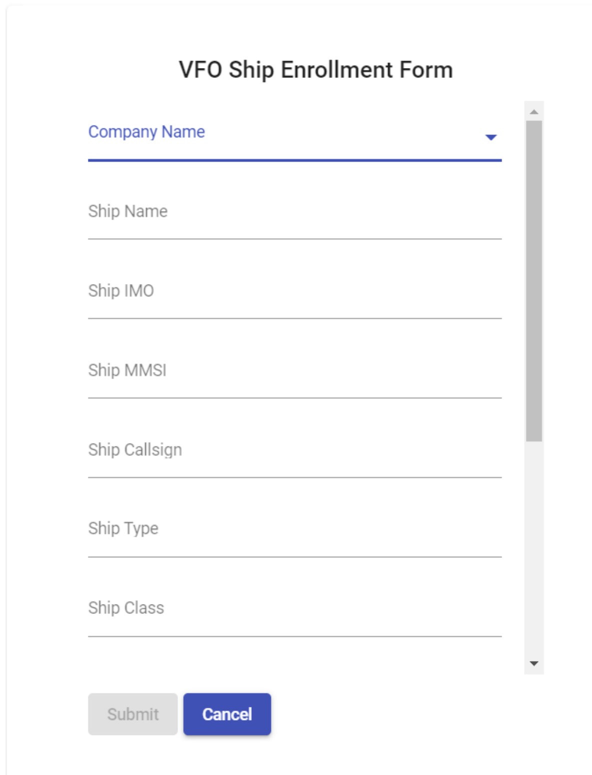


Figure 4 VFO ship enrollment form screenshot

SMC initiation tool: This feature allows admin users to initiate the automated model creation process for new ships. It has a simple UI so that users do not need coding / programming skills to make use of this feature. This feature utilizes the new ship model creation API. Figure 5 shows a screenshot of the ship model creation feature.

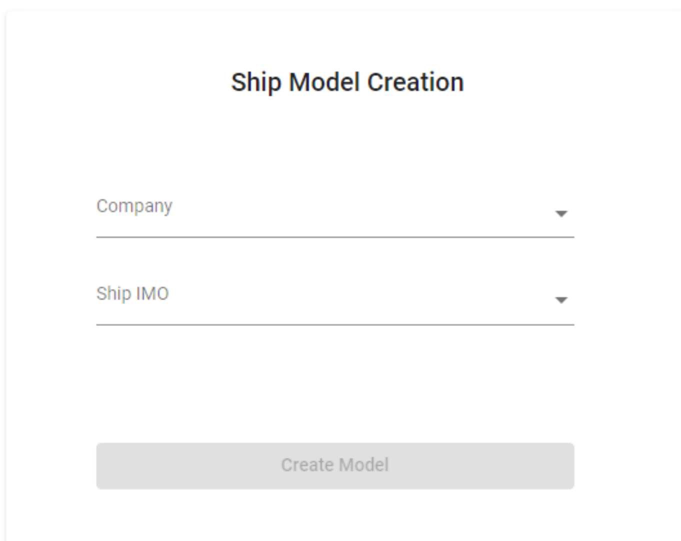


Figure 5 Ship model creation Screenshot

SMC progress tool: This feature allows admin users to check the progress of the model creation process for new ships. It has a simple UI so that users do not need coding / programming skills to make use of this feature. This feature utilizes the new Ship model progress API. Figures 6 and 7 show screenshots of the ship model creation progress tool.

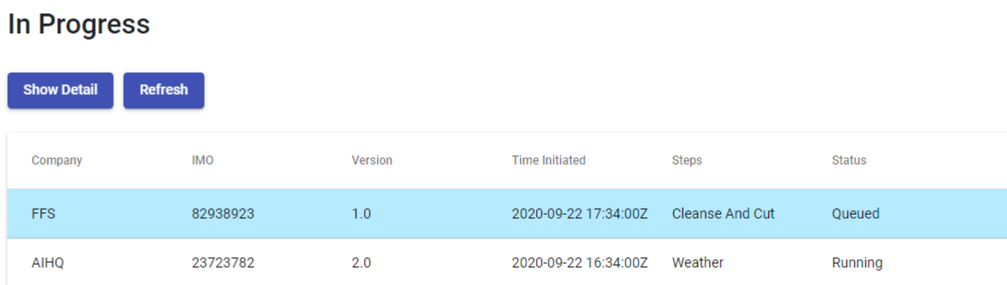


Figure 6 Ship model creation progress tool screenshot

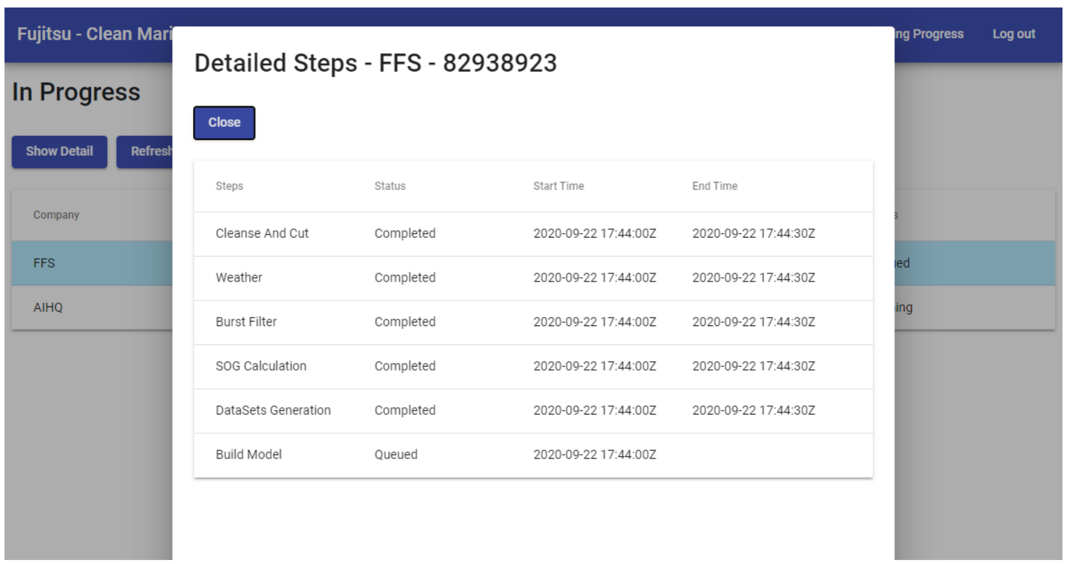


Figure 7 Ship model creation detailed steps screenshot

2.4 Summary of Where the Tool is at the End of the Software Development Work

Prior to the commencement of the Clean Marine project, much of the functionality in VFO could only be achieved by very manual processes. The software development portion of this project focused on automating several manual processes in preparation for sea trials.

With the completion of the deliverables in this milestone, models that previously took up to 2 weeks to create can now be done in hours. Moreover, admin users now have access to an interface to create the models, instead of relying on complex manual analysis and specialized programming skills.

3. SHORT-DISTANCE SEA TRIALS

From section 5.2.1 (“Sea Trial Definition and Requirements”) of the original contract with Transport Canada, sea trials are defined as follows:

"We define a short-distance sea trial as an attempt to use the VFO application on-board an actual ocean-going vessel in an operational setting. The purpose of the short-distance sea trials is to:

- *Evaluate the usability of the application by the end-user personas, and gather feedback on how the user experience might be improved*
- *Validate that the application works as expected in an operational setting, e.g. that there is sufficient bandwidth to the vessel for the application to work as expected*

The duration of a short-distance sea trial could be as little as one hour to try the application, plus one additional hour for the user to provide feedback to Fujitsu, for example, via a remote meeting."

3.1 Goals and Objectives of the Short-distance Sea Trials

The objective of the short-distance sea trials was to evaluate the usability of the implementation in an operational setting. In the context of software usage, an operational setting introduces multiple new factors which could affect operation, such as

- Low bandwidth, due to the Internet being accessed via satellite
- Different security settings that might, for example, block access to the website
- Different browsers, or versions of browsers
- Different screen sizes
- Different pointing devices such as mice, touchpads, or touchscreens
- Different computing resources such as RAM, CPUs, etc, that could affect the application's responsiveness
- Different personas, such as captains, who might use different terminology

3.2 Planning Short-Distance Sea Trials

3.2.1 High-Level Plan

The high-level outline of the plan for short-distance sea trials was follows:

a. Fujitsu recruits legal documents for software usage
b. Fujitsu creates sign-up web page
c. Fujitsu recruits sea trial partners
d. Partner(s) sign legal documentation via sign-up web page
e. Partner(s) identify vessel(s)
f. Fujitsu trains partner(s)
g. Fujitsu creates accounts, IDs and passwords
h. Fujitsu provides VFO account to partners
i. Partner(s) use VFO
j. Partner(s) provide data back to Fujitsu
k. Fujitsu writes report (this document)

The subsequent sections of this report provide more detail on each of these steps.

3.2.2 Legal documents

Fujitsu's Vessel Fuel Optimization solution, like any other software, requires use within an appropriate legal framework. To that end, Fujitsu required sea trial partners to (a) agree to its terms of use, and (b) accept its data privacy policy, before being allowed to use the VFO application. For the purposes of conducting sea trials, Fujitsu created a Terms of Use document and a Privacy Statement.

3.2.3 On-boarding website

To make the process of agreeing to the Terms of Use and the Privacy Statement simple for sea trial partners, Fujitsu created a sign-up web page. Appendix A of this report shows the appearance of this sign-up web page. Visitors to this web page who wished to try out the VFO web application were required to provide key information about themselves, and tick boxes acknowledging and accepting the Terms of Use and Privacy Statement.

3.2.4 Recruiting Sea Trial Partners

To conduct sea trials, one needs willing partners. Fujitsu spent considerable effort to recruit sea trial partners, including the following tactics:

- Leveraging its relationship with Kongsberg
- Leveraging its relationship with Transport Canada
- Participating in the newly-formed Vancouver Maritime Climate Commission (VMCC)
- Joining Vancouver's Chamber of Shipping and attending multiple of its events
- Presenting at Transport Canada's CMAC (Canadian Maritime Advisory Council) event
- Attending Canada's Digital Super Cluster session on maritime
- Cold calling on numerous vessel operators

While several of the activities led to good conversations, only three activities resulted in sea trial participation:

- the VMCC involvement allowed us to meet Metis Cybertechnologies, and the inclusion of the Desert Hope vessel for long-distance sea trials
- the conversation with Transport Canada led to an introduction to Horizon Maritime, which kindly provided Fujitsu with a short-distance sea trial
- cold calling on Blue Comet Seafoods led to an agreement to conduct a short-distance sea trial

Recruiting sea trial partners was one of the most challenging aspects of this project. The situation was certainly made worse by Covid-19, which forced vessel operators to focus on top priorities, leaving little allowance for experimental activities such as trying out new technologies such as VFO.

3.2.5 Horizon Star

For the first short-distance sea trial, Horizon-Maritime identified the Horizon-Star, which is a maritime supply vessel operating near Newfoundland. Table 8 provides details on the Horizon Star.

Table 8 Horizon Star details (photo from Horizon Maritime)

Photo	Details
	• Owner: Horizon Maritime • IMO number: 9752254 • MMSI number: 316014360 • Call sign: CFA2459 • Flag: Canada • Length: 103 meters • Breadth: 20 meters • Gross tonnage: 5204 metric tonnes

3.2.6 Blue Comet

For the second short-distance sea trial, Blue Comet Seafoods identified the "Blue Comet" vessel. Table 9 provides more details for the Blue Comet.

Table 9 Blue Comet details (photo by Todd Law)

Photo	Details
	• Owner: Blue Comet Seafoods • TCGC #: 370744 • Flag: Canada • Length: 10.09 meters • Breadth: 3.47 meters • Gross Tonnage: 14.44 metric tonnes

3.2.7 Short-distance Sea Trial Procedure

The approach for the short-distance usability sea trials was as follows:

1. Fujitsu provides training on VFO to the sea trial partner(s)
2. Fujitsu provides a set of tasks that the sea trial partner should attempt. Those tasks are specifically:
    - Logon to VFO

- Select a vessel
- Create a voyage
- Find the optimal route
- Perform a route comparison

3. Fujitsu provides user accounts to the sea trial partner
4. Sea trial partners attempt the tasks within VFO while on the vessel at sea
5. Fujitsu conducts a follow-up meeting with the sea trial partner to collect feedback. The meeting consisted of Fujitsu asking the following questions:
    - What was your experience like in using VFO?
    - Was it easy to use?
    - Was there enough Internet bandwidth in the operational setting for the screen, especially the map information, to stay reasonably updated?
    - Did you have any troubles performing the tasks?
    - Overall, on a scale from 1 to 10, what you rate the usability of the VFO application?

3.2.8 Training Short-distance Sea Trial Partners

After recruiting sea trial partners, Fujitsu trained them on how to use the Vessel Fuel Optimization application. Training was a straightforward process, delivered remotely via a Microsoft Teams meeting. Appendix B contains the training material, for reference.

Training sessions:

- Fujitsu delivered VFO training to the Horizon Star crew on January 12, 2021
- Fujitsu delivered VFO training to Blue Comet Seafoods on February 23, 2021

3.3 Results of the Trials

3.3.1 Operational Setting Results

Table 10 shows the operational settings of the Horizon Star and Blue Comet.

Table 10 Short-distance sea trials operational setting details

Vessel	Vessel Location	Personnel	Internet Connection	Browser
Horizon Star	Bay Roberts, Newfoundland	Captain: Robert Burke Chief Engineers: Jamie Hayes	Satellite, download bandwidth as follows: • 256 kbps Committed Information Rate (CIR) • 4096 kbps Maximum Information Rate	Chrome

Blue Comet	Near Granville Island, Vancouver, BC	Captain: Sasha Berger	1st attempt: Satellite, download bandwidth as follows: • 256 kbps 2nd attempt: Shaw Mobile network	Chrome

3.3.2 Usability Results

After providing training, we asked both sea trial partners to conduct a sequence of tasks. Please see Table 11 for the list of tasks, and the Horizon Maritime's success in performing these tasks.

Table 11 Results from short-distance sea trial with Horizon Maritime

Task	Success Status	Comments
Logging in	Completed	There seem to be no issues at this point and we can log in.
Creating a voyage	Completed	Was getting error "No recommended route found due to violation of wind speed limit. Please add or change waypoint(s)." for some voyages attempted. I believe this is just due to the limits put in.
Selecting a ship	Completed	
Specifying a ship's settings	Completed	Not able to change any of the settings (length, breadth, etc.) only able to change draught and depth. I'm assuming the full version would have the Horizon Star programed in with correct particulars.
Setting departure and arrival	Completed	
Setting "danger" waypoints	Completed	
Setting "must-go" waypoints	Completed	
Setting the speed	Completed	I'm assuming speeds (slow, normal etc.) will be adjust for our ship in the full version.
Setting the control point interval	Completed	
Searching for the optimal route	Completed	
Checking the route results	Completed	

Simulating the route	Completed	
Comparing against the great circle route	Completed	
Exporting the route	Completed	Exported in .rtz format. I believe I will have to use conversion software to be able to be used with our JRC ECDIS. Do you have any recommendations for this or is it possible to export from your software in a different format.

Similarly, Table 12 shows the results from the short-distance sea trials with the Blue Comet.

Table 12 Results from short-distance sea trial with Blue Comet

Task	Success Status	Comments
Logging in	Completed	
Creating a voyage	Completed	
Selecting a ship	Completed	User struggled to select the ship. The process for this requires multiple clicks of the mouse.
Specifying a ship's settings	Completed	
Setting departure and arrival	Completed	It was not obvious how to specify departure and arrival points
Setting "danger" waypoints	Not completed	During training, this step was described as "Optional" (this feature is an advanced feature, and is optional because it is not required to operate the tool)
Setting "must-go" waypoints	Not completed	During training, this step was described as "Optional" (this feature is an advanced feature, and is optional because it is not required to operate the tool)
Setting the speed	Completed	
Setting the control point interval	Completed	
Searching for the optimal route	Completed	
Checking the route results	Completed	Encountered a message "No weather past March 6"
Simulating the route	Partial	User did not notice the animation "play" button, but simply looked at the static representations of the wind, waves and current, rather than the animated "movie" preview of this information.

Comparing against the great circle route	Completed	
Exporting the route	Completed	User struggled to find the three dots under which the export menu is located.

We also asked both sea trial partners a set of questions to further understand their experiences. Table 13 & 14 show those questions and their answers for Horizon Maritime and Blue Comet respectively.

Table 13 Horizon Maritime's Short Distance Sea Trial Responses to Questions

Question	Response
What was your experience like in using VFO?	It was alright
Was it easy to use?	Yes.
Was there enough Internet bandwidth in the operational setting for the screen, especially the map information, to stay reasonably updated?	We have been trying to set up your program this past weekend. When I enter the username and password, I am asked to enter the vessel name, IMO # or MMSI #. I tried entering three of those however, I am given an error message "Invalid ship name, IMO or MMSI selected". Am I able to register our vessel or is this something you will do? Or does it need to be done at all? Nonetheless, I have attempted to play around with it by creating a voyage route. Unfortunately, it is very slow and while panning the screen or trying to zoom in, it freezes up and I have to refresh and start over again. This may have something to do with our internet speed. Please let me know your thoughts.
Did you have any troubles performing the tasks?	No.
Overall, on a scale from 1 to 10, what you rate the usability of the VFO application?	About an 8

Table 14 Blue Comet Seafood's Short Distance Sea Trial Responses to Questions

Question	Response
What was your experience like in using VFO?	It seems an easy enough program to use once you got the jist of it. There's obviously much more I could do with it. I could go around the Cape or through the Panama Canal, or play around with the speed.
Was it easy to use?	Yes, it was fairly easy to use.
Was there enough Internet bandwidth in the operational setting for the screen, especially the map information, to stay reasonably updated?	No. While using the VFO application froze after clicking on the OK button in the vessel configuration page.
Did you have any troubles performing the tasks?	Not so much
Overall, on a scale from 1 to 10, what you rate the usability of the VFO application?	8 or 9

3.4 Discussion/Analysis of the Trial Results

From the short-distance sea trials result data, we make the following observations:

- The application is not functional in some low-bandwidth environments
- The application's usability is generally good
- Improvements in usability could be made in the following areas:
    - Making the implementation resilient in low-bandwidth environments
    - Making vessel selection easier and more obvious
    - Making voyage specification easier and more obvious

3.5 Conclusion and Next steps for the Tool based on the Results of the Analysis

As possible next steps to address the limitations identified in the previous section, Fujitsu could make the following enhancements to VFO:

- Streamline the implementation to minimize the amount of data being transmitted between the client (the browser) and the server
- Tweak the user interface to improve the usability for key workflows such as defining the departure and arrival waypoints
- Enhance the export feature to include an option to match the format of the target ECDIS navigation system

4. LONG-DISTANCE SEA TRIALS

From Section 5.2.1 of the original contract with Transport Canada, we define long-distance sea trials as follows:

> *"We define a long-distance sea trial as a trans-oceanic voyage of at least 7 days in duration, of a vessel at least 300 gross tonnage in weight, where the VFO application is used to determine the vessel's routing. The purpose of a long-distance sea trial is to validate the performance of the algorithm. The reason for this minimum weight is that all vessels above this size are supposed to be equipped with an AIS transponder, which means historical vessel data is available, and therefore, our algorithms can be used. In practice, we expect that the actual weight of vessels will be larger."*

4.1 Goals and Objectives of the Long-distance Sea Trials

The goal of the long-distance sea trials was to evaluate the effectiveness of the VFO application and algorithm. The specific objectives were to:

- Quantify the savings in fuel consumption in VFO-found routes versus captain's routes and great circle routes (GCR), i.e. the shortest distance path over the water between two waypoints
- Quantify the reductions in CO_2 and CAC emissions in VFO-found routes versus captain's routes and GCR routes

4.2 Planning of the Long-Distance Sea Trials

4.2.1 High-level Plan

The high-level outline of the plan for long-distance sea trials was follows:

a. Fujitsu recruits legal documents for software usage
b. Fujitsu creates sign-up web page
c. Fujitsu recruits sea trial partners
d. Partner(s) sign legal documentation via sign-up web page
e. Partner(s) identify vessel(s)
f. Fujitsu trains partner(s)
g. Fujitsu acquires vessel data
h. Fujitsu uses VFO to create ship model, based on at least one year's worth of historical data
i. Fujitsu creates accounts, IDs and passwords
j. Fujitsu provides VFO account to partners
k. Partner(s) use VFO
l. Partner(s) provide data back to Fujitsu
m. Fujitsu writes report (this document)

4.2.2 Legal Documents

We used the same legal documents as from the short-distance sea trial for this purpose.

4.2.3 On-boarding Website

We used the same sign-up as from the short-distance sea trial for this purpose.

4.2.4 Recruiting Sea Trial Partners

We used the same recruiting activities as in the short-distance sea trials for this purpose.

4.2.5 Vessel Identification – Desert Hope

For long-distance sea trials, Metis identified the Desert Hope, which is a bulk carrier vessel mainly operating in the Atlantic between Europe, Africa, South America, and North America. Table 15 provides more details for the Desert Hope.

Table 15 Desert Hope details (photo from Atlantic Bulk Carriers)

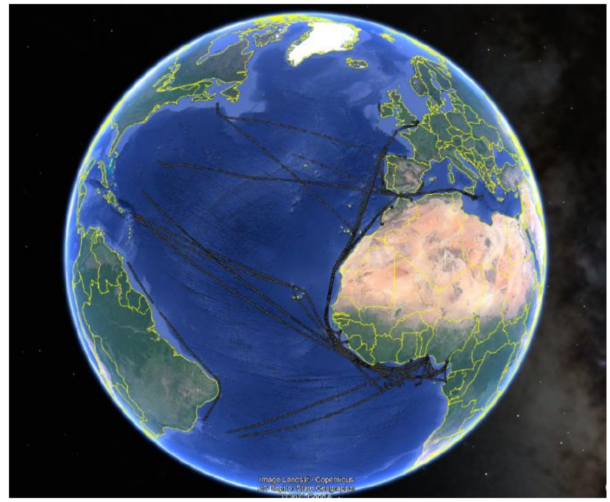
Photo	Details
	• Owner: Atlantic Bulk Carriers • IMO number: 9543756 • MMSI number: 538004411 • Call sign: V7WW7 • Flag: Marshall Islands • Length: 193.07 meters • Breadth: 32.26 meters • Gross tonnage: 33,631 metric tonnes

4.2.6 Data Acquisition

To create a model for the Desert Hope vessel, VFO required both historical weather data and historical vessel location data.

- Weather data was obtained from the Japan Meteorological Association via an ongoing subscription.
- Historical vessel location was obtained through AIS (Automatic Identification System) data which Fujitsu purchased for the Desert Hope vessel from exactEarth Limited. In the Desert Hope AIS data that was purchased, there were 55 voyages between April 4, 2019, and December 4, 2020. This can be visualized through the use of Keyhole Markup Language (KML), developed by Google, on either Google Maps or Google Earth. Table 16 shows the historical routes for the Desert Hope.

Table 16 Desert Hope historical route information

<table>
<tr><th>Google Maps</th><th>Google Earth</th></tr>
<tr><td>
</td><td></td></tr>
</table>

4.2.7 Ship Model Creation

For the purposes of the long-distance sea trials, Fujitsu used the data acquired in section 4.2.6 to build a model of the Desert Hope. The ship model was built from historical weather and AIS data. The automation work from the milestones 1 and 2 made the model creation process more efficient than the previous manual process.

Fujitsu used the weather data and historical vessel location data acquired to build a VFO model of the Desert Hope. At a high level, the steps used to create the model, were as follows:

1. Get historical AIS data of Ship to model
2. Cleanse data (e.g. removing anomalies)
3. Get historical Weather data
4. Combine historical AIS and historical Weather data
5. Cleanse data (e.g. eliminate records with missing weather data)
6. Build model with combined dataset
7. Test and evaluate model
8. Apply high dimensional statistical analysis formula on model
9. Use model (if testing and evaluation meets required criteria)

Steps 2 through 6 were completed using the new user interface developed in milestones 1 and 2.

4.2.8 Long-distance Sea Trial Procedure

The procedure for conducting the long-distance sea trial was as follows:

1. Identify captain's intended route and speed, which we call $R_{Captain}$
2. Every six hours repeat the following sequence of sub-steps:
    a. Set speed in VFO to the speed of the captain's intended route
    b. Set departure in VFO to position of boat (from previous calculation, if any)
    c. Set arrival in VFO to destination
    d. Set control point interval in VFO to correspond to six hours of travel time
    e. Get VFO to calculate its recommended route
    f. From VFO export the .rtz file containing the recommended waypoints

g. Extract the first waypoint (latitude and longitude) from the .rtz file, and record
h. Sail to the first waypoint
i. Record the time consumed

3. Combine the waypoints from step g and times from step i above to form the VFO route, which we call R_{VFO}
4. Record the fuel consumed

4.2.9 Training Long-distance Sea Trial Partners

As with the short-distance trial partners, Fujitsu trained its long-distance sea trial partner, Metis, using the same training material which is in Appendix B. Again, we delivered training remotely via a Microsoft Teams meeting. Fujitsu delivered VFO training to Metis for long-distance sea trials on December 10, 2020

4.3 Results of the Trials

4.3.1 Voyage Information

The Desert Hope undertook two (2) seven-day voyages in late 2020 through early 2021. Table 17 shows the summary data for voyages 1 and 2.

Table 17 Voyage summary data

Voyage	Date Range	Route Information	Coordinates
Voyage 1	Dec. 31, 2020 to Jan. 8, 2021	The Desert Hope travelled from a point in the Mediterranean Sea to a point near the island of Santa Cruz das Flores in the western Azores in the mid-Atlantic	Departure Coordinates: 37.817 North, 9.067 East Arrival Coordinates: 41.781 North, -34.268 West
Voyage 2	Jan. 8, 2021 to Jan. 15, 2021	The Desert Hope travelled from a point near the island of Santa Cruz das Flores in the western Azores in the mid-Atlantic, to a point near its destination port of Newark, New Jersey, USA	Departure Coordinates: 41.630 North, -37.049 West Arrival Coordinates: 40.495 -7 North, -73.065 West

Voyage segmentation to some degree is an arbitrary process. The two voyages identified above were part of a longer voyage from a port in Greece to the destination port of Newark. These voyages were chosen because they are representative of the expected operation of the VFO application, namely trans-oceanic passages, and were both at least seven full days in duration. Figures 8 and 9 show the departure and arrival points for Voyages 1 and 2 respectively, with the departure and arrival points of each voyage indicated by blue pins.

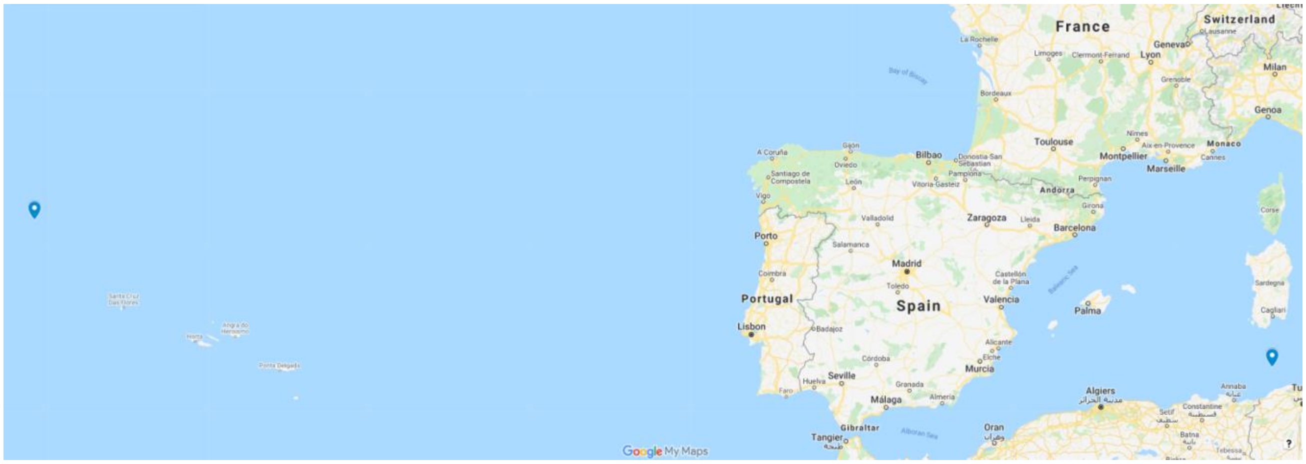


Figure 8 Voyage 1 departure and arrival points

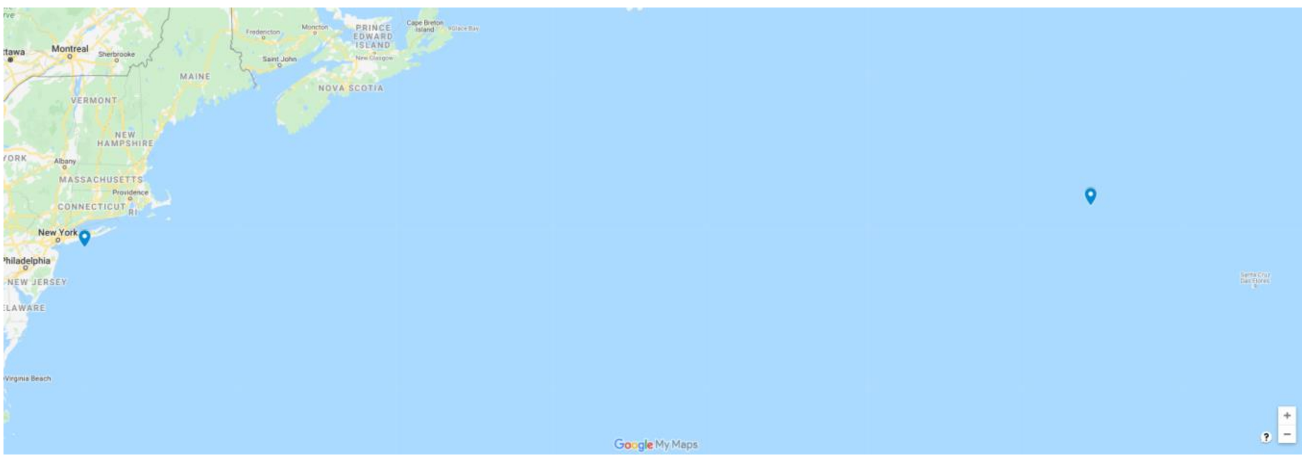


Figure 9 Voyage 2 departure and arrival points

4.3.2 Route Types

For each of the two voyages in the previous section, four types of routes were analyzed:

1. Captain's route ($R_{Captain}$) – the actual route taken by the Captain
2. VFO recommended route (R_{VFO}) – a route determined by iteratively recalculating the recommended route every six hours based on the latest weather forecast information
3. Great Circle Route (R_{GCR}) – the shortest path over the water between two waypoints
4. An ideal or near-ideal route (R_{Ideal}), also recommended by VFO, but based on *actual* weather information as opposed to *forecasted* weather

R_{Ideal} and R_{GCR} were generated programmatically using VFO. R_{Ideal} can only be calculated post-voyage, since actual weather is only known after a voyage is completed, not beforehand. The purpose of including R_{Ideal} in the analysis is to provide visibility into the potential gains in efficiency if weather forecast quality could be improved.

The maps in Figures 10 and 11 show the routes for Voyages 1 and 2 respectively.

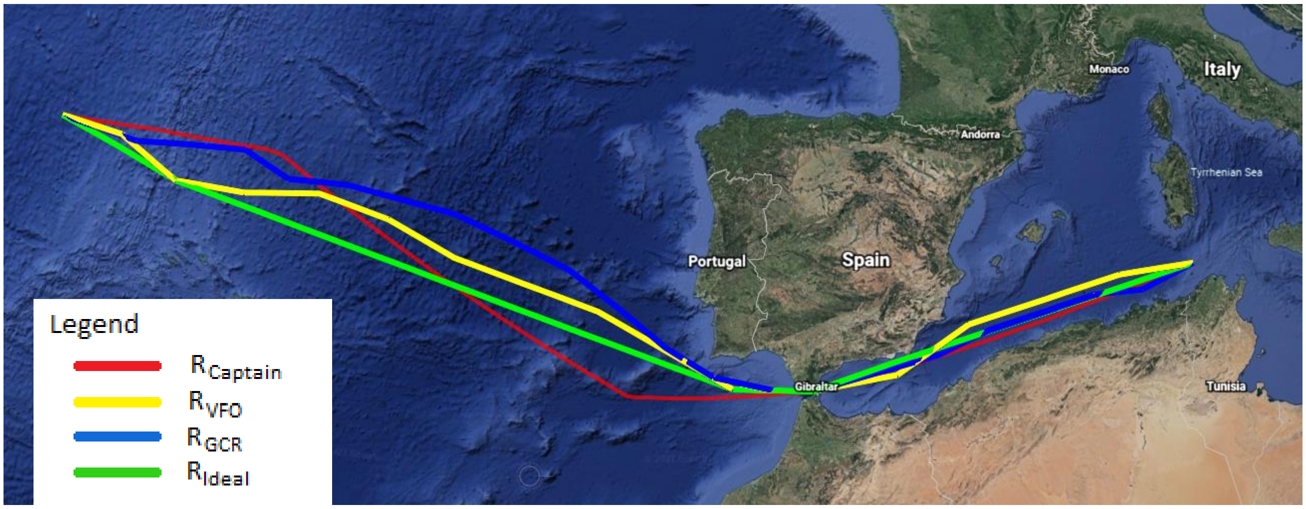


Figure 10 Voyage 1 routes

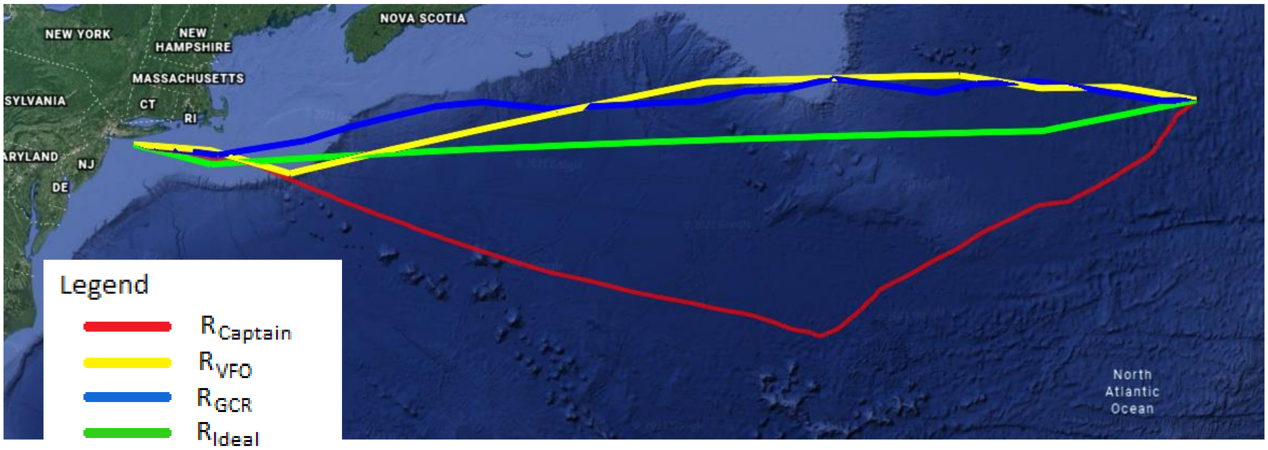


Figure 11 Voyage 2 routes

4.3.3 Route Summary Information

Tables 18 and 19 summarize the key information for all routes for Voyages 1 and 2 respectively:

Table 18 Summary route information for voyage 1

Route	Departure Time	Arrival Time	Voyage Time (hours)	Voyage Distance (nautical miles)
$R_{Captain}$	2020-12-31T19:47:12Z	2021-01-07T20:42:58Z	168.92944	2140.15730
R_{VFO}	2020-12-31T19:47:12Z	2021-01-07T16:49:59Z	165.04642	2123.85605
R_{GCR}	2020-12-31T19:47:12Z	2021-01-07T17:03:55Z	165.27879	2098.22507
R_{Ideal}	2020-12-31T19:47:12Z	2021-01-07T11:50:43Z	160.05951	2126.18062

Table 19 Summary route information for voyage 2

Route	Departure Time	Arrival Time	Voyage Time (hours)	Voyage Distance (nautical miles)
$R_{Captain}$	2021-01-08T06:37:40Z	2021-01-15T07:52:02Z	169.23944	1772.11308
R_{VFO}	2021-01-08T06:37:40Z	2021-01-14T18:09:19Z	155.52753	1636.22538
R_{GCR}	2021-01-08T06:37:40Z	2021-01-14T17:32:34Z	154.91520	1627.94068
R_{Ideal}	2021-01-08T06:37:40Z	2021-01-14T15:55:01Z	153.28931	1640.38410

4.4 Discussion/Analysis of the Trial Results

4.4.1 Voyage Time Comparison

The primary purpose of the VFO application is to reduce fuel consumption and corresponding CAC emissions, by recommending a more efficient route for the vessel. VFO achieves this by searching for a route that has the shortest travel time for a fixed fuel burn (speed is variable).

In the analysis of the long-distance sea trial results, the VFO route (R_{VFO}) was compared against the captain's route ($R_{Captain}$) and the Great Circle Route (R_{GCR}). For comparison from a fuel efficiency perspective, route voyage time was used to compare the routes.

Tables 20 and 21 show the comparison data between the VFO route against the captain's route and the GCR route to determine the improvement in efficiency.

Table 20 Voyage 1 change in travel time

Comparison	Absolute Change (hours)	Relative Change (%)
R_{VFO} versus $R_{Captain}$	-3.88305	-2.29%
R_{VFO} versus R_{GCR}	-0.23222	-0.14%
R_{Ideal} versus $R_{Captain}$	-8.86993	-5.25%
R_{Ideal} versus R_{GCR}	-5.21928	-3.16%

Table 21 Voyage 2 change in travel time

Comparison	Absolute Change (hours)	Relative Change (%)
R_{VFO} versus $R_{Captain}$	-13.71194	-8.10%
R_{VFO} versus R_{GCR}	0.61250	0.39%
R_{Ideal} versus $R_{Captain}$	-15.95013	-9.42%
R_{Ideal} versus R_{GCR}	-1.62589	-1.05%

4.4.2 Fuel Consumption Comparison

In addition to comparing voyage times, fuel consumption can also be compared for various routes.

As stated in a previous section, VFO does not provide absolute fuel consumption data. This data was obtained from Metis Cybertechnologies, who provided fuel consumption data for this report. Metis Cybertechnologies is one of Fujitsu's Sea Trials partners. Metis employs various techniques, including measuring fuel consumption directly on the vessel, as well as using their own machine learning model to provide fuel consumption estimates.

Metis collects data automatically every few minutes from gauges which are connected to the fuel lines going from the fuel tanks to the engines. The gauges collect regular readings from the fuel lines, and report the consumption data from to Metis's on-board IoT system called "Metis Ship Connect", and then on to Metis's cloud-based application. Since regulations require vessels to use different kinds of fuel in different jurisdictions, Metis is actually measuring fuel consumption for two different kinds of fuel, HFO and MGO. HFO stands for High-Sulphur Fuel Oil, and MGO stands for Marine Gas Oil, which are two different types of bunker fuel. Fuel consumption data in tables 22 and 23 include both actual measurements and estimates. We calculated estimates as being in direct proportion to travel times by solving equation (1) for $Fuel_{Estimated}$,

$$\frac{Fuel_{Estimated}}{Time_{Modeled}} = \frac{Fuel_{Actual}}{Time_{Actual}} \qquad (1)$$

where $Fuel_{Actual}$ comes from Metis's measurements, $Time_{Actual}$ comes from the AIS location data (which includes timestamps), $Time_{Modeled}$ is provided by VFO.

In practice, since there are two types of fuel, we calculated estimates for HFO and MGO as shown in equations (2) and (3).

$$\frac{Fuel_{Estimated-HFO}}{Time_{Modeled-HFO}} = \frac{Fuel_{Actual-HFO}}{Time_{Actual-HFO}} \qquad (2)$$

$$\frac{Fuel_{Estimated-MGO}}{Time_{Modeled-MGO}} = \frac{Fuel_{Actual-MGO}}{Time_{Actual-MGO}} \quad (3)$$

Tables 22 and 23 show the fuel consumption data for Voyages 1 and 2 respectively.

Table 22 Fuel consumption for voyage 1 routes

Route	Fuel Consumption (kg)		
	HFO	MGO	Total
$R_{Captain}$	230,134.36	0.5	230,134.86
R_{VFO}	224,844.48	0.49	224,844.97
R_{GCR}	225,161.04	0.49	225,161.53
R_{Ideal}	218,051.23	0.47	218,051.23

Table 23 Fuel consumption for voyage 2 routes

Route	Fuel Consumption (kg)		
	HFO	MGO	Total
$R_{Captain}$	119,957.68	101,412.71	221,370.39
R_{VFO}	110,238.62	93,196.17	203,434.79
R_{GCR}	109,804.59	92,829.25	202,633.84
R_{Ideal}	108,652.16	91,854	200,507.13

Using the fuel consumption data from Tables 22 and 23, we compare fuel consumption of the VFO route and ideal route against the captain's route and the GCR route. Tables 24 and 25 show the change in fuel consumption for Voyages 1 and 2 respectively.

Table 24 Voyage 1 change in fuel consumption

Comparison	Absolute Change (in kg)	Relative Change (%)
R_{VFO} versus $R_{Captain}$	-5,289.89	-2.30%
R_{VFO} versus R_{GCR}	-316.56	-0.14%
R_{Ideal} versus $R_{Captain}$	-12,083.63	-5.25
R_{Ideal} versus R_{GCR}	-7,110.30	-3.16%

Table 25 Voyage 2 change in fuel consumption

Comparison	Absolute Change (in kg)	Relative Change (%)
R_{VFO} versus $R_{Captain}$	-17,935.60	-8.10%
R_{VFO} versus R_{GCR}	+800.95	+0.40%

R_{Ideal} versus $R_{Captain}$	-29,863.26	-9.42%
R_{Ideal} versus R_{GCR}	-2,126.71	-1.05%

4.4.2.1 CO_2 and Sulphur Comparison

The EU estimates[1] that there are approximately 3.0-3.3 tonnes of CO_2 emitted per tonne of bunker fuel consumed. In addition to this, Sulphur content is 3.5% for High-Sulfur Fuel Oil (HFO), and between 0.10 and 0.5% for Marine Gas Oil (MGO)[2]. Using this data, VFO can be used to provide an estimate of the reduction in CO_2 and Sulphur provided by comparing the VFO route against the captain's route and the GCR route. VFO does not track fuel consumption data directly, but does provide travel times for each route. By comparing relative travel times, we can calculate the relative fuel consumption data, and similarly, the relative amount of CO2 and Sulphur for each of the route pairs.

Tables 26 and 27 show the comparison data. Note: For CO_2 emissions, 3.15 tonnes of CO_2 per ton of bunker fuel was used. For Sulphur emissions, 3.5% for HFO and 0.3% for MGO were used.

Table 26 Voyage 1 change in CO_2 and Sulphur

Comparison	CO_2 Change (in kg)	Sulphur Change (in kg)
R_{VFO} versus $R_{Captain}$	-16,660	-185.15
R_{VFO} versus R_{GCR}	-997.17	-11.08
R_{Ideal} versus $R_{Captain}$	-38,063.42	-422.93
R_{Ideal} versus R_{GCR}	-22,397.43	-248.86

Table 27 Voyage 2 change in CO_2 and Sulphur

Comparison	CO_2 Change (in kg)	Sulphur Change (in kg)
R_{VFO} versus $R_{Captain}$	-56,497.14	-2,805.13
R_{VFO} versus R_{GCR}	+2,522.98	125.27
R_{Ideal} versus $R_{Captain}$	-65,719.27	-3,263.01
R_{Ideal} versus R_{GCR}	-6,699.15	-332.62

4.4.3 Discussion of Results

From the long-distance sea trials result data, the following observations were made:

- For Voyage 1:
  - While VFO found a superior route to the captain's for both voyages, the VFO route in the first voyage was slightly worse than the GCR route. VFO is not expected to find a better route every single time, but on average, VFO will provide a significant reduction in fuel consumption and emissions. Compared to the captain's route, VFO, on average provided a reduction in voyage time of 5.20% against the captain's route,

which is the most meaningful comparison. We speculate that the performance could possibly be improved with more historical voyages to train the model.
    - Voyage 1's results may have been less impressive simply because the weather was not very interesting in that geography at that time, meaning that there are less opportunities to find efficiency gains by taking advantage of currents and wind, for example.

- For Voyage 2:
    - The captain's route ($R_{Captain}$) indicated by the red line in Figure 12, follows a significantly different route from any of the other routes in the diagram. We speculate that this is because the captain was wishing to avoid a storm that was brewing in the Atlantic, and the captain's strategy was possibly to avoid the storm. Interestingly, VFO also chose to avoid the storm, but rather than by a southerly route, VFO chose to go by a northerly route, and in fact found a significantly more efficient route by doing so.
    - While VFO in general finds efficient and safe routes between departure and arrival points, VFO does not take into account some safety considerations such as the presence of ice. The captain may have chosen a more southerly route for Voyage 2 around the storm to avoid ice. We acknowledge this as a limitation of VFO and suggest an enhancement to add awareness of ice and account for its safety implications.
- For both Voyages 1 and 2
    - Fujitsu did not judiciously choose the timing of the sea trial to provide opportunity for VFO to find higher efficiencies. Storms in the North Atlantic are common in the winter, and the timing of the sea trials simply fell during this season.
    - VFO produced significantly different results for both voyages. This is primarily due to the stochastic nature of weather. Also, more "interesting" weather patterns, such as storms along the captain's or GCR trajectory, create opportunities for VFO to find a more efficient route. Similarly, wind, current and waves which push against the vessel along the captain's or GCR trajectory allow for VFO to find routes which, rather than fighting the wind, current, and waves, use these things to its advantage.
    - The Ideal routes show the potential of VFO to find even more efficient routes when more accurate weather information is available. For voyage 2 in particular, VFO was able to find an alternate route which saves over 30,000 kg of fuel, 65,000 kg of $C0_2$, and 3,000 kg of Sulphur.
    - From a carbon emissions perspective, although the reduction for the second voyage, at over 17 tonnes of carbon dioxide, may appear attractive, this is approximately equivalent to the annual carbon footprint for one Canadian.
    - It is important to understand weather, and therefore VFO's performance from a statistical perspective. The two parameters that are most interesting are the *mean* and the *standard deviation* of the performance improvement. Empirically, by conducting sea trials, we can increase our understanding of the *accuracy* of the mean and the standard deviation, as well as the *confidence* level. Specifically, to compare the results of these two voyages, we would need more data, i.e. more voyages to

determine the mean with a certain level of confidence and accuracy, and then determine which voyage is closer to the mean.

4.5 Conclusion and Next Steps for the Tool based on the Results of the Analysis

4.5.1 Summary of Software Development Work

From this experience, we draw the following conclusions

- VFO is capable of finding routes that reduce fuel consumption and emissions by as much as 8.1% on real voyages
- With more accurate weather forecasts, VFO is capable of producing even better results, as much as 9.4% reduction in fuel consumption and emissions
- The amount of fuel and emissions reductions, however, varies significantly, and in some cases VFO may even introduce a small increase in fuel consumption and emissions

4.5.2 Next Steps

As possible next steps to improve the performance of VFO, Fujitsu could make the following enhancements to VFO:

- Conduct more sea trials to determine the mean and standard deviation of reductions with more accuracy and confidence
- Add a feature that takes into account additional safety considerations, such as a real-time awareness of ice, to reflect a human captain's strategies
- Enhance the export feature to include an option to match the format of the target ECDIS navigation system

5. CONCLUSIONS

5.1 Summary of the Overall Work of the Project

5.1.1 Summary of Software Development Work

The planned software development activities and tasks were completed as desired. With the completion of the activities and tasks, VFO is in a better state to be used in a real operational environment as a result of multiple automations that have been put in-place and also through the enhancements to the hosting and cloud computing environment. Additionally, VFO code quality has also been improved so it can be scaled further.

5.1.2 Summary of Planning and Execution of Sea Trials

The Fujitsu project team built on the foundation of software development milestones, and accomplished the following:

1. Created a detailed sea trial plan
2. Set up the legal framework to enroll sea trial partners
3. Created an on-boarding website for sea trial partners to sign-on
4. Recruited partners for sea trials
5. Provided training to sea trial partners
6. Created a model for the vessel, the Desert Hope, used for the long-distance sea trials
7. Executed two short-distance sea trials
8. Executed two long-distance sea trials

9. Collected results
10. Analyzed and evaluated the results
11. Created a final report and presentation

Several Fujitsu resources were utilized to complete all of these activities. They included:

- Business Development Specialists
- Lawyers
- Digital Marketing Specialists
- Data Scientists
- Software Engineers / Developers

Among all activities, the most challenging was the recruitment of sea trial partners. Recruiting activities required a significant amount of time and effort from Fujitsu which was not originally accounted for. Of note, the Covid-19 pandemic contributed to the challenges in recruiting sea trials partners.

Despite the challenges, Fujitsu was able to successfully execute and complete activities for both long-distance and short-distance sea trials.

5.2 Overall Next Steps for the Tool

In terms of next steps, Fujitsu needs to conduct a business assessment of this project to determine its future. The assessment should take into account

- the results of this report
- the technical requirements to bridge the gap between VFO's current state and a market-ready state
- market demand
- pricing considerations

5.3 Overall Project Conclusions

In support of the Clean Marine stream, the project delivered technical enhancements to, and supported sea trials for, Fujitsu's VFO technology, to validate its effectiveness in reducing fuel consumption and the emissions of GHGs and CACs. This project achieved its objectives of advancing the technical readiness level of the VFO application.

Fujitsu learned a great deal about the practicalities of deploying the service in practice, from both a technical and a market perspective. The main conclusions are:

- VFO is in general an easy to use tool, but usability could be improved through some minor enhancements, especially in low-bandwidth environments
- VFO can reduce fuel consumption, CO_2, and Sulphur emissions by as much as 8.1%, with a potential for even greater reductions with improved weather accuracy
- The challenges encountered in arranging sea trials are a strong data point to consider when considering the future of investment in this technology

REFERENCES

1. Argus Media, https://www.argusmedia.com/en/news/1831097-co2-cost-could-raise-bunker-price-25pc, January 2019.
2. Wikipedia, https://en.wikipedia.org/wiki/MARPOL_73/78 , March 2021.

Appendix A

VFO SEA TRIAL SIGN-UP WEBSITE

Cut fuel costs and reduce emissions without sensors, scrubbers or hull modifications.

Fujitsu AI Voyage Service

Boost ship efficiency with Artificial Intelligence & Machine Learning

Fujitsu's AI Voyage (FAIV) service uses the latest artificial intelligence (AI) technology to compute energy efficient vessel routes for ships to reduce fuel costs, voyage travel times, and greenhouse gas emissions, while preserving crew and ship safety.

The AI technology helps build a unique, accurate performance model of individual vessels under varying weather, sea, and vessel loading conditions. The model is used to select the most energy efficient vessel route-path using the latest weather and sea condition forecasts.

Benefits

- Reduced emissions
- Reduced fuel costs (up to 10%)
- Low initial investment
- Be up and running quickly
- Applicable to a broad range of vessels
- Secure

Fujitsu AI Voyage

Sign up to try it out

No-charge 15-day trial offer*

First Name:

Last Name:

Company Name:

Job Title:

Country:

Email Address:

Vessel Name:

*By registering, you confirm you have read and agree to the Terms of Use and agree that my data is subject to the Privacy Statement, including use for marketing purposes.

☐

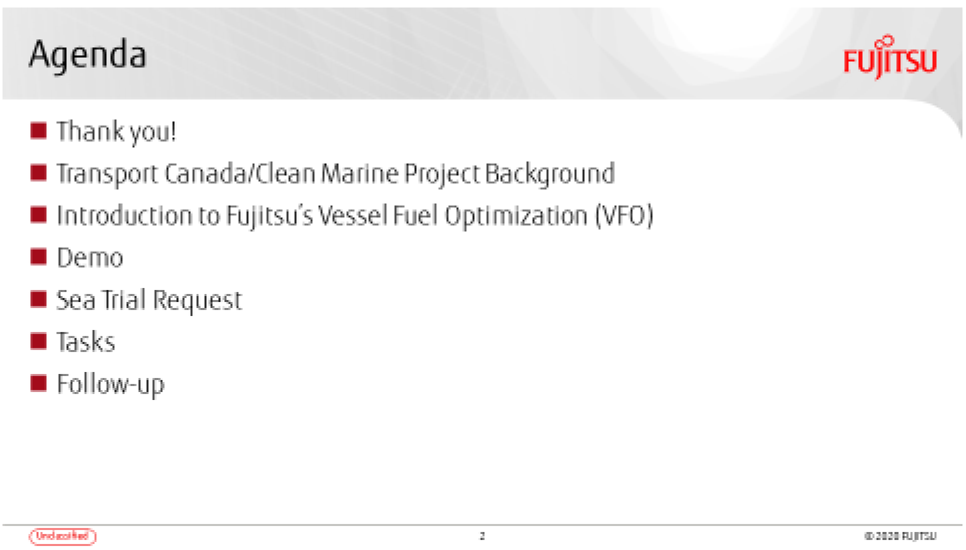
I agree to receive future communications from Fujitsu on this topic (required so we can send your logon ID and password)

☐

Sign Me Up

The statements provided herein are for informational purposes only and may be amended or altered by Fujitsu America, Inc. without notice or liability. Product description data represents Fujitsu design objectives and is provided for comparative purposes; actual results may vary based on a variety of factors. Specifications are subject to change without notice.

APPENDIX B
VFO TRAINING MATERIAL



Thank you!

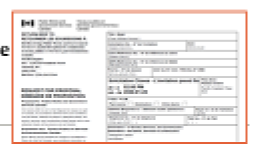
FUJITSU

We know you are very busy, so we greatly appreciate Horizon-Maritime taking the time to try out our technology!

Transport Canada/Clean Marine

FUJITSU

- Transport Canada, part of the Canadian federal government, issued an RFP on Dec. 2, 2019, to
  - Fund technology development which reduces CO2 and CACs, OR
  - Reduces noise impact on whales, OR
  - ...a combination of both
- Fujitsu responded to (just the first part) of this RFP in January 2020, proposing a project for Vessel Fuel Optimization, half paid by Fujitsu, half paid by Transport Canada
- Fujitsu was notified on April 7 that it will be awarded a contract
- Here is a high-level summary of what we need to deliver:
  - Phase 1 primarily focused on development work to automate tasks which are currently manual
  - Phase 2 exposes a new REST API for vessel model creation, as well as testing
  - **Phase 3 focuses on preparing for and supporting sea trial(s) ← current phase**
  - Phase 4 will focus on analyzing the data from the sea trial(s)



Vessel Operator Problems

FUJITSU

Minimize fuel costs	Regulation & Compliance	Long-term strategy to achieve goals
More expensive fuel will become mandatory	New ECA regulations: < 0.1% Sulphur in ECA zone <0.5% Sulfur outside ECA zone	Shipping industry targeting 50% GHG reduction by 2050

Solution: Vessel Fuel Optimization (VFO)

FUJITSU

- Ship route optimization technology using AI
- Fujitsu AI "learns" from historical weather and AIS data to build a "model" of a vessel, and then use that model to recommend optimal route that maximize:

Profitability | Safety | Energy-efficiency

- Implemented as a web application

Unclassified 6 © 2020 FUJITSU

Fujitsu Solution: Vessel Fuel Optimization (VFO)

FUJITSU

- Ship Performance Model
  - Using high-dimensional statistical analysis, an individual ship's performance at sea is accurately modelled in a variety of historical weather and current conditions.

Unclassified 7 © 2020 FUJITSU

Fujitsu Solution: Vessel Fuel Optimization (VFO)

FUJITSU

- Route Optimization
  - Using the vessel model, iteratively compute an optimized fuel efficient route using the latest available metrological and hydrographic forecasts throughout the voyage.

Our algorithms reflect real life operation strategies.

Unclassified 8 © 2020 FUJITSU

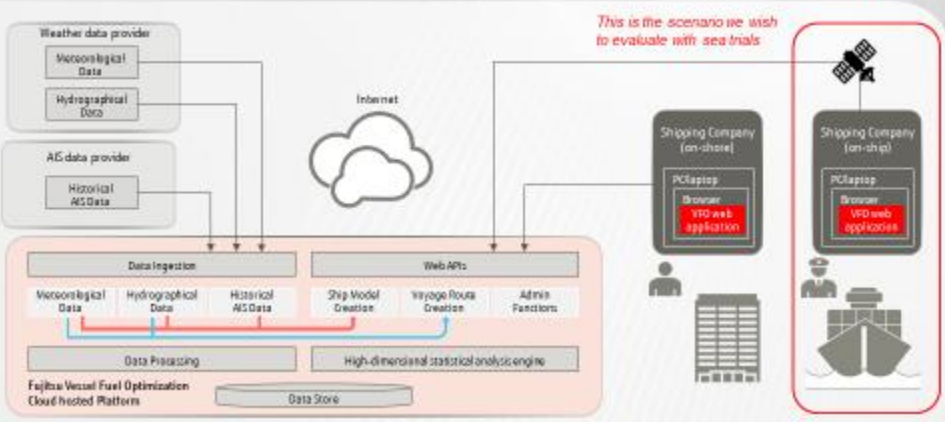
VFO Features and Benefits

FUJITSU

Features		Benefits
Provides efficient routes	→	• Reduced emissions • Reduced fuel costs (up to 10%)
No sensor installation No HW installation No SW installation	→	• Low initial investment • Be up and running quickly
Uses only publicly available ship info (ship ID, i.e. IM/MMSI number) Uses only publicly available weather (wave/wind/current) and AIS info	→	• Applicable to a broad range of vessels
Secured via multiple mechanisms	→	• Minimal risk to ship IT infrastructure

VFO: How it works

FUJITSU



FUJITSU

Demo Slide Holder

Usability Sea Trial Request

FUJITSU

Basically we are looking for vessel operators to evaluate the usability of the application in an operational setting.

- No need to install anything
- No effect on operation of vessel or equipment
- Total time commitment: 90 minutes
  - **30 minutes of training beforehand ← this training**
  - 30 minutes of using it on a vessel
  - 30 minutes to give us feedback

Prerequisites

FUJITSU

First, please ensure:

- Ensure you are on a vessel
- On the ocean
  - Does not have to be far out at sea
  - But should be accessing the Internet via satellite
- Have access to a browser (recommend Chrome)
- On a laptop or a desktop (tablets and smartphones are not supported)
- Have Internet access

Sea Trial Tasks

FUJITSU

Then, please try to perform the following tasks:

- Logon to VFO. Fujitsu will provide:
  - The URL
  - Logon ID
  - Password
- Select a vessel (this will be a "synthetic" vessel, not your ship)
- Create a voyage
  - Specify departure point
  - Specify arrival point
- Search for an optimal route, export the route as an .rtz file
- Try the route preview animation feature
- Perform a comparison against the great circle route (GCR)

After the Sea Trial

FUJITSU

We would like to do a follow-up session with you for 30 minutes, and ask you these questions:

- What was your experience like in using VFO?
- Were you able to log in?
- Was it easy to use?
- What browser did you use?
- Was the map on the screen show the weather animations smoothly?
- Were you able to move around the map (zoom in/out, pan left/right) easily?
- Did you have any troubles performing the tasks?
- Does the .rtz file match the expected format of your ECDIS system?
- Overall, on a scale from 1 to 10, what you rate the usability of the VFO application?