A **Decision Support Tool** for Arctic Oil Spill using Operations Research & Machine Learning

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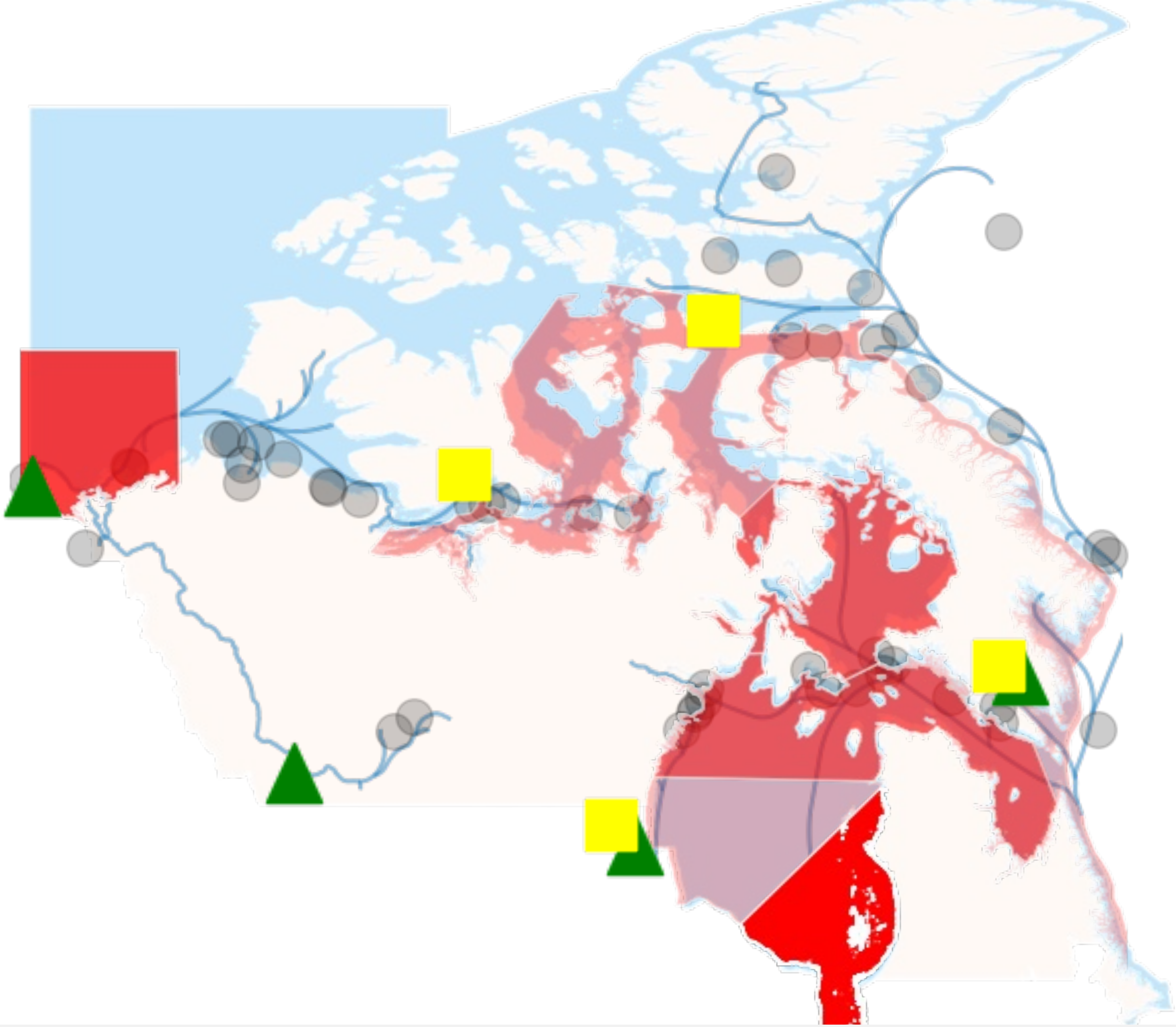


Current setup:
Mean Response time: 4hrs
Coverage: ~70%*

Proposed setup:
Mean Response time: 3hr 40min
Coverage: 84%

Facility/Supply: Oil Spill Response Stations
Demand: Oil Spill Incidents

Fig 1. Canadian Arctic: Facilities, Oil Spill, Sensitivities

Outline

1. Introduction

- Background: Oil Spill
- Problem Statement
- Data: Demand, Facility etc.

2. Optimization Model

- Multiobjective functions
- Constraints

3. Result

- Proposed location allocation configuration
- Allocation configuration & comparing with current setup
- Sensitivity analysis and Pareto Front

4. Discussion

- Contribution to Supply Chain
- Challenges in OR projects

Background

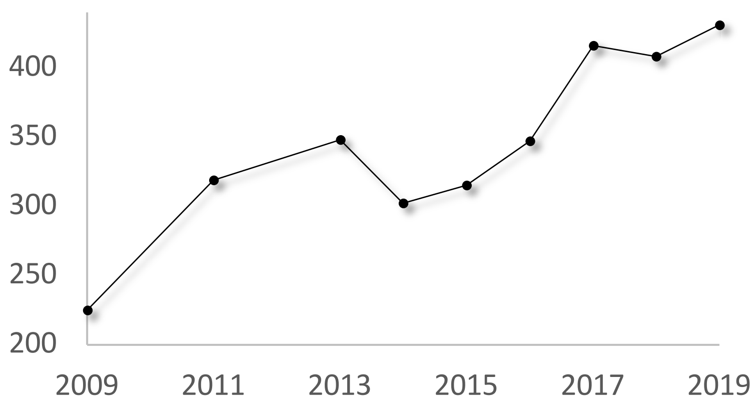


Fig 2. Number of shipping voyage
in Canadian Arctic doubled in last 10 years

- Arctic oil spill can be devastating for environment and local community.
- Harsh environments in Arctic complicate the response operation, insisting development of **Decision Support Tool** (DST)
- Oil spill resource allocation optimization improves strategic decision making
- Enables better Supply Chain Management, and Logistics Network
- **Stakeholder:** Canadian Coast Guard, Transport Canada

Problem Statement

- **Facility Location**
  - **How many facilities to build?**
  - **Where to build them in Arctic?**
- **Resource Allocation**
  - **How much resources to store in those facilities?**

Purpose:

- Respond to Arctic oil spills within predetermined time window
- Serve sensitive areas with high priority
- Mitigate negative consequences

Common Spill Response Technologies

Mechanical Containment & Recovery (MCR)

- Removing oil from the surface of the water by physical barriers and mechanical devices e.g. skimmers

Chemical Dispersant Use (CDU)

- Spraying chemical products into oil spill to disperse it into water, and to accelerate natural dispersion

In-situ Burning (ISB)

- Controlled-burning of oil in its original place of spill

Resource: Asset & Equipment

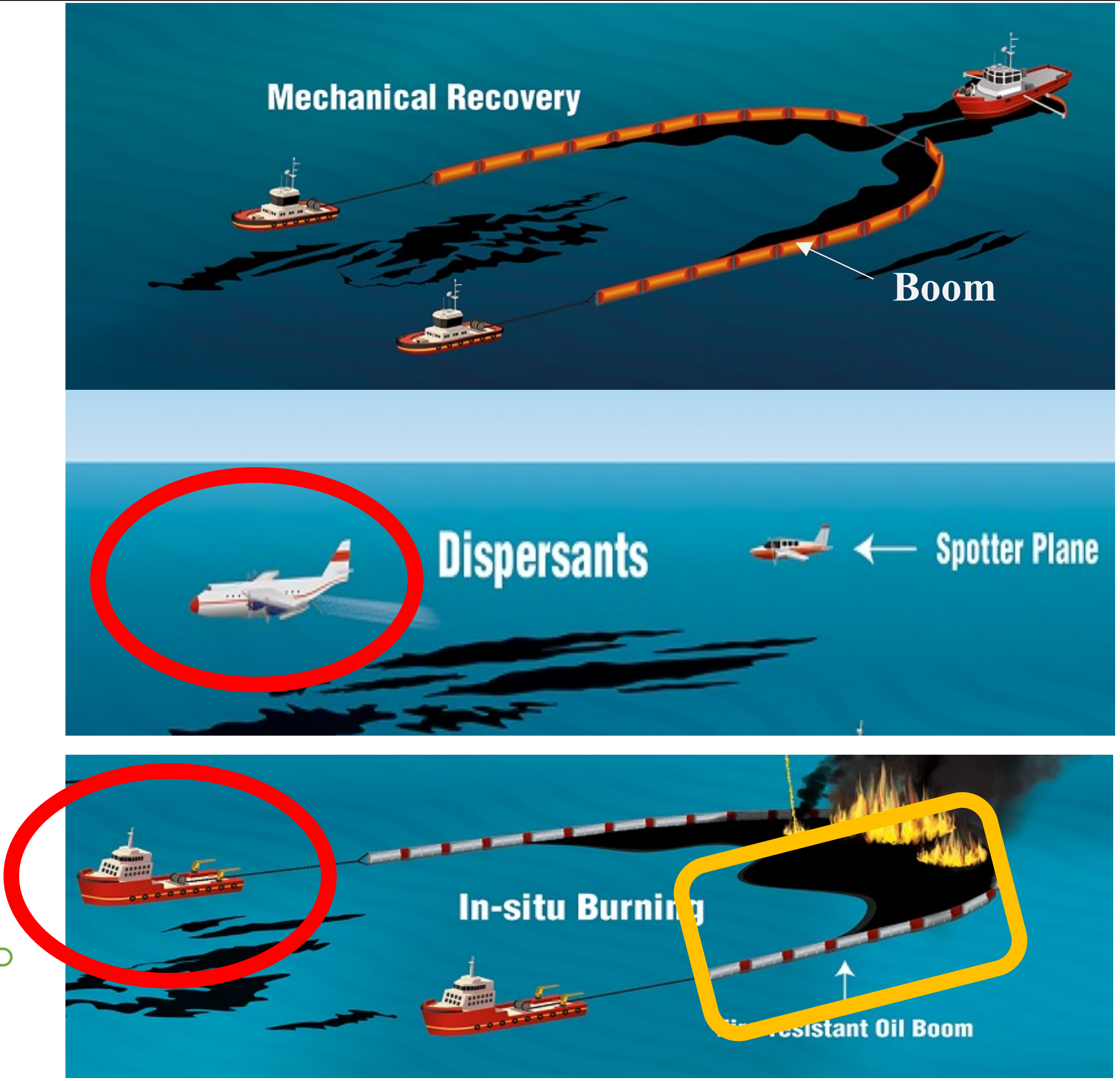
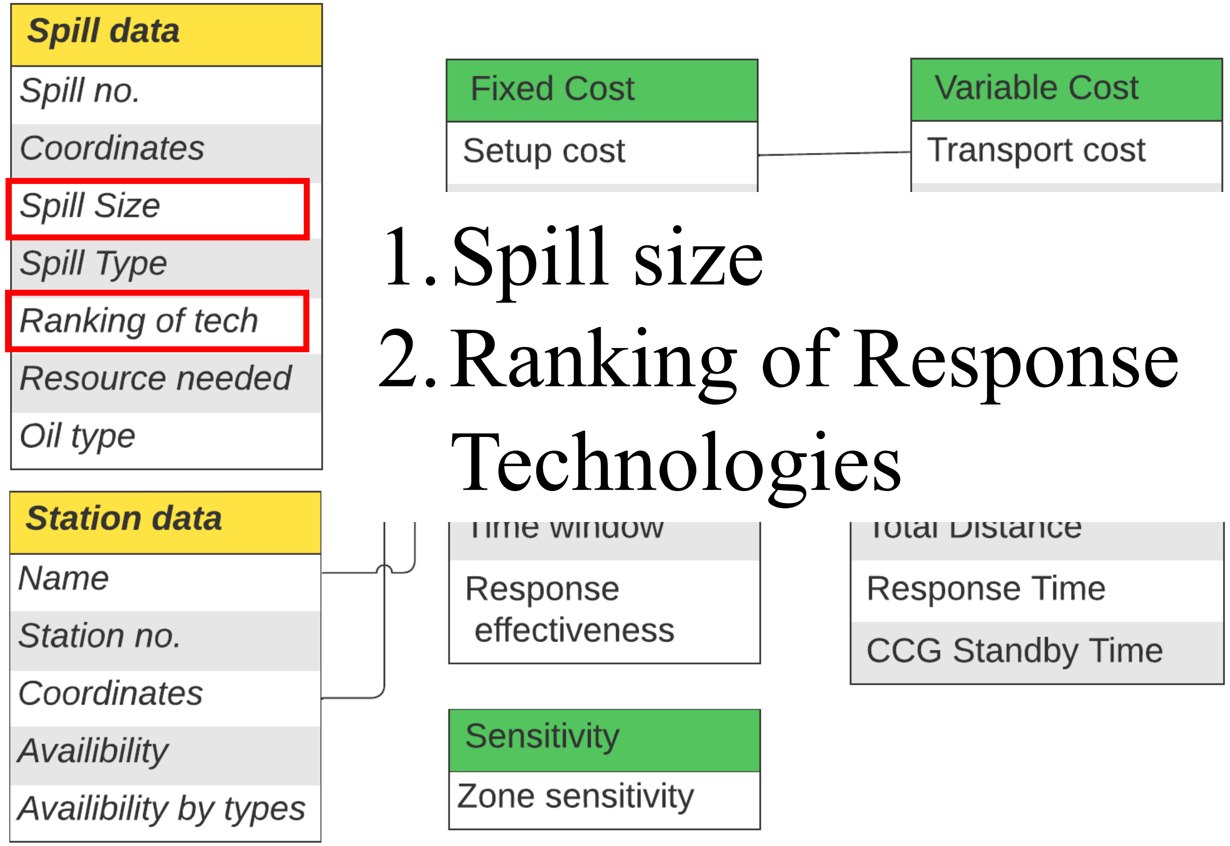


Fig 4. Response Technologies

Data

- **Summary of dataset**
  - Oil Spill
  - Response facility
  - Sensitivity
- **Storage**
  - Azure Blob Storage
  - Locally in Excel file or GeoDB
- **Tools**
  - **ArcGIS & SQL** for data processing
  - **DVC** for data version control
  - **GitHub** for code version control



1. Spill size
2. Ranking of Response Technologies

Table 1. List of input parameters*

* Not full database schema

Data: Previous Machine Learning Models

- Task: Predicting volume of oil spill and damage extent
- Models: Neural Network, Polynomial Regression, Gradient Boosted Regression Tree

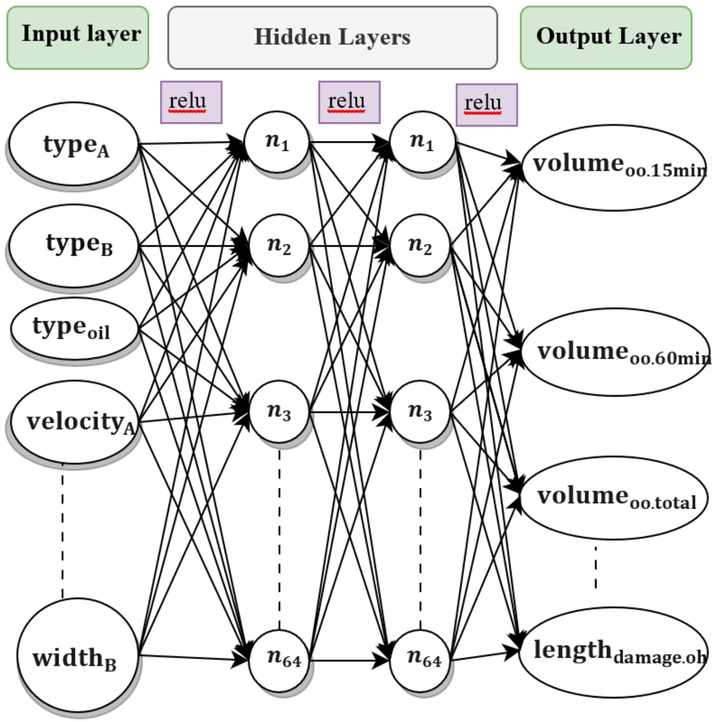


Fig 5.1 Architecture of Neural Network

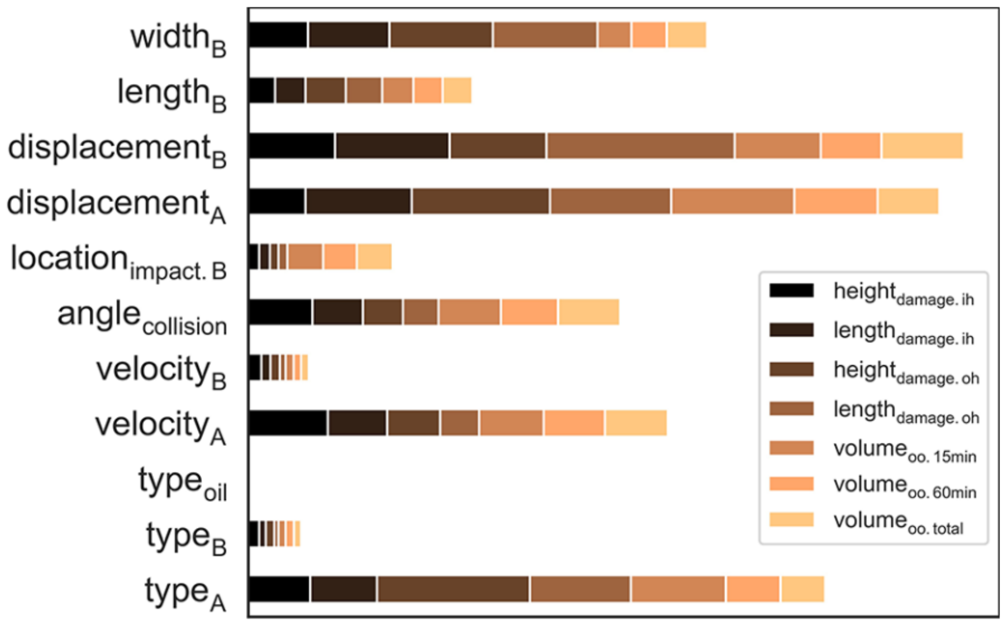


Fig 5.2 Variable importance plot of DNN modeling

Data: Previous Machine Learning Models

Task: Rank spill response technologies
Model: Bayesian Inference

Action:
A multi-class, multi-label classification system is developed. Bayesian Inference model is implemented using Naive Bayes Classifier
Multi-label: y = [y1, y2, y3] = [MCR, CDU, ISB].
Multi-class: [OK, Consider, Go Next Season, Unknown, Not recommended]

Result:
Based on oil and environmental conditions in Arctic, our model proposes which technology would be better to respond oil spill. The model has 0.79, 0.93 and 0.93 ROC-AUC score for different technologies.

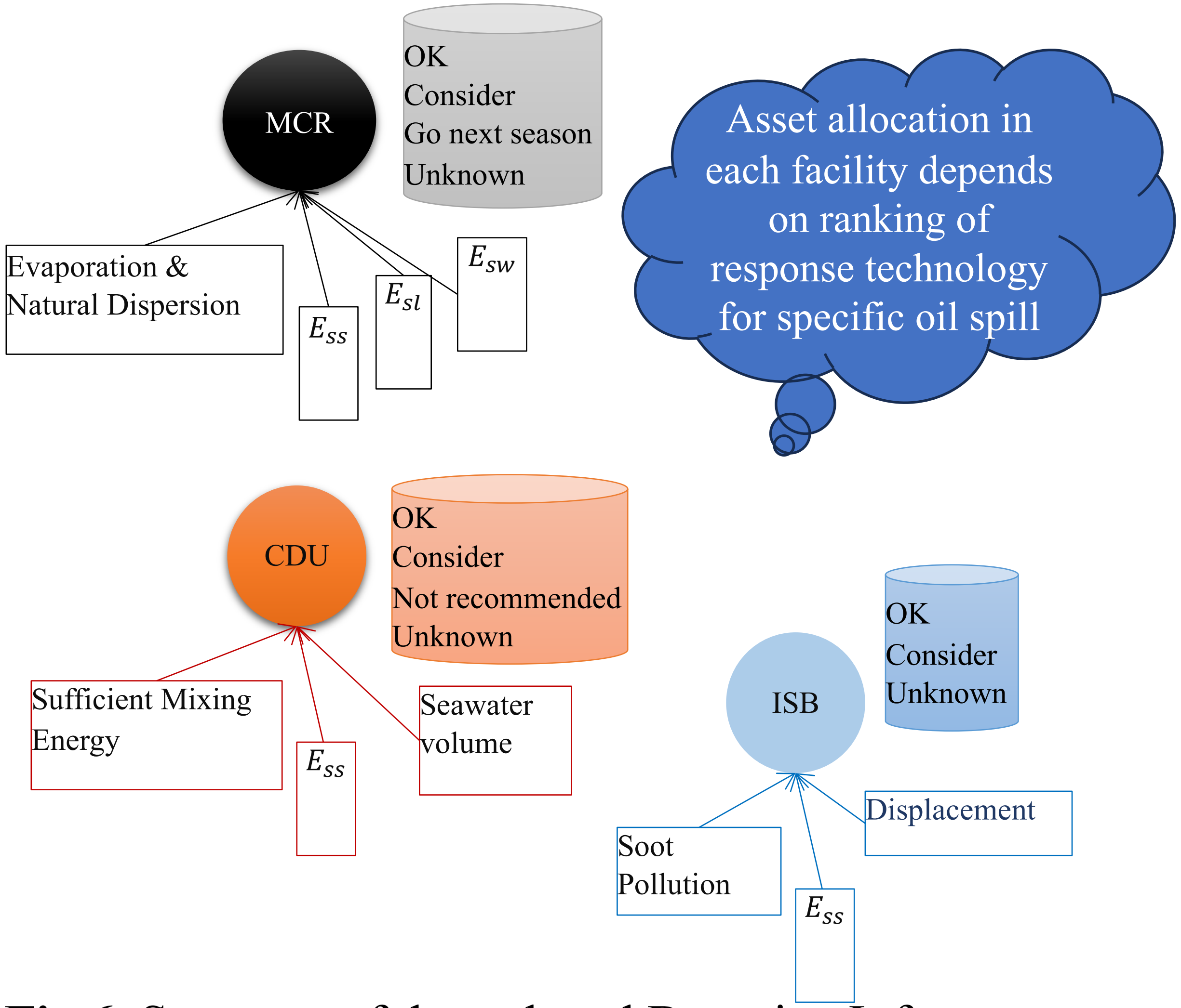
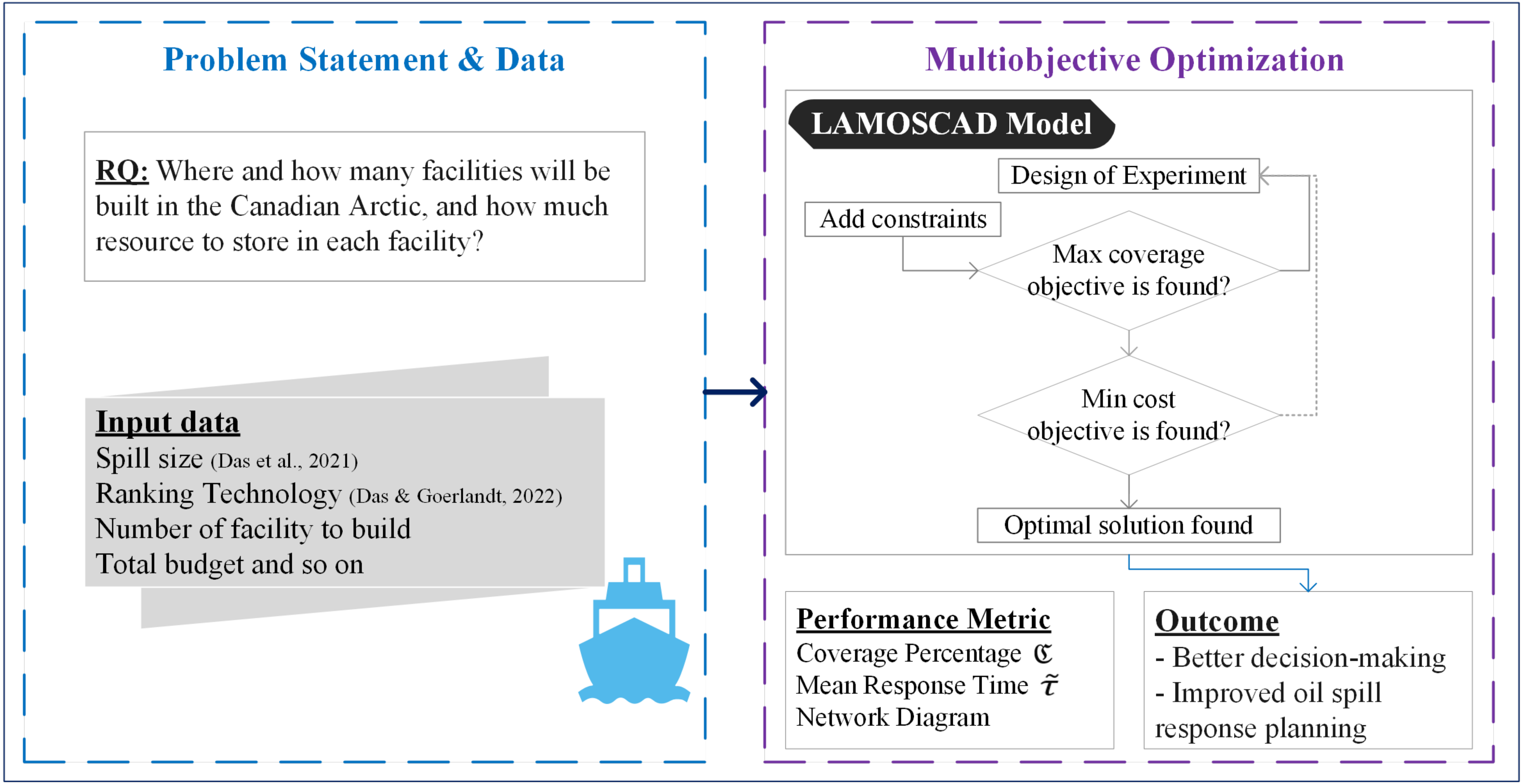


Fig 6. Structure of the reduced Bayesian Inference Model

Location Allocation Model



Problem Statement & Data
RQ: Where and how many facilities will be built in the Canadian Arctic, and how much resource to store in each facility?
Input data
Spill size (Das et al., 2021)
Ranking Technology (Das & Goerlandt, 2022)
Number of facility to build
Total budget and so on
Multiobjective Optimization
LAMOSCAD Model
Design of Experiment
Add constraints
Max coverage objective is found?
Min cost objective is found?
Optimal solution found
Performance Metric
Coverage Percentage $\mathfrak{C}$
Mean Response Time $\tilde{\tau}$
Network Diagram
Outcome
- Better decision-making
- Improved oil spill response planning

Conceptual Model

Objectives

- **Maximize spill coverage** of potential oil spill in Canadian Arctic, while incorporating sensitivity, response time
- **Minimize costs** of fixed and variables asset and equipment and response operations

Decision Variables

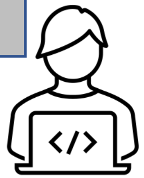
Facility Location: how many facility and where
Resource Allocation: which spills should each facility serve, quantity to stockpile in each facility

Constraints

- Spill: Response time is less than equal to maximally allowed response time; Deploy only amount needed to respond oil spill
- Facility: Resources sent from stations must be less than or equal to resources available to that station; oil spill o is covered by station s ($cover_{o,s}$ is equal to one) only when s is open; A limited number of stations to open
- Sensitivity & usage: Spill must be covered if happens in highly sensitive zone; Chemical and burning usages has local and federal limitations; Some non-disclosable constraints

Mathematical Model: Objectives

A Mixed Integer Programming



Objective 1: Maximize oil spill coverage
Objective 2: Minimize fixed and variable costs

Maximize	$(\sum_{o} w_1.Size_o + \sum_{o} w_2.Sensitivity_o - \sum_{o} w_3.TimeR_{o,s})\times cover_{o,s}$	**Obj 1**
Minimize	$\sum_{s} \mathrm{Cf}_s.select_s + \sum_{s}\sum_{o} Cu_{s,o}\, deploy^{r}_{s,o} + \sum_{s}\sum_{o}\sum_{v} CuTr.Distance_{s,o}\, send_{v,s,o}$	**Obj 2**

Set & Index

- $o \in Oil\ Spills$
- $s \in Stations$
- $r \in [m, c, i]$
- $v \in Vessels$

Decision Variables

- $cover_{os} = 1$ if spill o is covered by station s
- $select_s = 1$ if station s is selected
- $deploy^{r}_{s,o}$ The quantity of resource r is deployed from station s to oil spill zone o
- $send_{v,s,o}$ The number of vessel v to send form s to o

Mathematical Model: Constraints

Name	Equation	Description	Eq.
Mandatory Spill Coverage	$\boldsymbol{cover_o} = \mathbf{1}$ if $\text{sensitivity}_o > SensitivityTh$	Spill must be covered if happens in highly sensitive zone	(9)
Maximum time allowed	$\text{Time}R_{s,o} \leq \text{TimeRMax}$	Response time is less than equal to maximally allowed response time	(10)
Max facility to open	$\sum_s select_s = \boldsymbol{NumberStMax}$ *	A limited number of stations to open	(11)
Deploy from facility	$\sum_o \text{deploy}_{s,o}^r \leq \text{Available}_s^r * \text{select}_s \quad \forall r\, \forall s$	Resources sent from stations must be less than or equal to resources available to that station.	(12)
Minimum quantity	$\sum_r \text{deploy}_{s,o}^r \geq 10\% * \text{Demand}_o \quad \forall s$ if $\text{Demand}_o > \text{QuantityMin}_s$	Quantity of resource sent from stations must be greater than a pre-determined threshold	(13)
Deploy from open facility	$cover_{o,s} \leq select_s \quad \forall o\, \forall s$	An oil spill o is covered by station s ($cover_{o,s}$ is equal to one) only when s is open	(14)
Usage limit	$\sum_s deploy_o^{r=c} \leq Limit_p^{r=c} \quad \forall o$	Chemical and burning usages has local and federal limitations	(16)
Demand deployment	$\sum_s deploy_{s,o}^r \leq Demand_o^r \quad \forall o$	Deploy only amount needed to respond oil spill	(17)

Solution algorithm

- B&C (why this algorithm)?

- A bender cut is added as lazy constraint (how? Which bender cut)
- Master problem X_s
- Sub problem $Y_{o,s}, Z_{s,o}^{r}, V_{s,o}^{v}$

Results

Result: Facility Location

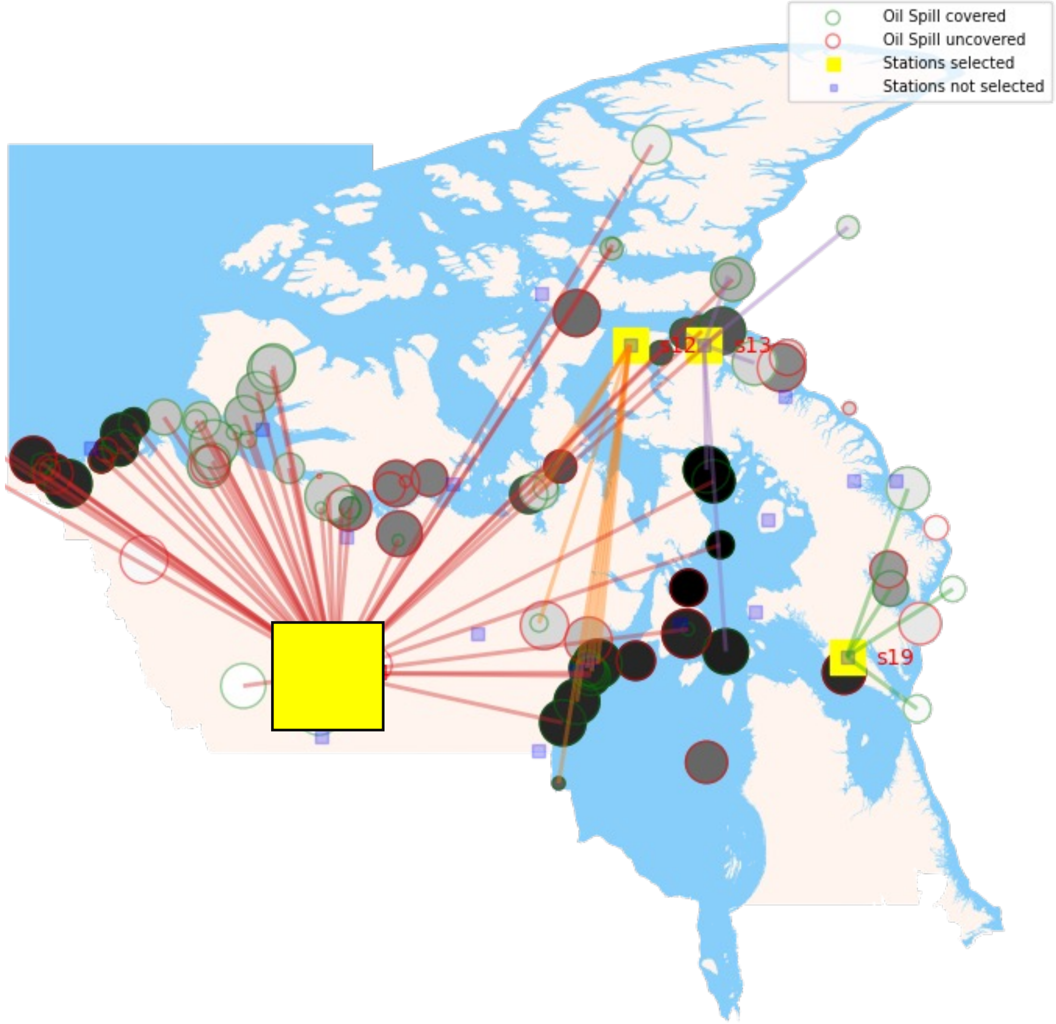


Fig 9. Network Diagram of Facility Location

Question: How many facility to build?

- Our model determines that 4 stations would suffice, if Hay River continues as hub

Question: Where to build those facilities?

- Shown in the Network Diagram in Fig 9.

Question: Stockpile requirement of resources

- Quantitative information regarding assets and equipment

Table 2. Resource Allocation

	Assets			Equipment		
Stations	Helicopter	Vessel & ships	Ice breaker	M	C	I
St 4	14	0	1*	0	1964	0.0
St 12	10	0	1	0	0.0	5538
St 13	2	13	1	33	0.0	0.0
St 19	3	20	1	51	953	0.0

Alternate configuration: can we use it?

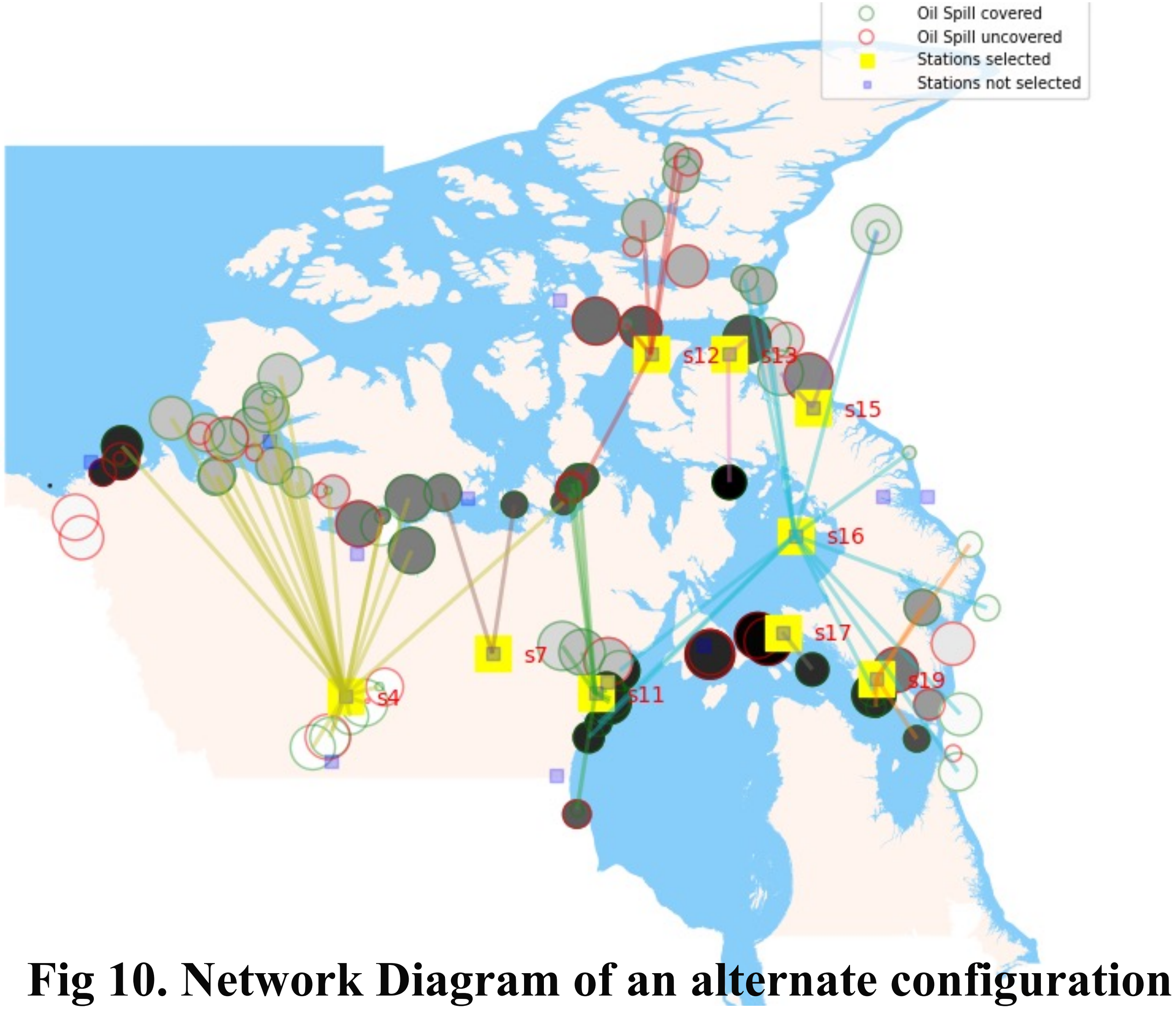


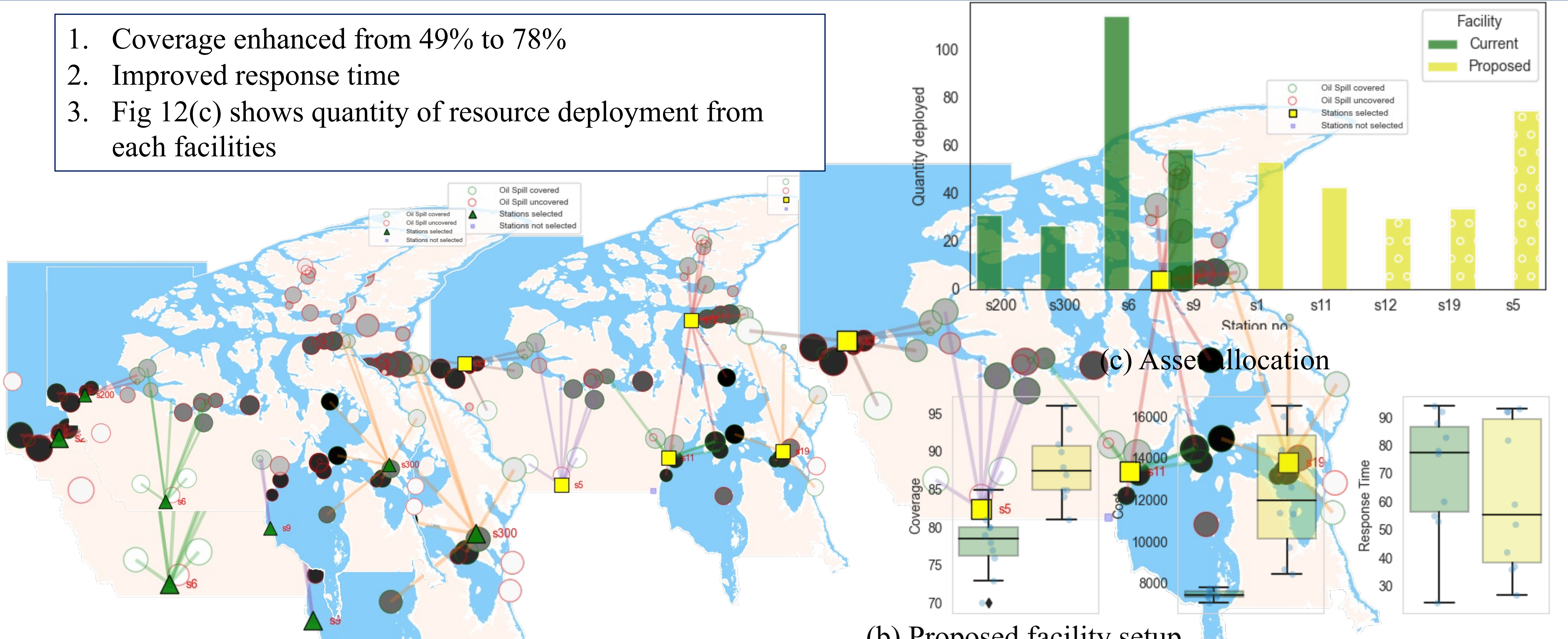
Fig 10. Network Diagram of an alternate configuration

NumberStMax =10, DistanceMax = 20, TimeRMax = 220

- Alternates configuration improves response time
- Yet, building too many facilities is NOT recommended in Arctic

Current vs Proposed Setup

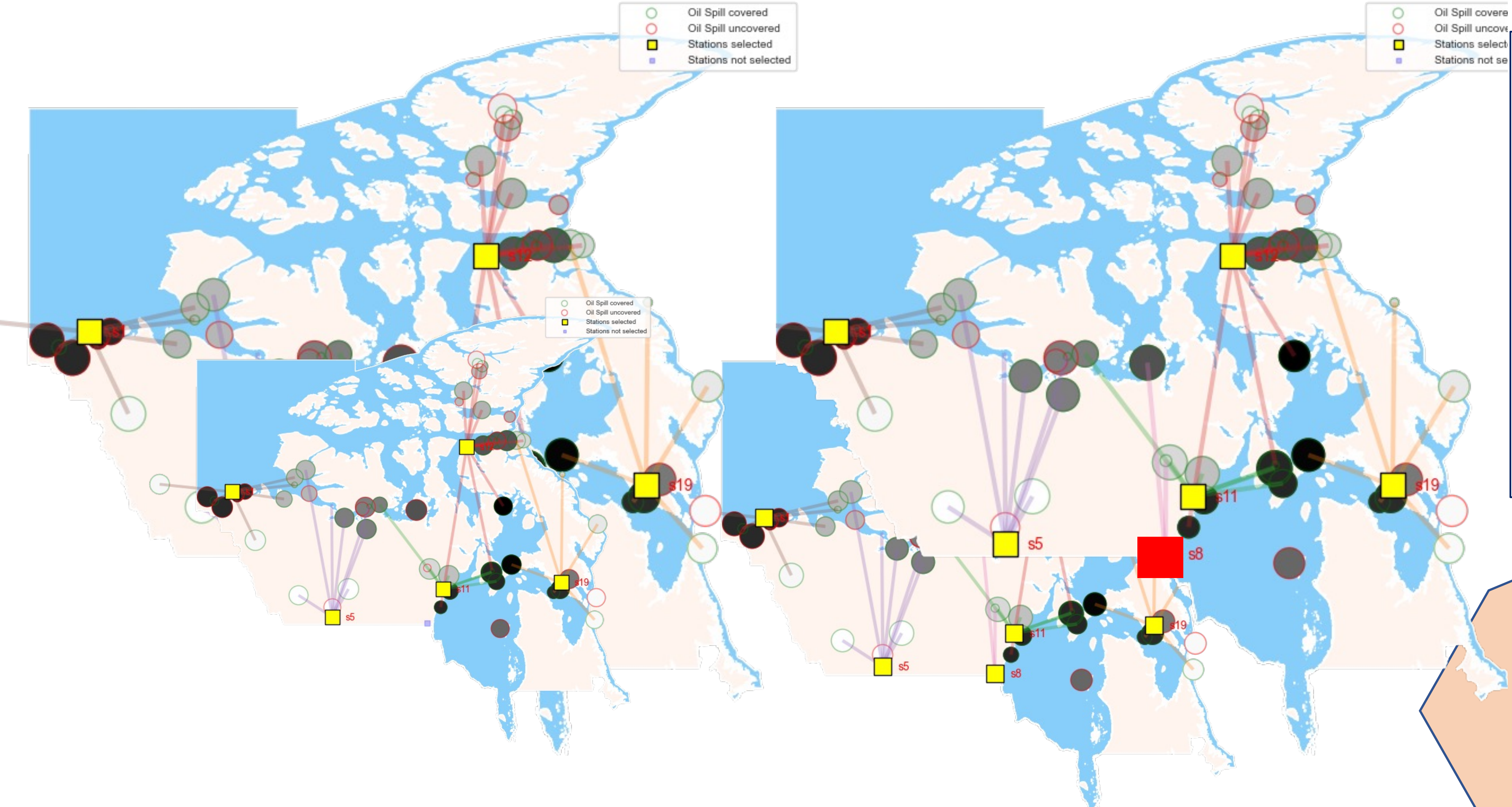
1. Coverage enhanced from 49% to 78%
2. Improved response time
3. Fig 12(c) shows quantity of resource deployment from each facilities



(a) Current facility setup (b) Proposed facility setup (c) Asset allocation (b) Proposed facility setup (d) Current vs proposed setup for 10 set of scenarios

Fig 12. Facility location modeling

Additional budget improve response?



(a) with 5 facilities

(b) with 6 facilities

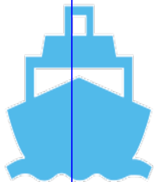
Fig 13. Network Diagram

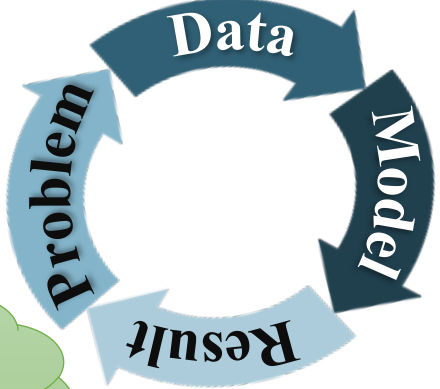
Build one new facility at additional capacity results in

- 10% more coverage
- Mean response time dropped; 3hrs 50min to 3hrs 40min
- The additional facility would cost around CAD 2-4M

- A common modeling approach in **large scale SCM**.
- if you need to build new one facility, where to build it to **maximize demand coverage**

Location Allocation Optimizer



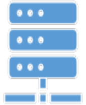


RQ: where & how many facility to build and how many resource to stockpile

Background: Arcti

Data Engineering & Analytics:

- Geolocation of facilities and potential oil spills
- Demand of different type of resources (asset & equipment)
- Effectiveness and availability of resources in a facility
- Fixed and variable costs



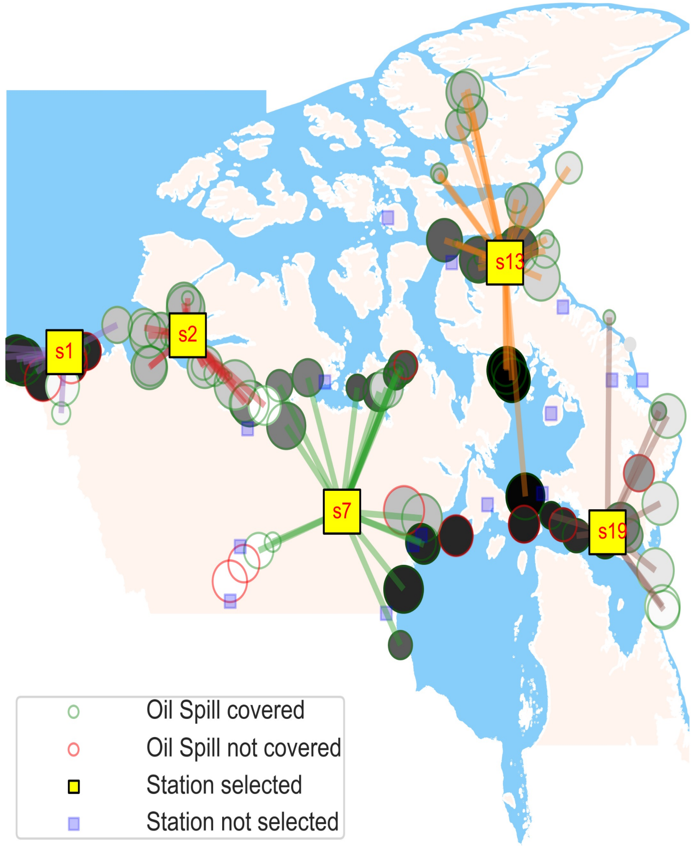
Multiobjective optimization

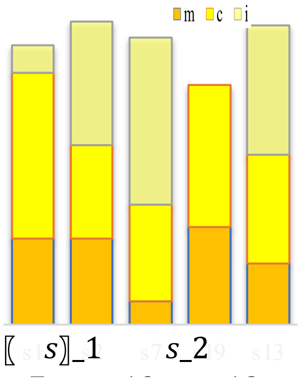
Obj1: Max spill coverage

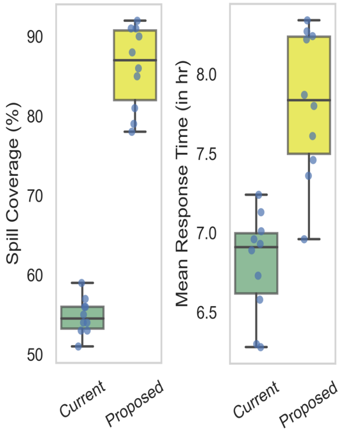
Obj2: Min cost

python GUROBI OPTIMIZATION

Optimization Model







Outcome: 16% higher coverage. 30% reduction of response time for hypothetical spills.

Add some equations

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Question?