Logistics Arctic Airship Network Delivery (LAAND)

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Agenda

- Context of Project
- Model
- Results
- Further Work
- Conclusions

Context of Project

Problem Statement - Background

- Canadian Arctic region suffers from a lack of transportation that affects cargo deliveries for food, material and equipment over several months of year due to weather
- Permanent roads and rail lines do not extend to most of the far northern areas
  - Gravel roads are flooded during the warmer months and frozen over in winter months (Cost: $3 million per km)
  - Ice road serviceability: less 30 days per year since 1996 (Seasonal Cost: $3,500 to $6,000 per km over proven routes)
- Communities and businesses lack routine cargo support
  - Goods and food prices extremely high – ex: $20 carton of OJ
  - Long delays in heavy equipment deliveries

Problem Statement - Objective

- Evaluate the feasibility of a cargo logistical system using an airship in the Canadian Arctic
  - Goal of **220** days for airship operations constrained by weather, crew limits and maintenance constraints
  - Serving native populations and mining, gas and oil industry
- Determine forward-operating-bases (FOBs) locations to provide airship refueling
- Evaluate food and supply demand needs based on population of remote communities

What is an Airship?

- A power driven aircraft kept buoyant by a gas (Helium)
  - Lighter than air
- Modernized materials and engineering technology
- Built for cargo or passengers
- Low fuel costs
- Operable through all terrains
- Operable in all seasons

Airship Cruise Speed	65 km/hr
Max Cargo Size	10 tons
Airship Travel Range	500 - 800 nMiles
Max Wind Speed - Loading	64 km/hr
Engine Service	400 hours
Overhaul Engines	3000 hours

Methodology

- Develop an event-based simulation model of an airship logistical supply system.
  - Programmed in C++
- Account for weather conditions using historical record
  - Used Canadian Records for Year 2015
- Start with a 1 month simulation period and expand to a year.
- Use different parameters for airship capabilities and operations.
- Used Network to determine the delivery sites to service and the location of Forward Operating Bases.
- Gaps in weather data were filled with uniform(5,30)

Assumptions

- 2015 Weather Data for the Canadian Arctic is representative of future weather
- Weather values were assumed to represent the entire day
- Operational limits
  - Pilot hours limitations - flying time and rest periods
  - Wind speed affects load and unloading ability
  - Project vehicle range or vehicle limitations
  - Airship is always at max weight capacity
  - Only 1 airship is operating during simulation

Assumptions (2)

- Delivery site locations - towns and industrial sites
  - Selection criteria: Population > 100 people
- All refueling sites have endless fuel
- No maintenance breakdowns en route
- Demand at the various delivery sites for goods
- Refuel, Loading/Unloading, Maintenance/Overhaul times are constants.

Service Area of Operations

- Base Site: Schefferville, QC
- Site will be for cargo loading, refueling and airship maintenance

Delivery Sites

- Have been evaluating delivery sites to supply – 62 overall
  - Focus has been on northern sites in Quebec, Nunavut and Northwest Territories – from census data with minimum of 100 inhabitants
- Number of sites have been narrowed down to 22
  - Required sites to be within 800 nautical miles to enable airship to reach destination
  - Use of Forward Operating Bases (FOBs) used to extend range from supply site

Route and FOB Analysis

- Used Network Analysis to determine which sites are reachable with distance limitations and which sites would be desirable as FOBs
  - Forward Breadth and Minimum Spanning Tree Algorithms used
- Calculating distances from sites for simulation travel
  - Use Great Circle Distance formula (spherical trig)

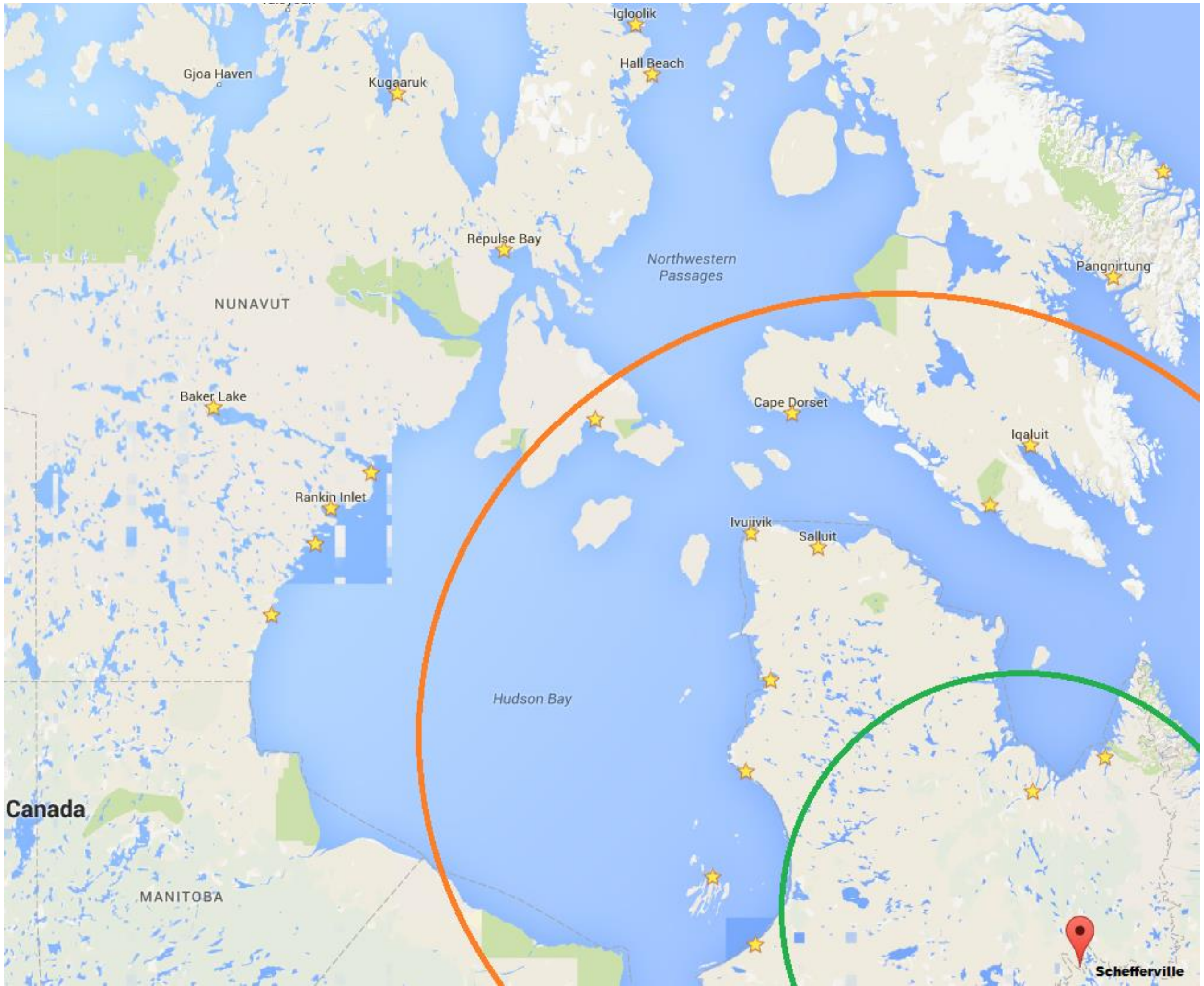
$$\Delta\sigma = \arccos\left(sin\phi_1 * sin\phi_2 + cos\phi_1 * cos\phi_2 * \text{cost}(\Delta\lambda)\right)$$

$$d = r\Delta\sigma$$

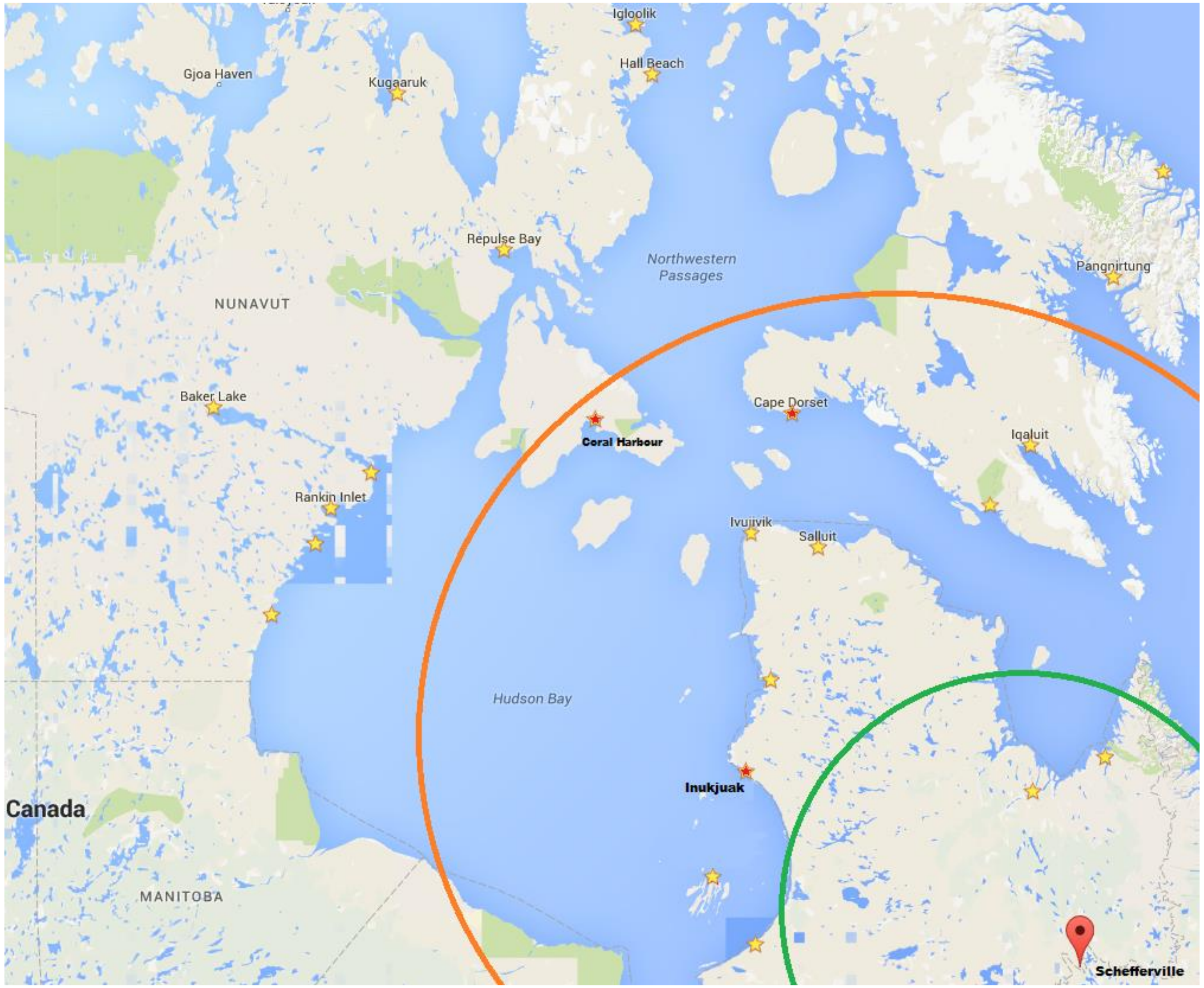
$$where\ \Delta\sigma = angle\ of\ earth, \qquad r = radius\ of\ earth,$$

$$\phi = latitude\ \ \lambda = longitude$$

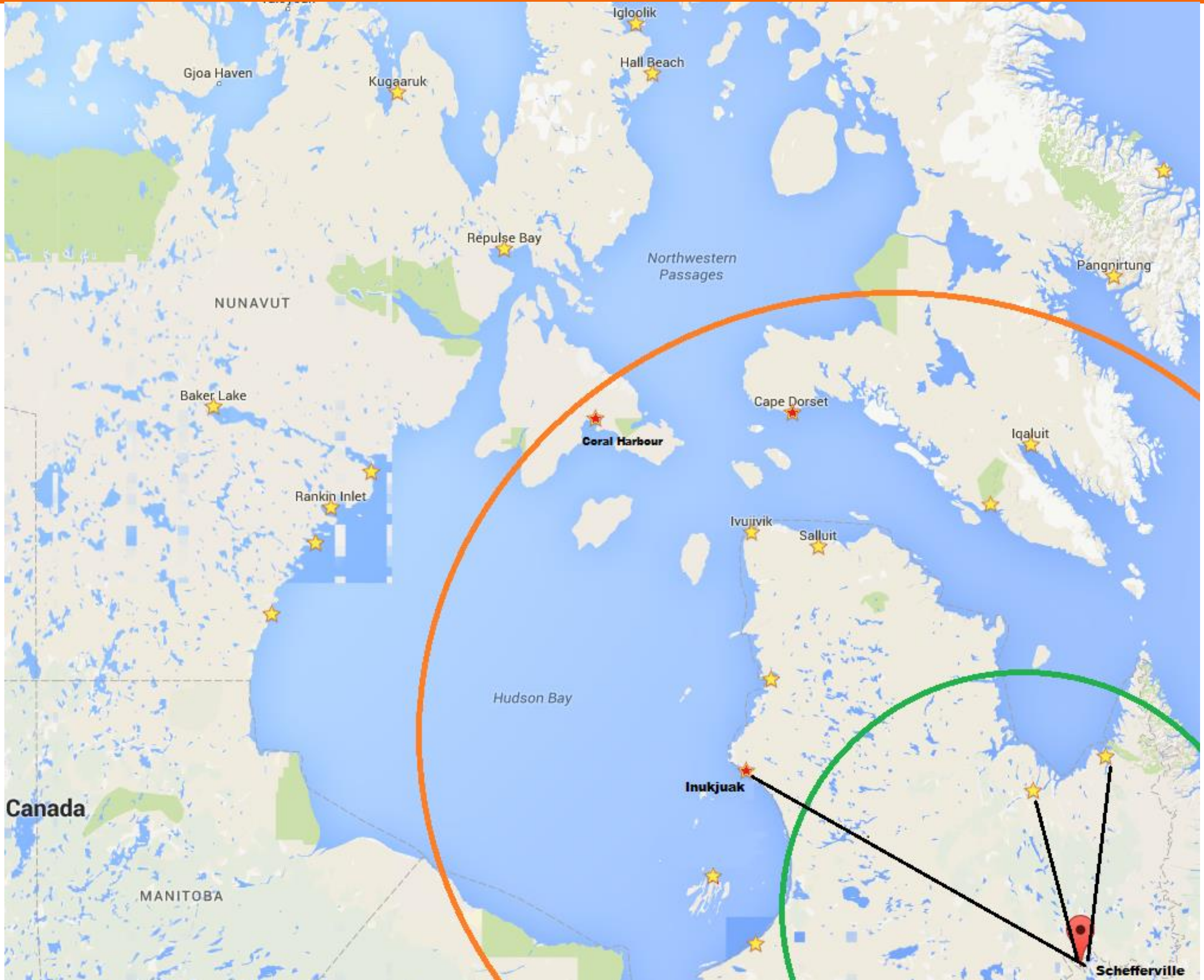
Map of Delivery Range



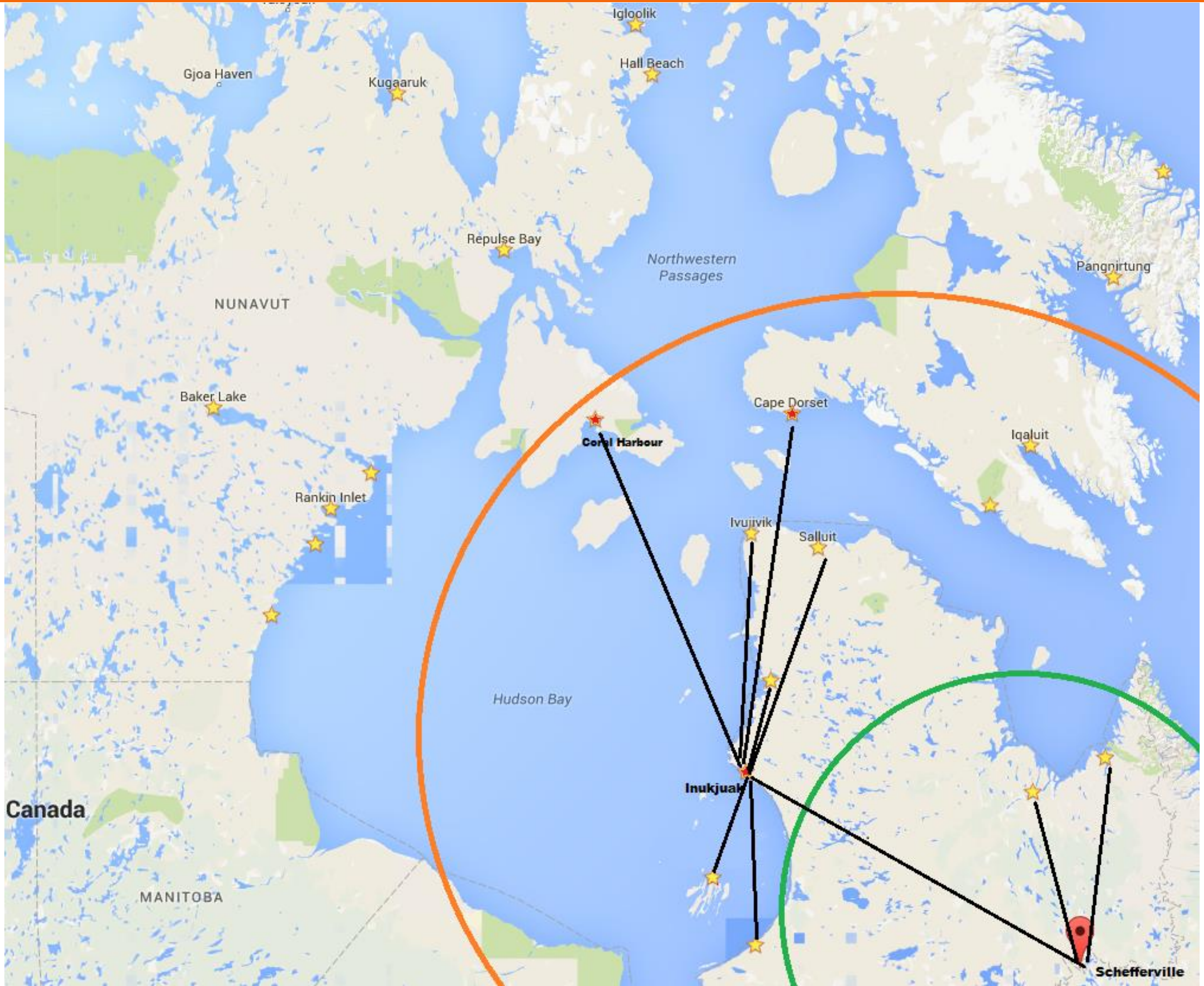
Map With Designated FOBs



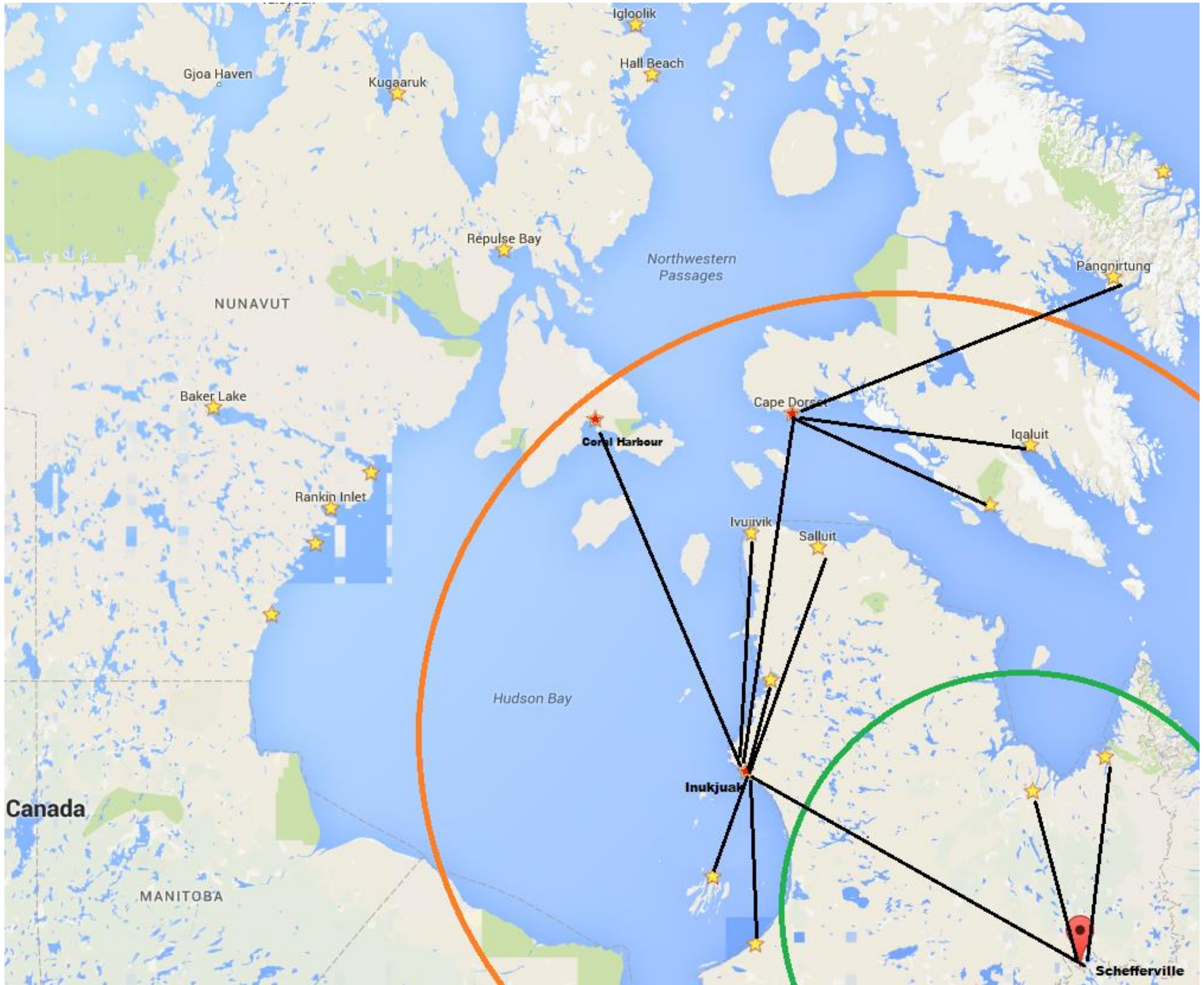
Home: Schefferville



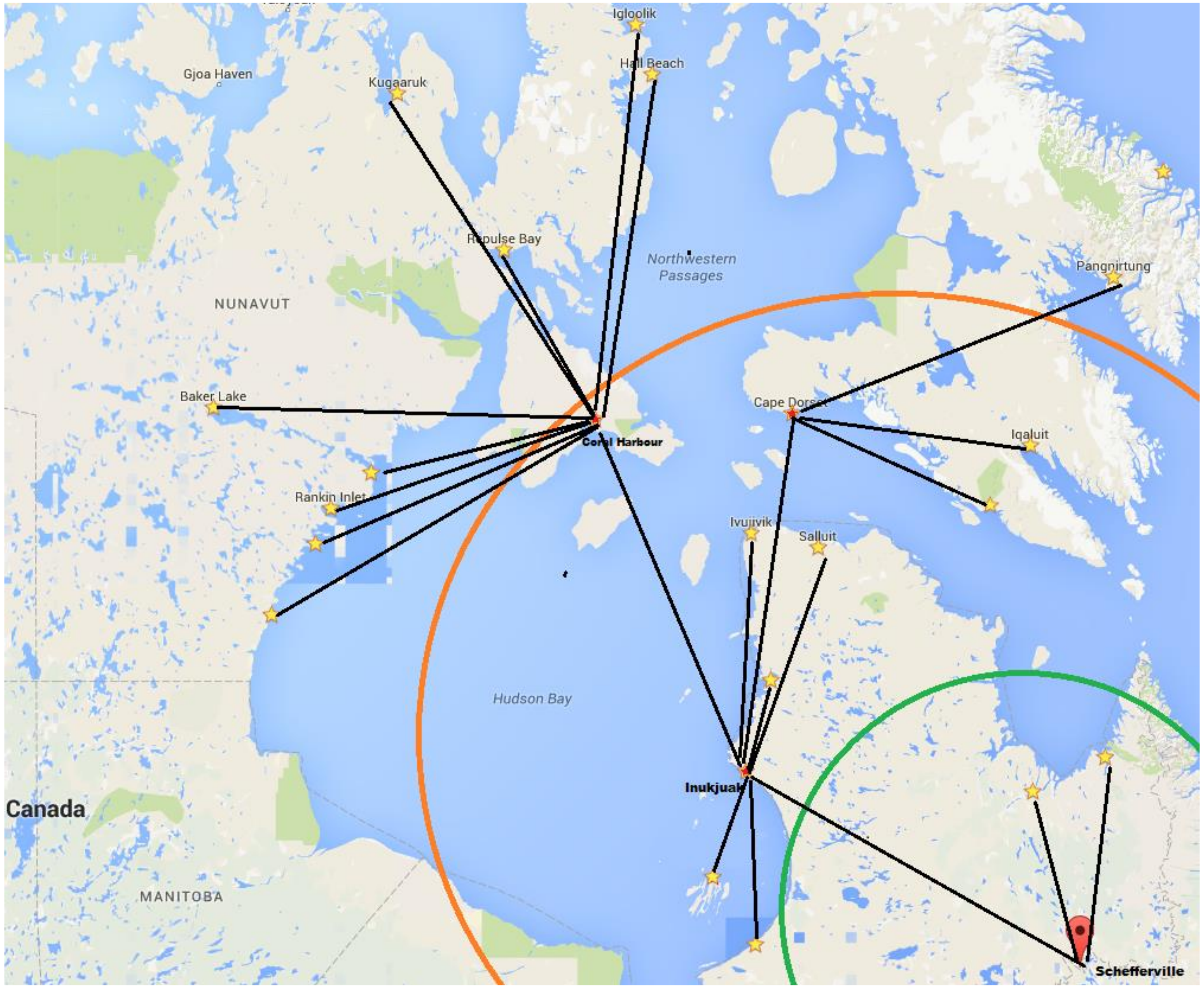
FOB 1: Inukjuak



FOB 2: Cape Dorset



FOB 3: Coral Harbour



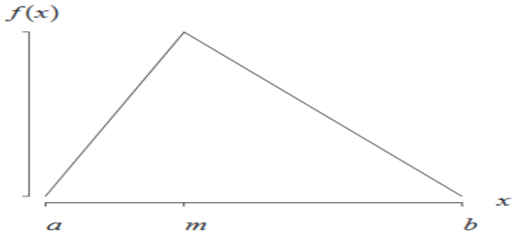
Estimating Demand Requirements

- Planning factor for daily food/water consumption:
  - Lower bound - 2.375 lbs/person/day, 3.207 lbs/person/day (including sundries)[1]
  - Upper bound - 4 lbs/person/day[2]
- Industry average for days' worth of inventory for small/rural grocery stores
  - 24-25 days inventory on hand[3]
- Perishability (Shelf Life):
  - Short term (produce, meats, media): 0-10 days[3]
  - Medium term: 10-30 days[3]
- Determine delivery volume needs and frequency:
  - Realistic product mix
  - Size of supported population at each location
  - Determine or estimate storage space at destinations (i.e. 400 sq ft - 2400 sq ft)[3]

Sources: 1. US Army, FM 101-10-1/2, *STAFF OFFICERS' FIELD MANUAL ORGANIZATIONAL, TECHNICAL, AND LOGISTICAL DATA PLANNING FACTORS (VOLUME 2),* October 1987, 2. Precision Nutrition, Inc., http://www.precisionnutrition.com, 3. Rural Grocery Store Start-Up and Operations Guide. Illinois Institute for Rural Affairs, Western Illinois University

Site Demand Frequency Estimates

- Triangle distribution for shipment frequency for each site
- Estimate values based on consumption rates, product perishability, and industry standards for keeping inventory on hand.



$$f(x) = \begin{cases} \frac{2(x-a)}{(b-a)(m-a)} & a < x < m \\ \frac{2(b-x)}{(b-a)(b-m)} & m \le x < b. \end{cases}$$

Geographic code	Geographic name	Population, 2011	Consumption (lbs) /Month	Shipment Frequency (Days) a (min value)	m (most likely)	b (max value)
2499135	Salluit	1347	161640	**4**	**7**	**21**
2499085	Inukjuak	1597	191640	**3**	**7**	**21**
2499090	Kangiqsualujjuaq	874	104880	**6**	**7**	**21**
2499095	Kuujjuaq	2375	285000	**2**	**7**	**21**
2499075	Kuujjuarapik	657	78840	**7**	**8**	**21**
2499120	Puvirnituq	1692	203040	**3**	**7**	**21**
2499140	Ivujivik	370	44400	**7**	**14**	**21**
6205015	Arviat	2318	278160	**2**	**7**	**21**
6205023	Baker Lake	1872	224640	**3**	**7**	**21**
6204007	Cape Dorset	1363	163560	**4**	**7**	**21**
6205019	Chesterfield Inlet	313	37560	**7**	**16**	**21**
6205014	Coral Harbour	834	100080	**6**	**7**	**21**
6204011	Hall Beach	546	65520	**7**	**9**	**21**
6204012	Igloolik	1454	174480	**3**	**7**	**21**
6204003	Iqaluit	6699	803880	**1**	**7**	**21**
6204005	Kimmirut	455	54600	**7**	**11**	**21**
6208047	Kugaaruk	771	92520	**6**	**7**	**21**
6204009	Pangnirtung	1425	171000	**4**	**7**	**21**
6204010	Qikiqtarjuaq	520	62400	**7**	**10**	**21**
6205017	Rankin Inlet	2266	271920	**2**	**7**	**21**
6205027	Repulse Bay	945	113400	**5**	**7**	**21**
6204001	Sanikiluaq	812	97440	**6**	**7**	**21**
6205016	Whale Cove	407	48840	**7**	**12**	**21**

FOBs highlighted in gray

Model

Model Parameters

Airship Parameters

- Cruise Speed
- Max Cargo Size
- Load Time
- Unload Time
- Refuel Time
- Location
- Status
- Drag Coefficient
- Maintenance and Overhaul requirements

Delivery Sites

- Location
- Demand Frequency
- Last delivery date
- Refuel Point

Pilot

- Flight Hours Limit per time period
- Total hours worked

Weather Data

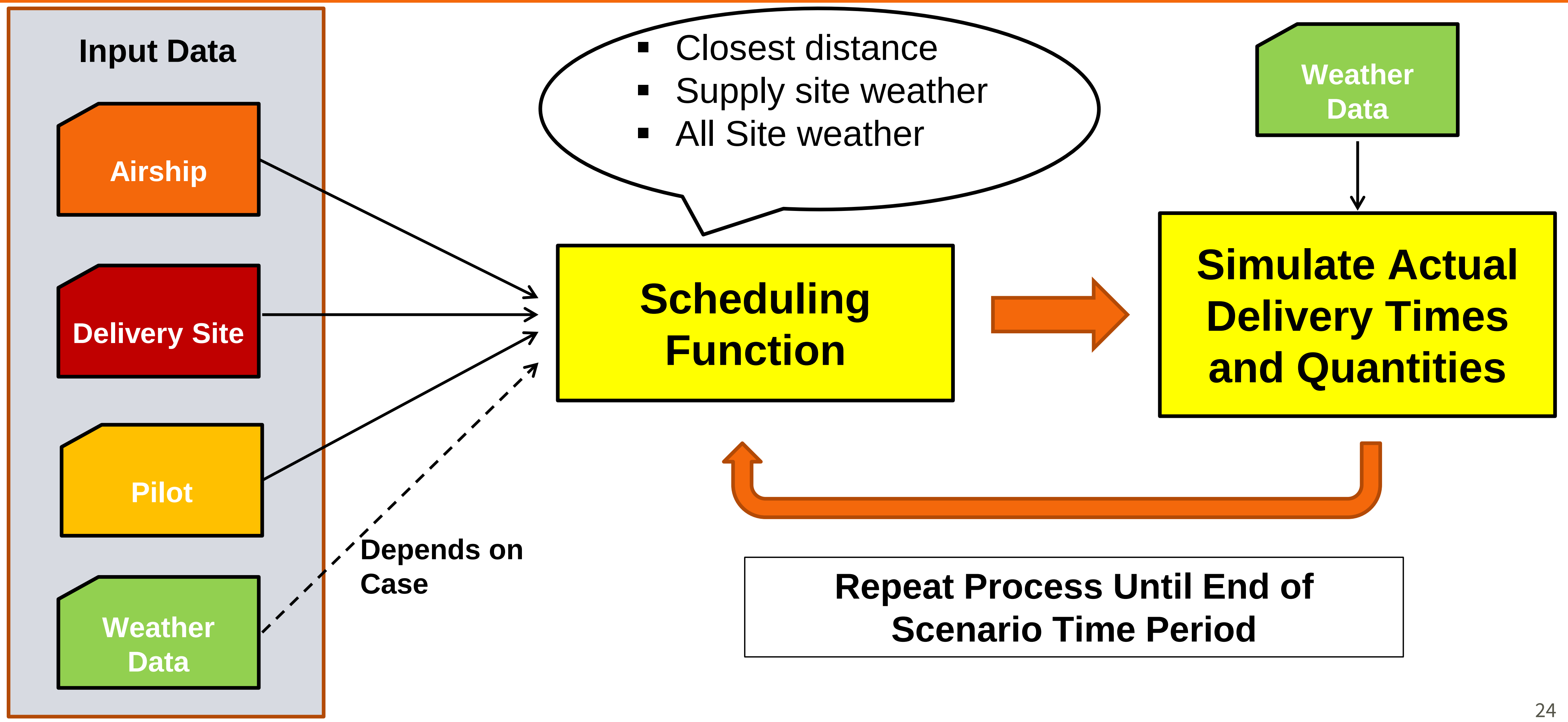
- Location of Sites
- Wind Speed
- Wind Direction
- Max allowable wind gust

Case Parameters

- Following parameters represent the base case that variation cases will be compared against.

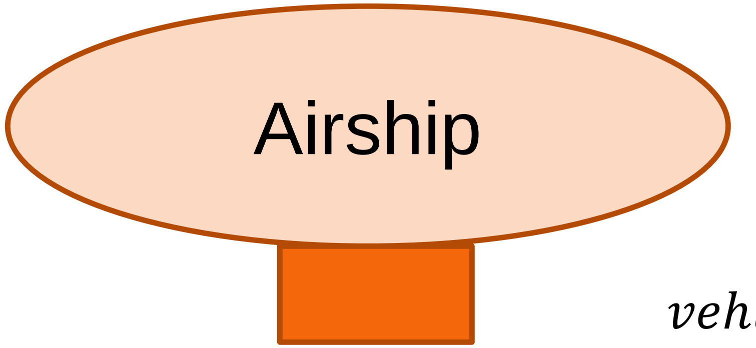
Cruise Speed	65 km/hr
Load/Unload Time	0.5 hours
Refuel Time	0.5 hours
Drag Coefficient	0.3
Max Wind Gust	64 km/hr
Pilot Hours	8 hr / day
Site Demand Frequency	14 days

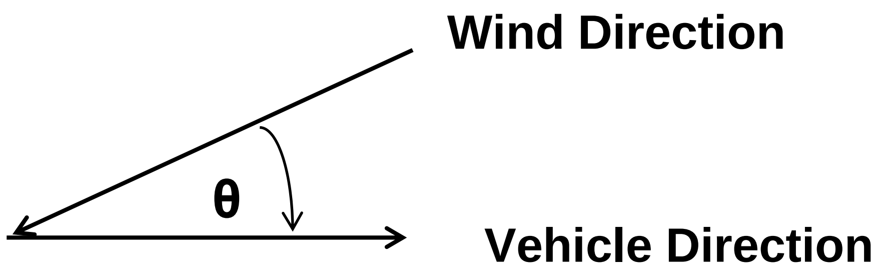
Airship Delivery Model



Weather Model

- Weather will be used for the start site and destination site
  - Conditions will be changed at the halfway point between sites
- Wind speed and direction will be simulated on the airship vehicle based on the drag coefficient given to the airship





$$vehicle\ speed = (cruise\ speed) * (\,1\ - C_D * (wind\ speed) * \cos\theta)$$

Cases Examined

Case 1 # Of Hours a Pilot Can Operate: • 8 hour flight time per pilot – 2 pilots per airship • No flight limits for pilots • Pilots swapped at refuel sites	**Case 2: Fuel and Loading Times:** • Fuel and loading times 0.5 hour • Fuel and loading times 1 hour • Fuel and loading times 0.25 hours
Case 3: Schedule with Weather: • Closest site scheduled • Supply site weather used • All sites weather used	**Case 4: Drag Coefficient:** • Drag coefficient of 0.3 • Drag coefficient of 0.2 • Drag coefficient of 0.4

Results

Expected Model Output

- Number of sites delivered
  - Location of sites
- Days airship is in operation (per year)
  - Determine the feasibility of 220 days of revenue generating missions. (220 Days, 10 hours/Day)
- Tons of goods delivered
- Total distance traveled
- Number of weather holds
- Number of maintenance and overhauls performed
- Number of refuel visits

Case 1: # Of Hours Pilot Can Operate

Value	Base – 16 hrs/day	Unlimited Pilot Hours	Pilot Swap At Refuel
Total Deliveries	194	234	233
Operation Time (days)	323	330	329
Number of Refuels	286	419	415
Maintenance	18	18	19
Overhauls	2	2	2
Weather Delays	17	22	22
Unique Sites Delivered	9	11	11

- Both the unlimited pilot hours and pilot swap cases showed a large improvement (21 %) over the base case.
- Pilot swap possible alternative if regulations don't allow flexible pilot hours
- Refuel numbers also show a large increase

Case 2: Refuel and Loading Times

Value	Base – 1/2 Hour Load and Refuel	1 Hour Load and Refuel	1/4 Hour Load and Refuel
Total Deliveries	194	183	194
Operation Time (days)	323	322	323
Number of Refuels	286	265	286
Maintenance	18	18	18
Overhauls	2	2	2
Weather Delays	17	17	17
Unique Sites Delivered	9	9	9

- The ½ and ¼ hour load and refuel times show 6 % increase over the 1 hour time
- Negligible difference between ½ and ¼ hour cases

Case 3: Weather Knowledge

Value	Base – Closest Site	Supply Site Weather	All Site Weather
Total Deliveries	194	195	195
Operation Time (days)	323	333	333
Number of Refuels	286	298	303
Maintenance	18	18	18
Overhauls	2	2	2
Weather Delays	17	4	6
Unique Sites Delivered	9	11	11

- Total deliveries had negligible difference with scheduling based on weather knowledge
- Weather delays reduced with forecast ability
- Additional constraints should be considered for future analysis

Case 4: Drag Coefficient

Value	Base $C_D = 0.3$	$C_D = 0.2$	$C_D = 0.4$
Total Deliveries	194	194	191
Operation Time (days)	323	329	331
Number of Refuels	286	290	282
Maintenance	18	18	18
Overhauls	2	2	2
Weather Delays	17	18	14
Unique Sites Delivered	9	9	9

- Negligible differences in results due to drag coefficient
- Weather modeling balances out increases and decreases in speed due to round trips

Further Work

Further Work

- Continue expanding knowledge of airship operations
- Continue doing research on airship performance/operation
- Add complexity of airship performance
- Collect and use hourly weather data
- Incorporate demand analysis performed in model
- Use stochastic modeling instead of deterministic
- Begin estimating costs

Conclusions

Conclusions

- Airship operations are complex based on physical hardware (engines and airframe), regulations, and lack operational experience
- Completed > 220 revenue generating mission days
- Largest increase in performance when existing pilot flight hours limitations removed
- Weather knowledge reduced the number of weather delivery delays, but didn't increase the overall number of appreciable deliveries
- Reload/refuel times between 15 minutes and 1 hour yielded ~10% increase in performance
- Drag coefficients had negligible effect on overall performance.
  - Might differ with a more complex model.
- Very high number of refuel site visits is a concern
  - Refuel sites are highly critical to the success of airship operations.
  - Possible need to reconfigure network and location of base site.

Questions?