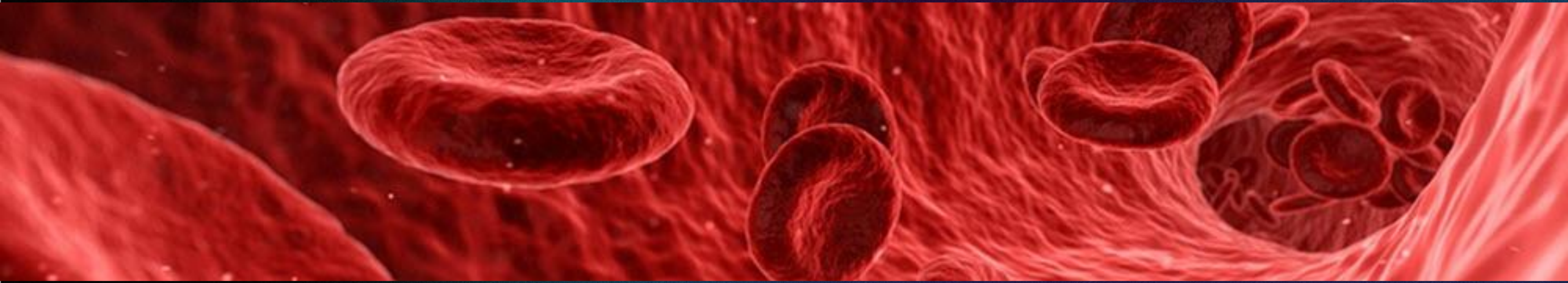
The Distribution of Blood for a Stat Order in Northern Health Authority of British Columbia



MATH 402W
Simon Fraser University

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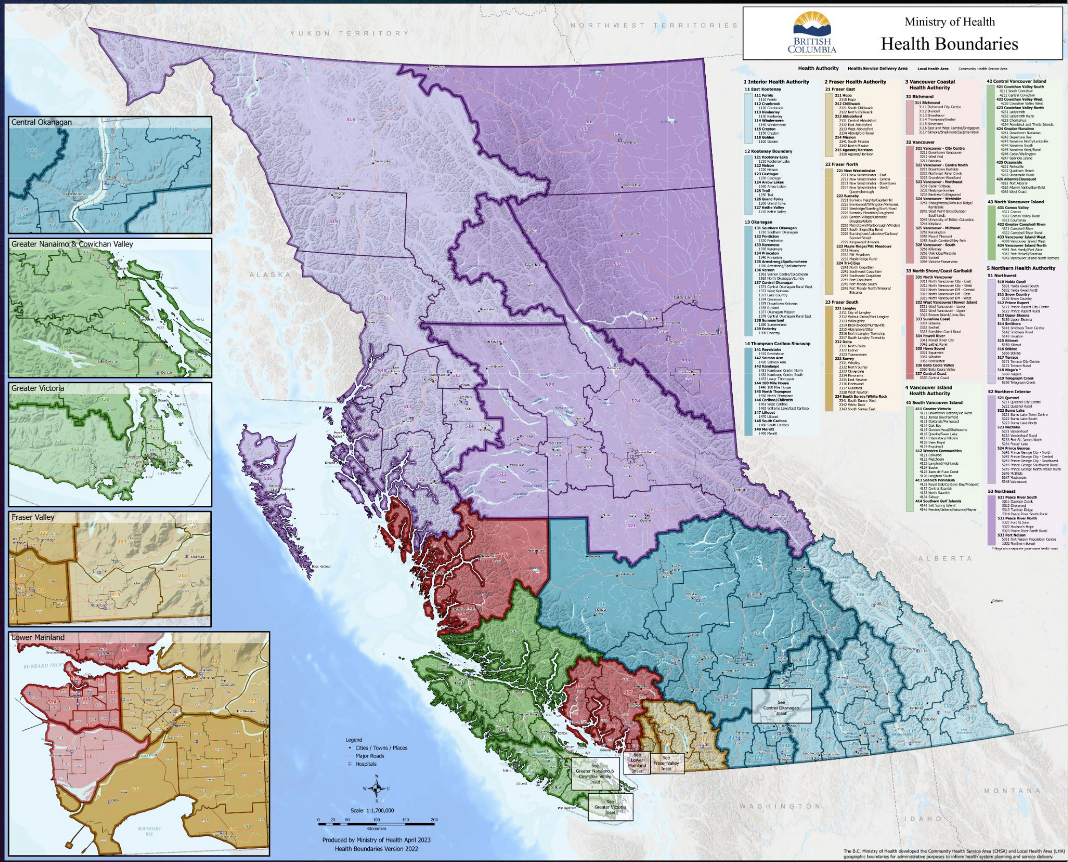
Client: BC Provincial Blood Coordinating Office (PBCO)

BC Provincial Blood Coordinating Office

promoting good stewardship in transfusion medicine

BC Health Authorities (HA)



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Problem:

Emergency orders, or stat orders, can come at any time from any location.

Sites without enough blood on hand have to get their orders filled by other sites, which introduces a problem.

We will determine which hospitals the blood should be drawn from, and how much from each.

Background:

Issues:

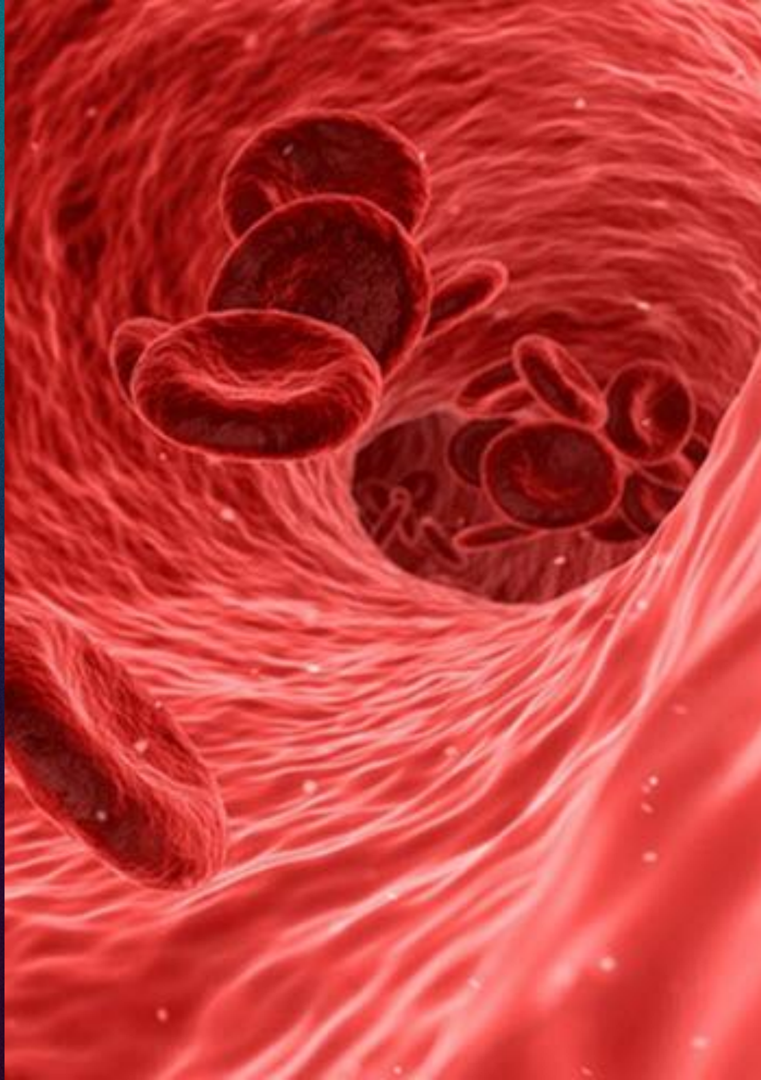
- Limited supply
- Precise storage conditions
- Limited shelf life

Current strategy:

- Hub-and-spoke distribution
- Redistribution before expiry

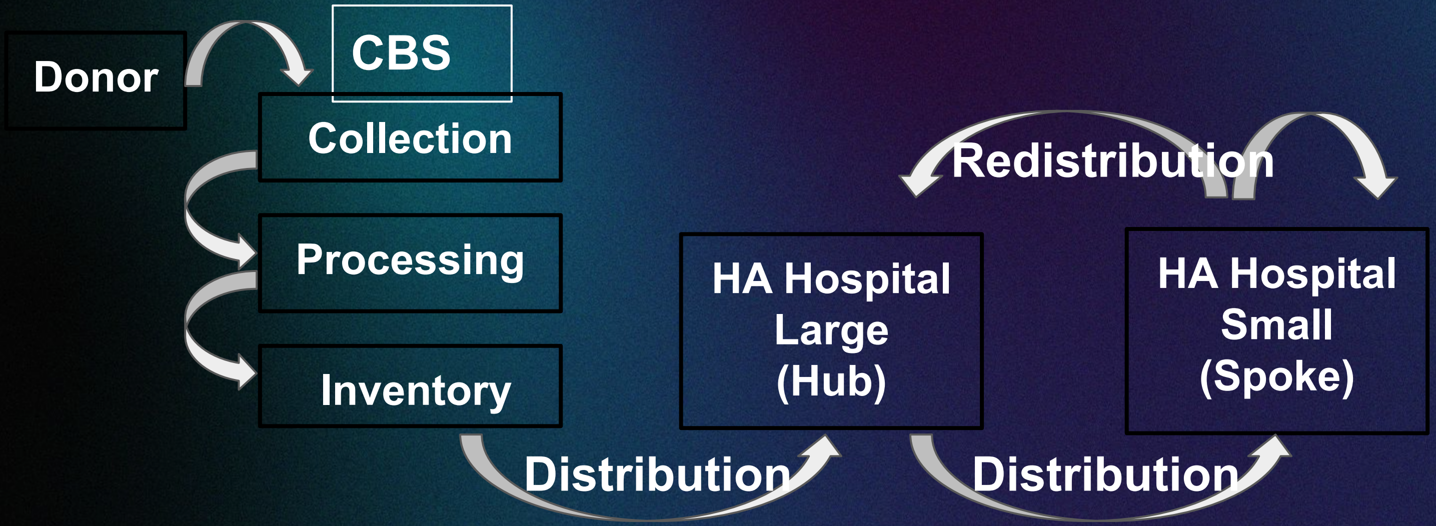
Proposed strategy:

- Optimized distribution and redistribution
- Redistribution between spoke sites



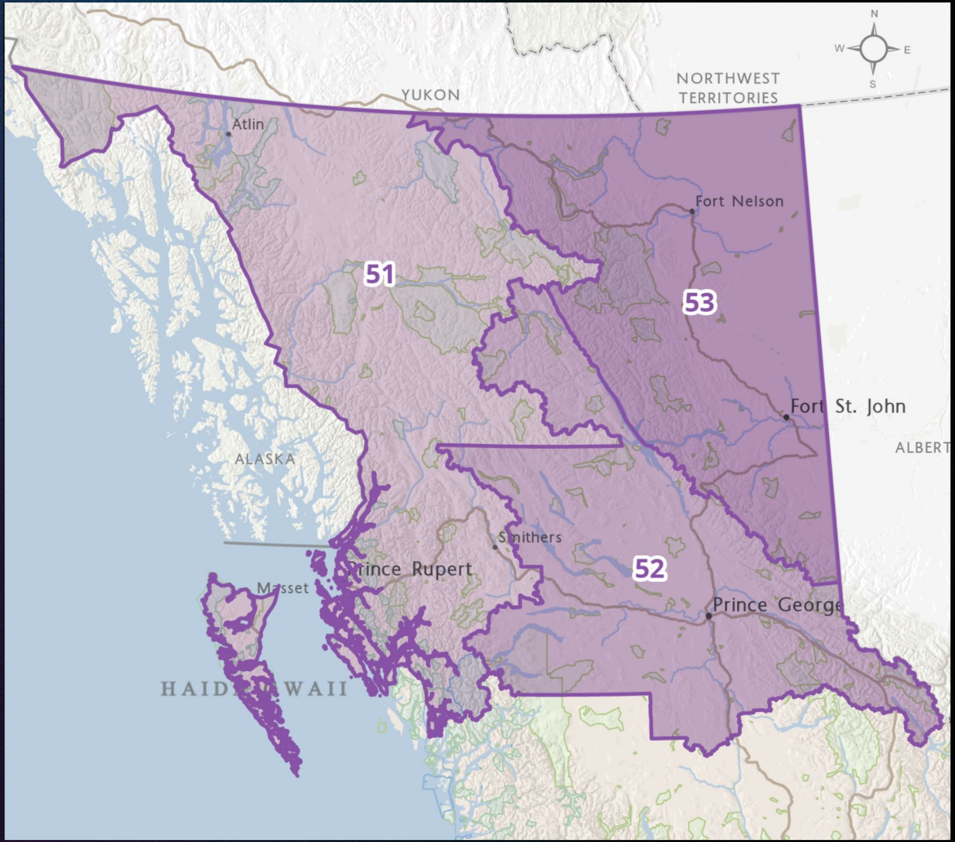
The Current System:

Blood is processed by Canadian Blood Services (CBS), and distributed to each health authority's "hub". These hubs act as central storage locations for the rest of the network, which draws blood directly from them. These smaller locations are called "spokes". When Red Blood Cell units (RBCs) are close to expiry, they are redistributed to the hub sites to be used at the larger hospitals.



Northern Health Authority (NH)

- Rural
- Large geographical area
- Lower infrastructure and population density
- More severe weather
- Internal courier service - Northern Health Courier (NHC)



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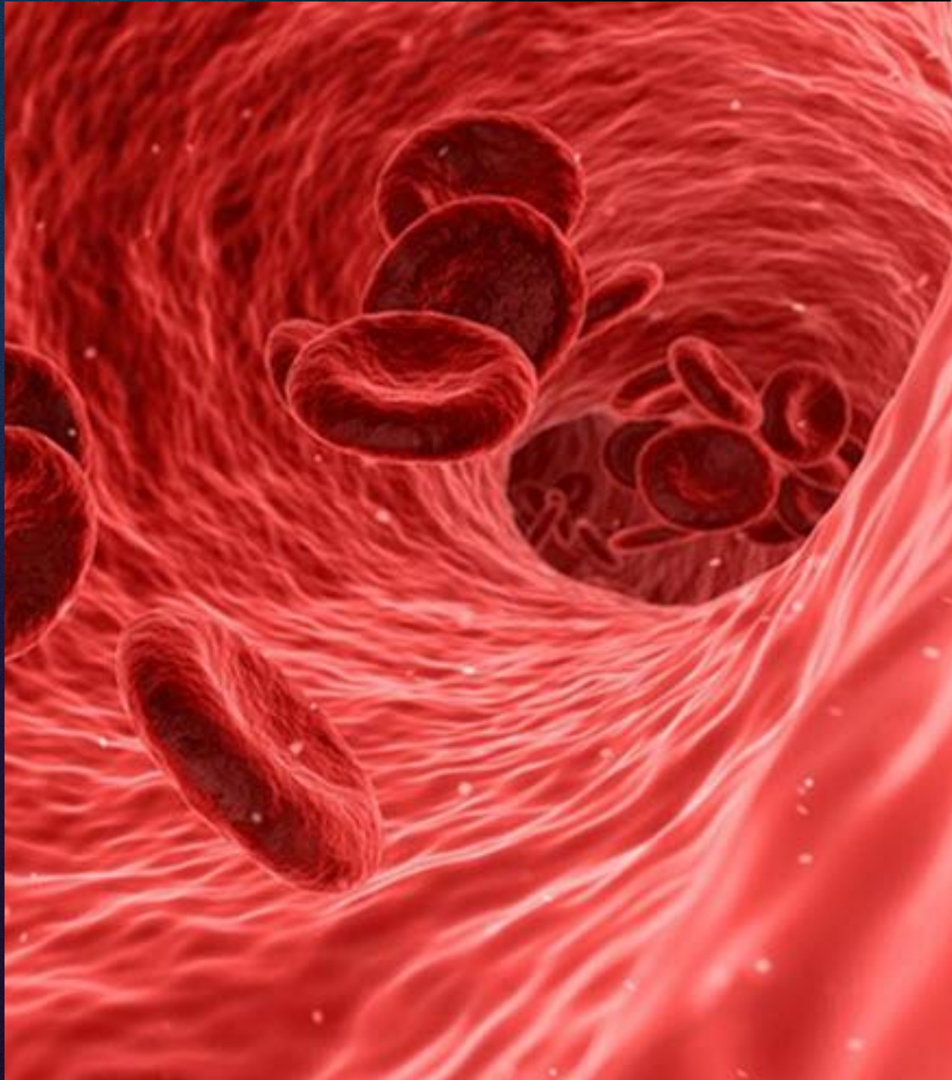
Red Blood Cells

Red Blood Cells are distributed in Red Blood Cell units, often shortened to RBCs.

There are 8 distinct blood types, and it can be dangerous to give a person blood that is of a different type to them. O- type blood is called the “universal donor”, because it can be given to recipients of any blood type.

For this reason, it is preferentially stocked, especially in remote areas. For our model, we decided to work only with O- blood.



Mathematical Model: Using linear programming to optimize the transportation problem of a stat order to find an optimal solution to the objective function of minimizing time for supply to meet demand.

$$\textit{Minimize} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{i,j} x_{i,j}$$

$$\textit{subject to} \sum_{i=1}^{n} x_{i,j} = s_i \ (i = 1, 2, \dots n)$$

$$\sum_{j=1}^{m} x_{i,j} = d_j \ (j = 1, 2, \dots m)$$

$$\textit{such that} \sum_{i=1}^{n} s_i = \sum_{j=1}^{m} d_j$$

$\textit{where } m =$ number of supply sources

$n =$ number of demand destinations

$s_i =$ number of units from supply source

$d_j =$ number of units required at demand destination

$x_{i,j} =$ number of units transported

$C_{i,j} =$ cost of units transported

Using Built in Microsoft Excel (MS) Solver Tool - Simplex Algorithm

Output / Input	M_1	M_2	M_3	M_4	M_{dummy}	$Supply_i$
W_1	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$x_{1,4}$	$x_{1,5}$	s_1
W_2	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	$x_{2,4}$	$x_{2,5}$	s_2
W_3	$x_{3,1}$	$x_{3,2}$	$x_{3,3}$	$x_{3,4}$	$x_{3,5}$	s_3
W_4	$x_{4,1}$	$x_{4,2}$	$x_{4,3}$	$x_{4,4}$	$x_{4,5}$	s_4
$Demand_j$	d_1	d_2	d_3	d_4	d_5	$C_{i,j}$

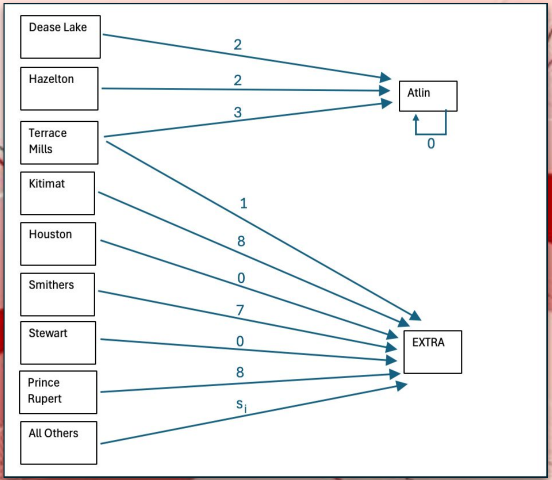
Example transportation matrix

W_i = Warehouse
M_i = Market
s_i = Supply Available
d_j = Demand
$x_{i,j}$ = Number of Units Transported from *i* to *j*
$C_{i,j}$ = Total Cost

Extra dummy warehouse added with a transportation cost of 0 to balance the problem and make the total demand equal to the total supply

Output / Input	*Atlin*	*Dease Lake*	*Hazelton*	*Terrace Mills*	*Extra*	$Supply_i$
Atlin	0	0	0	0	0	0
Dease Lake	2	0	0	0	0	2
Hazelton	2	0	0	0	0	2
Terrace Mills	3	0	0	0	1	4
$Demand_j$	7	0	0	0	1	5304

Transportation Matrix of Stat Order of 7 for Atlin



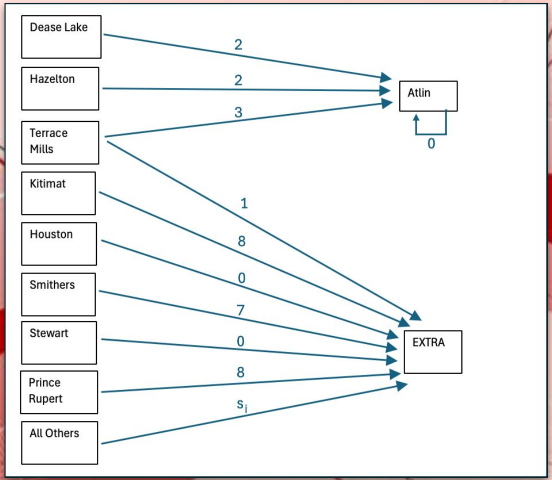
Using Built in Microsoft Excel (MS) Solver Tool - Simplex Algorithm

Input \ Output	M_1	M_2	M_3	M_4	M_{dummy}	$Supply_i$
W_1	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$x_{1,4}$	$x_{1,5}$	s_1
W_2	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	$x_{2,4}$	$x_{2,5}$	s_2
W_3	$x_{3,1}$	$x_{3,2}$	$x_{3,3}$	$x_{3,4}$	$x_{3,5}$	s_3
W_4	$x_{4,1}$	$x_{4,2}$	$x_{4,3}$	$x_{4,4}$	$x_{4,5}$	s_4
$Demand_j$	d_1	d_2	d_3	d_4	d_5	$C_{i,j}$

- Each Warehouse and Market was designated as the same Hospital (ie: delivering from W_2 to M_2 would be to the same site)
- Supply = Daily Average Inventory - Min Supply Level
- Demand = Amount needed for stat order (can vary depending on situation)
  - Demand of Dummy Site =
    Total Demand - Stat Order Demand
- Cost is the travel time between hospital sites
  - Travel time chosen over distance since time is the most important factor in an emergency
  - "If it needs to get done, it gets done"

Input \ Output	*Atlin*	*Dease Lake*	*Hazelton*	*Terrace Mills*	*Extra*	$Supply_i$
Atlin	0	0	0	0	0	0
Dease Lake	2	0	0	0	0	2
Hazelton	2	0	0	0	0	2
Terrace Mills	3	0	0	0	1	4
$Demand_j$	7	0	0	0	1	5304

Transportation Matrix of Stat Order of 7 for Atlin



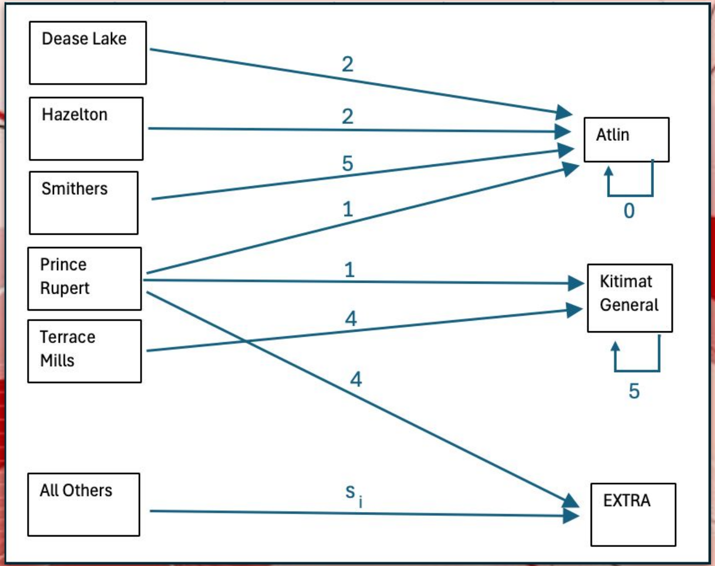
Using Built in Microsoft Excel (MS) Solver Tool - Simplex Algorithm

The results show that in an emergency, a site should draw RBC from a nearby site to meet the demands. Even if this nearby site does not have sufficient supply to meet the total demand, it will allow for a buffer before the remainder of the demand can be received.

Results were similar when comparing the size of the site requesting the stat order.
Small = no inventory, medium = 1-4 units, large = >5 units.
Main difference was medium and large sites dilute their own supply first and then draw from nearby sites.

Input \ Output	*Atlin*	*Dease Lake*	*Kitimat General*	*Prince Rupert*	*Hazelton*	*Terrace Mills*	*Smithers Buckley*	*Extra*	$Supply_i$
Atlin	0	0	0	0	0	0	0	0	0
Dease Lake	2	0	0	0	0	0	0	0	2
Kitimat General	0	0	5	0	0	0	0	0	5
Prince Rupert	1	0	1	0	0	0	0	4	6
Hazelton	2	0	0	0	0	0	0	0	2
Terrace Mills	0	0	4	0	0	0	0	0	4
Smithers Buckley	5	0	0	0	0	0	0	0	5
$Demand_j$	10	0	10	0	0	0	0	4	8445

Transportation Matrix for Multiple Stat Orders of 10 for Atlin and 10 for Kitimat General



Updating Model: Pareto Front Optimization Using a Weighted Cost Objective Function

$$
\begin{aligned}
Minimize \sum_{i\neq j} y_{i,j}(\alpha \cdot CD_{i,j} + (1-\alpha)\cdot CT_{i,j}) \\
subject\ to \sum_{i\neq j} y_{i,j} = 1\ (outgoing flow) \\
\sum_{i\neq j} y_{j,i} = 1\ (incoming flow) \\
I_i \geq \sum_{i\neq j} y_{i,j}\cdot d_j \\
I_i \geq Imin_i \\
I_i \leq Imax_i
\end{aligned}
$$

α = weighting travel distance and travel time

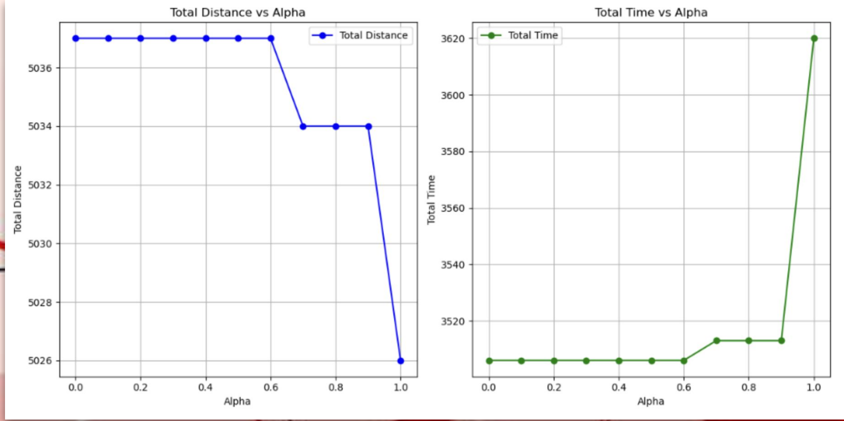
Inventory maintained above minimum and below maximum

Pareto Front Optimization:

Using real-time traffic data

Multi-objective - minimize both transportation distance and delivery time

Stay within inventory constraints of hospital sites



Total Distance vs Alpha and Total Time vs Alpha

- We can see there is not much difference between minimizing distance vs minimizing time

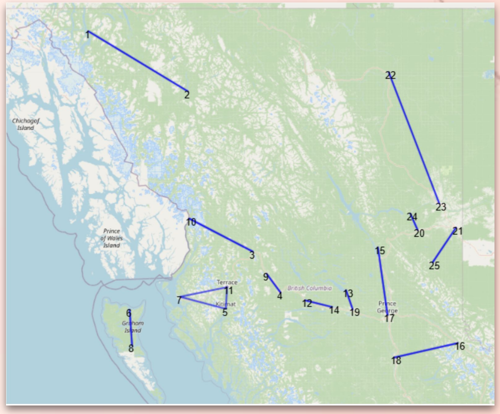
Pareto Front Optimization:

One-to-One Relationship:

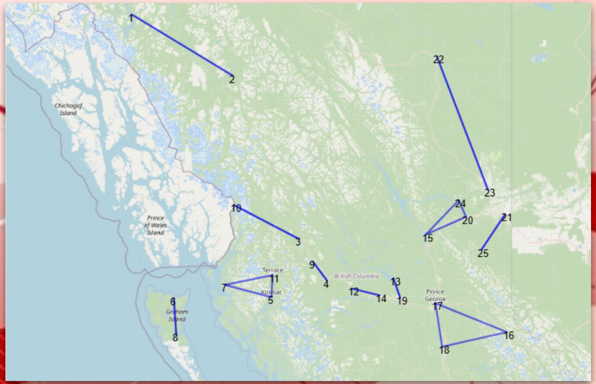
Determines which hospital site to reach out to first in an emergency.

Can update this to be one-to-many, many-to-one, or many-to-many. This would require more computing time and calls to API data.

Similar results between offline and real-time data. This either indicates there was no major traffic delays or that real-time data gives similar results.



Offline Data with One-to-One Relation:



Real-Time Morning Traffic Data with One-to-One Relation:

Pareto Front Optimization:

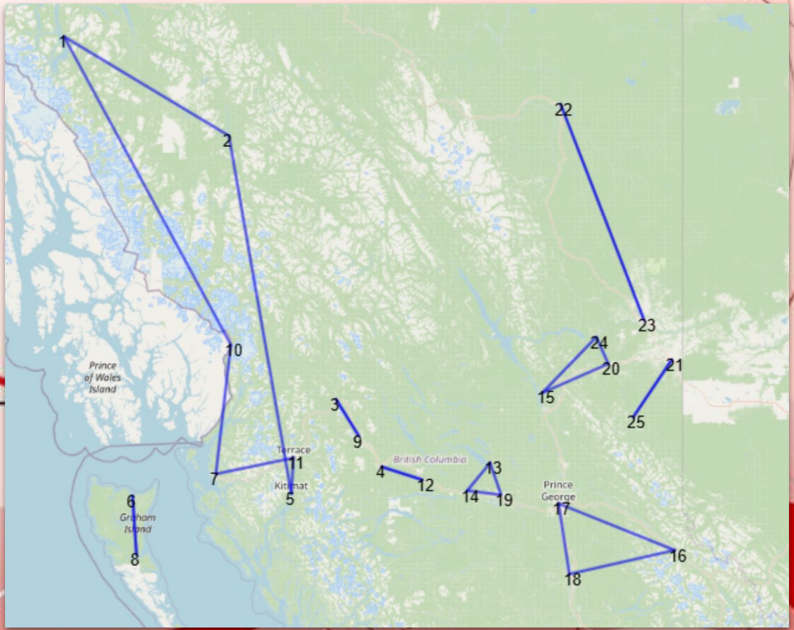
Redistribution of RBC using a one-to-one method.

Map indicates where a supply should be redistributed to avoid expiry

Allows for redistribution between all sizes of sites

Model manages blood supply by redistributing between hospital sites. Maintain objective and minimizing cost and time.

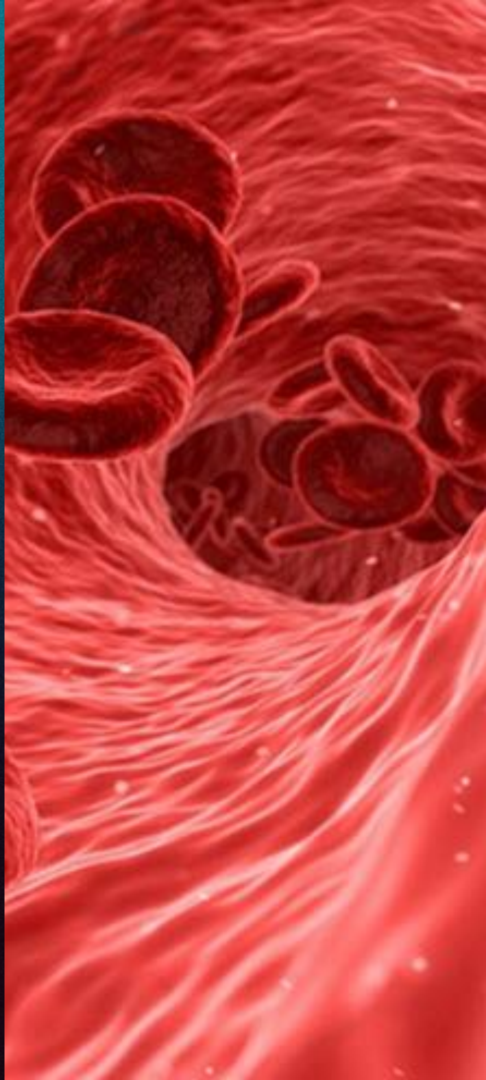
Model works to keep sites above their min and below their max



Optimal Redistribution with a One-to-One Relation:

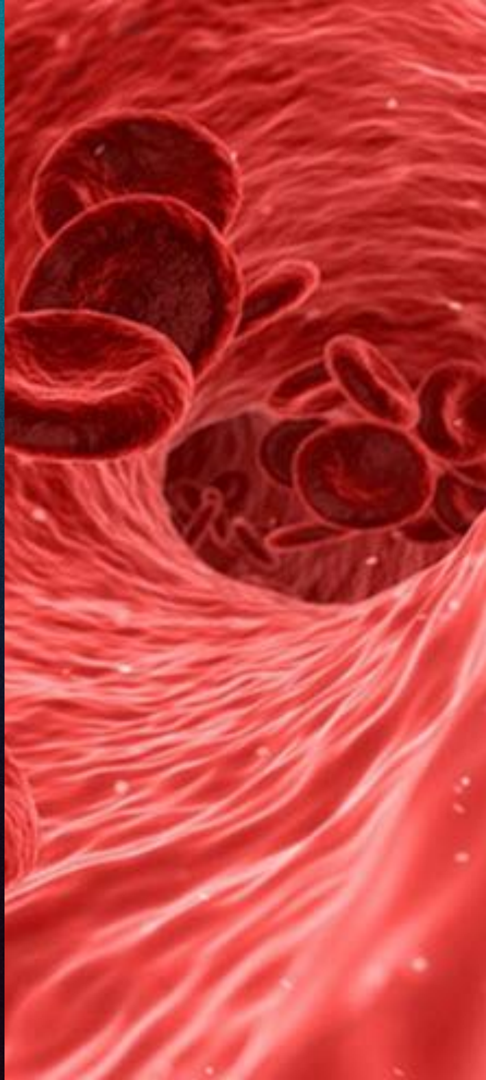
Applications:

- Model can be applied to other HA in BC
    - Island and Interior Health both have internal courier service already in place and have more rural population (compared to Fraser or Coastal Health)
- Transportation problem can be modified for redistribution with the proper manual inputs
    - Depleted hospitals that supplied during the stat order will need inventory brought back up above min level
- Redistribution avoids having to order from CBS directly and helps to avoid expiry of blood products
- Model can be applied to other blood products or hospital products or other remote locations within Canada
- MS Excel is simple and robust
    - Does not require reliable internet (manual inputs)
    - Widely used software and can be operated by all health clinics



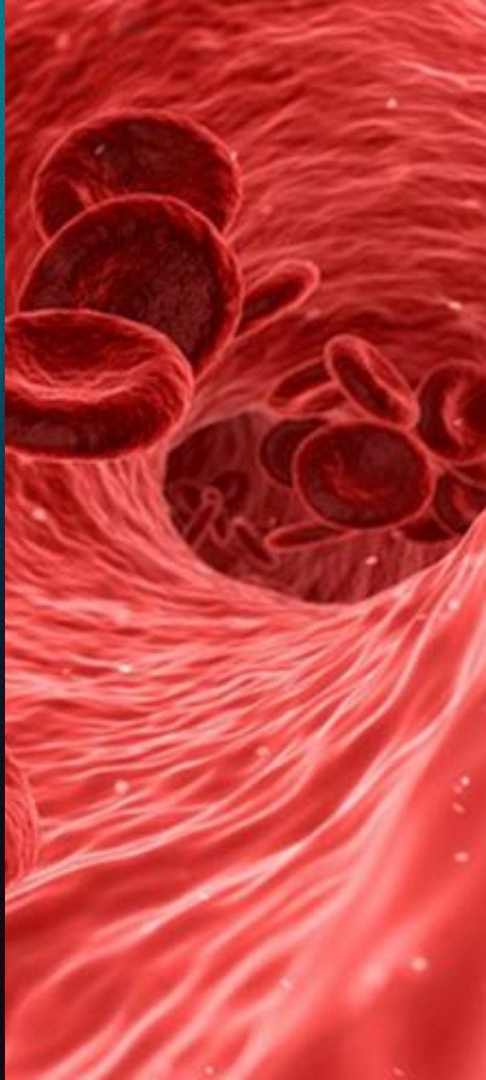
Limitations:

- Only considers ground transportation - no air
    - There may be cases where air is more efficient
- MS Excel requires manual inputs
    - Each location needs to reliably update inventory levels
    - MS Excel also limited to matrix size of 200
- Currently, model only uses estimate inventory values
    - Not actual values
- Assumed that redistribution can happen at any time in any location
    - This is often not the case, particularly for smaller rural sites where 24-hour support is not always available
    - Not every staff may be trained to package blood products correctly
- Our real-time data was collected over a short period in March
    - Did not include any heavy snow storms or weather events that could have disrupted the supply chain
    - Makes it difficult to understand how much traffic should be factored into decision making



Improvements:

- Connect estimate inventory numbers to real-time inventory for each hospital
- One-to-one method can be update to have multiple inflows and multiple outflows
- Implement machine learning to simulate distribution between hospital sites
    - Give a better understanding of actual travel times and gives a better estimate of associated costs
- Implement real-time data to transportation algorithm



Acknowledgments:

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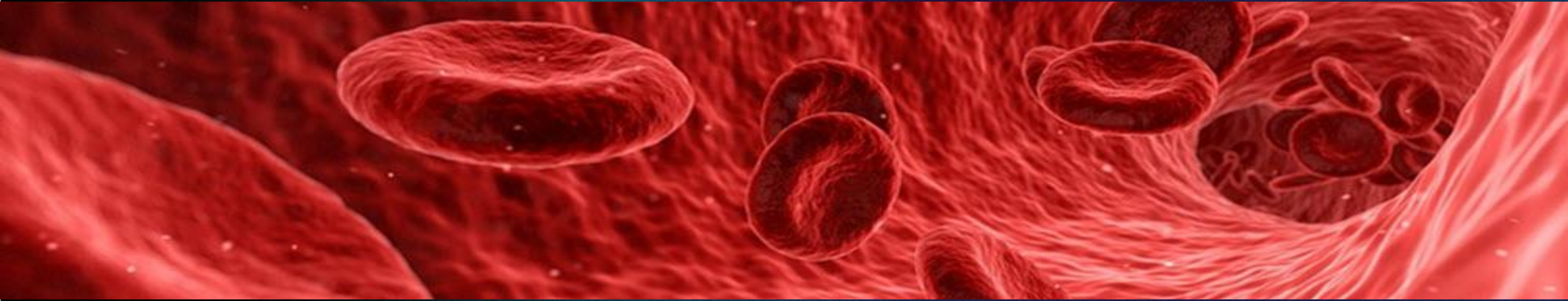
Sarah McMahon - Island Health - Technical Specialist for Transfusion Medicine
Barbara Zielke - Interior Health - Technical Specialist for Transfusion Medicine
Sandy Rutherford - Professor Math 402W SFU



Questions?