Understanding and improving global health supply chains: Analysis of USAID's global supply chain data

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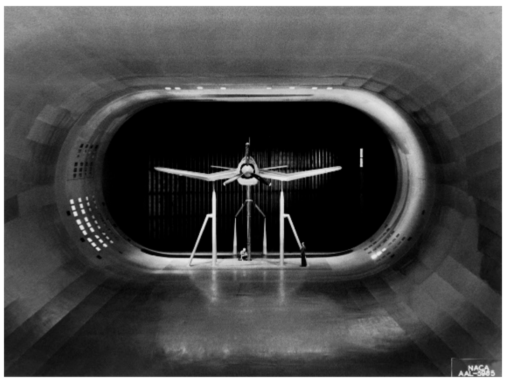
Agenda

- Goal: Use the USAID dataset to understand choices to run the supply chain
- Extract cost drivers from observed data
- Build models that preserve country level demand satisfaction
- Understand flows to costs link and mode choice
- Optimize flows to understand alternatives
- Insights for practice

Concept



Insights for improving the real world

Use estimated impact
to explore ideas for Improvement

Modeling the system
(our wind tunnel)

Build a representation
Of the system to test alternatives

Data regarding purchases, shipments, lead times, fulfillment

Used for analysis, record keeping, benchmarking, evaluation etc

Real World

Complex, challenging,
Uncertain, political ….

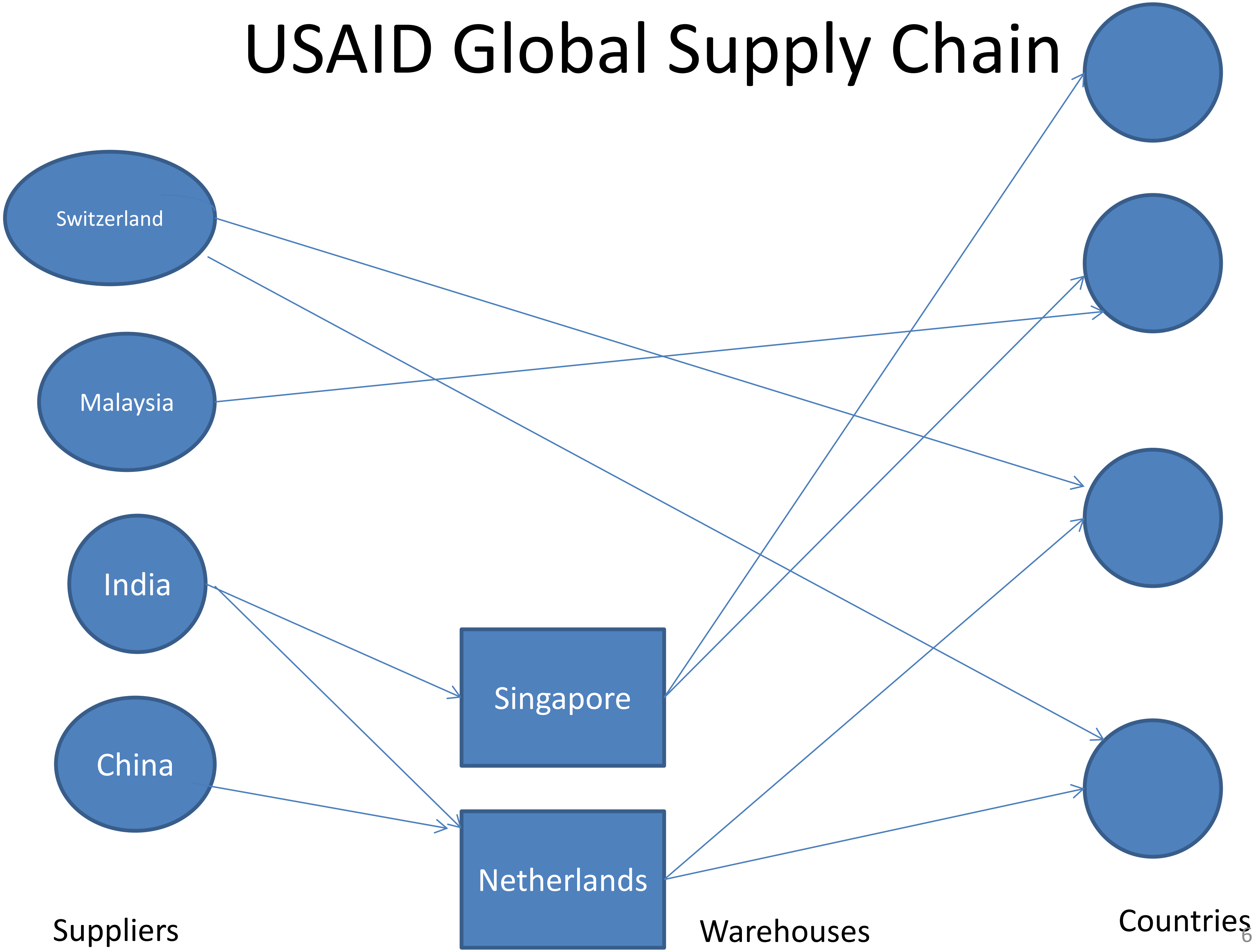
USAID data set

- We use the dataset of global flows of healthcare products within the USAID system – this dataset is provided for download at the following site
- https://www.fbo.gov/index?s=opportunity&mode=form&id=22f58fa6ed72933becc15f3c0b670d61&tab=core&_cview=1 (J9)

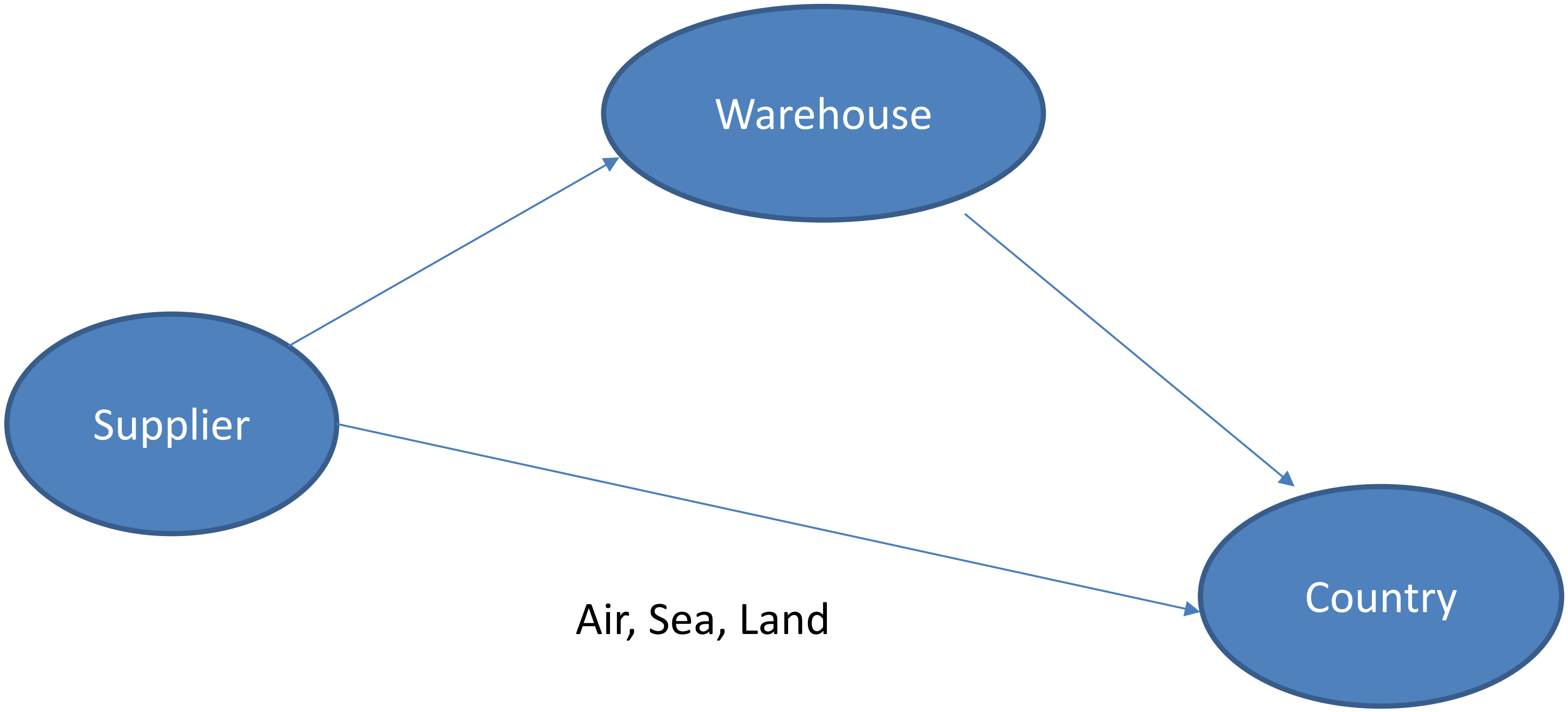
Supply Chain Data

- Purchase order tracking
- Units and associated cartons and weight by PO
- Shipment modes
- Supplier, Warehouse, Destination
- Incoterms
- **Logistics Costs - Includes transport, customs etc to deliver to destination warehouse from supplier**

USAID Global Supply Chain



Paths



Product Groups

- Malaria
- HIV/AIDS
- RH – Reproductive Health

Data summary

Row Labels	Sum of Units Received	Count of Shipments	Total Delivery Costs	
Source to Customer	312050924	422	28427627.04	63.75%
Source to Warehouse	1121881132	281	5399504.774	12.11%
Warehouse to Customer	1191624933	537	10766093.98	24.14%
Grand Total	2625556989	1240	**44593225.79**	

Data for 2011-2012.

Approximation of these flows

- Regression of delivery costs vs weight shows highest predictive power
- Adjusted lead times to reflect observed average lead time
- New costs for flows using these fitted lead times and fitted costs

Fitted Model of costs and Lead time

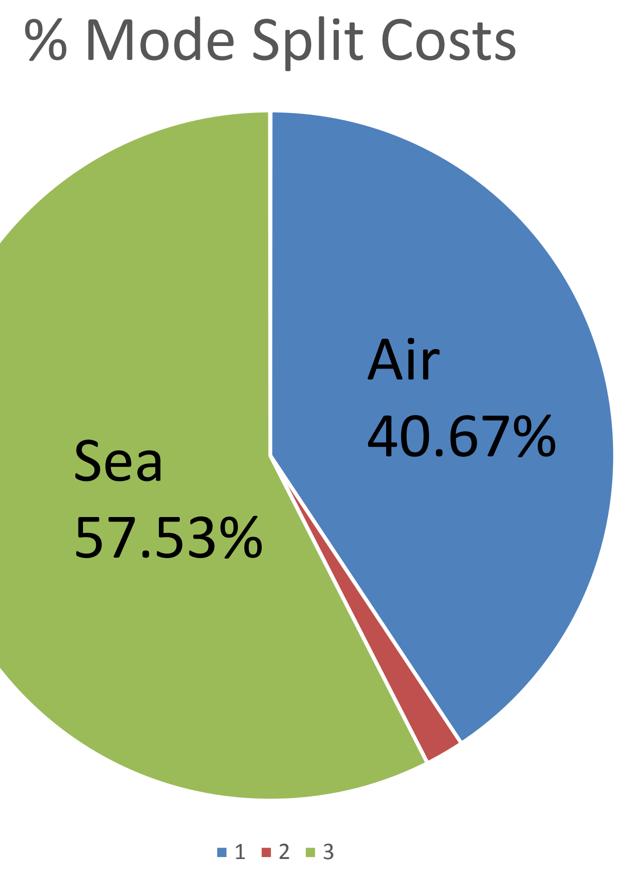
Row Labels	Sum of Units Received	Count of Shipment ID	Sum of Cost with GAMS input	
Source to Customer	312050924	422	29254616.1	62.78%
Source to Warehouse	1121881132	281	5712500.171	12.26%
Warehouse to Customer	1191624933	537	11635045.38	24.97%
Grand Total	2625556989	1240	**46602161.65**	

Overall costs in the model are 4.5% higher than original

88.1% of total warehouse units flow through warehouses

Inbound of $5.7 million, outbound of $11.6 million covers warehouse delivery costs
But the ratio of inbound and outbound shipments is about 2 – so low break bulk role …

Mode choice across all paths



Delivery Costs by destination country

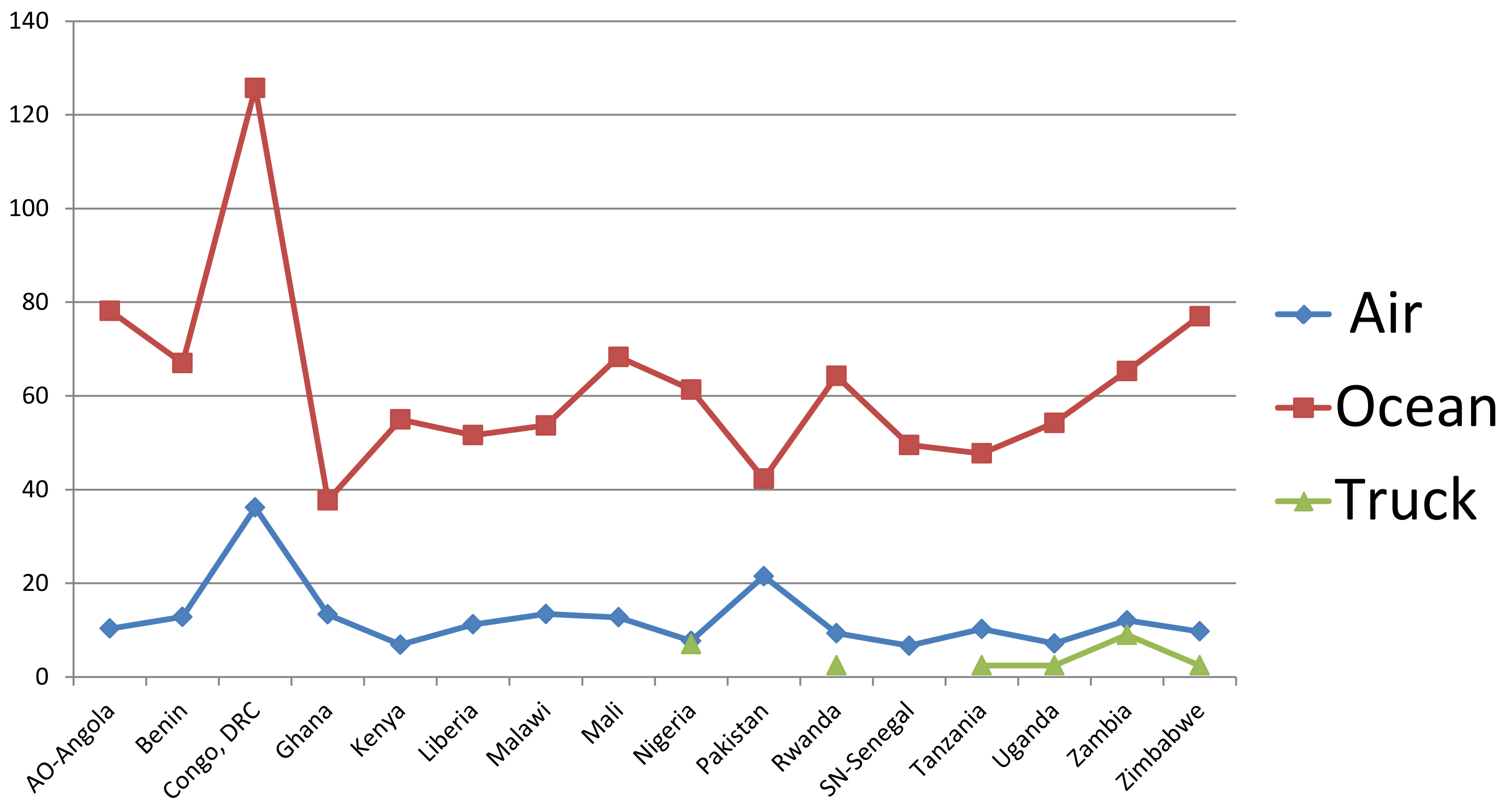
Country	Sum of Units Received	Count of Shipments	Sum of Cost with GAMS input	% of Total	Cumulative %
Angola	36018735	33	6490168.346	15.87%	15.87%
Congo, Democratic Republic of	122259422	38	4489122.551	10.98%	26.85%
Nigeria	23973926	51	2347739.796	5.74%	32.59%
Zambia	67583264	54	2304571.868	5.64%	38.23%
Malawi	9259461	37	2240937.928	5.48%	43.71%
Benin	21079337	27	1842559.955	4.51%	48.22%
Uganda	40049124	48	1769566.144	4.33%	52.54%
Mali	3542386	26	1718429.481	4.20%	56.75%
Kenya	47353327	47	1714499.484	4.19%	60.94%
Rwanda	28035440	19	1529661.212	3.74%	64.68%
Pakistan	352029100	36	1527821.237	3.74%	68.42%
Tanzania	30490843	59	1472625.497	3.60%	72.02%
Zimbabwe	159023484	34	1428839.34	3.49%	75.51%
Mozambique	19082259	36	1238042.515	3.03%	78.54%
Ghana	20809984	36	1206264.285	2.95%	81.49%
Senegal	22214396	57	1198954.419	2.93%	84.42%

16 Countries account for 85% of total costs

Product Cost Split

Row Labels	Sum of Cost with GAMS input	
Malaria	28172225.52	60.45%
HIV/AIDS	11113176.39	23.85%
RPH	7316759.738	15.70%
Grand Total	46602161.65	

Lead Time (days)



Average Air Lead time of 12.8 days,
Ocean of 62.9 days even though transit time is around 16-20 days

Questions

- Why are the warehouses in Africa (South Africa, Kenya and Ghana) not used more often?
- Why are the warehouses in Netherlands and Singapore doing so little break bulk ?
- Why are more products not shipped through the warehouses ?
- How can we get more advance planning and ordering for products if they are used steadily ?
- Why is the lead time for sea shipments so much more than air despite transit times of 16-20 days ?

Model (wind tunnel)

- Create an inventory model at each country by product so that alternate shipment choices do not impact demand satisfaction
- Maintain the number of shipments so delivery processing costs are maintained
- Track inbound and outbound in warehouses to maintain material balance
- Track costs for delivery and inventory and maintain order triggers to be consistent

- Assumed – stable demand, predictable lead times, transport costs as modeled – for first model

Mathematical Model

2.1 Parameters

I	Set of suppliers indexed by i, $i = 1, ..., I$
J	Set of candidate warehouse sites indexed by j, $j = 1, ..., J$
K	Set of countries indexed by k, $k = 1, ..., K$
P	Set of products indexed by p, $p = 1, ..., P$
M	Set of modes of transportation indexed by m, $m = 1, ..., M$
T	Set of time periods indexed by t, $t = 1, ..., T$

Table 1: Sets.

h_j	Inventory holding costs per unit at warehouse j
h_k	Inventory holding costs per unit at country k
c_{ik}^m	shipping cost per unit from supplier i to country k with mode of transportation m
c_{ij}^m	shipping cost per unit from supplier i to warehouse j with mode of transportation m
c_{jk}^m	shipping cost per unit from warehouse j to country k of product p with mode of transportation m
C_j	cost of capacity at warehouse j
C_k	cost of capacity at country k

d^t_{kp}	average demand of product p from country k at period t
n_j	total number of shipments at warehouse j throughout the planning horizon
n_k	total number of shipments at country k throughout the planning horizon
L_{ijm}	average lead time from supplier i to warehouse j with mode of transportation m
L_{ikm}	lead time from supplier i to country k with mode of transportation m
L_{jkm}	lead time from warehouse j to country k with mode of transportation m
$prod_{ip}$	1 if supplier i manufactures product p, 0 otherwise

x^t_{ikpm}	shipment quantity at period t from supplier i to country k of product p with mode of transportation m
q^t_{ijpm}	shipment quantity at period t from supplier i to warehouse j of product p with mode of transportation m
y^t_{jkpm}	shipment quantity at period t from warehouse j to country k of product p with mode of transportation m
inv^t_{jp}	inventory at warehouse j of product p at period t
inv^t_{kp}	inventory at country k of product p at period t
cap_j	maximum inventory handled during planning horizon at warehouse j
cap_k	maximum inventory handled during planning horizon at country k
n^t_{jm}	1 if at warehouse j there is a shipment of mode m at period t, 0 otherwise
n^t_{km}	1 if at country k there is a shipment of mode m at period t, 0 otherwise

Table 4: Decision variables.

$$
\begin{aligned}
min \qquad & \sum_{j\in J} h_j \sum_{t\in T}\sum_{p\in P} inv^t_{jp} + \sum_{k\in K} h_k \sum_{t\in T}\sum_{p\in P} inv^t_{kp} + \sum_{j\in J} C_j cap_j + \sum_{k\in K} C_k cap_k \\
+ \; & \sum_t \sum_p \sum_m (\sum_i \sum_k c_{ikm} x^t_{ikpm} + \sum_j \sum_k c_{jkm} y^t_{jkpm} + \sum_i \sum_j c_{ikm} q^t_{ijpm}),
\end{aligned} \tag{1}
$$

$$ \tag{2} $$

Balance constraint

$$
\sum_{t\in T}\sum_{m\in M}\sum_{i\in I} q^t_{ijpm} = \sum_{t\in T}\sum_{m\in M}\sum_{k\in K} y^t_{jkpm}, \forall j \in J, p \in P, \tag{3}
$$

Fixed shipments constraint

$$
\sum_{t\in T}\sum_{m\in M}\sum_{i\in I} \lceil \frac{\sum_{p\in P} q^t_{ijpm}}{\sum_{p\in P} q^t_{ijpm} + 1} \rceil = n_j, \forall j \in J, \tag{4}
$$

$$
\sum_{t\in T}\sum_{m\in M} (\sum_{i\in I} \lceil \frac{\sum_{p\in P} x^t_{ikpm}}{\sum_{p\in P} x^t_{ikpm} + 1} \rceil + \sum_{j\in J} \lceil \frac{\sum_{p\in P} y^t_{jkpm}}{\sum_{p\in P} y^t_{jkpm} + 1} \rceil) = n_k, \forall k \in K, \tag{5}
$$

Capacity constraints

$$\sum_{p\in P} inv_{jp}^{t} \leq cap_j, \sum_{p\in P} inv_{kp}^{t} \leq cap_k, \forall t \in T, j \in J, k \in K \tag{15}$$

Inventory constraints

$$inv_{jp}^{0} = inv_{jp}^{T}, inv_{kp}^{0} = inv_{kp}^{T}, \forall j \in J, k \in K, p \in P, \tag{16}$$

$$inv_{jp}^{t} = \sum_{m\in M}\sum_{i\in I} q_{ijpm}^{t-L_{ijpm}} + inv_{jp}^{t-1} - \sum_{m\in M}\sum_{k\in K} y_{jkpm}^{t}, \forall t \in T, j \in J, p \in P \tag{17}$$

$$inv_{kp}^{t} = \sum_{m\in M}(\sum_{i\in I} x_{ikpm}^{t-L_{ikpm}} + \sum_{j\in J} y_{jkpm}^{t-L_{jkpm}}) + inv_{kp}^{t-1} - d_{kp}^{t}, \forall i \in I, p \in P, k \in K, \tag{18}$$

Assignment supplier-product

$$\sum_{t\in T}\sum_{m\in M}(\sum_{k\in K} x_{ikpm}^{t} + \sum_{j\in J} q_{ijpm}^{t}) \leq prod_{ip}G, \forall i \in I, p \in P \tag{19}$$

Non-negativity and integrality constraints

$$x_{ikpm}^{t}, q_{ijpm}^{t}, y_{jkpm}^{t}, inv_{jp}^{t}, inv_{kp}^{t}, cap_j, cap_k \geq 0, \tag{20}$$

$$n_{jm}^{t}, n_{km}^{t} \in \{0,1\} \forall t \in T, m \in M, j \in J, k \in K. \tag{21}$$

Cost Comparison by Shipment type				
GAMS solution				
Row Labels	Sum of Total Shipments	Count of Product	Sum of Total Cost	
Source to Country	945491841.4	128	22481946.51	65.74%
Source to Warehouse	663763733	26	3876298.766	11.33%
Warehouse to Country	558226056.3	222	7839994.168	22.93%
Grand Total	2167481631	376	**34198239.44**	

Model suggested cost is $34,19 million vs original cost of $46.6 million
But how and what do we learn ?

Flows, Modes, Products

26.6 % savings possible ?

Costs by Route	Original 46.6 m	Optimized 34.19 m
Source to Country	62.78%	65.74%
Source to Warehouse	12.26%	11.33%
Warehouse to Country	24.97%	22.93%

Costs by Product Type	Original	Optimized
Malaria	60.45%	61.48%
HIV/AIDS	23.85%	22.70%
RPH	15.70%	15.83%

Country Delivery (Units)	Original	Optimized
Direct	20.75%	62.87%
Through Warehouse	79.25%	25.75%

Cost by Mode	Original	Optimized
Air	40.67%	22.37%
Land	1.80%	0.62%
Ocean	57.53%	77.01%

Ship more direct, use more ocean shipments to save costs

Product Flows

	Original	Optimized	
Malaria			25.37%
Air	54.42%	29.23%	
Land	0.29%		
Ocean	45.30%	70.77%	
HIV/AIDS			30.01%
Air	11.74%	5.03%	
Land	0.21%	0.02%	
Ocean	88.04%	94.95%	
RPH			26.03%
Air	31.68%	20.57%	
Land	10.06%	3.88%	
Ocean	58.26%	75.55%	

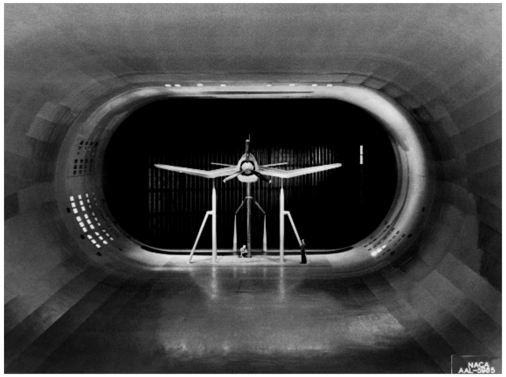
	Original	Optimized
Malaria		
Source to Country	**95.87%**	**87.03%**
Source to Warehouse	**2.01%**	**4.68%**
Warehouse to Country	**2.12%**	**8.29%**
HIV/AIDS		
Source to Country	**18.64%**	**53.33%**
Source to Warehouse	**35.61%**	**22.63%**
Warehouse to Country	**45.75%**	**24.04%**
RPH		
Source to Country	**2.38%**	**0.84%**
Source to Warehouse	**16.23%**	**20.98%**
Warehouse to Country	**81.39%**	**78.18%**

Move more Malaria direct, move more HIV and RPH through warehouse, less air usage

Intuition regarding results

- Projected potential reduction in costs of 26.6%
- Use less air shipments to decrease transport costs
- Ship more Malaria direct and less by air
- Ship more HIV/AIDS and RPH through the warehouse and less by air
- Reduced costs for all three product types by 25.3%, 30 % and 26% respectively for Malaria, HIV/AIDS and RPH
- Are these results robust ?

Question: How good is your wind tunnel in predicting actual impact ?



Robustness checks

The results remain similar if we add country holding costs – there is a shift in shipment types but similar overall cost reductions

Impact of constraining # of shipments – similar results

Impact of poor demand forecasts ?
Depends on when you know how much you need and lead time

Impact of customs clearance lead time variability – when do you know it and can you plan a buffer ?

Summary

- The question regarding how else a system can be run is common
- Available datasets reflect costs for current flows – need some way to calibrate the problem for alternatives
- Demand realizations not known, service level not known
- Choices made to run the system need to be tested by a systems model
- Should we keep adding constraints to recreate the current solution ? Should we assume the original solution is optimal ? Or should we just offer alternatives ?
- How do we get buy-in without getting people into a defensive mode ?
- Use for MBA students ?
- What is the research opportunity ?

THANK YOU

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