Supply Chain Network Optimization for International Commodity Trading

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MIT Supply Chain MANAGEMENT

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About the authors

Prior to MIT, Sebastian Abt worked in several supply chain related positions at Jungbunzlauer International, one of the world's leading producers of biodegradable ingredients of natural origin. He received his Bachelor of Science in Business Administration and his Master of Arts in Asian Studies from the University of Geneva.

Prior to MIT, German Tisera worked in financial audit and advisory at KPMG and in supply chain operational audit at LafargeHolcim, leading global construction materials company. He received his Bachelor of Science in Accounting and his Master of Business Administration, from Universidad Nacional de Cordoba.

Agenda

- Introduction
- Methodology
- Results
- Q&A

Introduction

products Python-Gurobi routes margin

supply contribution

model

Slag

customers

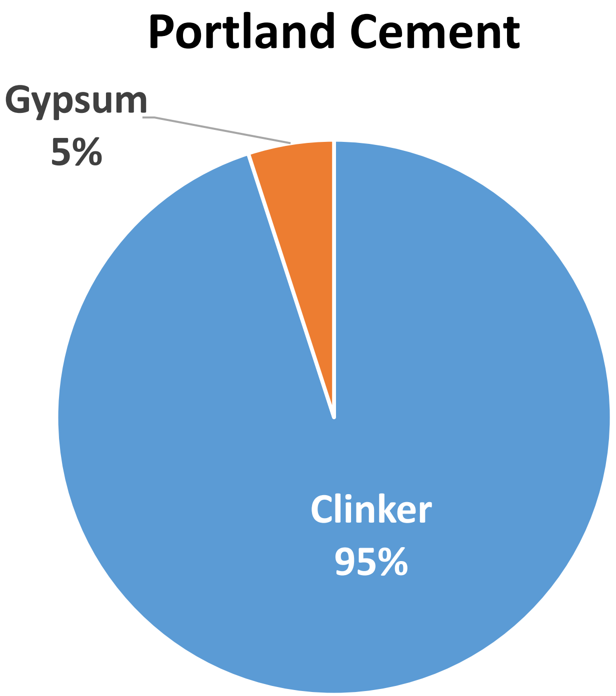
cement demand

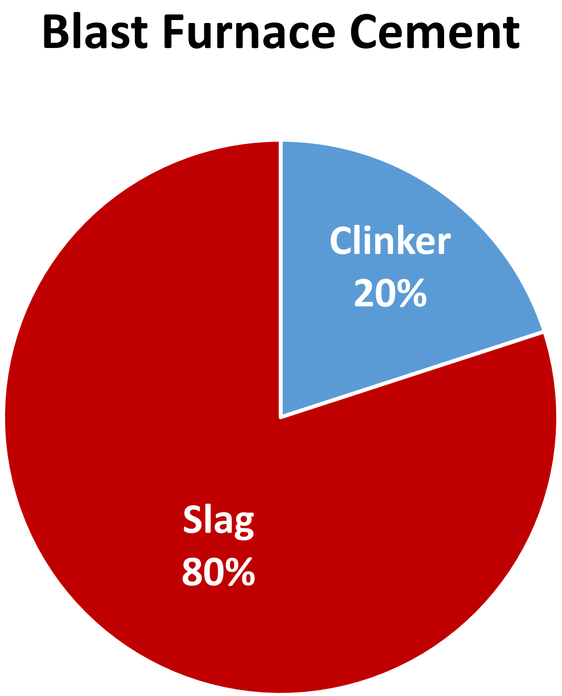
transportation optimization

vessels network incoteum

Cement types and raw material origin

Cement types:





Raw material origin:

Clinker:
Limestone quarries & kiln usage

Slag:
Byproduct of iron production

Slag in the cement industry

✓ Economical advantages

✓ Environmental advantages

✓ Resource preservation

x Increasing demand

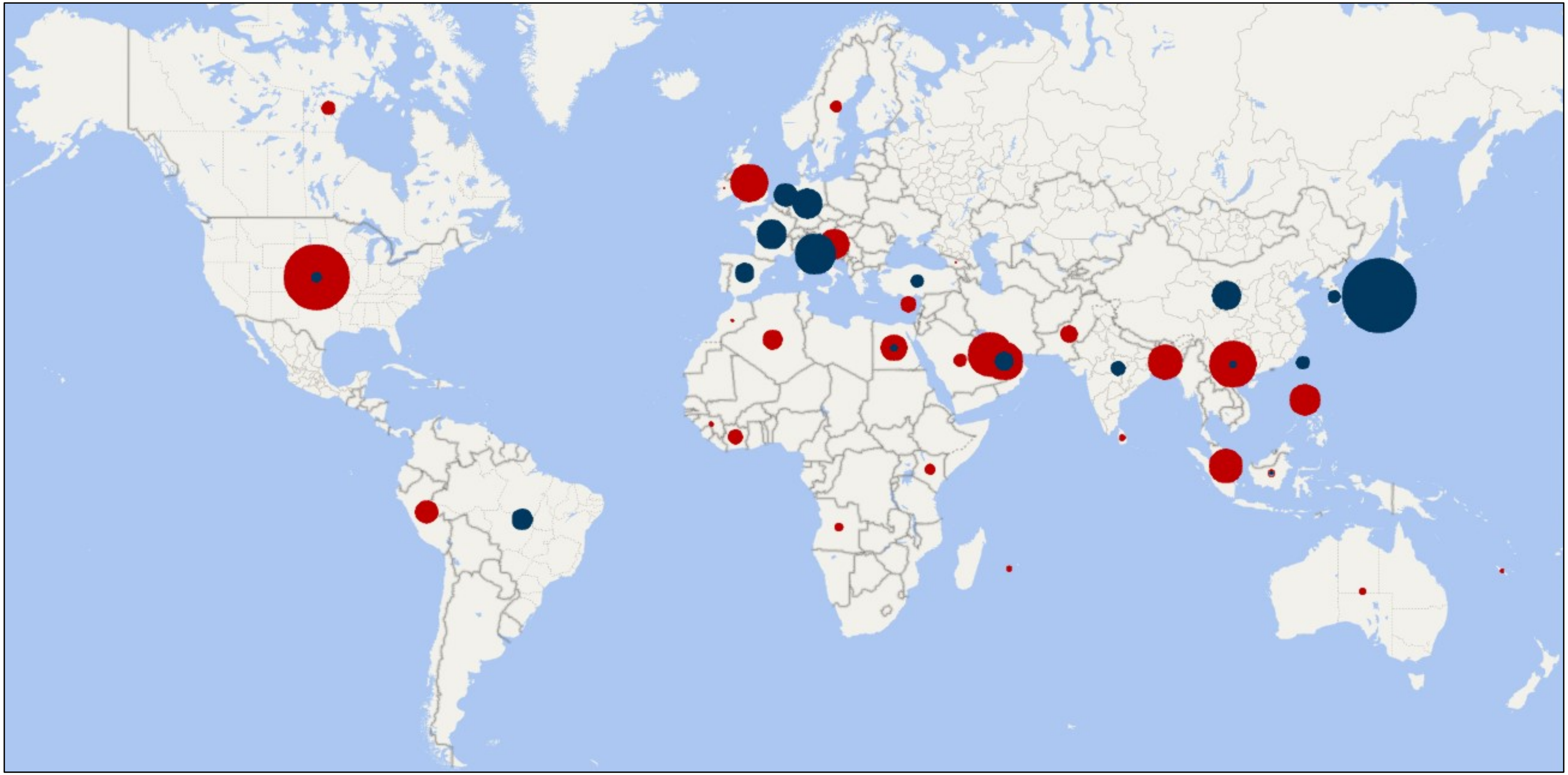
x Limited availability

x Distance between sources and destinations

The sponsor company

- The company deals only with seaborne import and export operations of cementitious materials, gypsum, solid fuels and other dry bulk goods, through a diverse network of bulk vessels
- Present in 120 countries; trading 30 million tons of cement, clinker, slag and other bulk materials (2016)
- Main sources of slag are in Asia, being Japan the most relevant one

Slag supply chain network



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Research question

- Are there opportunities to improve the current supply chain network delivering higher margins, cost efficiencies, while creating additional value to customers?

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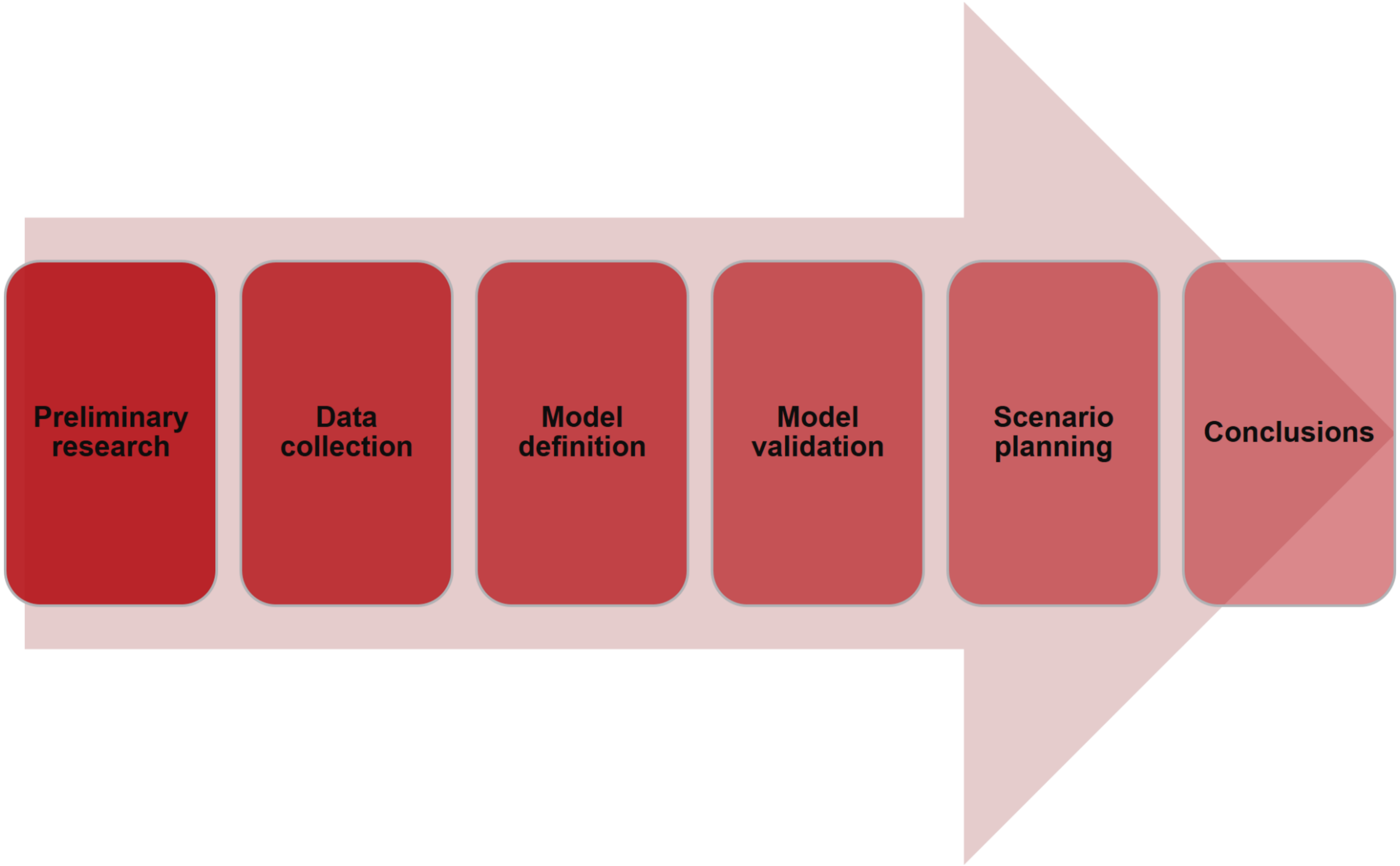
Methodology



Model formulation

OBJECTIVE to maximize the sum of contribution margins (ω) across the supply chain
HOW ? Using a Mixed Integer Linear Program (MILP)

$$max \sum_{g} \sum_{h} \sum_{i} \sum_{j} \underbrace{x_{ghij}} \; \underbrace{\omega_{ghij}}$$

- Supply nodes → 64
- Demand nodes → 47
- Products → 9
- Incoterms → 2

- Revenue (Pricing policy)
- Purchase cost
- Logistic costs
- Import costs (duties/tariffs)

Model formulation

Subject to:

- **Supply constraints:** maximum and minimum supply available at different supply nodes
- **Total demand constraints:** maximum and minimum total demand for a customer, without considering product quality
- **Specific demand constraints:** maximum and minimum specific demand for a specific product quality
- **Ship constraints:** maximum shipment capacity and the minimum shipment load linked to a type of vessel; ensuring the model only allocates complete vessels

Model developed with…

python™
- Programming language

GUROBI OPTIMIZATION
- Algorithm for optimization

pandas
$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$
- Interface Excel > Python

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Scenario analysis

- Baseline 2017
- [SC02]: Model validation
- [SC03]: New routes
- [SC04]: New routes + customer pricing
- [SC05]: CO_2 benefits
- [SC06]: Increased import duties
- [SC07]: Increased freight rates
- [SC08]: Reduction in supply

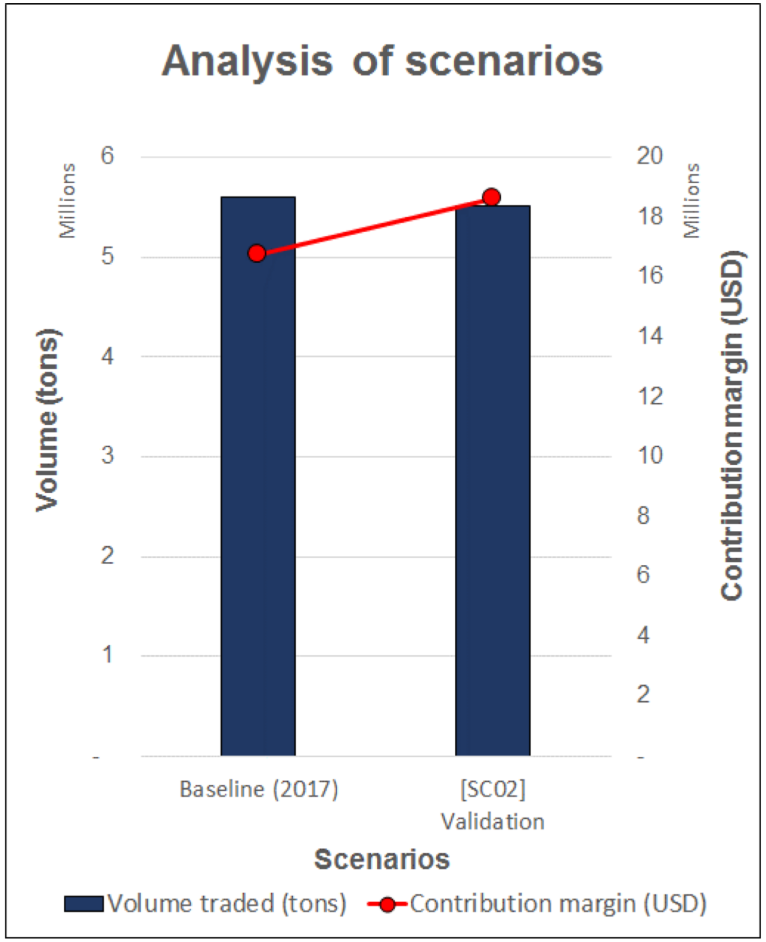
Current network optimization (SC02, SC03)

Political impact (SC05)

Risk mitigation (SC07, SC08)

[SC02]: Model validation

- Elimination of routes with negative margins.
- Release of volumes allocated to negative and low margin customers, and reallocation to customers with higher margins (CIF customers).
- The model reduces the contribution margin by $ 296,000 for FOB customers but increases the contribution margin by $ 2.15 million for CIF customers.
- Allocation of routes in the Baseline are not far from the ones allocated by the model.

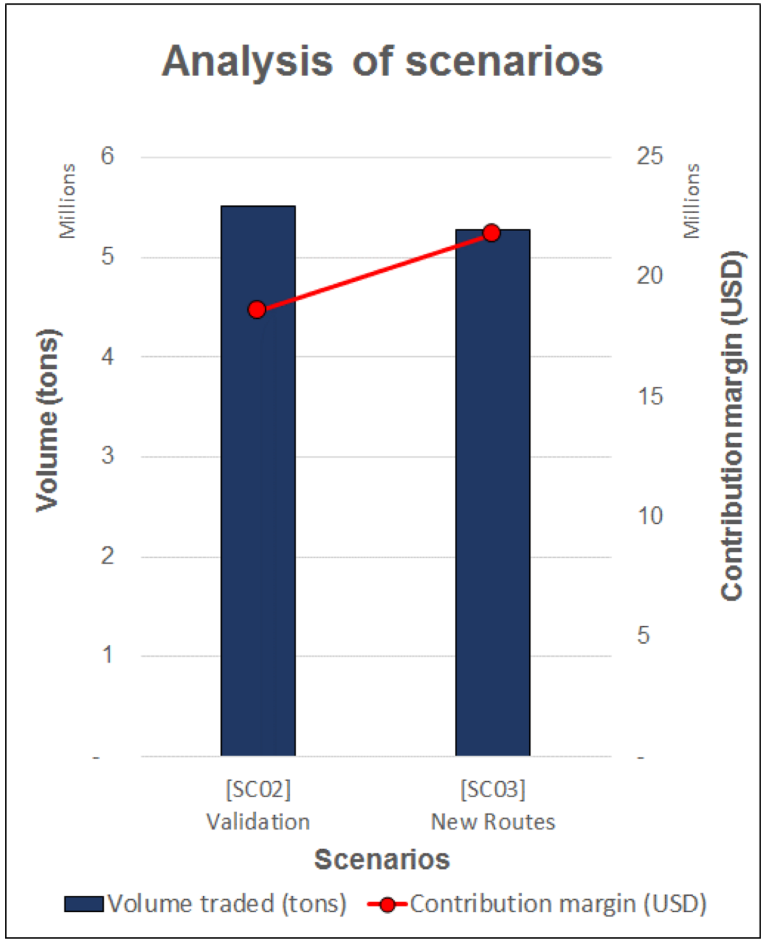


Δ Volume: -94,677 (-2%)

Δ Contribution: $ 1,855,013 (11%)

[SC03]: New routes

- From a total of 106 new routes, the optimal solution uses only 11, the most relevant being:
  - Brazil to Ivory Coast / Ghana
  - France to Croatia
  - Japan (Chiba) to Vietnam
- The solution provided by the model changes significantly.
- Total contribution increases, as new routes provide a better solution in terms of margin optimization.

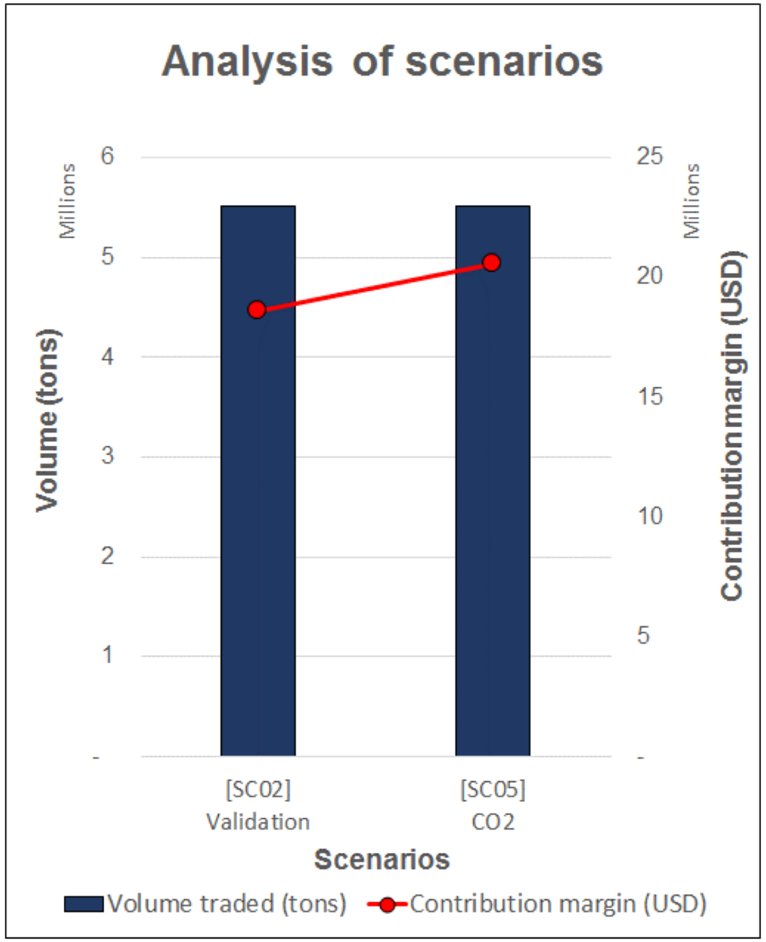


Δ Volume: -237,560 (-4%)

Δ Contribution: $ 3,203,319 (17%)

[SC05]: CO_2 benefits

- Scenario includes future CO_2 tax savings (based on Border Carbon Adjustment)
- Only physical difference: allocation of increased quantity to UK and Sweden (approx. 4,500 tons)
- Carbon taxes have a very limited effect on the optimal allocation of flows

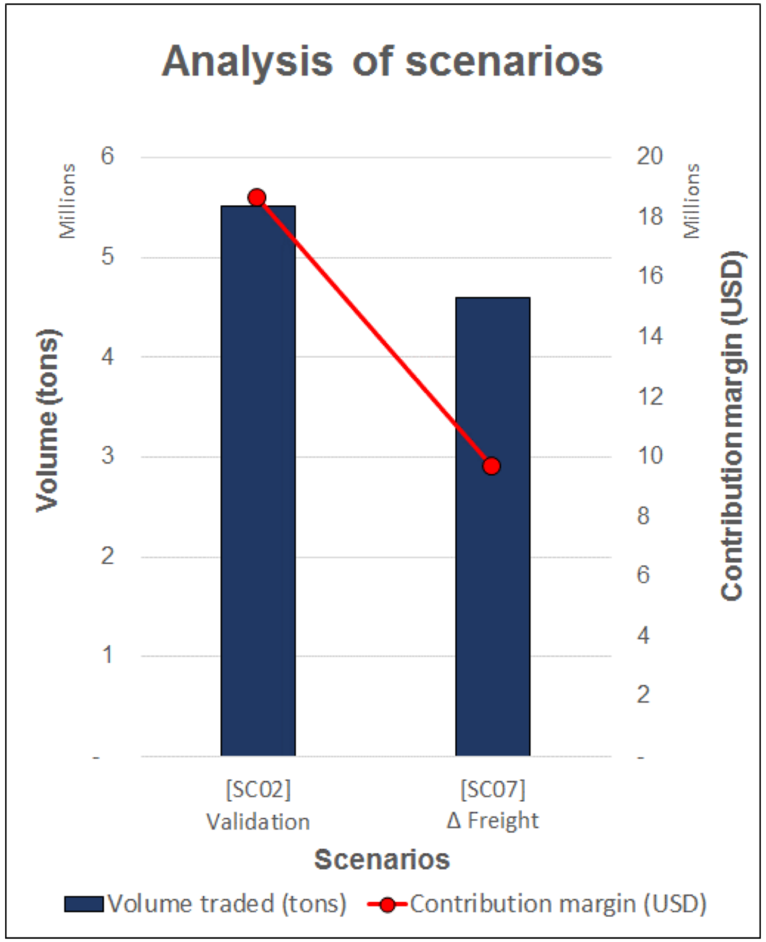


Δ Volume: -4,500 (0%)

Δ Contribution: $ 1,967,684 (11%)

[SC07]: Increased freight rates

- Transport costs increased by 20% from the baseline.
- Total contribution margin drops by $ 8.9 million (-48% vs SC02) when transport prices increase by 20%.
- The model leaves demand unattended for those customers which are far from the supply nodes:
  - Peru
  - United Arab Emirates
  - Ivory Coast
  - Ghana
- The number of profitable routes in the network reduces significantly.



Δ Volume: -909,660 (-17%)

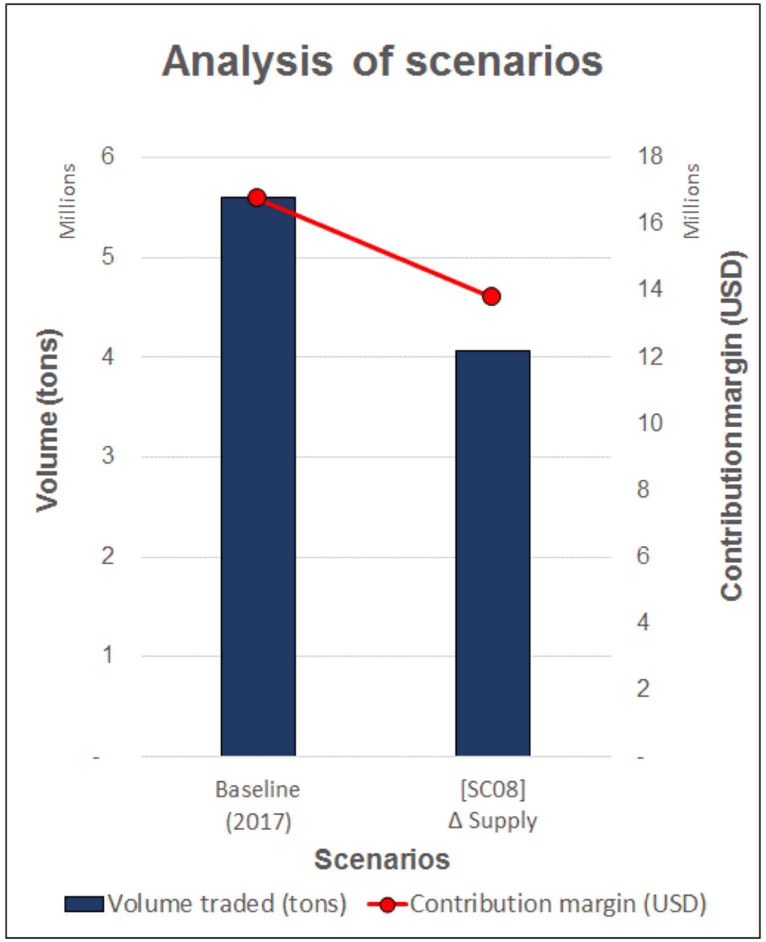
Δ Contribution: -8,963,690 (-48%)

[SC08]: Reduction in supply

- 50% availability for the main supplier (Japan).

- Customers with low margin are not sourced: (less volume traded).
  - Philippines
  - Peru
  - Vietnam
  - Egypt
  - United Arab Emirates

- The model has enough flexibility to reallocate the volumes available in the nodes to the most profitable customers, thus restricting the supply to those customers with margins below the average.



Δ Volume: -1,544,237 (-28%)

Δ Contribution: -2,961,124 (-18%)

Key takeaways

- Optimization of the current network already yields a high return, while being robust against future developments
- Pricing strategy, transportation cost, and supply/demand changes have an important impact on profitability and supply chain design, while CO_2 taxes and duties have a rather limited impact
- It is important to hedge against transport and supply/demand uncertainty by engaging in long-term contracts with strategic customers and transportation providers
- The model is a decision support tool; management needs to decide the final allocation of volumes

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Q&A

Thanks…

Backup slides

Slag production process

Backup slides

Objective function:

$$Maximize \sum_{g=1}^{n}\sum_{h=1}^{m}\sum_{i=1}^{o}\sum_{j=1}^{p} x_{ghij}\{r_{ghij} - c_{ghij} - (t_{ghij} + a_{ghij} + b_{ghij}) - d_{ghij}(c_{ghij} + t_{ghij} + a_{ghij} + b_{ghij})\}$$

Backup slides

Subject to:

$$\sum_{g=1}^{n}\sum_{j=1}^{p} x_{ghij} \leq S_{hi} \ \forall\, h,i \in \mathrm{S}$$ (maximum supply constraint)

$$\sum_{g=1}^{n}\sum_{j=1}^{p} x_{ghij} \geq W_{hi} \ \forall\, h,i \in \mathrm{W}$$ (minimum required supply constraint)

$$\sum_{h=1}^{m}\sum_{i=1}^{o} x_{ghij} \leq D_{gj} \ \forall\, g,j \in \mathrm{D}$$ (maximum total demand constraint)

$$\sum_{h=1}^{m}\sum_{i=1}^{o} x_{ghij} \geq E_{gj} \ \forall\, g,j \in \mathrm{E}$$ (minimum total demand constraints)

Backup slides

Subject to (cont.):

$$\sum_{g=1}^{n}\sum_{i=1}^{o} x_{ghij} \leq F_{hj} \; \forall \; h, j \; \in \; \mathrm{F}$$ (maximum specific demand constraint)

$$\sum_{g=1}^{n}\sum_{i=1}^{o} x_{ghij} \geq G_{hj} \; \forall \; h, j \; \in \; \mathrm{G}$$ (minimum specific demand constraint)

$$\sum_{h=1}^{m} x_{ghij} \leq \; y_{gij} \, U_{gij} \; \forall \; \mathrm{g, i}, j \; \in \; \mathrm{U}$$ (maximum capacity per ship constraint)

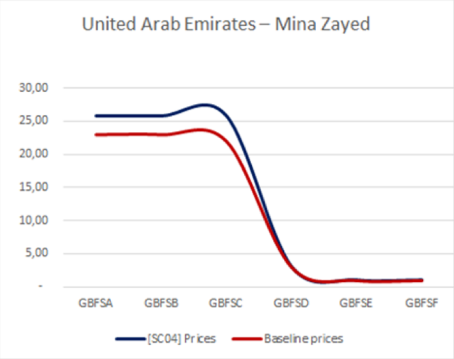
$$\sum_{h=1}^{m} x_{ghij} \geq \; y_{gij} \; \beta \; U_{gij} \; \forall \; \mathrm{g, i}, j \; \in \; \mathrm{U}$$ (minimum capacity per ship constraint)

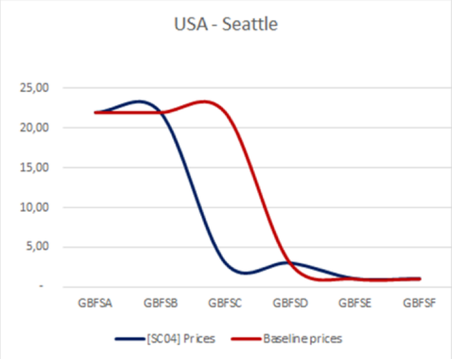
$\forall \; x_{ghij} \; \exists \; T$ (use of available routes constraint)

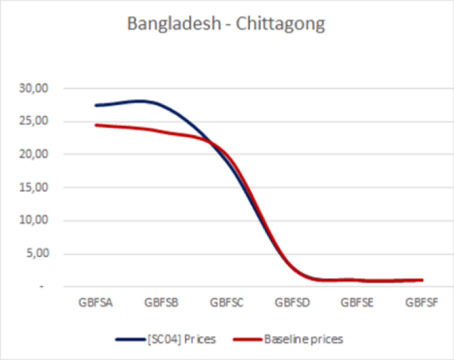
$x_{ghij} \geq 0 \; \in \; R$ (non-negativity constraint and real number)

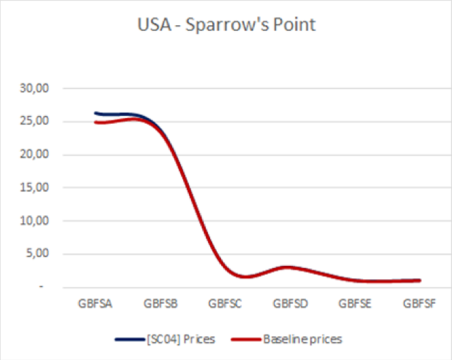
$y_{gij} \geq 0 \; \in \; Z$ (non-negativity constraint and integer number)

[SC04] – 4.3.2. New routes and value-based pricing









	Baseline* (2017)	**[SC03]**	**[SC04]**	**Difference (ABS)** [SC03] vs [SC04]	**(%)**	**Difference (ABS)** Base vs [SC4]	**(%)**
Volume traded (tons)	5,607,137	5,274,900	4,999,800	(275,100)	5%	(607,337)	-11%
Cont. margin (USD)	17,197,480	21,810,012	24,693,287	2,883,275	13%	7,495,807	44%
FOB							
Volume traded (tons)	904,817	772,100	739,100	(33,000)	-4%	(165,717)	-18%
Cont. margin (USD)	856,450	952,298	787,298	(165,000)	-17%	(69,152)	-8%
CIF							
Volume traded (tons)	4,702,320	4,502,800	4,260,700	(242,100)	-5%	(441,620)	-9%
Cont. margin (USD)	16,341,030	20,857,714	23,905,989	3,048,275	15%	7,564,959	46%
Route match rate	68%						
Mean of differences	15,609						
SD of differences	77,344						

CO_2 emission benefits

Country	Country / Region	European Union	ETS (USD/tCO2e)	CO2 Tax (USD/tCO2e)	Chosen value (USD/tCO2e)	CO2e region	savings without BCA	Savings with BCA
Austria	Austria	EU	5		5	Europe	3	1
Belgium	Belgium	EU	5		5	Europe	3	1
Bulgaria	Bulgaria	EU	5		5	Europe	3	1
Canada	Alberta		23	15	23	North America***	21	4
Canada	British Columbia			23	23	North America***	21	4
Canada	Ontario		14		14	North America***	13	3
Canada	Quebec		14		14	North America***	13	3
Chile	Chile			5	5	South America*	3	1
China	Beijing		8		8	China	6	1
China	Chongqing		1		1	China	1	0
China	Fujian		5		5	China	3	1
China	Guangdong		2		2	China	1	0
China	Hubei		2		2	China	1	0
China	Shanghai		6		6	China	4	1
China	Shenzhen		5		5	China	3	1
China	Tianjin		2		2	China	1	0
Colombia	Colombia			5	5	South America*	3	1
Croatia	Croatia	EU	5		5	Europe	3	1
Cyprus	Cyprus	EU	5		5	Europe	3	1
Czech Republic	Czech Republic	EU	5		5	Europe	3	1
Denmark	Denmark	EU	5	25	25	Europe	17	3
Estonia	Estonia	EU	5	2	5	Europe	3	1
Finland	Finland	EU	5	66	66	Europe	45	9
France	France	EU	5	33	33	Europe	23	5
Germany	Germany	EU	5		5	Europe	3	1
Greece	Greece	EU	5		5	Europe	3	1
Hungary	Hungary	EU	5		5	Europe	3	1
Iceland	Iceland			11	11	Europe	8	2
Ireland	Ireland	EU	5	21	21	Europe	14	3
Italy	Italy	EU	5		5	Europe	3	1
Japan	Japan			3	3	Japan, Australia, NZ	2	0
Japan	Saitama		13		13	Japan, Australia, NZ	10	2
Latvia	Latvia	EU	5	5	5	Europe	3	1
Liechtenstein	Liechtenstein			84	84	Europe	58	12
Lithuania	Lithuania	EU	5		5	Europe	3	1
Luxembourg	Luxembourg	EU	5		5	Europe	3	1
Malta	Malta	EU	5		5	Europe	3	1
Mexico	Mexico		1	3	3	Central America*	2	0
Netherlands	Netherlands	EU	5		5	Europe	3	1
New Zealand	New Zealand		12		12	Japan, Australia, NZ	9	2
Norway	Norway		3	52	52	Europe	36	7
Poland	Poland	EU	5	1	5	Europe	3	1
Portugal	Portugal	EU	5	7	7	Europe	5	1
Romania	Romania	EU	5		5	Europe	3	1
Slovakia	Slovakia	EU	5		5	Europe	3	1
Slovenia	Slovenia	EU	5	18	18	Europe	12	2
South Korea	South Korea		18		18	Asia**	14	3
Spain	Spain	EU	5		5	Europe	3	1
Sweden	Sweden	EU	5	126	126	Europe	87	17
Switzerland	Switzerland		6	84	84	Europe	58	12
United Kingdom	United Kingdom	EU		22	22	Europe	15	3
Ukraine	Ukraine			1	1	Europe	1	0
USA	California		14		14	North America***	13	3
USA	Connecticut		3		3	North America***	3	1
USA	Delaware		3		3	North America***	3	1
USA	Maine		3		3	North America***	3	1
USA	Maryland		3		3	North America***	3	1
USA	Massachusetts		3		3	North America***	3	1
USA	New Hampshire		3		3	North America***	3	1
USA	New York		3		3	North America***	3	1
USA	Rhode Island		3		3	North America***	3	1
USA	Vermont		3		3	North America***	3	1

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[SC06] – increased Duties

Countries / Regions	Current duties	New duties	Remarks
Brazil	4%	8%	BRIC - increased threat to USA
South Korea	2%	4%	Assumed general "low" duties for geopolitical partnership
China	0%	15%	Economic rival
India	0%	8%	BRIC - increased threat to USA
Rest Asia	0%	4%	Assumed general "low" duties for geopolitical partnership
Middle East & Turkey	0%	4%	Assumed general "low" duties for geopolitical partnership

	Baseline* (2017)	[SC06]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,607,137	5,512,460	(94,677)	-2%
Contribution margin (USD)	16,751,680	18,606,693	1,855,013	11%
FOB				
Volume traded (tons)	904,817	873,440	(31,377)	-3%
Contribution margin (USD)	856,449	559,955	(296,495)	-35%
CIF				
Volume traded (tons)	4,702,320	4,639,020	(63,300)	-1%
Contribution margin (USD)	15,895,230	18,046,737	2,151,507	14%
Route match rate	77%			
Mean of differences	937			
SD of differences	59,513			

*Baseline quantities using margins from [SC06] for comparability.

Summary of scenarios