Supply Chain Network Optimization for Global Distribution of Cementitious Materials

By Hans Josef Sebastian Abt & Germán Daniel Tisera
Advisor: Dr. Josué C. Velázquez-Martinez
Topic Area(s): Optimization, Supply Chain Planning, Resilience

Summary: This research focuses on a supply chain network optimization model for global distribution of slag. Companies trading cementitious materials face an increasingly volatile economic environment and continuous challenges to ensure the availability of strategic raw materials. Therefore, the ability to globally source slag represents a competitive advantage for companies. We developed a Mixed Integer Linear Program (MILP) to find solutions that maximize total contribution margin for a global trading company. Our research shows opportunities to increase contribution margin by 11% through an optimized allocation of existing volumes in the current network. Scenario-planning techniques indicates that prices and transport costs are the main determining factors for the company's profitability, while duties/tariffs and CO_2 taxes only play a minor role.

Prior to MIT, Hans Josef 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.

KEY INSIGHTS

1. Yearly optimization of existing networks can already yield strongly improved results.
2. CO_2 taxes and duties have limited effect on commodity networks, while prices, transport costs, demand and supply patterns have the strongest influence on profitability.
3. Hence, trading companies should opt for risk hedging activities, limiting volatility of transport cost, price and demand.

Introduction

The cement industry is the backbone of any economy. No major infrastructure would be possible without this product. Hence, global cement companies rely on well-established supply chain networks and sourcing strategies to secure strategic raw materials. Slag represents both an opportunity and a threat for cement companies. An opportunity because more stringent environmental regulations are currently affecting clinker production, leaving slag as the most environmentally-friendly solution in the cement production process. A threat because increasing demand and lower levels of production have pushed prices up and contributed to increased competition in the market to secure long-term provision.

In this context, the sponsor company deals with seaborne import and export operations of cementitious materials and other dry bulk goods, through a global network of suppliers and customers (see Figure 1). The company employs different strategies to optimize contribution margin on each transaction. However, the expectation is that the company can obtain higher margins by optimizing the network for a whole year, instead of focusing on single shipments.

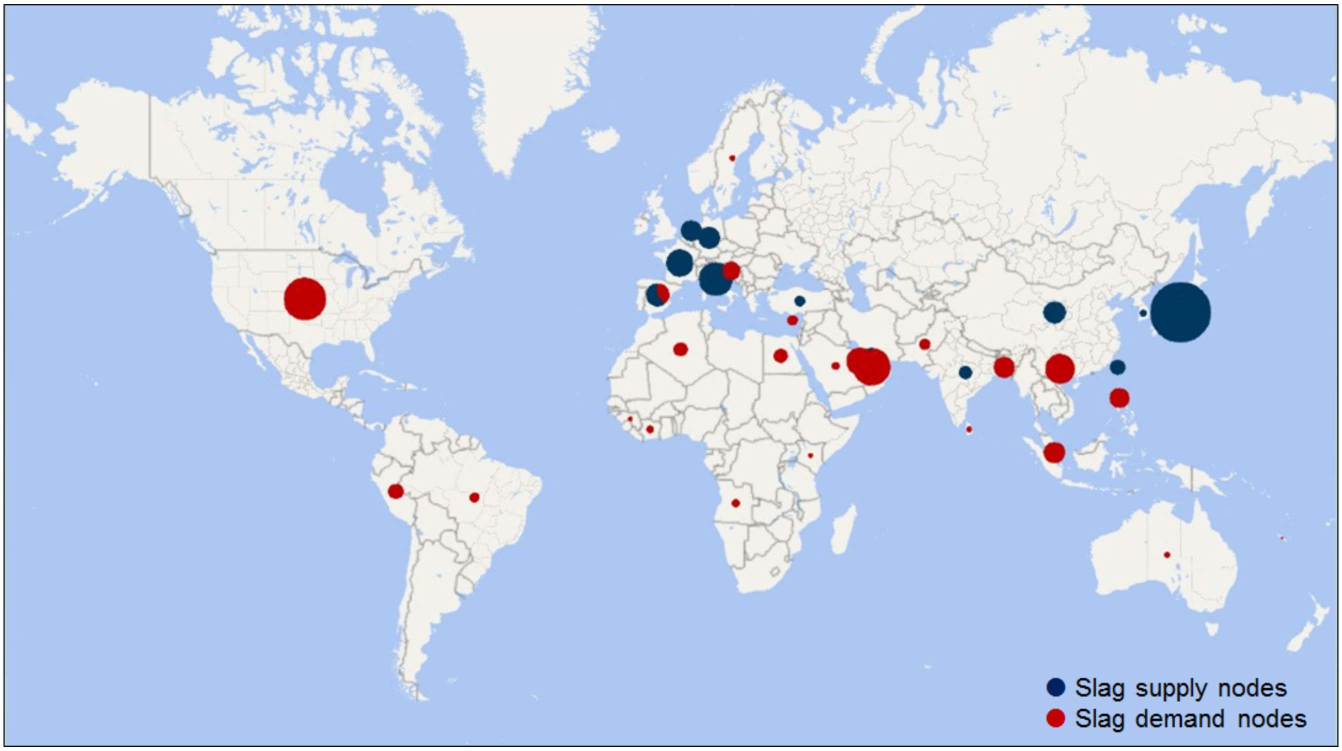

Figure 1 – Slag supply chain network

Therefore, we introduce an optimization model to support management decision-making through a Mixed Integer Linear Program (MILP) to find solutions that maximize total contribution margin. This is complemented by scenario planning to determine the parameters which have the strongest impact on the profitability of the firm.

Methodology

We approached the research problem following a 6-step methodology:

- Process understanding
- Data collection
- Model definition
- Model validation
- Scenario planning and sensitivity analysis.
- Draw conclusions

Model Formulation

The model is an example of a transportation problem, this type of model being a subset of the minimum cost flow problem. This kind of model is defined by a number of supply nodes, demand nodes and variable costs related to the transportation between the nodes. Constraints are represented by the maximum amount of supply available and the minimum demand to source. It is important to note that if a problem has the constraints given above and is a maximization problem, like our formulation, then it still can be considered a transportation problem.

Our model uses the following variables:

- The flow of product from a source to a customer using a specific incoterm (x_{ghij})
- The number of full shipments from a source to a customer using a specific incoterm (y_{gij}).

This last variable is an auxiliary variable to ensure that the model allocates only fully loaded ships.

Next, we define the objective function of our model. Our goal is to maximize the total contribution margin defined as the difference between:

- Revenues: defined as the price paid by the customer and the proportional tax savings from CO_2 emissions.
- Costs: including the FOB price of the product, transport costs, other logistic costs, insurance and import duties.

We define four sets of constraints:

- Supply constraints: maximum and minimum supply available at the different sources.

- Total demand constraints: maximum and minimum total demand for a customer, without considering product quality.
- Specific demand constraints: maximum and minimum specific demand per product quality for a specific product type. This input provides the range in which the model combines products with different qualities to achieve the minimum total demand required by the customer for a specific product type.
- Ship constraints: maximum shipment capacity linked to a type of vessel available for a certain route, and the minimum shipment load under normal conditions of operation.

The objective function is then solved following the parameters and constraints described above. The model is implemented in Python 3.6 and uses Gurobi Optimizer 7.5.2 for the optimization.

Results

In Table 1 we present the results for the seven scenarios that we use to validate the outcome of the model and to perform sensitivity analysis.

In our base scenario [SC02] we validate the model using actual data observed during 2017 and comparing the simulation with the baseline.

In [SC03], we evaluate the impact of new routes on the total margin. [SC04] uses the same new routes but introduces value-based pricing for specific customers. The impact of carbon tax benefits is evaluated in [SC05]. [SC06] and [SC07] evaluate the impact of increased import duties/tariffs in different countries and increased freight rates, respectively. Finally, in [SC08], we paint a scenario where the main supplier for slag only has 50% of its supply available.

In [SC02], we increase the contribution margin by USD 1.85 million (11%), while reducing volume traded by 95,000 tons. This is possible because the model eliminates routes with negative margins and supplies the minimum amount of demand (80%) for unprofitable customers. As FOB customers are generally less profitable, the model also moves volume from FOB customers to CIF. Overall, route match rate is high (82%), so the current network design is not far from the optimized scenario.

With the inclusion of new routes in [SC03], the model increases the contribution margin by USD 5.06 million (30%), compared to the baseline while reducing volume traded by 332,000 tons. While we add new profitable trading routes, we raise the number of possible arcs in the model, increasing the potential to find a better optimal solution.

In [SC04], with the inclusion of new routes and value-based pricing assumptions, the model reallocates volumes to customers with higher margins, increasing contribution by USD 2.8 million (13%), compared to [SC03], while decreasing volume traded by 275,100 tons.

The inclusion of carbon tax benefits ([SC05]) did not yield a major difference between [SC05] and [SC02]. Only 4,500 tons were allocated differently in comparison to [SC02]. This implies that other parameters have a stronger impact on allocation rather than the carbon tax benefit.

	Baseline (2017)	[SC02]	[SC03]	[SC04]	[SC05]	[SC06]	[SC07]	[SC08]
Total								
Volume traded (tons)	5,607,137	5,512,460	5,274,900	4,999,800	5,516,960	5,512,460	4,602,800	4,062,900
Contribution margin (USD)	16,751,680	18,606,693	21,810,012	24,693,287	20,574,377	18,606,693	9,643,003	13,790,556
FOB								
Volume traded (tons)	904,817	873,440	772,100	739,100	877,940	873,440	739,100	882,860
Contribution margin (USD)	856,450	559,955	952,298	787,298	1,608,755	559,955	788,415	547,301
CIF								
Volume traded (tons)	4,702,320	4,639,020	4,502,800	4,260,700	4,639,020	4,639,020	3,863,700	3,180,040
Contribution margin (USD)	15,895,230	18,046,738	20,857,714	23,905,989	18,965,622	18,046,738	8,854,588	13,243,255

Table 1 - Analysis of results for different scenarios

A similar picture can be drawn in [SC06]. Increased duties/tariffs do not modify the optimal routes in comparison to [SC02].

On the other hand, increased freight rates have a distinctive impact: total contribution margin drops by USD 8.9 million (-48%) compared to the baseline when transport prices increase by 20%. Even though route match rate is high (74%), the optimization model leaves demand unattended for those customers which are far from the source nodes.

The effect of a reduction in the supply from the main supplier ([SC08]) reduces contribution margins by USD 2.96 million (18%), while reducing volume traded by 1.54 million tons. Route match rate is low (65%), as the optimization model leaves demand unattended for those customers with lower margins.

Conclusion

The different scenarios show that the optimization of the current network can yield a high return ([SC02]), while being already robust against future developments, such an introduction of higher duties/tariffs ([SC06]) or carbon taxes ([SC05]).

The addition of new routes ([SC03]) and a value-based pricing strategy ([SC04]) plays an important role in the design of the supply chain; as does increased transportation costs. In [SC07], the 20% increase in transportation costs leads to a decrease of approximately 48% of total contribution margin. Increased transportation cost impacts as well the network design as the model avoids allocating additional volumes to customers that are far from supply nodes. This is an issue for strategic customers located far from sources of slag. Hence, this tool makes a suggestion about the best allocation of products, but management needs to decide the final allocation of quantities. The same decisions have to be taken for [SC08], where slag availability is limited, and the model only allocates product to most profitable customers.

In Figure 2 we present a comparative overview of the results of our model.

The different scenarios showed that pricing strategy, transportation cost, and supply/demand changes have an important impact on the sponsor company's profitability and supply chain design, while CO_2 taxes and duties have a rather limited impact. This implies that it is important to hedge against transport and supply/demand uncertainty by engaging in long-term contracts with strategic customers and transportation providers.

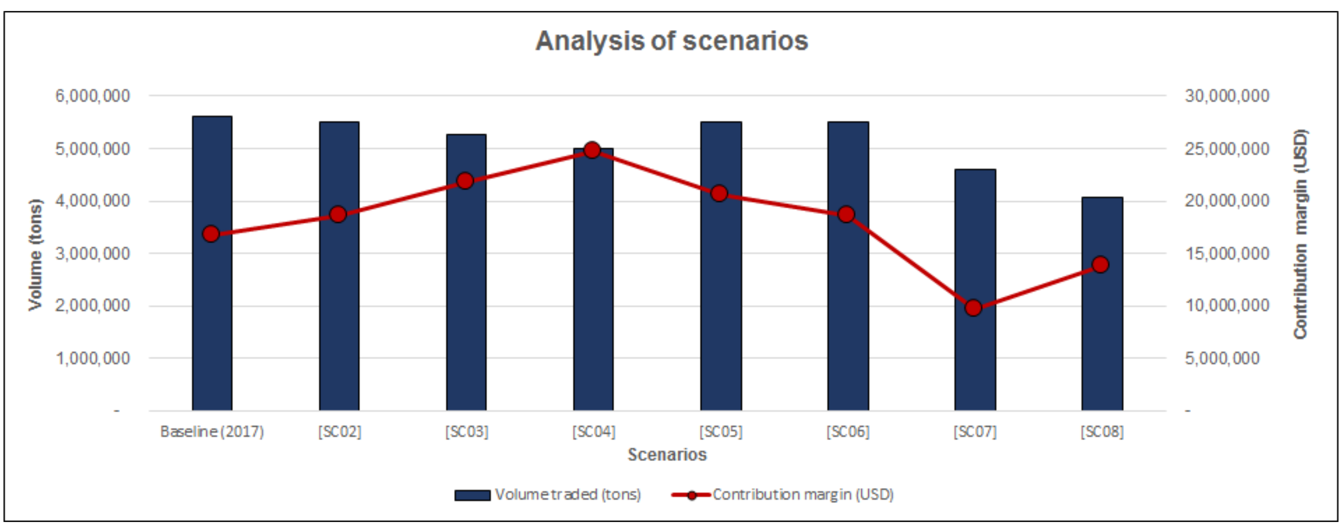

Figure 2 – Comparative results of volume and contribution for different scenarios.