The Greening of a Large Urban Distribution Network

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Abstract

Alquería (Productos Naturales de la Sabana S.A.S.) is one of the most influential business organizations in the Colombian dairy market. Founded in 1959, it manufactures and distributes dairy products and beverages through a supply chain network composed of 7 processing plants and 15 distribution centers.

Competitive pressures and the need to reduce costs led to a review of the company's distribution network in Bogotá, Colombia's capital city plagued by traffic congestion and environmental challenges. Motivated by Alquerías's strong corporate commitment to sustainability, balancing fiscal and environmental objectives became the driving force of the study and the evaluation of alternative network options.

A mathematical programming-based model was implemented to optimize and compare the various network configurations, and minimizing total CO_2 emissions replaced total costs as the model's optimization objective. In this paper, we describe the methodology applied to formulate the network model and derive its coefficients.

The results have been very rewarding. A redesigned configuration that combines a brand new distribution center and a pair of cross docks will have a very positive impact on overall network profitability while at the same time reducing total CO_2 emissions by over 30%.

KEYWORDS

Carbon footprint, Distribution network design, Sustainability, Supply chain optimization, Green supply chains

1. Introduction

The scope and dimension of food distribution systems supplying urban areas are proportional to their size and population. These systems contribute to traffic congestion and environmental problems and are also seriously affected by them.

We would be hard-pressed to find a better example than Bogotá, the capital of Colombia. In its 2019 annual rankings of the most congested cities in the world, the transportation data firm INRIX Research ranks Bogotá as the third most congested city in the world, and the worst in terms of total hours per year lost in congestion. "Global Traffic Scorecard", (INRIX, 2019).

The redesign of distribution networks in large, highly congested urban areas such as Bogotá has to balance business and environmental factors to be truly successful. Against this backdrop, the combined Technologix Decision Sciences - SDI Systems consulting team undertook the challenging task of redesigning Alquería's Bogotá area distribution network.

Alquería is the third-largest producer and marketer of dairy products in Colombia. The Bogotá and surrounding areas represent 40% of total national demand. On average, 12 million liters of dairy products are consumed monthly, supplied by roughly 145 fixed routes servicing 45,000 customer destinations daily.

The Bogotá region distribution operation was being handled by the main plant warehouse in Cajicá (35 km from downtown Bogotá) and two distribution facilities in the metropolitan area: a main distribution center in the North (Calle 80) and a small cross-dock operation in the South (Cedi Sur). At the time of this study, out of the 145 daily routes 14 were being serviced out of Cajicá, 108 out of Calle80 and the remaining 22 out of the Cedi Sur cross-dock facility.

The purpose of this project was to evaluate a set of network configuration options and identify the alternative that would minimize total operating costs. For this study, the composition of each route had to be considered fixed.

In Alquería's case, each route is contracted out to individual trucking firms under distinctive financial terms. These terms are not necessarily consistent across all routes nor directly related to the distance/time travelled. Under these circumstances, it would be practically impossible to apply the classic, cost-driven network modelling approach commonly applied in these situations.

We opted instead to focus on the optimization of total CO_2 emissions, a welcome approach for an organization so committed to sustainability and the environment at large.

Emissions are directly proportional to the distance travelled, and the hypothesis was that a reduction in total distances travelled would eventually be reflected in renegotiated contracts under more attractive terms. Furthermore, emissions are also a function of the type/size of cargo vehicles, allowing us to evaluate the impact of transferring products in large vehicles from the plant warehouse to other facilities to shorten the distance travelled by the actual route.

Distances were calculated holistically, measuring them from the starting point of the driver's journey to his return at the end of the day (see Figure 1 below), instead of only measuring from the originating facility (warehouse or cross-dock).

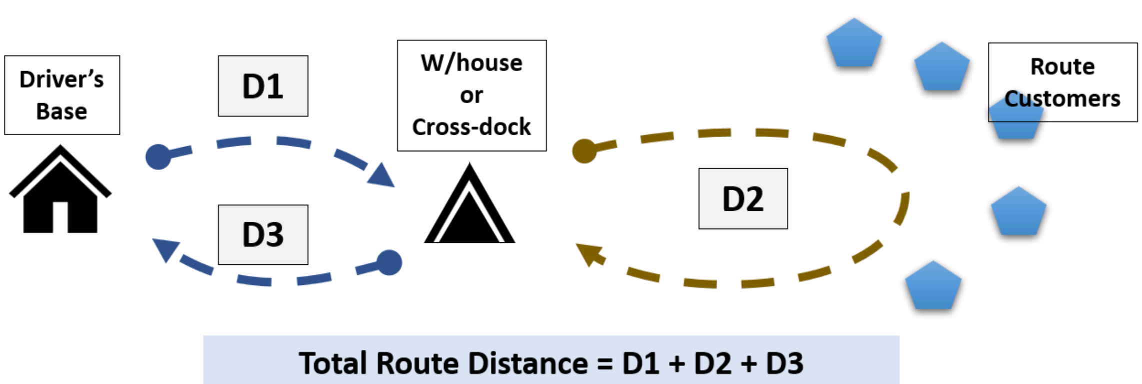

Figure 1: Calculation of total route distances

2. Literature Review

The growing importance of environmental issues and sustainability has motivated an extensive body of research on new approaches that factor CO2 emissions in the modeling, design and optimization of supply chains and urban distribution networks. Zang, P. et al (2019) present a literature review on carbon-constrained operations models, while Memari, A. et al. (2016) and Eskandarpour, M. (2015) offer a comprehensive literature review on the extensive research work done to date on green supply chain design and related topics. In their paper, Elhedhli, S., Merrick, R. (2012) present a green supply chain design optimization model that incorporates the cost of carbon emissions into the objective function.

There are few references to studies such as the one presented in this article in which the composition of routes in an urban distribution network are restricted by contractual relations with transport providers. Similarly, the method applied to calculate total route distances (see Figure 1 above) differs from the more traditional approach of measuring from the originating warehouse or cross-dock location (D2 in Figure 1 above).

The complexity of urban transportation in Bogotá, Colombia, has been well documented. It is considered the city with the worst vehicular congestion in Latin America by the "Global Traffic Scorecard". (INRIX, 2019). Mittal et al (2018) point out that improving the utilization of vehicles is a major contributor to CO_2 emission reductions. The use of cross-docks in urban areas is known to improve the utilization and efficiency of the fleet, therefore contributing to the goal of reducing emissions.

3. Methods and Procedures

Once the decision was made to optimize emissions there were several logical and conceptual 'how's' that had to be resolved before the operation could be modelled and analyzed:

a) How to define and model demand
b) How to calculate the distance travelled by each route
c) How to estimate emissions
d) How to calculate emissions for all feasible facility-route combinations
e) How to capture all of this in a tidy network model

a) How to define and model demand
Alquería's is a classic milk-run operation (in their case both logistically and physically!) where every route runs daily and stops at each customer destination.

Since the composition of each route in this study was fixed, we saw no added value in explicitly modeling all 45,000 individual customer destinations. Instead, we aggregated demand for each route (j), defining a singular demand point with the following parameters:

DEM (j) = Σ dem (i), ∀ i ε(j)
LAT/LONG COORDINATES (j) = Σ [lat/long (i) * dem (i)] / DEM (j)
Where:
DEM (j) = Average daily demand for route (j)
dem (i) = average daily demand for stop (i) in route (j)
Lat/long (i) = latitude or longitude coordinate for stop (i) in route (j)

b) How to calculate the total distance travelled by each route
As depicted in Figure 1 above, the total distance travelled by each route is composed of three segments:
- ✓ D1 - The empty trip from the driver's base to the loading facility
- ✓ D2 - The distance travelled to customers and back to the loading facility
- ✓ D3 - The empty trip from the loading facility back to the driver's base

Calculating D1 and D3 (D1=D3)
- ✓ We know the lat/long coordinates for each driver's base location
- ✓ We know the lat/long coordinates for every facility in the network

- ✓ We use the sets of location information above to extract driving distance estimates for every feasible route/facility combination (with the help of the Google Maps function in batch mode)

Calculating D2

- ✓ We know the lat/long coordinates for every facility in the network
- ✓ We calculated the lat/long coordinates for every route's demand point (LAT/LONG COORDINATES (j))
- ✓ We use the sets of location information above to extract driving distance estimates for every feasible route/facility combination (with the help of the Google Maps function in batch mode)

In all calculations, true road distance estimates (not 'straight lines') were applied.

c) How to estimate total emissions

Jason Mathers (2015) describes two approaches to estimate total CO_2 emissions from a truck move:

- ✓ Based on the vehicle type, its cargo weight and the distance travelled
- ✓ Based on the vehicle type and distance travelled

Given that in our study a complete trip is composed of both loaded and empty miles we opted for the second, more generic approach. The calculations are as follows:

Estimated CO_2 Emissions = D x EF
Where:
D – Distance travelled
EF – Mode-specific emissions factor

Information on mode-specific emissions factors are generated by several sources, including the U.S. Environmental Protection Agency (EPA), the Instituto Mexicano de Transporte (2014) and EDF's Green Freight Handbook.

d) How to calculate total emissions for a specific route

The total emissions estimate for any given Alquería route needs to factor two components:

- ✓ EmT2 - The estimated emissions generated directly by the route itself
- ✓ EmT1 - The estimated emissions generated by the transfer of the route's volumes from the plant warehouse (Cajicá) to the originating facility for that route

To calculate the EmT2 component, we multiply the emissions factor for that truck type by the total route distance as described in (b) above. For the EmT1 component we assign to the route its share of total transfer emissions based on weight.

Based on the type of vehicles servicing the Bogotá region, we applied the following mode-specific emissions factors in the calculations:

- ✓ EmT2 (3.5 to 7.5 tons capacity) = 690 grams of CO2 per km
- ✓ EmT1 (25 to 30 tons capacity) = 900 grams of CO2 per km

Example:

EmT2: Direct Route Emissions

- ✓ Total distance travelled = 70 km
- ✓ Total CO_2 Emissions = 70 km x 690 grams CO_2 per km = 52.5 kg of CO_2 = 0.0525 tons CO_2

EmT1: Transfer Related Emissions

- ✓ Distance from plant warehouse to facility = 30 km
- ✓ Average size of transfer load = 25 tons
- ✓ Estimated emissions per transfer load = 30 km x 900 grams of CO_2 per km
  = 27,000 grams CO_2 = 0.027 tons CO_2
- ✓ Average daily route volume = 8 tons
- ✓ Ratio of route to total transfer volume = 8 / 25 = 0.32
- ✓ Route share of total transfer emissions = 0.32 x 0.027 = 0.00864 tons CO_2

Total estimated emissions for route = 0.0525 + 0.00864 = 0.06114 tons CO_2

Figure 2 below summarizes the logic and describes the flow of parameters and calculations:

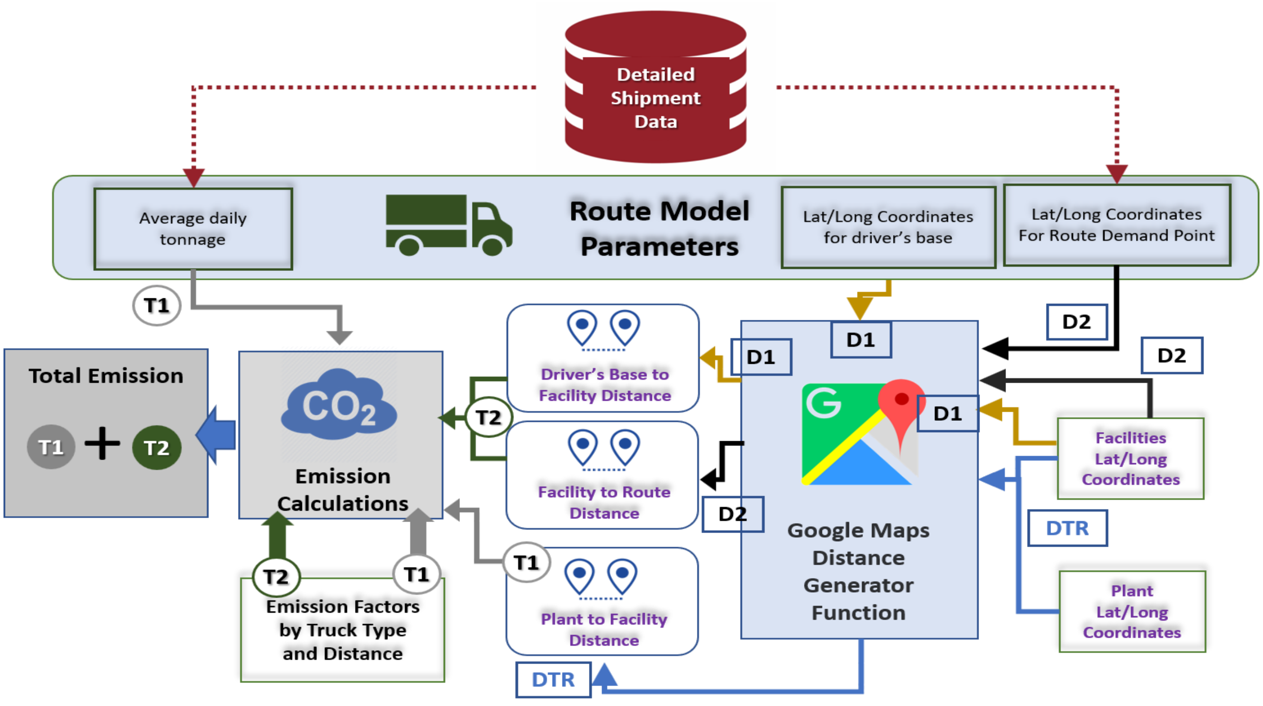

Figure 2: Summary of logic and calculations

D1	Driver's base to facility distance calculation	**D2**	Facility to route demand point distance calculation
T1	EmT1 - Transfer-related estimated emissions	**T2**	EmT2 - Route-related estimated emissions
DTR	Plant warehouse to facility distance calculation		

e) How to capture all of this in a tidy network model

We implemented a customized mathematical programming-based network model using **Opti-Net™**, Technologix's supply chain network optimization platform.

For a set of pre-defined configurations, the model allocated routes to sources to minimize total system emissions, subject to capacity and flow restrictions. The resulting emissions for each scenario were weighed against projected fixed and operating costs to help identify the best course of action. We defined and ran a total of 14 different scenarios, all of them sharing the same design principle of the plant warehouse feeding a main distribution center closer to the metropolitan area and a number of cross-dock facilities strategically located.

4. Experimental/Numerical Setting

Following is a summary of the external data and parameters used in this study as well as the coefficients calculated to feed the various scenarios:

Input data

- ✓ Detailed daily shipments by customer and product
- ✓ Customer lat/long coordinates
- ✓ Route composition
- ✓ Drivers' base lat/long coordinates
- ✓ Facility data: lat/long coordinates, capacity restrictions, etc.

Calculated data and model coefficients

- ✓ Aggregated route parameters (demand, lat/long coordinates)
- ✓ Distances (between facilities, from facilities to routes, from driver's base to facilities)
- ✓ Total estimated emissions for each feasible [facility – route] combination

5. Results and Discussion

As part of this project, we ran three sets of scenarios: Base case, optimized base case and new network configurations.

The base case scenario models the existing configuration and related flows. Its resulting total emissions level served as a baseline value against which we compared all other scenarios.

The optimized base case scenario looks for ways to improve the allocation of routes to depots under the existing configuration and restrictions. The 8% reduction in total emissions that we identified represent the 'quick hits' of this study –immediate benefits generated by short-term adjustments to flows.

The new network configuration scenarios we analyzed were built around 5 potential sites for a new main distribution center replacing the existing one at Calle 80, combined with two new cross-dock locations in the southern area of the city.

One of the 5 potential new sites combined with the cross docks reduced total emissions by 33%. The other 4 were all at the 25% mark. Figure 3 below summarizes total emission estimates for the most relevant scenarios.

Figure 3: Total Daily CO_2 Emissions (Tons)

6. Future Research

There are two areas where future research seems warranted: Optimizing the composition of routes and refining the calculation of emissions estimates.

In this study, the composition of each route was considered a fixed input. With such a large urban operation comprised of thousands of customer destinations, we see an opportunity to further reduce the total distance travelled and emissions (and hence operating costs) by evaluating and dynamically optimizing the composition of routes.

7. Acknowledgements

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