# Network Design Model for Fuel Retail

by

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MIT Supply Chain
MANAGEMENT

MIT GLOBAL
SCALE NETWORK

## Company and problem

Sponsor company: small chain of fuel stations in Brazil

- Revenue in 2017: US$ 10M
- Company owns its own fleet
- Intention to expand: Where to place new stations?

Fuel market:

- Low profit margins (2-3%)
- Price-sensitive customers
- Significant transportation costs

Research question: Can we add competitiveness and profitability to a fuel retailer's expansion strategy by modeling the entire SC Network?

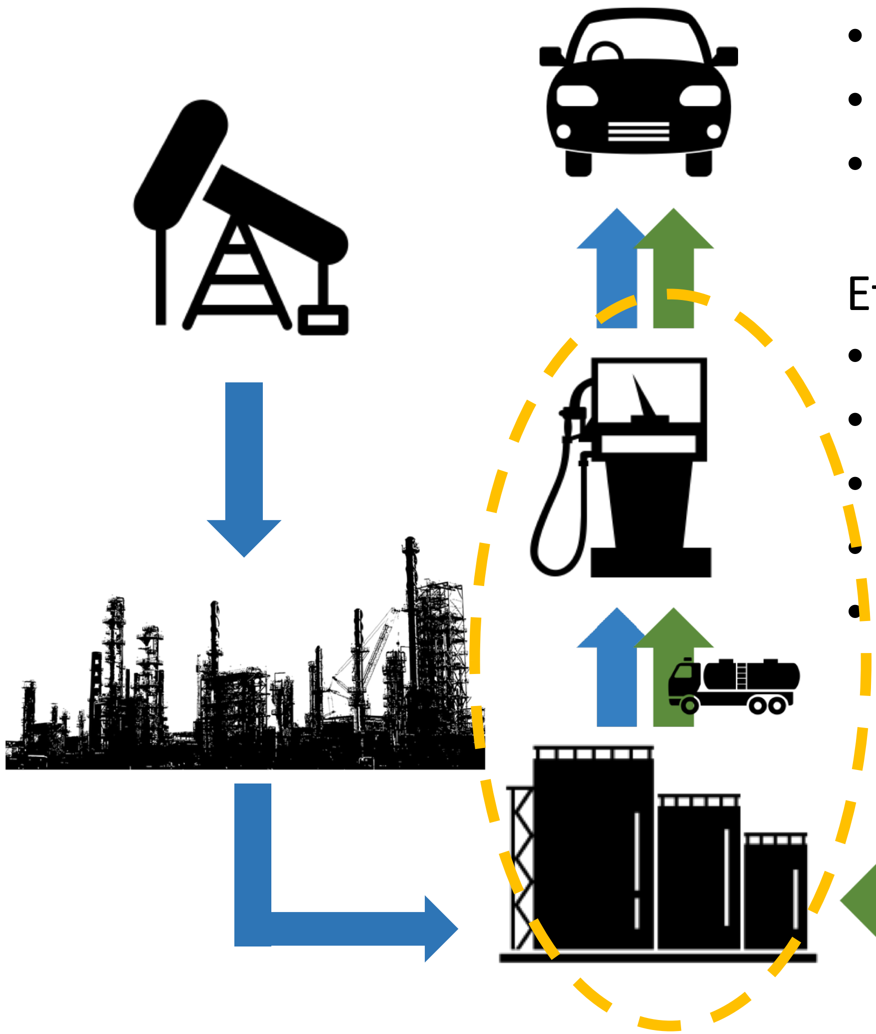


# Network Design Model for Fuel Retail



## Fuel Supply Chain

Gasoline and diesel:

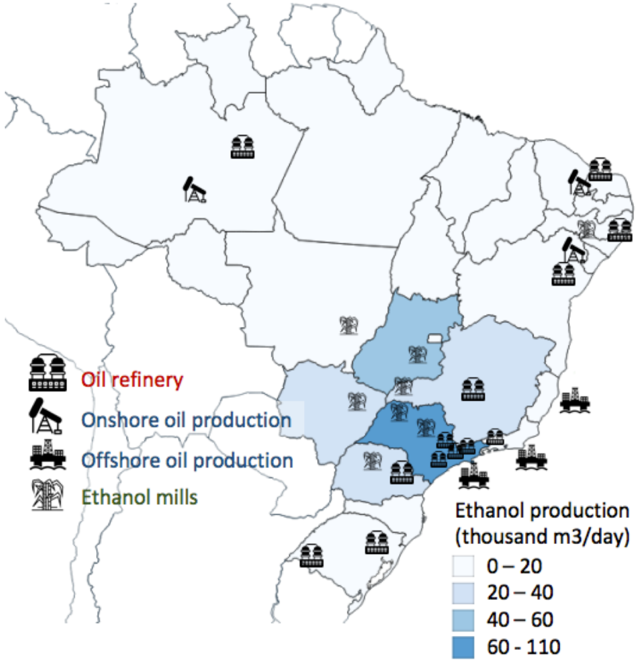


Ethanol in US:

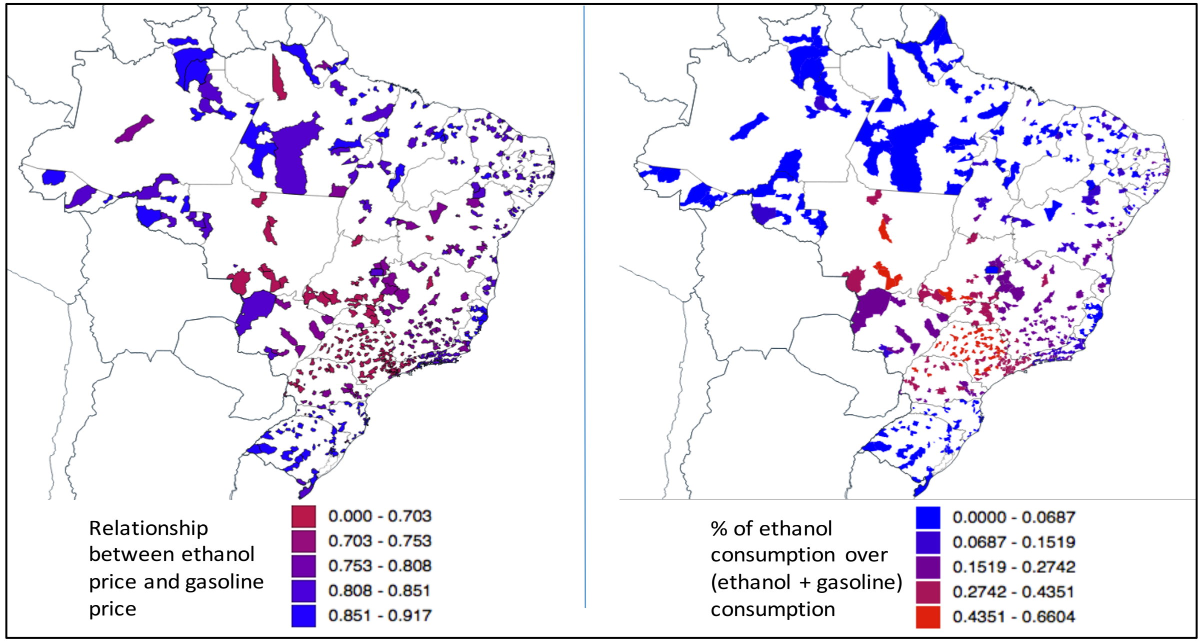
- Requires subsidizing
- Dirtier than coal
- Very few vehicles and stations

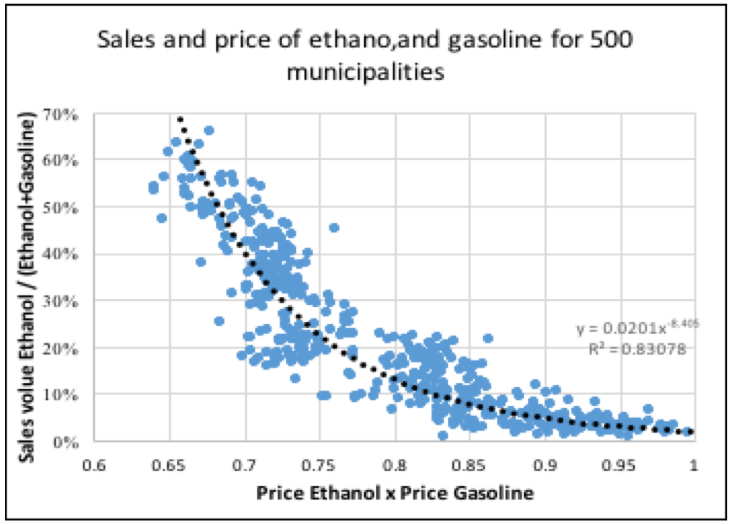
Ethanol in Brazil:

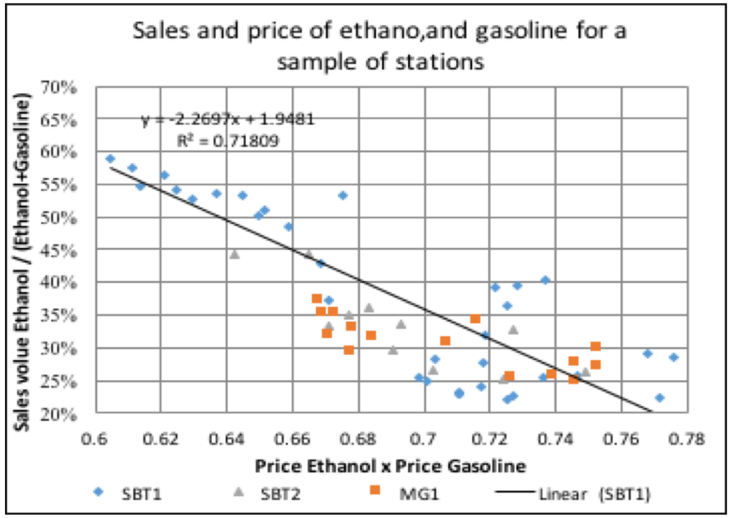
- Competitive against gasoline
- Cleanest fuel massively used
- Compatible with 90% of cars
- Present in 100% of stations
- Interesting multi-commodity network optimization problem




## Ethanol and gasoline prices and sales volumes




- Ethanol and petrol fuels are produced in different regions: Production, prices and consumption are geographically correlated;
- Transportation between distributors and retail stations are done by road;
- RENOVA-BIO project in Brazil may increase demand by 40%

# Network Design Model for Fuel Retail

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## Model formulation

**Data from public sources:**

> Monthly fuel prices (retail and wholesale) at each city
> Year-by-year consumption of fuels at each city
> Population and GDP data for each city.
> Inflation data.

anp Agência Nacional do Petróleo

**Assumptions:**

> Total sales volume similar for stations
> Facility costs per month proportional to city GDP/capita

**Monte Carlo simulations**

**Data from company:**

> Price of all fuels, day-by-day, since 2013.
> Cost of fuel purchased from distributors.
> Sales volume of each fuel at each day.
> Financial data and expenses.
> Fleet specification

AUTO POSTO SBT

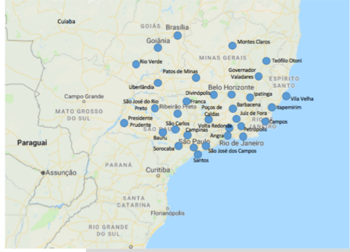
> Fuel retail price for each node
> Fuel wholesale price for each node
> Sales volume per month per station per fuel
> Facility fixed costs per month

Multi-commodity Network Design Model

python

M.I.L.P

GUROBI OPTIMIZATION



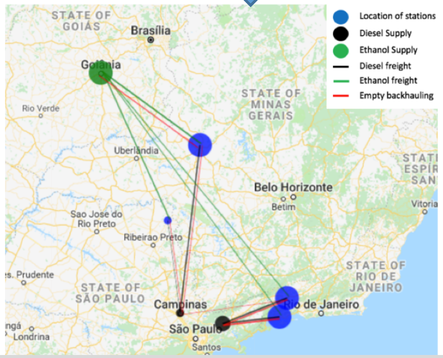
Google Maps API

**Routes and topographies between nodes**

Fuel Consumption Model

MATLAB

**Route costs**




**Optimum design for maximum profit:**

> Number of stations per node
> Supply sources and routes

## Model formulation

Objective function:

$$Max\ Profit = \sum_{ijk} T_{ijk} \times R_{jk} \times V - \sum_{ijk} T_{ijk} \times W_{ijk} \times V - \sum_{ijk} T_{ijk} \times c_{ijk} - \sum_{j} f_j \times S_j$$

(Revenue; Cost of Goods Sold (COGS); Cost of transportation; Cost of facilities)

s.t.

$$\sum_{i} T_{ijk} < D_{jk} \quad \forall\, j,k$$

(Demand constraint)

$$\sum_{j} T_{ij} = \sum_{j} T_{ji}$$

(Conservation of trucks)

$$S_j \in \mathbb{N},\ T_{ijk} \in \mathbb{Z} > 0$$

$$S_j < SM_j$$

$$\sum_{j} S_j < SM$$

(Maximum number of facilities)

Where:

$T_{ijk}$ = Number of cargo runs carrying product k from node i to node j (decision variable)

$R_{jk}$ = Retail price of product k at station located in node j

V = Volume carried by tanker truck

$W_{ijk}$ = Wholesale price of product k at distributor in i to destination j

$c_{ijk}$ = Transport cost for moving with cargo k from i to j

$f_j$ = Fixed monthly cost for a station located in node j

$S_j$ = number of stations in node j (decision variable)

$t_{jk}$ = Tax rate over product k at node j

$D_{jk}$ = Demand for product k per station at node j

$SM_j$ = Number of maximum allowed stations at node j

SM = Number of maximum allowed stations overall

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Agência Nacional do Petróleo

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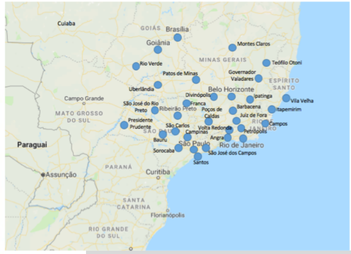
Multi-commodity Network Design Model

M.I.L.P



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Routes and topographies between nodes

Fuel Consumption Model

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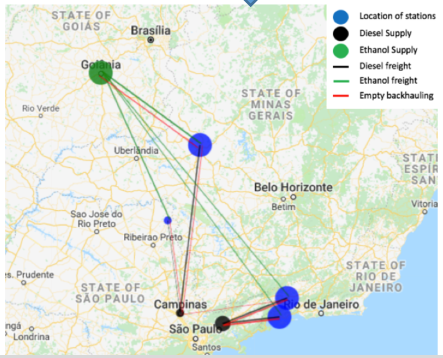
Route costs

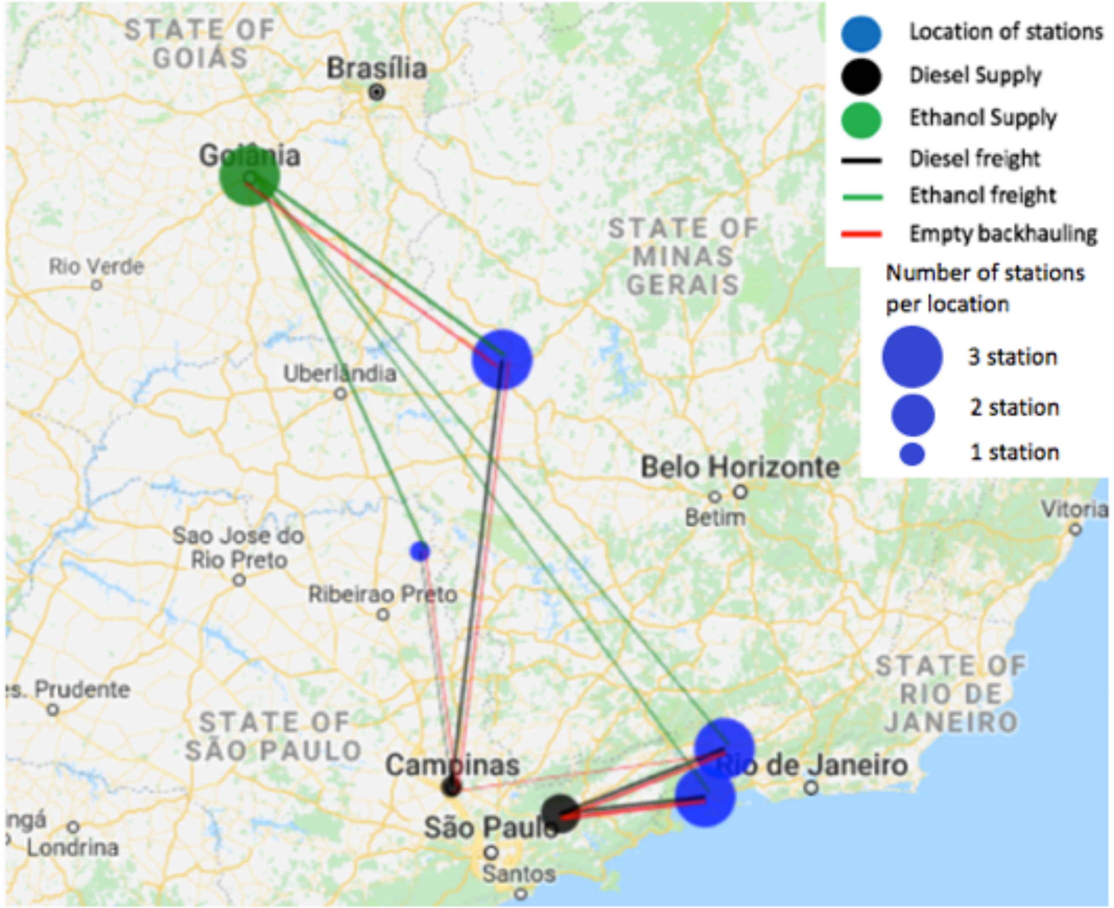



**Optimum design for maximum profit:**
> Number of stations per node
> Supply sources and routes

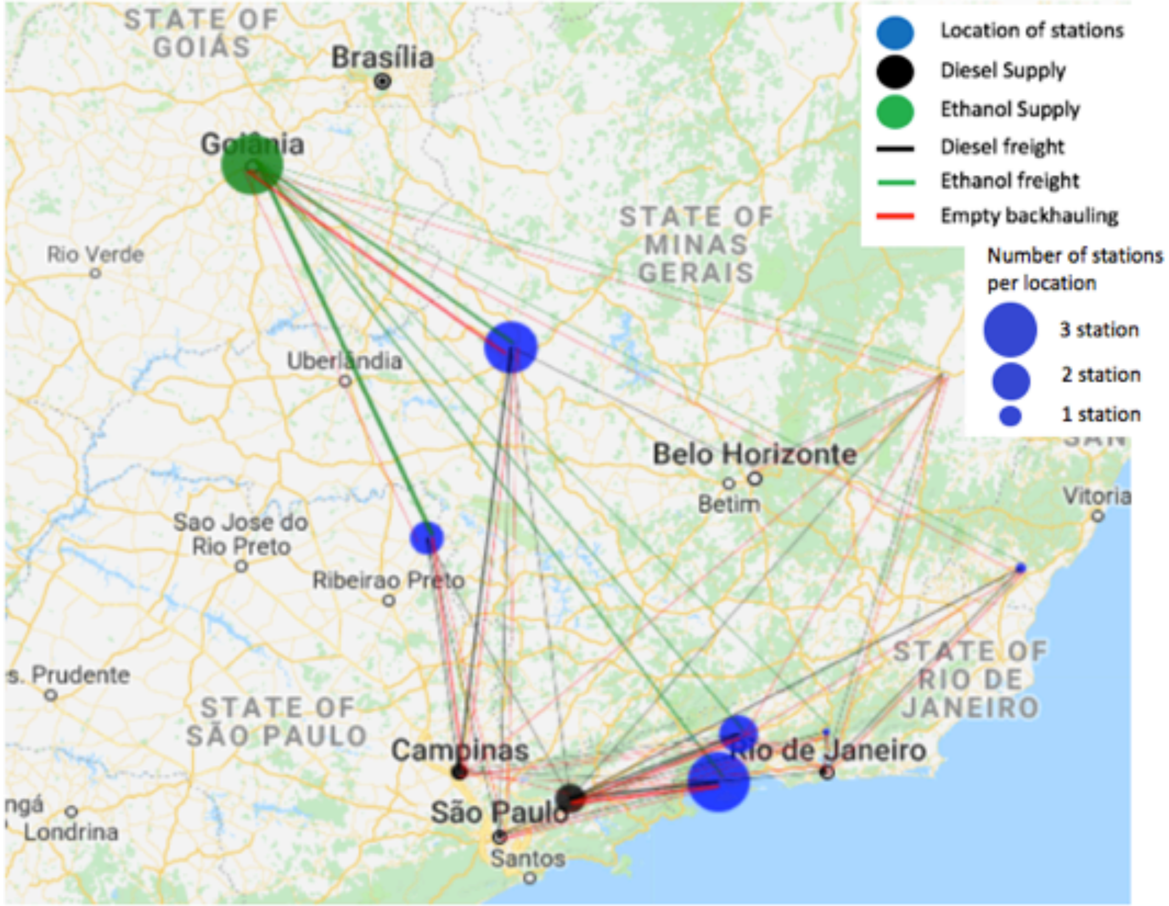
# Network Design Model for Fuel Retail



## Results




**Deterministic**
Fleet utilization: 65%




**Probabilistic**
500 Monte-Carlo simulations

# Network Design Model for Fuel Retail

## Results

| Operating Income as function of sales volume | Model result – Complete case | Model result – not considering topography | | Model result – not considering backhauling cost | |
|---|---|---|---|---|---|
| **Sales volume (liters per month)** | EBITDA - in 1,000` US$ | EBITDA - in 1,000` US$ | Difference to Regular case | EBITDA - in 1,000` US$ | Difference to Regular case |
| 120,000 | 12.9 | 12.8 | -1% | 12.5 | -3% |
| 100,000 | 9.3 | 9.2 | -1% | 9.0 | -3% |
| 80,000 | 5.8 | 5.7 | [illegible] | 5.5 | -5% |
| 60,000 | 2.3 | 2.3 | 0% | 2.3 | 0% |
| 40,000 | 0.0 | 0.0 | 0% | 0.0 | 0% |

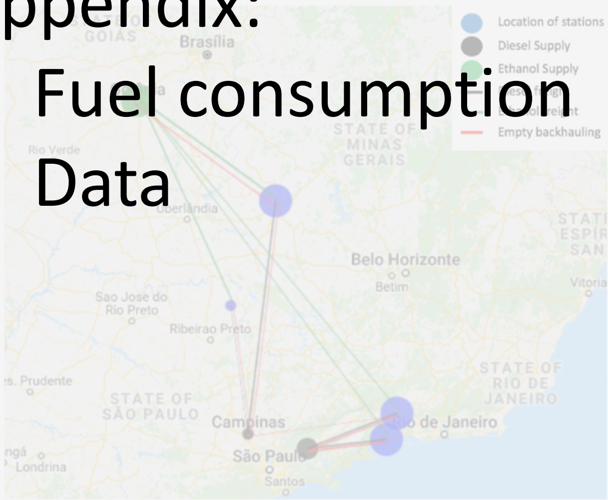
# Q&A

Appendix:

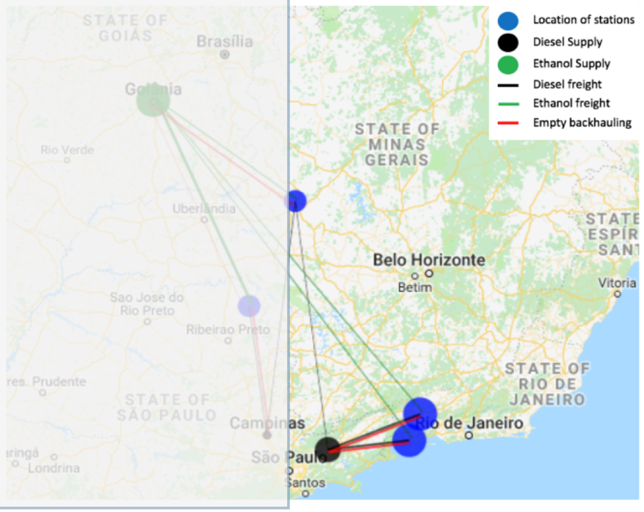
- Fuel consumption
- Data

**Result take-away:**

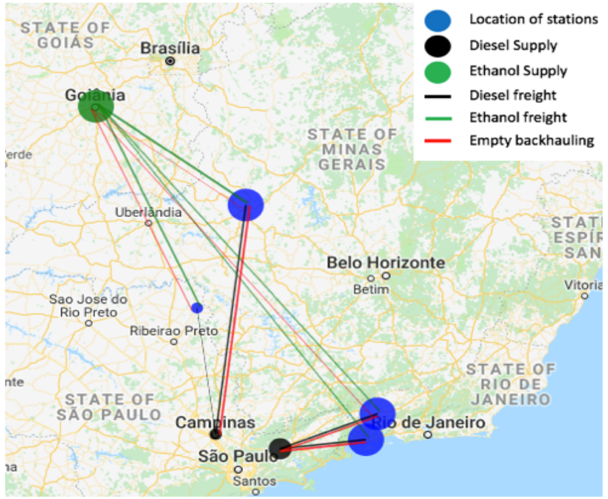
- Truck routing (backhauling) -> 20% higher fleet utilization and 5% higher profit in the model;
- Route topography -> design with 2% higher profit;
- Assumptions about fixed costs and sales volume - In real life, historical or inferred values and use this model to select among potential retail locations.




**Complete case**




**Not considering topography**

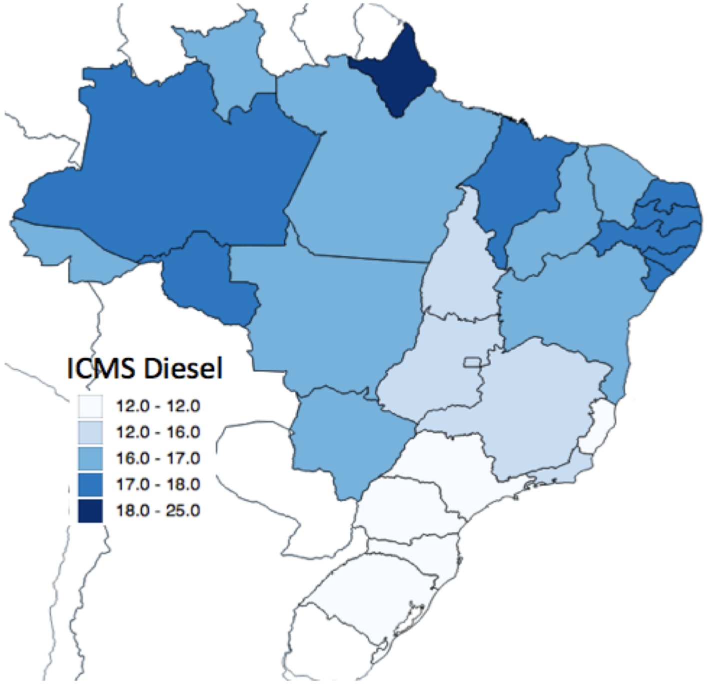


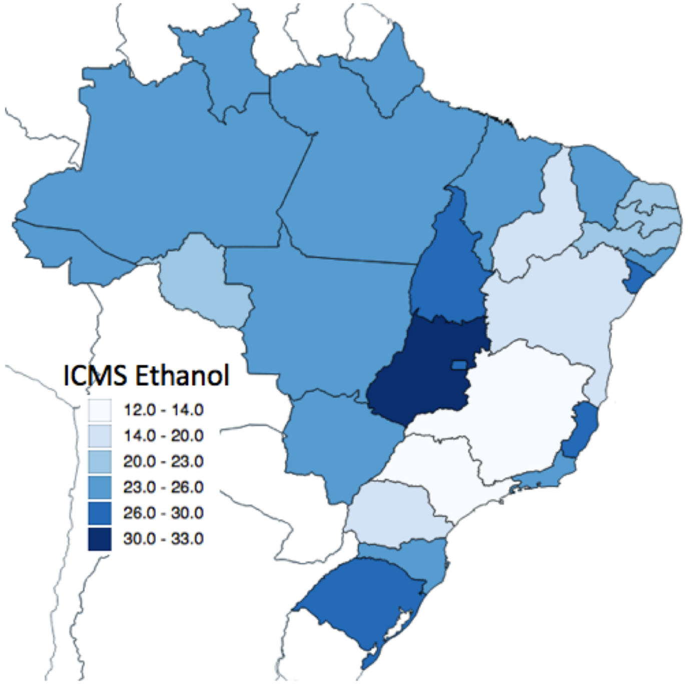

**Not considering backhauling cost**

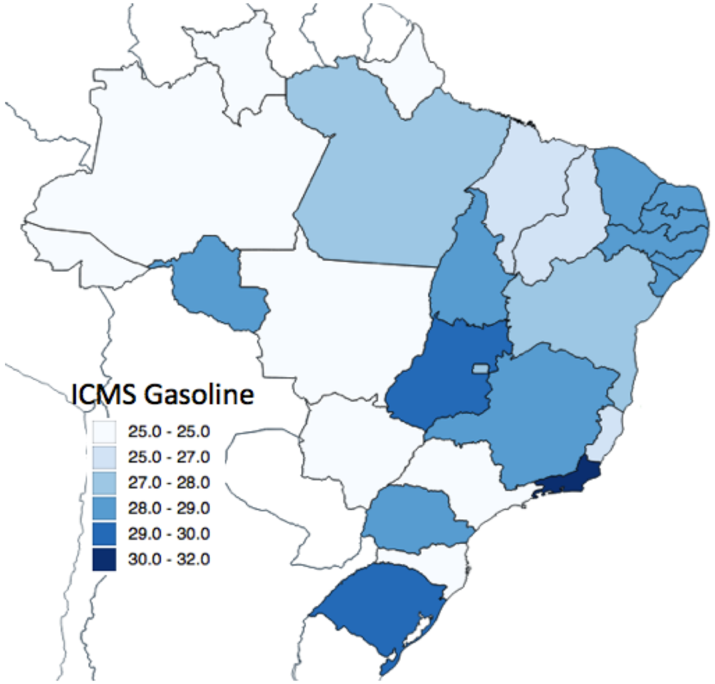
# Network Design Model for Fuel Retail



## Fuel tax per state



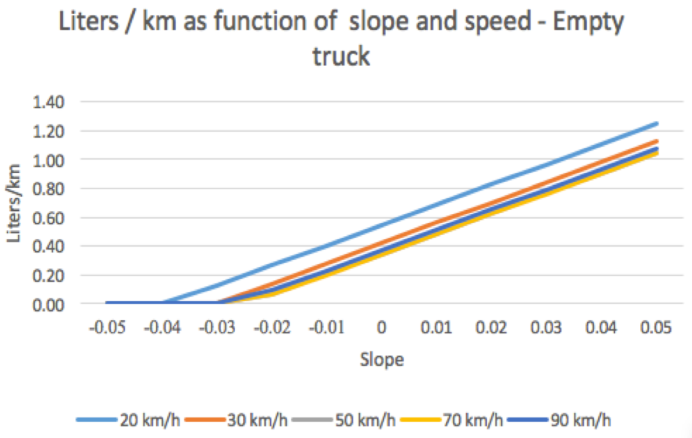



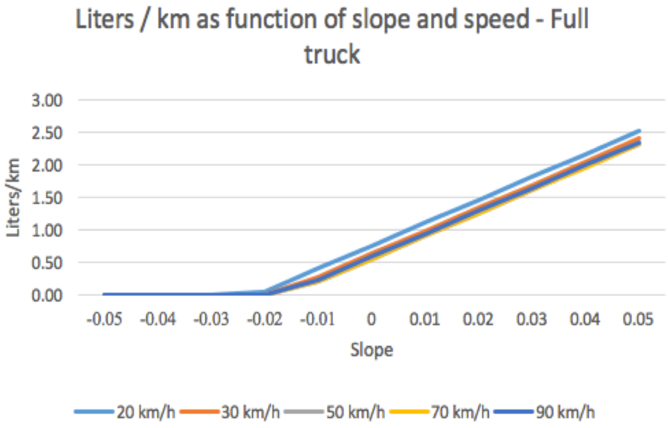
MIT Supply Chain Management

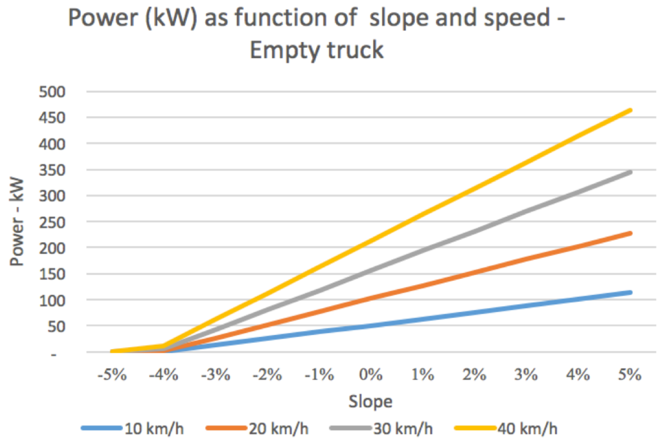
# Network Design Model for Fuel Retail

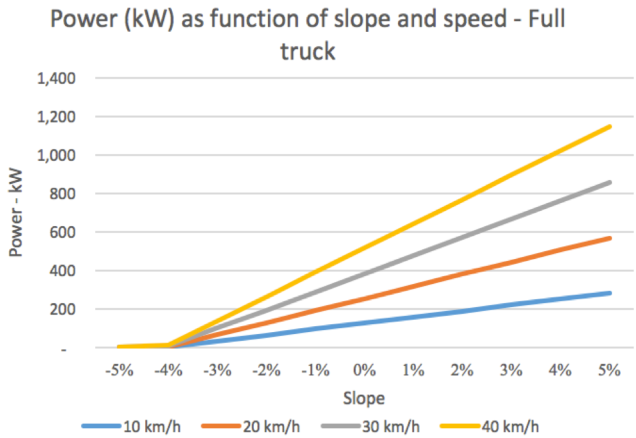
MIT GLOBAL SCALE NETWORK

## Company and problem




$$F(\alpha_{(\theta)}, l, v, d) = \frac{\lambda d}{v}\{kNV + \gamma[(w + l)\alpha_{(\theta)}v + \beta v^3]\}$$

*Where:*

$\lambda$ = *Conversion factor (l/kJ)*

$k$ = *Engine friction factor (kJ/rev/l)*

$N$ = *Engine speed (rev/s)*

$V$ = *Engine displacement (l)*

$\gamma$ = *Conversion factor based on engine efficiency*

$w$ = *Curb-weight (kg)*

$\alpha_{(\theta)}$ = *Vehicle specific arc constant* = $\tau + g \sin\theta + gC_r \cos\theta$

$\tau$ = *Acceleration* ($m/s^2$)

$g$ = *Gravitational acceleration* ($m/s^2$)

$C_r$ = *Coefficient of rolling resistance*

$\theta$ = *Road angle*

$\beta$ = *Vehicle specific arc constant* = $0.5\, C_d\, \rho\, A$

$C_d$ = *Coefficient of aerodynamic drag*

$\rho$ = *Air density* ($kg/m^3$)

# Network Design Model for Fuel Retail



## Route costing

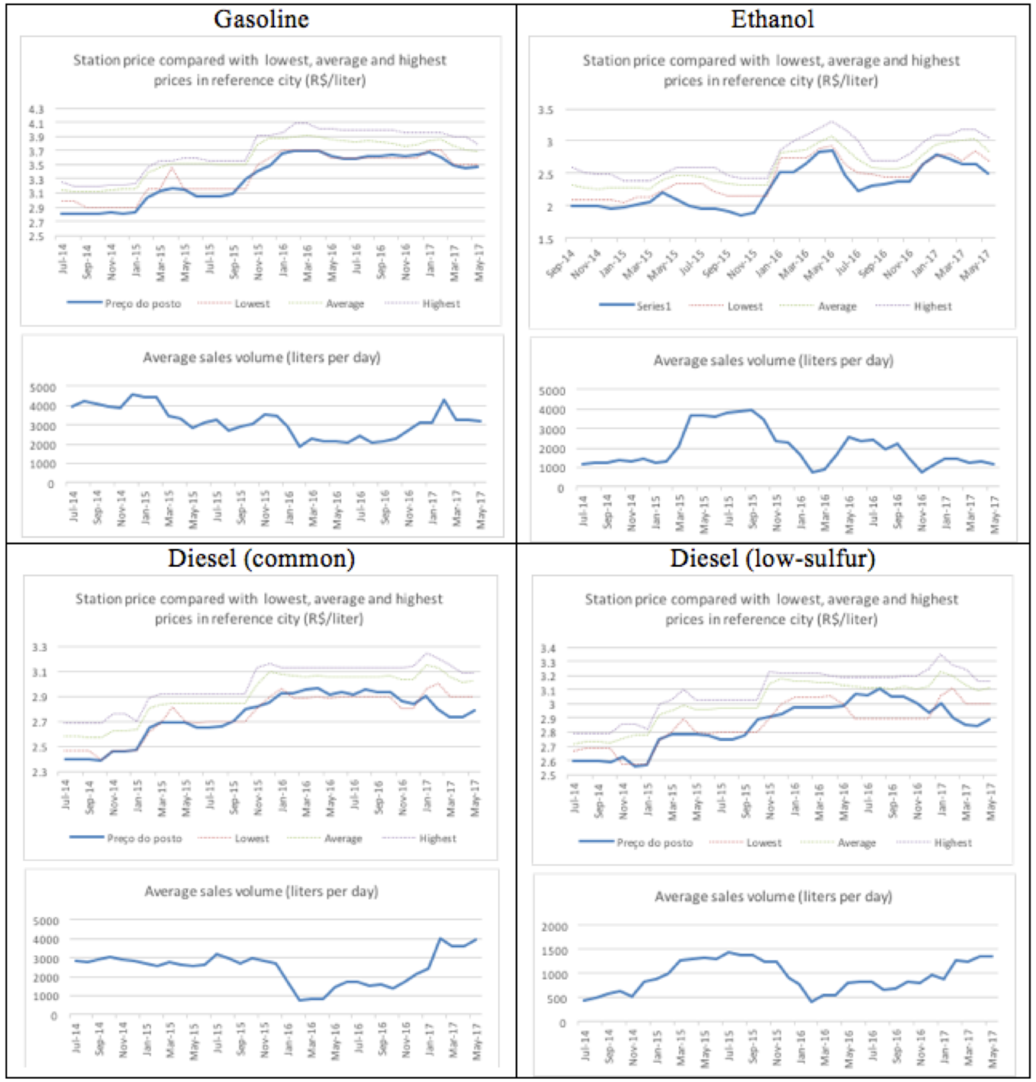
| Tanker Truck Transportation Costs (considering a 30,000 liter truck) | | Fixed cost (US$/year) | Variable cost - full (US$/km) | Variable cost - empty (US$/km) |
|---|---|---|---|---|
| **Equipment (truck and tank)** | | | | |
| Capital cost | Truck purchased for US$ 90k, with 1% IR | $10,800 | | |
| Depreciation | Purchases for US$ 90k, sells for US$ 45k after 500k km | | $0.09 | $0.09 |
| State vehicle tax | 1.5% of the truck value | $1,050 | | |
| Documentation | US$1100 per year | $1,100 | | |
| **Maintenances** | | | | |
| Tires | 18 tires, $400 each, run 350k km with two $120 repairs | | $0.03 | $0.03 |
| Oil and Filter | Filters ($60) and 2 drums of oil ($50) each 10k km | | $0.02 | $0.02 |
| Brake | US$ 50 per wheel, 6 wheels, each 6k km | | $0.07 | $0.04 |
| Other maintenance | $1k per year | $1,000 | | |
| **Safety and security** | | | | |
| Equipment insurance | US$ 500 per month | $6,000 | | |
| Cargo insurance | $70 per 200km trip | | $0.35 | |
| Tracking service | $60 per month | $720 | | |
| **Driver** | | | | |
| Salary | $600 per month plus benefits | $14,400 | | |
| Trip expenses | $25 per day | $7,800 | | |
| Toll | $3 per axle each 150km. 5 axle if full, 3 axle if empty | | $0.10 | $0.06 |
| **Total costs** | | **$42,870** | **$0.59** | **$0.24** |

MIT Supply Chain MANAGEMENT

# Network Design Model for Fuel Retail

MIT GLOBAL SCALE NETWORK

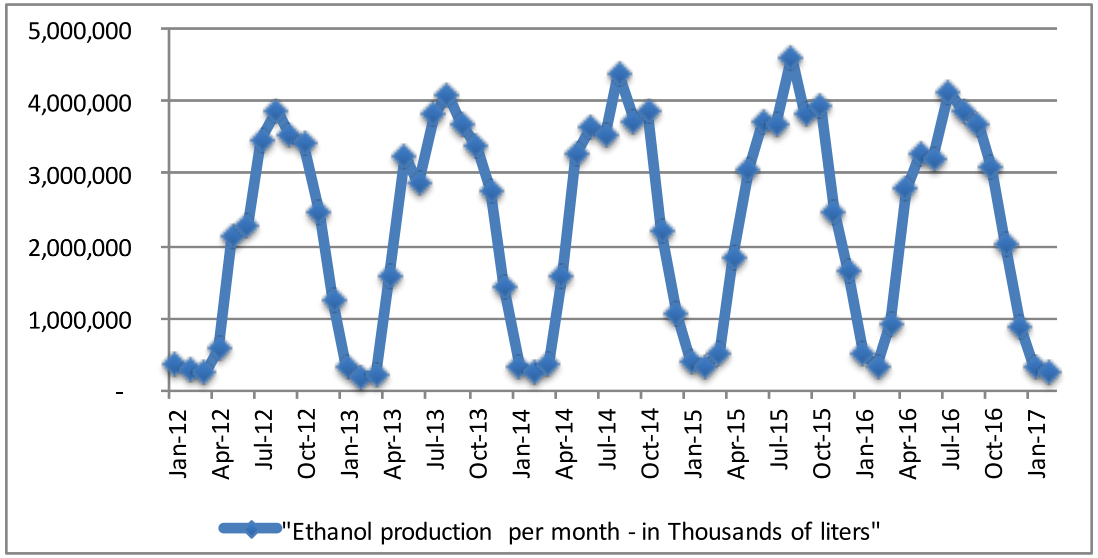
## Company data




| **Income statement** (in 1,000` US$) | | **Per month** |
|---|---|---|
| | Revenue | US$ 200.0 |
| - | COGS | US$ 181.3 |
| = | Gross Income | U$ 18.3 |
| - | Operating Expenses | US$ 12.0 |
| | *fuel transportation* | US$ 4.0 |
| | *fleet fixed costs* | US$ 2.0 |
| | *labor* | US$ 4.0 |
| | *running expenses* | US$ 2.0 |
| | Operating Income (EBITDA) | US$ 6.3 |
| - | Depreciation & Amortization | US$ 1.7 |
| | *station equipment* | US$ 1.7 |
| | Operating Income (EBIT) | US$ 4.7 |
| - | Income Tax (24%) | US$ 1.1 |
| | Net Oper. Prof. After Taxes (NOPAT) | US$ 3.6 |
| **Adjustments** | | |
| + | Depreciation & Amortization | US$ 1.7 |
| **Free Cash Flows** | | **US$ 5.2** |

## Ethanol feedstock and seasonality

| Country | Ethanol feedstocks | Ethanol yield (l/hectare) |
|---|---|---|
| Brazil | Sugar cane (100%) | 6641 |
| USA | Corn (98%) | 3770 |
| | Sorghum (2%) | 1365 |
| China | Corn (70%0 | 2011 |
| | Wheat (30%) | 1730 |
| E.U. | Wheat (48%) | 1702 |
| | Sugar beet (29%) | 5145 |
| Canada | Corn (70%) | 3460 |
| | Wheat (30%) | 1075 |



# Network Design Model for Fuel Retail



## Gasoline pricing in Brazil