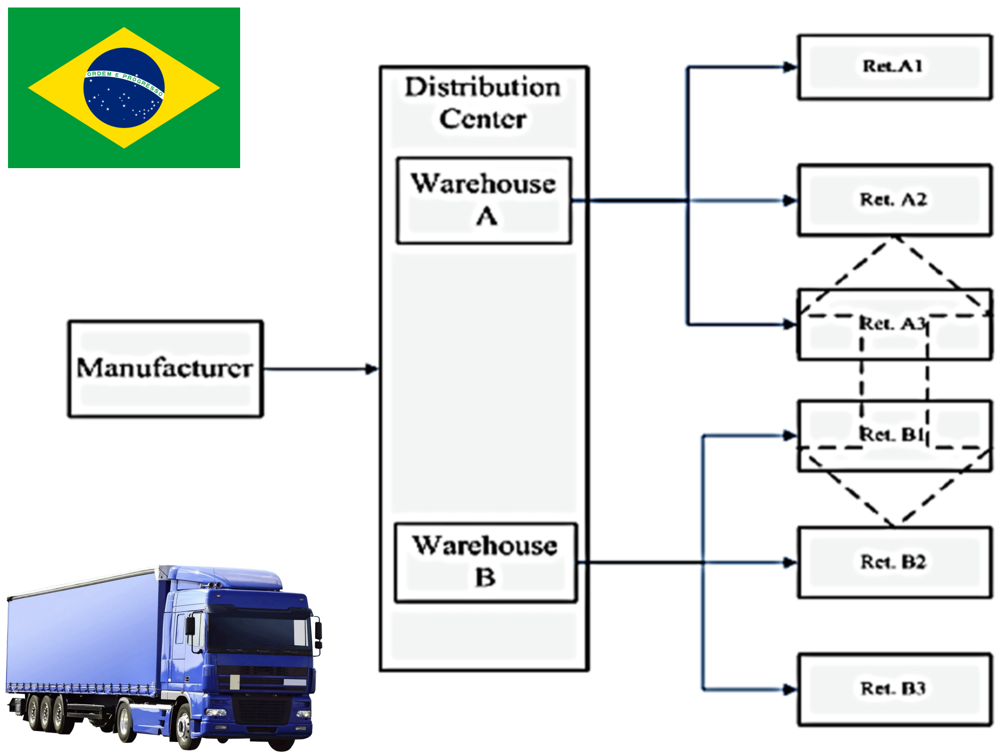
BAMS 508 Optimal Decision Making II

Final Group Project (Project 1)

SambaSonic - Transshipment in Brazil



Instructor: Steven Schecter

10 December 2023

Angga Adi Saputra | 51010908 | angga23@student.ubc.ca
Eno Yao | 43354034 | enoyao@student.ubc.ca
Namith Mohan | 45130770 | namith22@student.ubc.ca
Randeep Singh | 96564877| rndeep47@student.ubc.ca

Executive Summary

Background

SambaSonic, an emerging company, is strategically expanding to enhance market share by efficiently meeting the rising demand for Cavaquinho during the vibrant Brazilian Carnival seasons. Recognizing the instrument's cultural significance, SambaSonic aims to capitalize on the festival's buzz. We have taken into account the construction of new factories, implementing a new transit hub, addressing potential penalties, and working within a specified budget in order to achieve this.

Problem Statement

Upper management aims to fulfill potential demand of Cavaquinho in retail over the Carnival season to harness the festivity as a means to build brand awareness. The company places significant value on meeting customer demand, with a penalty cost of $800 per unit for every missed opportunity. To accommodate the expected surge in demand during the Carnival season, SambaSonic is contemplating the construction of new factories in Patos de Minas (PF) and/or Uberaba (PF2), each incurring a $9 million investment. Additionally, the consideration of a new transit hub in Campo Belo (PTH), costing $3 million, is on the table to ensure On-Time-In-Full (OTIF) product delivery. Despite ambitious growth plans, the expansion strategy is constrained by a budget limitation of $13 million, requiring careful allocation of resources to maximize impact.

Objective

The primary objective of this project is to meet demand requirements fully at the most optimum total costs associated with production, shipment, and demand penalties. Additionally, the project aims to strategically incorporate new investments while complying with the specified budget constraints.

Business Case

Data Collection - This project utilizes data from International Journal of Production Economics - Optimization in inventory-routing problem with planned transshipment: A case study in the retail industry in combination with data retrieved from independent research.

Model Selection - The model solution adopts the Transshipment approach in combination with Linear Programming (LP) models. LP models are well-suited for problems where the relationships are linear. The flexibility of LP models is crucial for addressing complex transshipment problems with diverse cost considerations, capacity constraints, and other factors.

The **decision variables** used are as follows.

DECISION VARIABLES	DEFINITION
A_B	Units produced/stored at node **A** and transported to node **B**
PDi	Unfulfilled demand at nodes Ri, i = 1 to 6
PF, PF1, PTH	Binary decision variables that control the decision on establishing potential factories and transit hub

Key Findings

Before implementing the proposed factories and the additional transit hub, the optimisation software Gurobi identified a supply shortage in the logistics network, with 215 units not met, incurring a substantial opportunity cost of $172,000. Notably, São Paulo (R5) faced a shortage of 120 units, costing $96,000, and Vila Velha (R6) lacked 95 units, incurring a $76,000 opportunity cost. The total cost was $491,746.82.

After establishing Patos de Minas (PF) and Campo Belo (PTH) resolved the shortage. Factories now send 662 units, meeting the demands. Campo Belo (PTH) handles the additional volume. The total cost reduced to $473,425.42, eliminating opportunity costs and ensuring fulfillment across all retailers.

Conclusion

SambaSonic's supply chain analysis focused on enhancing efficiency through new factories and transit hubs. The existing model revealed significant shortcomings in meeting retailer demands, leading to a substantial opportunity cost of $491,746.82. The updated model strategically establishes a factory in Patos de Minas (PF) and a transit hub in Campo Belo (PTH), effectively addressing unfulfilled demand and minimizing costs. The expanded production and optimized transit hub eliminate the supply shortage, resulting in the elimination of opportunity costs and a significant overall cost reduction. In conclusion, the updated shipping network proves operationally efficient and aligns with SambaSonic's growth objectives within budget constraints.

Table of Content

Introduction

Background

Logistics serves as the backbone of the retail industry, enabling businesses to flourish in a competitive market. At its core, logistics is all about coordinating various essential tasks within the retail world, like transportation and warehousing among many others. Optimization in logistics is key to keep everything in sync and allow retailers to sustain.

This report focuses on a logistical problem faced by SambaSonic, a Brazilian-based musical instrument manufacturer operating in 9 cities across the country. The company has a number of factories, transit hubs, and retailers in different locations to supply various retailers in Brazil.

Among the various musical instruments produced by SambaSonic, the Cavaquinho holds a prominent cultural significance in Brazil, especially gaining popularity during the annual Brazilian Carnival seasons (Farrant, D., 2023). As a new growing company, management at SambaSonic have identified a valuable opportunity in meeting the demand for this instrument. The management believe, by maximizing fulfillment during the Carnival season SambaSonic could get significant tailwind from the buzz generated throughout the festival.

The strategic importance of optimizing their supply chain becomes apparent, as the company aims to meet the heightened demand and leverage the festival's vibrant atmosphere for enhanced brand visibility and customer engagement.

In anticipation of the expected rise in demand during the Carnival season, SambaSonic is contemplating the establishment of new factories. Two potential locations under consideration are Patos de Minas and Uberaba, with each new factory estimated to cost the company $9 million. Concurrently, to streamline handling and shipping for increased demand, a new transit hub at Campo Belo is under evaluation, with an estimated cost of $3 million.

However, there is a critical financial consideration, as SambaSonic faces a budget limitation for its expansion plan, capped at $13 million in total. This financial constraint necessitates careful consideration and strategic allocation of resources to optimize the supply chain while staying within the specified budget.

Citation

This report adopts concepts from a case in the International Journal of Production Economics - Optimization in inventory-routing problem with planned transshipment: A case study in the retail industry (Peres, I. T., Repolho, H. M., Martinelli, R., & Monteiro, N. J., 2017), in conjunction with external data collected and added constraints. Location nodes data, base cost figures, as well as data processing approach on route efficiency in the sections to follow are obtained from aforementioned case study, while other supporting data are obtained from independent research.

Problem Statement

As a new growing company, SambaSonic is at an expansion stage where their main objective is to grow brand awareness and market share by **capturing as much demand for Cavaquinho at the most optimized cost possible.** In achieving this, there are several factors that come into consideration.

- **Demand increase -** Upper management wants to pinpoint retail centers with unfulfilled demand to identify potential opportunities.
- **Demand penalty -** Based on market research, the shortfall for every demand missed based on the opportunity cost for every unit sold and potential exposure gain is valued at **$800/unit**
- **Potential factories -** In order to meet expected rise in demand during the Carnival season, SambaSonic may need to invest in building new factories in 2 potential locations - **Patos de Minas (PF)** and/or **Uberaba (PF2)**, costing the company $9 million each.
- **Potential transit hub -** To ensure On-Time-In-Full (OTIF) product delivery, SambaSonic is considering investing in a new transit hub - **Campo Belo (PTH)** costing the company $3 million.
- **Budget** - there is a budget limitation of SambaSonic expansion plan at **$13 million in total**

Objective

The primary goal of this project is to fulfill the demand required while minimizing overall cost of production, shipment, demand penalty, and establishing new investments and still adhering to the budget constraint.

Business Case

Baseline Figures

INFRASTRUCTURE	LOCATION (NODE)	CAPACITY (Monthly)
Existing Factory (F)	Uberlandia (F1)	456
Transit Hubs (TH)	Contagem (TH1)	278
	Ribeirão Preto (TH2)	169

Currently SambaSonic has established a manufacturing plant in Uberlandia with production capacity of 456 Cavaquinho/month. The company also has 2 transit hubs, in the city of Contagem and Ribeirão Preto, with storage and processing capacity of 278 and 169 Cavaquinho respectively.

INFRASTRUCTURE	LOCATION (NODE)	DEMAND (Monthly)
Retail/Demand Nodes - (R)	Campinas (R1)	80
	Praia Grande (R2)	24
	Rio de Janeiro (R3)	230
	São José dos Campos (R4)	28
	São Paulo (R5)	205
	Vila Velha (R6)	95

SambaSonic supplies 6 different musical instrument retailers in 6 different cities; Campinas (R1), Praia Grande (R2), Rio de Janeiro (R3), São José dos Campos (R4), São Paulo (R5), and Vila Velha (R6). The Demand column shown on the table above illustrates the forecasted demand for Cavaquinho in each individual retailer during the Carnival season, illustrating the anticipated demand figures required to be fulfilled.

OBJECT FUNCTION	BASE SCENARIO
Variable Distribution Cost (USD)	130,760
Fixed Distribution Cost (USD)	25,700

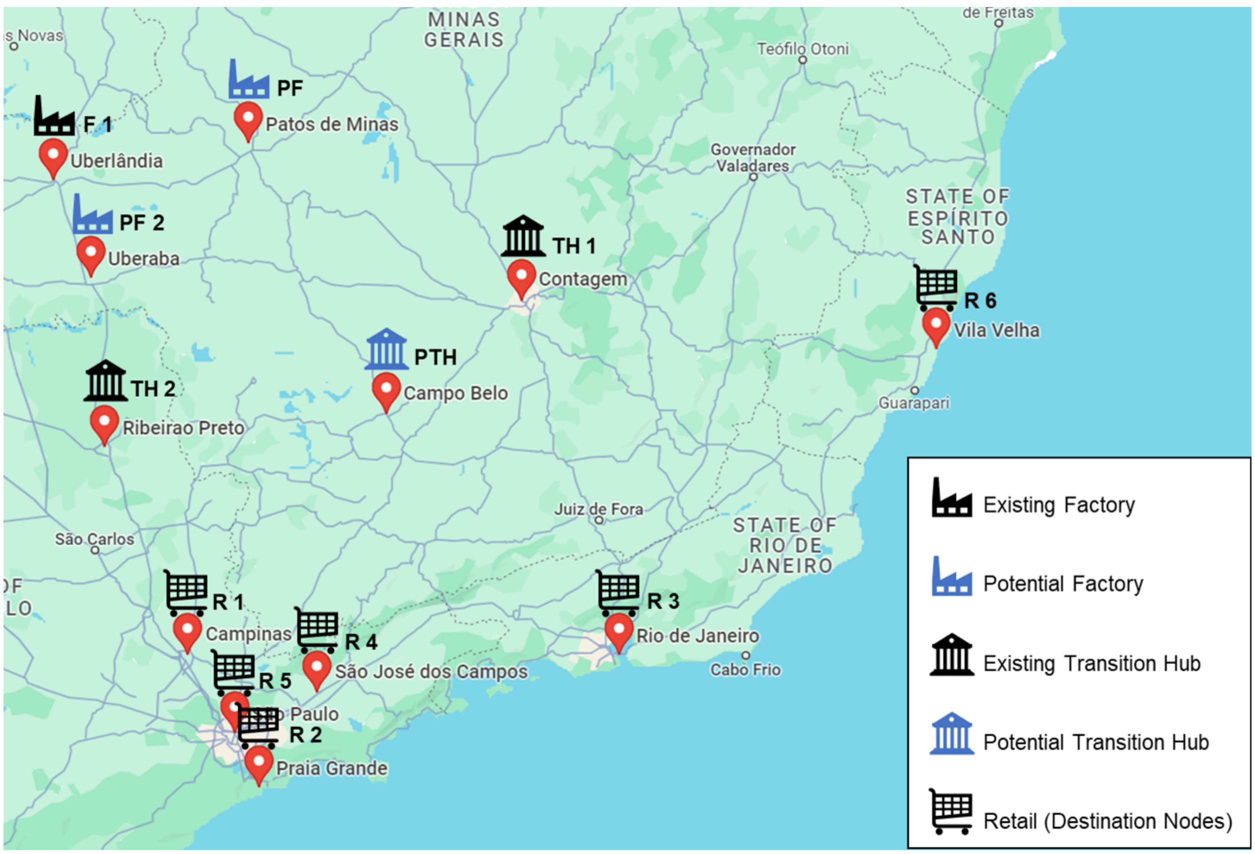
The fixed distribution costs are assumed to be the same for every node. However the variable distribution costs are used as a base value and adjusted based on the route efficiency between each node.

Proposed Decisions

INFRASTRUCTURE	LOCATION (NODE)	CAPACITY (Monthly)	COST ($ Mn)
Proposed Factories (PF)	Patos de Minas (PF)	320	9
	Uberaba (PF2)	312	9
Proposed Transit Hubs (PTH)	Campo Belo (PTH)	350	3

In anticipation of the forecasted demand, SambaSonic needs to decide if they need to invest in new factories and transit hub facilities. Establishing 1 new manufacturing plant costs $9 million each, while a transit hub would require $3 million investment.

Illustration



Supporting Data

Baseline Data

DISTANCE (1000 Km)	Uberlandia (F1)	Patos de Minas (PF)	Uberaba (PF2)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	-	0.22	0.11	0.53	0.28	0.48	0.50	0.66	1.00	0.71	0.60	1.09
Patos de Minas (PF)	0.22	-	0.92	0.39	0.41	0.34	0.63	0.81	0.82	0.78	0.72	0.92
Uberaba (PF2)	0.11	0.25	-	0.47	0.17	0.42	0.39	0.56	0.88	0.54	0.48	0.99
Contagem (TH1)	0.53	0.39	0.47	-	0.50	0.21	0.57	0.64	0.45	0.59	0.57	0.54
Ribeirão Preto (TH2)	0.28	0.41	0.17	0.50	-	0.36	0.22	0.41	0.72	0.37	0.32	1.03
Campo Belo (PTH)	0.48	0.34	0.41	0.21	0.35	-	0.41	0.48	0.49	0.36	0.41	0.73
Campinas (R1)	0.50	0.63	0.39	0.57	0.23	0.40	-	0.19	0.49	0.15	0.10	0.93
Praia Grande (R2)	0.66	0.81	0.56	0.64	0.41	0.48	0.19	-	0.51	0.16	0.08	0.94
Rio de Janeiro (R3)	1.00	0.82	0.88	0.45	0.72	0.49	0.49	0.51	-	0.35	0.44	0.52
São José dos Campos (R4)	0.71	0.78	0.54	0.59	0.37	0.36	0.15	0.16	0.35	-	0.09	0.78
São Paulo (R5)	0.60	0.72	0.48	0.57	0.32	0.41	0.10	0.08	0.44	0.09	-	0.87
Vila Velha (R6)	1.09	0.92	0.99	0.54	1.03	0.73	0.93	0.94	0.52	0.78	0.87	-

ROUTE TIME (Days)	Uberlandia (F1)	Patos de Minas (PF)	Uberaba (PF2)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	-	0.10	0.06	0.30	0.10	0.30	0.20	1.00	1.00	1.00	0.30	1.00
Patos de Minas (PF)	0.10	-	0.15	0.20	0.20	0.20	0.30	0.40	0.50	0.40	0.40	0.60
Uberaba (PF2)	0.06	0.15	-	0.28	0.10	0.25	0.20	0.30	0.46	0.28	0.25	0.60
Contagem (TH1)	0.30	0.20	0.28	-	0.30	0.10	0.30	1.00	0.20	0.30	0.30	1.00
Ribeirão Preto (TH2)	0.10	0.20	0.10	0.30	-	0.20	0.10	0.20	1.00	0.20	0.20	2.00
Campo Belo (PTH)	0.30	0.20	0.25	0.10	0.20	-	0.20	0.30	0.30	0.20	0.20	0.50
Campinas (R1)	0.20	0.30	0.20	0.30	0.10	0.20	-	0.10	0.20	0.10	0.10	1.00
Praia Grande (R2)	1.00	0.40	0.30	1.00	0.20	0.30	0.10	-	0.30	0.10	0.10	1.00
Rio de Janeiro (R3)	1.00	0.50	0.46	0.20	1.00	0.30	0.20	0.20	-	0.20	0.20	1.00
São José dos Campos (R4)	1.00	0.40	0.28	0.30	0.20	0.20	0.10	0.10	0.20	-	0.10	1.00
São Paulo (R5)	0.30	0.40	0.25	0.30	0.20	0.20	0.10	0.10	0.20	0.10	-	1.00
Vila Velha (R6)	2.00	0.60	0.60	1.00	2.00	0.50	1.00	1.00	1.00	1.00	1.00	-

Distance and time data were collected in order to retrieve transit cost variability from Factory nodes to Transit nodes and from Transit nodes to Retail/Demand nodes. Units utilized are in 1000 km and in Days respectively to obtain route efficiency which will be processed in the section to follow.

Data Processing

SPEED (1000 Km/Day)	Uberlandia (F1)	Patos de Minas (PF)	Uberaba (PF2)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	-	2.18	1.78	1.75	2.80	1.59	2.52	0.66	1.00	0.71	2.00	1.09
Patos de Minas (PF)	2.17	-	6.03	1.94	2.06	1.68	2.10	2.03	1.63	1.95	1.80	1.53
Uberaba (PF2)	1.80	1.61	-	1.69	1.71	1.67	1.94	1.85	1.91	1.93	1.92	1.66
Contagem (TH1)	1.75	1.94	1.69	-	1.67	2.07	1.88	0.64	2.26	1.98	1.90	0.54
Ribeirão Preto (TH2)	2.80	2.06	1.70	1.67	-	1.78	2.23	2.04	0.72	1.86	1.59	0.52
Campo Belo (PTH)	1.59	1.68	1.67	2.08	1.77	-	2.05	1.61	1.62	1.79	2.03	1.47
Campinas (R1)	2.52	2.09	1.95	1.88	2.27	2.00	-	1.89	2.47	1.48	0.99	0.93
Praia Grande (R2)	0.66	2.03	1.85	0.64	2.04	1.61	1.85	-	1.69	1.58	0.78	0.94
Rio de Janeiro (R3)	1.00	1.63	1.91	2.26	0.72	1.62	2.47	2.54	-	1.74	2.18	0.52
São José dos Campos (R4)	0.71	1.95	1.93	1.97	1.86	1.79	1.48	1.60	1.74	-	0.90	0.78
São Paulo (R5)	2.00	1.80	1.92	1.90	1.59	2.03	0.95	0.76	2.18	0.90	-	0.87
Vila Velha (R6)	0.54	1.53	1.66	0.54	0.52	1.47	0.93	0.94	0.52	0.78	0.87	-

Based on distance and travel time data collected, speed data were calculated with standard formula of $\frac{Distance\ (1000\ Km)}{Route\ Time\ (Days)}$. Routes with greater travel speeds are assumed to be more efficient routes. The same routes are ranked for each node as a destination and assigned a variable transport cost accordingly.

RANK	Uberlandia (F1)	Patos de Minas (PF)	Uberaba (PF2)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	-	1	7	7	1	10	1	10	9	11	3	4
Patos de Minas (PF)	3	-	1	4	3	6	4	3	7	2	6	2
Uberaba (PF2)	5	10	-	8	7	7	6	5	4	3	4	1
Contagem (TH1)	6	6	9	-	8	1	7	11	2	1	5	9
Ribeirão Preto (TH2)	1	3	8	9	-	5	3	2	10	4	7	10
Campo Belo (PTH)	7	8	10	2	6	-	5	6	8	5	2	3
Campinas (R1)	2	2	2	6	2	3	-	4	1	8	8	6
Praia Grande (R2)	10	4	6	10	4	9	8	-	6	7	11	5
Rio de Janeiro (R3)	8	9	5	1	10	8	2	1	-	6	1	11
São José dos Campos (R4)	9	5	3	3	5	4	9	7	5	-	9	8
São Paulo (R5)	4	7	4	5	9	2	10	9	3	9	-	7
Vila Velha (R6)	11	11	11	11	11	11	11	8	11	10	10	-

The following table shows total cost of manufacturing, shipping and transshipping products between factory, transhipping, and retail nodes.

TOTAL COSTS (USD)	Uberlandia (F1)	Patos de Minas (PF)	Uberaba (PF2)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)				151.46	150.92	151.74						
Patos de Minas (PF)				151.19	151.10	151.37						
Uberaba (PF2)				151.56	151.46	151.46						
Contagem (TH1)							565.16	566.52	563.79	563.45	564.48	565.84
Ribeirão Preto (TH2)							564.14	563.79	566.18	564.14	565.16	566.18
Campo Belo (PTH)							564.82	564.82	565.50	564.48	563.79	563.79
Campinas (R1)												
Praia Grande (R2)												
Rio de Janeiro (R3)												
São José dos Campos (R4)												
São Paulo (R5)												
Vila Velha (R6)												

Model Formulations

From the data on costs provided in the case and combining it with variable transportation costs between different nodes, we have the following total costs per unit of product.

TOTAL COSTS PER UNIT PRODUCT (USD)	Contagem (TH1)	Ribeirão Preto (TH2)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	151.46	150.92						
Contagem (TH1)			565.16	566.52	563.79	563.45	564.48	565.84
Ribeirão Preto (TH2)			564.14	563.79	566.18	564.14	565.16	566.18

Using this data as well as the opportunity cost of unfulfilled demand we can formulate the following objective function to minimize:

$$f(cost) = 151.46 * F1\_TH1 + 150.92 * F1\_TH2 + 565.16 * TH1\_R1 + 566.52 * TH1\_R2 + 563.79 * TH1\_R3 + 563.45 * TH1\_R4 + 564.48 * TH1\_R5 + 565.84 * TH1\_R6 + 564.14 * TH2\_R1 + 563.79 * TH2\_R2 + 566.18 * TH2\_R3 + 564.14 * TH2\_R4 + 565.16 * TH2\_R5 + 566.18 * TH2\_R6 + 800 * (PD1 + PD2 + PD3 + PD4 + PD5 + PD6)$$

Where,

A_B : Units produced/stored at **A** and transported to **B**
PDi : Unfulfilled demand at nodes R1-6

The function is constrained by

- the production capacity at Uberlandia (F1)
  $F1\_TH1 + F1\_TH2 \leq 456$

- the storage capacities at transit hubs Contagem (TH1) and Ribeiro Preto (TH2) respectively
  $TH1\_R1 + TH1\_R2 + TH1\_R3 + TH1\_R4 + TH1\_R5 + TH1\_R6 \leq 278$
  $TH2\_R1 + TH2\_R2 + TH2\_R3 + TH2\_R4 + TH2\_R5 + TH2\_R6 \leq 169$

- required demand at retail destinations of Campinas (R1), Praia Grande (R2), Rio de Janeiro (R3), São José dos Campos (R4), São Paulo (R5), and Vila Velha (R6) respectively
  $TH1\_R1 + TH2\_R1 + PD1 \geq 80$
  $TH1\_R2 + TH2\_R2 + PD2 \geq 24$
  $TH1\_R3 + TH2\_R3 + PD3 \geq 230$
  $TH1\_R4 + TH2\_R4 + PD4 \geq 28$
  $TH1\_R5 + TH2\_R5 + PD5 \geq 205$
  $TH1\_R6 + TH2\_R6 + PD6 \geq 95$

- flow in = flow out constraints for each transit hub
  $F1\_TH1 - (TH1\_R1 + TH1\_R2 + TH1\_R3 + TH1\_R4 + TH1\_R5 + TH1\_R6) \geq 0$
  $F1\_TH2 - (TH2\_R1 + TH2\_R2 + TH2\_R3 + TH2\_R4 + TH2\_R5 + TH2\_R6) \geq 0$

The proposed models introduce two new factories: at Patos de Minas (PF) and Uberaba (PF2), and one new transit hub: at Campo Belo. Their total costs per unit of product are detailed in the table below.

TOTAL COSTS PER UNIT PRODUCT (USD)	Contagem (TH1)	Ribeirão Preto (TH2)	Campo Belo (PTH)	Campinas (R1)	Praia Grande (R2)	Rio de Janeiro (R3)	São José dos Campos (R4)	São Paulo (R5)	Vila Velha (R6)
Uberlandia (F1)	151.46	150.92	151.74						
Patos de Minas (PF)	151.19	151.1	151.37						
Uberaba (PF2)	151.56	151.46	151.46						
Contagem (TH1)				565.16	566.52	563.79	563.45	564.48	565.84
Ribeirão Preto (TH2)				564.14	563.79	566.18	564.14	565.16	566.18
Campo Belo (PTH)				564.82	564.82	565.5	564.48	563.79	563.79

From the cost data we get the following cost function to minimize:

$$\begin{gathered}
\mathit{f(cost)} = 151.46 * \mathit{F1_TH1} + 150.92 * \mathit{F1_TH2} + 151.74 * \mathit{F1_PTH} + 151.19 * \mathit{PF_TH1} \\
+ 151.1 * \mathit{PF_TH2} + 151.37 * \mathit{PF_PTH} + 151.56 * \mathit{PF2_TH1} + 151.46 * \mathit{PF2_TH2} \\
+ 151.46 * \mathit{PF2_PTH} + 565.16 * \mathit{TH1_R1} + 566.52 * \mathit{TH1_R2} + 563.79 * \mathit{TH1_R3} \\
+ 563.45 * \mathit{TH1_R4} + 564.48 * \mathit{TH1_R5} + 565.84 * \mathit{TH1_R6} + 564.14 * \mathit{TH2_R1} \\
+ 563.79 * \mathit{TH2_R2} + 566.18 * \mathit{TH2_R3} + 564.14 * \mathit{TH2_R4} + 565.16 * \mathit{TH2_R5} \\
+ 566.18 * \mathit{TH2_R6} + 564.82 * \mathit{PTH_R1} + 564.82 * \mathit{PTH_R2} + 565.5 * \mathit{PTH_R3} \\
+ 564.48 * \mathit{PTH_R4} + 563.79 * \mathit{PTH_R5} + 563.79 * \mathit{PTH_R6} + 800 * \mathit{(PD1 + PD2 + PD3 + PD4} \\
\mathit{+ PD5 + PD6)}
\end{gathered}$$

Where,

A_B : Units produced/stored at A and transported to B, including the proposed nodes
PDi : Unfulfilled demand at nodes R1-6

The function is constrained by the following constraints:

- the production capacity at Uberlandia (F1), Patos de Minas (PF), and Uberaba (PF2) respectively
  $\mathit{F1\_TH1} + \mathit{F1\_TH2} + \mathit{F1\_PTH} \leq 456$
  $\mathit{PF\_TH1} + \mathit{PF\_TH2} + \mathit{PF\_PTH} \leq 320$
  $\mathit{PF2\_TH1} + \mathit{PF2\_TH2} + \mathit{PF2\_PTH} \leq 312$

- the storage capacities at transit hubs Contagem (TH1), Ribeiro Preto (TH2) and Campo Belo (PTH) respectively
  $\mathit{TH1\_R1} + \mathit{TH1\_R2} + \mathit{TH1\_R3} + \mathit{TH1\_R4} + \mathit{TH1\_R5} + \mathit{TH1\_R6} \leq 278$
  $\mathit{TH2\_R1} + \mathit{TH2\_R2} + \mathit{TH2\_R3} + \mathit{TH2\_R4} + \mathit{TH2\_R5} + \mathit{TH2\_R6} \leq 169$
  $\mathit{PTH\_R1} + \mathit{PTH\_R2} + \mathit{PTH\_R3} + \mathit{PTH\_R4} + \mathit{PTH\_R5} + \mathit{PTH\_R6} \leq 350$

- required demand at retail destinations of Campinas (R1), Praia Grande (R2), Rio de Janeiro (R3), São José dos Campos (R4), São Paulo (R5), and Vila Velha (R6) respectively
  $\mathit{TH1\_R1} + \mathit{TH2\_R1} + \mathit{PTH\_R1} + \mathit{PD1} \geq 80$

$TH1\_R2 + TH2\_R2 + PTH\_R2 + PD2 \geq 24$
$TH1\_R3 + TH2\_R3 + PTH\_R3 + PD3 \geq 230$
$TH1\_R4 + TH2\_R4 + PTH\_R4 + PD4 \geq 28$
$TH1\_R5 + TH2\_R5 + PTH\_R5 + PD5 \geq 205$
$TH1\_R6 + TH2\_R6 + PTH\_R6 + PD6 \geq 95$

- Decision control constraints for proposed nodes : Patos de Minas (PF), Uberaba (PF2) and Campo Belo (PTH)
  $PF\_TH1 + PF\_TH2 + PF\_PTH - M * PF \leq 0$
  $PF2\_TH1 + PF2\_TH2 + PF2\_PTH - M * PF2 \leq 0$
  $F1\_PTH + PF\_PTH + PF2\_PTH - M * PTH \leq 0$
  $PTH\_R1 + PTH\_R2 + PTH\_R3 + PTH\_R4 + PTH\_R5 + PTH\_R6 - M * PTH \leq 0$

  where
  PF : Binary decision variable for Patos de Minas
  PF2 : Binary decision variable for Uberaba
  PTH : Binary decision variable for Campo Belo
  M : Large constant to invalidate or penalize solutions that violate original constraints

- flow in = flow out constraints for transit hubs Contagem, Ribeiro Preto, and Campo Belo
  $F1\_TH1 + PF\_TH1 + PF2\_TH1 + - (TH1\_R1 + TH1\_R2 + TH1\_R3 + TH1\_R4 + TH1\_R5 + TH1\_R6) \geq 0$

  $F1\_TH2 + PF\_TH2 + PF2\_TH2 - (TH2\_R1 + TH2\_R2 + TH2\_R3 + TH2\_R4 + TH2\_R5 + TH2\_R6) \geq 0$

  $F1\_PTH + PF\_PTH + PF2\_PTH - (PTH\_R1 + PTH\_R2 + PTH\_R3 + PTH\_R4 + PTH\_R5 + PTH\_R6) \geq 0$

- an additional budget constraint of **$13 million**
  $151.19 * PF\_TH1 + 151.1 * PF\_TH2 + 151.37 * PF\_PTH + 151.56 * PF2\_TH1 + 151.46 * PF2\_TH2 + 151.46 * PF2\_PTH + 564.82 * PTH\_R1 + 564.82 * PTH\_R2 + 565.5 * PTH\_R3 + 564.48 * PTH\_R4 + 563.79 * PTH\_R5 + 563.79 * PTH\_R6 + 3000000 * PTH + 9000000 * PF + 9000000 * PF2 \leq 13000000$

Model Results

Baseline Model

Optimal solution for the current network model SambaSonic is operating with (from Gurobi):

```
# print optimal objective value
m.objVal
[25] ✓ 0.0s
... 491746.82000000007

# print optimal decisions (if not listed, that means their optimal value = 0)
m.printAttr('X')
[26] ✓ 0.0s
...
    Variable            X
-------------------------
      F1_TH1          278
      F1_TH2          169
      TH1_R3          230
      TH1_R4           28
      TH1_R5           20
      TH2_R1           80
      TH2_R2           24
      TH2_R5           65
         PD5          120
         PD6           95
```

We can infer from the solution that with the existing network there is a supply shortage. Uberlandia (F1) is sending

- 278 units to Contagem (TH1) and
- 169 units to Ribeirão Preto (TH2),

In total the factory is producing and sending **<u>447</u>** units to the two transhubs.

For the transit hubs, Contagem (TH1) is sending

- 230 units to Rio de Janeiro (R3),
- 28 units to São José dos Campos (R4),
- 20 units to São Paulo (R5),

while Ribeirão Preto (TH2) is sending

- 80 units to Campinas (R1),
- 24 units to Praia Grande (R2) and
- 65 units to São Paulo (R5),

In total the transit hubs are sending **<u>447</u>** units to the retails which is all the production amount from the factory.

However, the total demand of the retails is **<u>662</u>** units which means there is a significant supply shortage of 662 - 447 = **<u>215</u>** units. This supply shortage results in an outstanding amount of opportunity cost of 215*800 = $172,000.

As we can see from the solution, the existing model is unable to completely fulfill the demand from retailers in **São Paulo (R5) and Vila Velha(R6)**. The supply to São Paulo (R5) is only 85 units which is 120 units short of meeting the demand of 205 units. This supply shortage causes an opportunity cost of 800*120 = $96,000. The current model also fails to supply Vila Velha (R6) with any product at all where it has a demand for 95 units. This supply shortage results in an opportunity cost of 800*95 = $76,000. This enormous amount of opportunity cost contributes to a total cost of $491,746.82. The cost of operating in this network model without the opportunity cost is $319,746.82.

Optimal Solution

Optimal solution with the proposed network model with 2 new factories, and 1 new transit hub to choose from (from Gurobi) :

```
# print optimal objective value
m.objVal
[49]  ✓ 0.0s
...   473425.42
```

```
# print optimal decisions (if not listed, that means their optimal value = 0)
m.printAttr('X')
[50]  ✓ 0.0s
...
    Variable            X
-------------------------
       F1_TH1          238
       F1_TH2          104
       PF_TH1           20
       PF_PTH          300
       TH1_R3          230
       TH1_R4           28
       TH2_R1           80
       TH2_R2           24
       PTH_R5          205
       PTH_R6           95
          PTH            1
           PF            1
```

The updated model has been configured to integrate the decision-making process regarding the establishment of three new proposed sites: factories in Patos de Minas and Uberaba, and a transit hub in Campo Belo.

Based on the solution obtained from the updated model, setting up a factory at Patos de Minas (PF) and a transhub at Campo Belo (PTH) is the most optimal way of capturing the unfulfilled demand while minimizing costs.

By setting up a factory in Patos de Minas (PF), we increase the production and the supply of the product which means there will be enough goods to send from factory to transit hubs to fulfill the demand from the retailers. In order to receive, hold and tranship this increased production, there is a need for an increase in the capacity of transhubs, to prevent a bottle neck constraining the network. The transit hub at Campo Belo (PTH) serves as a strategically located distribution center, efficiently connecting the factory in Patos de Minas (PF) to various retailers and end consumers.

In the new network model, Uberlandia (F1) is sending

- 238 units to Contagem (TH1) and
- 104 units to Ribeirão Preto (TH2),

while Patos de Minas(PF) is sending

- 20 units to Contagem (TH1) and
- 300 units to Campo Belo (PTH)

In total the factories are producing and sending out **662** units. This significantly increases the amount of units sent from factories to transhubs from 447 units to 662 units.

After setting up the new transhub Campo Belo (PTH), Contagem (TH1) is sending

- 230 units to Rio de Janeiro (R3),
- 28 units to São José dos Campos (R4),

Ribeirão Preto (TH2) is sending

- 80 units to Campinas (R1),
- 24 units to Praia Grande (R2),

new transhub Campo Belo (PTH) is sending

- 205 units to São Paulo (R5) and
- 95 units to Vila Velha (R6),

in total **662** units.

With sufficient production at the factories and capacity at the transhub, all the demands of 662 units at the retailers are met which means there will not be any opportunity cost. The cost of operating with the new shipping network is $473,425.42.

While this is an increase from the original operating cost of $319,746.82 it mitigates the $172,000 lost in unfulfilled demand and saves a net amount of

=> 319,746.82 + 172,000 - 473,425.42 = **$18,321.4**

Discussion & Conclusion

The project's comprehensive analysis focused on SambaSonic's supply chain enhancements through the strategic addition of new factories and transit hubs. The core objective was to scrutinize how these infrastructural expansions impact the total cost, in particular the opportunity cost that is caused by the supply shortage.

The existing network model reveals significant shortcomings in meeting retailer demands, particularly in São Paulo (R5) and Vila Velha (R6). São Paulo (R5) experiences a supply deficit, resulting in opportunity cost, while Vila Velha (R6) is left completely unsupplied, also incurring opportunity cost, totalling to a substantial opportunity cost of $172,000. Operating within this network model without accounting for opportunity costs results in a considerable amount of $319,746.82.

The current logistics structure does not capture the potential demand completely and is costly, showing room for strategic adjustments to ensure seamless fulfillment and minimize opportunity costs.

The updated model presents a strategic solution for SambaSonic's expansion by establishing a factory in Patos de Minas (PF) and a transit hub in Campo Belo (PTH). This configuration effectively addresses unfulfilled demand while also minimizing costs. The increased production capacity in Patos de Minas (PF) ensures a sufficient supply to meet retailer demands. The addition of the strategically positioned transit hub in Campo Belo (PTH) facilitates seamless distribution, connecting the factory to various transit hubs and end retails.

Under the new network model, Uberlandia (F1) and Patos de Minas (PF) collectively send out 662 units. The expanded production substantially exceeds the previous production of 447 units, effectively eliminating the supply shortage. The optimized transit hub operation ensures smooth distribution, with all retailers receiving their demanded 662 units. This results in the elimination of opportunity costs, and a significant reduction in the overall cost to $473,425.42.

In conclusion, the updated shipping network proves to be operationally efficient and cost-effective. The strategic placement of the factory and transit hub ensures optimal fulfillment of retailer demands, marking a substantial improvement over the previous model. This model aligns perfectly with SambaSonic's objective of maximizing brand growth while staying within budget constraints.

References

Farrant, D. (2023, February 28). *15 different types of Brazilian musical instruments*. Hello Music Theory: Learn Music Theory Online. https://hellomusictheory.com/learn/brazilian-instruments/

Peres, I. T., Repolho, H. M., Martinelli, R., & Monteiro, N. J. (2017, November 1). *Optimization in inventory-routing problem with planned transshipment: A case study in the retail industry*. International Journal of Production Economics; Elsevier BV. https://doi.org/10.1016/j.ijpe.2017.09.002