Summary of the Project - Phase 2

Optimizing Gamein 2021

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1. Abstract

GAMEIN is a Supply Chain and Production Planning simulator. The following report develops an Integer Programming Multi Level Capacitated Lot Sizing Problem (MLCLSP) model to search for the optimal winning strategy. This model is solved for a simplified form of the simulator single provider, single retailer, and three finished products. Sensitivity analysis on different parameters is conducted, and the influence of various parameters on each finished product's production amount is measured. In the end, a horizon for further research is illustrated.

2. Introduction

2.1. What is GAMEIN

GAMEIN is a supply chain, production planning and business management serious simulation multi-player game designed by the scientific student association of the Sharif University of Technology. The game's main target population is undergraduate and graduate students familiar with supply chain management basics, but participants with any background are allowed to play. Although the core idea which the game is built around remains the same, the game itself is redesigned each year. A team named Idea & Game Development is tasked with designing the game, including the game scenario, gamification elements, Mathematical Modelings, Data Generation, Simulating the game, and predicting players' behaviors. Afterward, another team is named Technical Team is tasked with creating the game's software using programming languages, mainly JavaScript, C#, Python, by using Unity software and transferring the blueprints into a video game.

2.2. Short History of GAMEIN

GAMEIN first was held by a group of volunteer industrial engineering students in the year 2017 as a contest between students recreating beer game and approximately 20 participants. In the following years it was enhanced and features where added to the game. Finally at year 2019 it was turned into a simulator completely simulating a complete supply chain and production planning problem with approximately 70 team taking part. In the following year 2020 some minor improvements where made. At last in the year 2021 the game was further improved and dynamic demands and dynamic pricing of raw materials where added to the game, which resulted in a more realistic simulation showing the real behaviors of a real supply chain with exactly 300 team and almost 1200 players.

2.3. Core concepts of the game

Players compete inside a predetermined industry, and in the end, players with the most business value are declared the winners. For example, in 2020, players competed in the automobile production industry, or 2019, players competed in the processed food industry. In 2021 players competed in beverage market. However, other prizes are allocated to other achievements; Therefore, other metrics are also measured; for example, the player with the most efficient supply chain management system can be considered a prize. Fig 1. illustrates the core logic of the game. Firstly, Raw Materials that players use to produce Semi-finished Products are supplied by Raw Material Suppliers(AI). Players can buy their required materials by paying Cash to the Raw Material Suppliers(AI). Secondly, players start producing Semi-Finished Products, which are used in producing End Products, using the raw materials they have bought. It is worth mentioning that players can trade Semi-Finished products among themselves, enabling some players only to produce a single type of semi-finished product and maintain large profit margins by reaching economies of scale. Afterward, trading their semifinished products with other players. Finally, the End Product Market buys the End Products that players have manufactured based on an algorithm considering batch size, brand value, price, and distance.

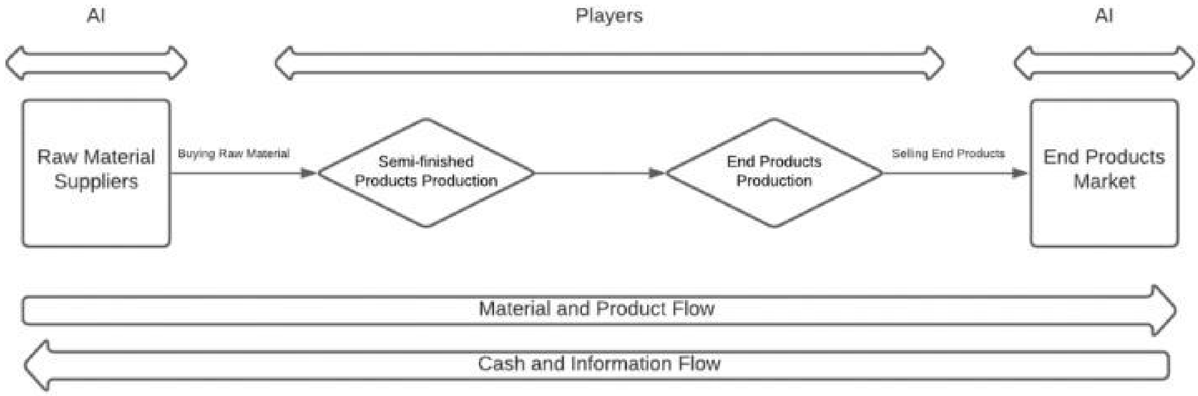

Figure 1: Game Diagram

3. Developing the Model

In GAMEIN 14 different providers of raw materials exist in different locations. Each provider only supplies specific raw materials. Players place orders on these providers to acquire their required feedstock to produce semi-finished products. Semi-finished products are allowed to be traded among players; this means that players can sell their produced goods or buy required goods. Next, semi-finished products are consumed to produce finished products. Ultimately, at the end of each week, players sell their stock of finished products to retailers (AI). Raw material prices in GAMEIN are sensitive to changes in demand over time. For example, suppose one specific raw material at a specific provider is under increasing demand by the players. In that case, the price will rise, and in contrast, if the demand for that particular raw material decreases over consecutive periods so the prices will fall. At the end of the supply chain, an algorithm based on several factors including, lot size, price, distance, and the brand score, determines the amount of a specific finished product that a specific player can sell to a particular retailer. This means that players may not be able to sell products equal to the demand amount they have predicted. In the manufacturing process, players are affected by variable production costs, fixed setup costs, maintenance costs, inventory costs, and transportation costs. Also, each machine has a limited production capacity. Each player has three inventories allocated to raw materials, semi-finished products, and finished products, each with a specific size. The main goal of each player is to increase his company's value during the 100 weeks of the game. To do so, they need to cleverly manage their supply chain and production lines to maximize their revenue. This is achieved first by choosing the finished product they want to produce after forecasting market demands and calculating the approximate revenue margin of each finished-products. Next, they need to develop a supplier selection method to minimize transportation and order costs of raw materials. Later on, a decision must be made on which semi-finished products to produce for self-consumption, which to produce for selling at the market (to other players), and which to buy from the market (from other players). Finally, a schedule must be made to manage ordering times, the inventory level of raw materials, semi-finished and finished products, and production lot size.

3.1. Simplification Assumptions

For this project, some assumptions are made to simplify the case to create a basic model. After that, the basic model will be used as the basis of more complex models that are planned to be developed in the future. These assumptions are as follows:

- All the raw materials are supplied through one provider.
- Finished products are sold to one retailer.
- Transportation Costs are excluded from the model.
- The finished products are limited to only Soda 1000 CC, Beer 1000 CC, Energy During 500 CC, and the semi-finished and raw materials in these three finished-products bill of material.
- Maintenance costs are excluded.
- Setup times are considered zero, but setup costs are included.
- Raw materials are bought in predetermined lot sizes. A constraint implements this in the model.
- The system can produce limited numbers of finished products in each period. A constraint implements this in the model.
- The system can produce limited numbers of semi-finished products in each period. A constraint implements this in the model.

- The objective function is to maximize profit by subtracting costs from the total revenue of selling products.
- If the player cannot meet the demands, the sales will be lost.
- The time horizon is limited to six weeks due to the limitations of the free version of CPLEX.

3.2. BOM

The bill of material of this simulator consists of three levels (Tri-level) of Raw Materials, Semi-Finished Products, and Finished Products. In this report, three Finished-Products (Soda 1000 CC, Beer 1000 CC, Energy Drink 500 CC) are. The Semi-Finished Products are Soda Concentrate, Malt Concentrate, Energy Concentrate, Carbonic Gas, Aluminum Bottle, and Plastic Bottle. The Raw Materials are Cereal Sprout, Sugar, CSD essence, HOP essence, HOP, Preservative, Caffeine, Aluminum, and Polymer. The BOM graphics are shown below in Figures 2, 3, 4 and 5.

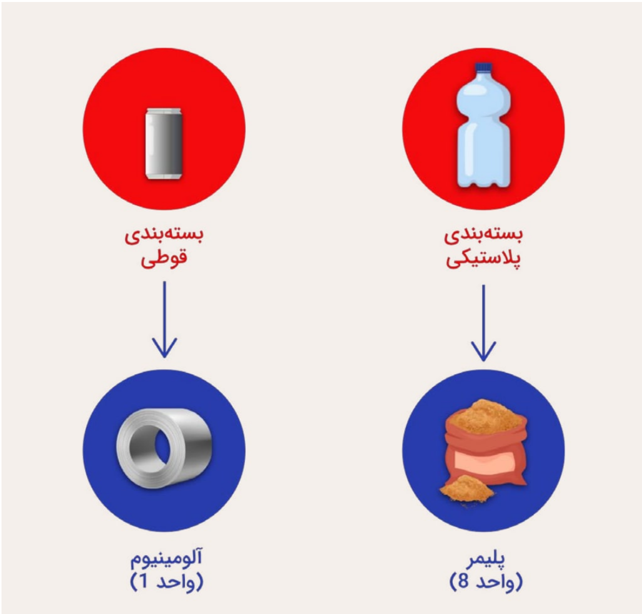

Figure 2: BOM 1

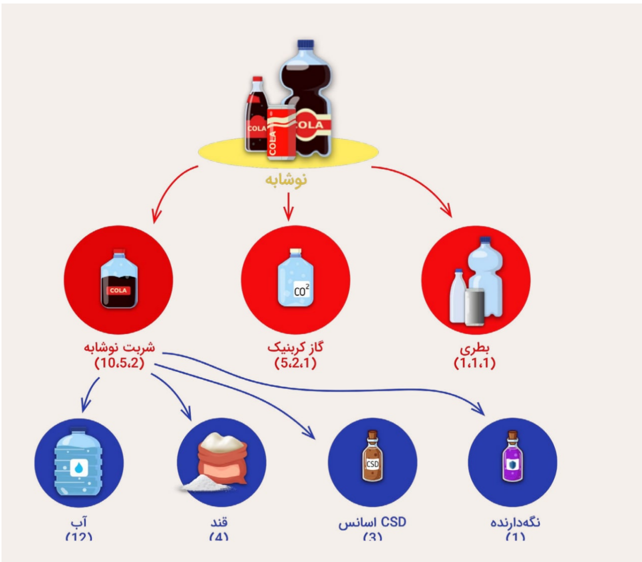

Figure 3: BOM 2

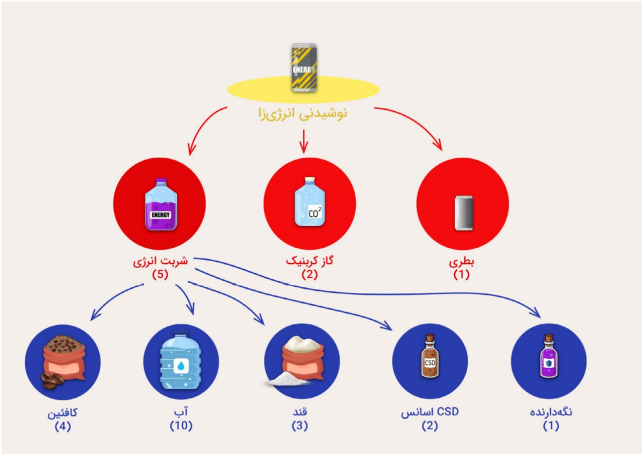

Figure 4: BOM 3

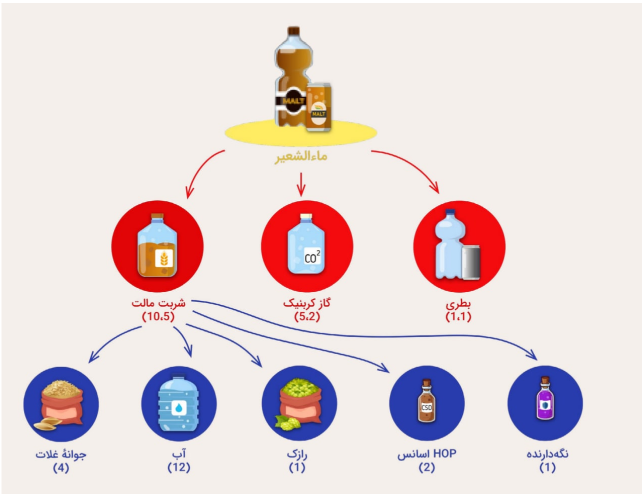

Figure 5: BOM 4

3.3. Basic Model

Based on the case description and the simplification assumptions, an Integer Programming TRI-Level Capacitated Lot Sizing Problem (TLCLSP) model is developed.

3.3.1 Model Sets, Parameters and Variables

The Sets, parameters and variables of the model and their description are shown in the following tables.

Table 1: Model Sets and Parameters

Name	Description
i	set of finished products
j	set of semi-finished products
k	set of raw materials
t	set of time horizon for production period
ICR	Inventory costs for raw materials
ICS	Inventory costs for semi-finished products
ICF	Inventory costs for finished products
MPR_{kt}	Market Price of raw material k at time t
MPS_{jt}	Market Price of semi-finished product j at time t
SBR	Sell/Buy price ratio for S products
MPF_{it}	Market Price of finished product i at time t
$PVCS$	Variable production costs for semi-finished products
$PVCF$	Variable production costs for finished products
$SCPS$	setup costs for semi-finished products
$SCPF$	setup costs for finished products
D_{it}	Demand for finished product i at time t
$BOMS_{jk}$	Number of raw material k used to produce one semi-finished product j
$BOMF_{ij}$	Number of semi-finished product j used to produce one finished product i
$IFCap$	Capacity of finished product Inventory
$ISCap$	Capacity of semi-finished product Inventory
$IRCap$	Capacity of raw material Inventory
$PFCap$	Capacity of finished product production
$PSCap$	Capacity of semi-finished product production
$PFSL$	number of different finished products allowed to be produced in each period
$PSSL$	number of different semi-finished products allowed to be produced in each period
LSR	LOT-SIZE coefficient for raw material orders

Table 2: Model Variables

Name	Decription
IR_{kt}	Inventory of raw material k at the end of period t
IS_{jt}	Inventory of semi-finished product j at the end of period t
IF_{it}	Inventory of finished product i at the end of period t
BF_{it}	Backlog of finished product i at the end of period t
SR_{kt}	Order/Supply of raw material k in period t
KSR_{kt}	Order/Supply of raw material k in period t Lot size quantifier
OSC_{jt}	Order Contracts of semi-finished product j in period t
SSC_{jt}	Sale Contracts of semi-finished product j in period t
PS_{jt}	Production of semi-finished product j in period t
PSS_{jt}	if semi-finished product j is produced in period t then 1; else 0
PF_{it}	Production of finished product i in period t
PFS_{it}	if finished product i is produced in period t then 1; else 0
CIR	Total inventory costs for raw materials
CIS	Total inventory costs for semi-finished products
CIF	Total inventory costs for finished products
CSR	Total order costs for raw materials
CPS	Total production costs for semi-finished products
CPF	Total production costs for finished products
TC	Total Costs
TR	Total Revenue

3.3.2 Model Equations

The constraints are divided into two main groups; the first group the balance equations are divided into three sub-levels, the first equation tries to meet the market demand for finished products, the second equation is responsible for making sure that enough semi-finished product exists for producing finished products by either manufacturing semi-finished products or buying them from the market, the third equation acts the same as the second just for raw material relation to semi-finished products and the fourth equations makes sure that raw materials are ordered in specified lot sizes. The second group of constraints Consists of inventory capacity equations. The third group of constraints is devoted to the production capacity of each week. Next are constraints that calculate the total cost of Inventory, total production costs including set up fees and contract costs, total costs, and total revenue from selling semi-finished and finished products.

$$\max Profit = TR - TC \tag{1a}$$

$$s.t.:$$

$$BalanceEquations \begin{cases} IF_{i,t-1} - IF_{it} + PF_{it} + BF_{it} = D_{it} & \forall i,t \quad (1b) \\ \sum_i BOMF_{ij} \cdot PF_{it} = IS_{j,t-1} + PS_{jt} - IS_{jt} + OSC_{jt} - SSC_{jt} & \forall j,t \quad (1c) \\ \sum_j BOMS_{jk} \cdot PS_{jt} = IR_{k,t-1} + SR_{kt} - IR_{kt} & \forall k,t \quad (1d) \\ SR_{kt} = KSR_{kt} \cdot LSR & \forall k,t \quad (1e) \end{cases}$$

$$Setup\ Limitations \begin{cases} PF_{it} \leq PFS_{it} \cdot M & \forall i,t \quad (1f) \\ PS_{jt} \leq PSS_{jt} \cdot M & \forall j,t \quad (1g) \\ \sum_i PFS_{it} \leq PFSL & (1h) \\ \sum_j PSS_{jt} \leq PSSL & (1i) \end{cases}$$

$$Inventory\ Cap \begin{cases} \sum_i IF_{it} \leq IFcap & \forall t \quad (1j) \\ \sum_j IS_{jt} \leq IScap & \forall t \quad (1k) \\ \sum_k IR_{kt} \leq IRcap & \forall t \quad (1l) \end{cases}$$

$$Production\ Cap \begin{cases} \sum_i PF_{it} \leq PFcap & \forall t \quad (1m) \\ \sum_j PS_{jt} \leq PScap & \forall t \quad (1n) \end{cases}$$

$$Inventory\ Costs \begin{cases} CIR = \sum_k \sum_t ICR \cdot IR_{kt} & (1o) \\ CIS = \sum_j \sum_t ICS \cdot IS_{jt} & (1p) \\ CIF = \sum_i \sum_t ICF \cdot IF_{it} & (1q) \end{cases}$$

$$Supply\ \&Production\ Costs \begin{cases} CSR = \sum_k \sum_t MPR_{kt} \cdot SR_{kt} & (1r) \\ CPS = \sum_j \sum_t (PVCS \cdot PS_{jt} + OSC_{jt} \cdot MPS_{jt} + PSS_{jt} \cdot SCPS) & (1s) \\ CPF = \sum_i \sum_t (PVCF \cdot PF_{it} + PFS_{jt} \cdot SCPF) & (1t) \end{cases}$$

$$Total\ Costs\&Revenue \begin{cases} TC = CIR + CIS + CIF + CSR + CPS + CPF & (1u) \\ TR = \sum_i \sum_t (D_{it} - BF_{it}) \cdot MPF_{it} + \sum_j \sum_t SSC_{jt} \cdot MPS_{jt} * SBR & (1v) \end{cases}$$

$$Initial\ Inventory \begin{cases} IF_{i0} = 0 & \forall i \quad (1w) \\ IS_{j0} = 0 & \forall j \quad (1x) \\ IR_{k0} = 0 & \forall k \quad (1y) \end{cases}$$

all variables and parameters are non-negative integers.

4. Data Gathering

The data used in this report consist of two types. First are the common knowledge data and those published before the official launch for players to plan their strategies and build their optimization models. This data group includes BOM, Inventory Cost per Unit, Setup Fixed Cost, Production Variable Cost, Transportation Costs, Production Rates, Inventory Capacities. This type of data was gathered from the GAMEIN official website. The second group of data is those that players were unaware of but only had a general knowledge of the trends. For example, demands were classified, but players knew how the trends were to predict the markets. This type of data was gathered from the simulator database after the end of the contest. Other mentionable data are price behaviors either in raw materials or semi-finished products. This type of data was not predetermined and generated based on player behaviors; this data was extracted from the database. And finally, complete datasets on the player situation through the game, including their orders, production, and decisions they made.

Table 3: Model Parameters Initial Value

Name	value	Name	value
i	3	k	9
j	5	t	6
ICR	1	ICF	5
ICS	3	$PVCS$	5
$PVCF$	100	$SCPS$	375000
$SCPF$	150000	$IFCap$	60000
$ISCap$	240000	$IRCap$	3000000
$PFCap$	3000	$PSCap$	35000
$PFSL$	1	$PSSL$	5
SBR	0.8	LSR	1000

5. Tools

The model was solved using CPLEX solver and was modeled using Pyomo Library by Python Version 3.8.

6. Solving

As mentioned in the previous section, we implemented a Python program to solve and analyse this problem. The code and plots (high-resolution files) are attached to this report, and we only provide tables for the most important decision variables, that is, the production and inventory variables. Also it is worth mentioning that this solution can bring us a profit of $889,534,010$ currency units.

Table 4: Decision Variables for FInal Products

Table 5: Production

PF - T	1	2	3	4	5	6
soda	0	0	1921	2125	2508	0
beer	3000	0	0	0	0	0
energy	0	1715	0	0	0	0

Table 6: Inventory

IF - T	1	2	3	4	5	6
soda	1288	0	0	0	0	0
beer	2317	1745	891	0	0	0
energy	0	1486	1145	767	321	0

Table 7: Decision Variables for Semi-FInal Products

Table 8: Production

PS - T	1	2	3	4	5	6
sodaliq	35000	35000	35000	35000	35000	35000
pbottle	0	0	0	0	0	0
energyliq	0	0	0	0	0	0
abottle	0	0	0	0	0	0
maltliq	0	0	0	0	0	0

Table 9: Inventory

IS - T	1	2	3	4	5	6
sodaliq	35000	0	0	0	9920	0
pbottle	0	35000	0	0	0	0
energyliq	0	0	0	240000	0	0
abottle	0	0	0	0	0	0
maltliq	205000	205000	0	0	0	0

Table 10: Decision Variables for Semi-FInal Products (Sales and Orders)

Table 11: Orders

OSC - T	1	2	3	4	5	6
sodaliq	0	0	0	0	0	0
pbottle	3000	35000	0	2125	2508	0
energyliq	0	8575	0	240000	0	0
abottle	0	1715	0	0	0	0
maltliq	235000	0	0	0	0	0

Table 12: Sales

SSC - T	1	2	3	4	5	6
sodaliq	0	70000	15790	13750	0	44920
pbottle	0	0	33079	0	0	0
energyliq	0	0	0	0	240000	0
abottle	0	0	0	0	0	0
maltliq	0	0	205000	0	0	0

Table 13: Decision Variables for Raw Materials

Table 14: Supply

SR - T	1	2	3	4	5	6
grain	0	0	0	0	0	0
hop	0	0	0	0	0	0
hopcsd	0	0	0	0	0	0
cns	35000	35000	140000	0	0	0
caffeine	0	0	0	0	0	0
sugar	280000	0	140000	420000	0	0
csd	105000	105000	420000	0	0	0
al	0	0	0	0	0	0
plastic	0	0	0	0	0	0

Table 15: Inventory

IR - T	1	2	3	4	5	6
grain	0	0	0	0	0	0
hop	0	0	0	0	0	0
hopcsd	0	0	0	0	0	0
cns	0	0	105000	70000	35000	0
caffeine	0	0	0	0	0	0
sugar	140000	0	0	280000	140000	0
csd	0	0	315000	210000	105000	0
al	0	0	0	0	0	0
plastic	0	0	0	0	0	0

It can be infered from the optimal solution that it is efficient to out-source our production for all of the semi-final products except the sodaliq, which is proved to our bottleneck product. Furthermore, it can be seen that our model tries to sell its surplus products to other players, that is, it sells the remainder of its ordered semi-final products back to the market, as the lot-size is not small.

7. Sensitivity Analysis

After solving the model, it needs to be analysed what happens if our parameters change. To do so, we ran sensitivity analysis on the following parameters:

7.1. Demands for final products

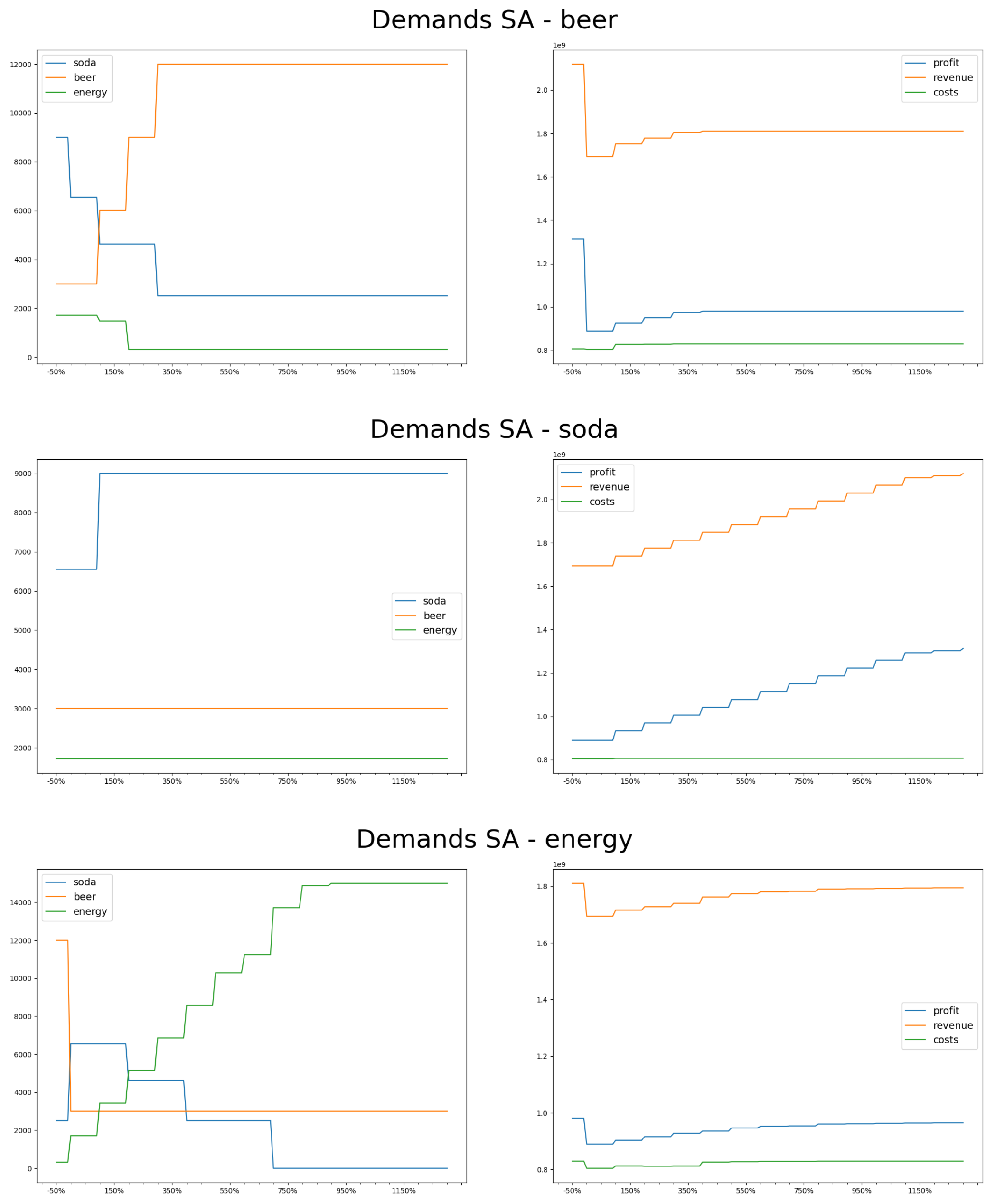

Figure 6: Sensitivity Analysis on the demands for different final products

From the first plot in Fig. 6 we learn that if the demand for beer is increased more than 350%, the system uses all of its capacities and cannot fulfill the demands for beer by declining other orders.
On the other hand, under the same circumstances for the soda, our system can still profit from the increase in demands.
Finally, as energy drinks are not a bottleneck in our system, as well as they are worthy to produce, we can fulfill the demand even if it is risen by 900%.

7.2. Market Prices for final products

Figure 7: Sensitivity Analysis on the market prices for different final products

7.3. Lot size

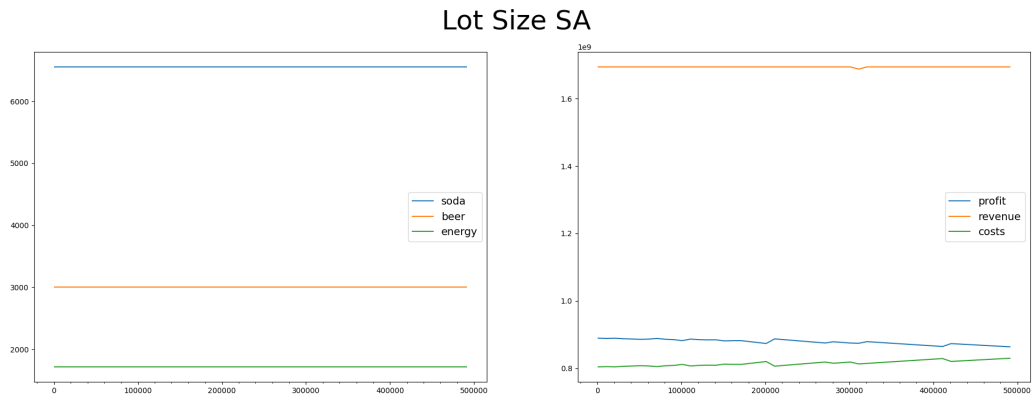

Figure 8: Sensitivity Analysis on the lot size

Fig. 8 proves that the more lot size causes loss in the profit, which is caused by the extra semi-final products that are received from the market, and the difference in buying from and selling those items to the market.

7.4. Sell to Buy ratio for semi-final products

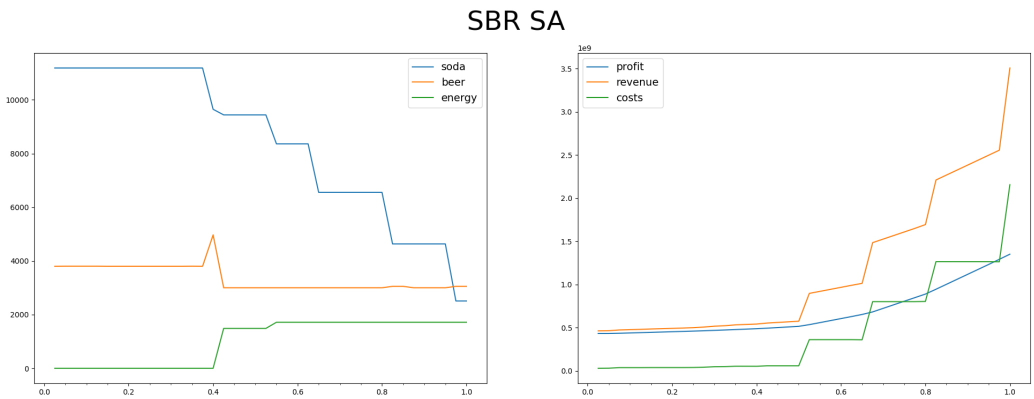

Figure 9: Sensitivity Analysis on the SBR parameter

Fig. 9 exhibits that if SBR is increased, our profit increases, which is totally intuitive as we can sell our wastes (extra semi-final products) at a better price, as well as avoiding fixed costs by selling semi-final products instead of setting up our own plant.

8. Future challenges

It is planned to include multi-providers and multi-retailers in future models; to do so, supplier selection and retailer selection constraints are needed to be added to the model, to do so, transportation costs will be added to the model, and a new index will be added to the price parameters, demand parameters, and SR parameters. And as the final goal, real players' behavior will be fitted to the model results, and the behavior of winning and losing teams will be analyzed. For another research, players could be asked to answer some questions on their knowledge on Optimization, Supply Chain Management, Production Planning, Revenue Management. The data gathered could be used in some behavioral studies to evaluate the effectiveness of current education in these subjects.