Georgia Tech College of Engineering
H. Milton Stewart School of
Industrial and Systems Engineering

ISYE 6202 Supply Chain Facilities

Casework 1.1

FruitSoul Demand and Capacity Modeling Under Full Clairvoyance

Professor Benoit Montreuil
Doctoral students Metin Inan and Ashwin Pothen

- *The casework is meant to be realized in self-organized teams of up to 3 students, yet may be realized solo, with the number of students in the team having no influence on the grading.*
- *The casework deliverables are due at the latest on September 29th at 23h59.*
- *The casework is shaped around a set of mandatory tasks, each having a significant grading weight, purposefully not revealed to the class.*
- *For each task, you must rigorously describe your methodology, present your results, analyze them, and discuss them relative to the current task and, when pertinent, relative to previous tasks.*
- *For computational algorithms and simulations, exploitation of Python and linked tools is preferred. Using spreadsheets such as Microsoft Excel/VBA is tolerated. All developed codes are to be provided.*
- *The casework is built around a fictitious enterprise and using a realistic yet simplified synthetic dataset, assuming that the current date is April 11th, 2024.*

Overall Introduction

FruitSoul has launched was founded in 2021 by an entrepreneurial team to market and produce the MindBlow food supplement that is based on a combination of natural ingredients and of new nutrients developed and patented by the team in previous years in partnership with a leading research and development firm.

The MindBlow food supplement has been approved by the US Food and Drugs Administration. Numerous experts have performed rigorous comparative tests with competitive alternatives, with FruitSoul significantly outperforming them in terms of the targeted health and performance benefits.

FruitSoul has developed a set of nine mixes of its powerful food supplement with savory natural fruit combinations that has been tested by both renown dietitians as well as sampled groups of consumers, receiving high praise:

1. **Apple & Mango**: A mix of crispness and tropical sweetness.
2. **Blackberry & Pear**: Rich and earthy flavor combined with subtle sweetness.
3. **Blueberry & Lemon**: Refreshing and vibrant sweet-acidic-zesty flavor.
4. **Cherry & Lime**: Bold balance of deep sweetness and sharpness.
5. **Grape & Pomegranate**: Classic sweetness enhanced by the tart and bitter notes.
6. **Orange & Passion Fruit**: A tangy and sweet experience.
7. **Peach & Raspberry**: Soft sweetness paired with tanginess.
8. **Pineapple & Coconut**: Tropical piña colada style.
9. **Strawberry & Kiwi**: Sweet and slightly tart.

The FruitSoul mixes are sold in high quality jars with artistically designed labels to emphasize the power of the supplement, the savor of each fruit combination, and the soul style. The jars come in three sizes, respectively 8, 16, and 32 volumetric ounces, with heights of 4, 5.2, and 6.8 inches, and maximum diameters of 2.4, 3.2, and 4 inches. The combination of one supplement processed into nine mixes and three jar sizes leads to a portfolio of 27 distinct products.

Since its sales and operations launching in early January 1st, 2022, FruitSoul sells exclusively through its website, channeling customers through active presence in social media, with heavy focused advertising and discounts, and support from a set of stars from the music scene, the sports scene, and the techno-entrepreneurial scene, as well as from top food and health focused influencers. FruitSoul launches a few major promotions a year that boost its sales significantly during the promotion period, with the largest promotion occurring during Cyber Week in November of each year.

On its website, FruitSoul has a four-step customer experience process. First it guides the customer towards identifying the desired product-s and the quantity desired. Second, once the customer has selected, FruitSoul requires the location of the customer and his-her earliest, preferred, and latest delivery dates. Third, based on the above customer provided information and its current shipping and delivery capabilities, FruitSoul then provides the dates at which it can ship and then deliver each demanded item, after what the customer confirms for each product whether he-she is buying it and when he-she wants it delivered in the feasible time horizon. Fourth, if the customer does not buy anything, he-she leaves the site, otherwise he-she proceeds toward payment before happily leaving the site.

The joined “FruitSoul Demand Log” spreadsheet provides the demand history of FruitSoul built from the records of the process above. It provides information on each customer demand since FruitSoul’s launching. Information includes for each demand, the demand record number, the demand date, the customer location at state level, the demanded product and the quantity demanded for each product, as well as the customer’s earliest, preferred, and latest delivery dates. For this study, FruitSoul has purposefully not provided the actual decision whether the customer did buy the product-s given the provided earliest shipping and delivery dates.

Task 1: Based on the provided demand log, compute the following five tridimensional demand histories of the quantity of units of each product (dimension P) in each state location (dimension L) in each day since FruitSoul launch (dimension T):

1. *Demand request history: how many product units of each product have demand been made known to the company by customer-s in each day.*
2. *Preferred demand delivery history: for how many product units of each product have each day been demanded as preferred delivery day.*
3. *Earliest demand delivery history: for how many product units of each product have each day been demanded as earliest acceptable delivery day.*
4. *Latest demand delivery history: for how many product units of each product have each day been demanded as latest acceptable delivery day.*
5. *Smoothed demand delivery history: how many products units are estimated to have their delivery demand potentially realized in each day. The smoothing exploits the distinct earliest, preferred, and latest dates, to spread each product unit demand into demand fractions for each of the feasible day.*

Provide a macroscopic version of these five demand histories, successively aggregating all products into a single product portfolio and aggregating all states into a single overall market territory, and finally aggregating both.

Analyze your results and provide key insights.

Task 2: Investigate whether there is at the macroscopic level indication of demand growth over the horizon, day-of-week seasonality, weekly or 4-weekly seasonality, and promotional impact. Provide whenever pertinent estimates of growth trend, seasonality factors, and promotional impact factors. Analyze your results and provide key insights.

Task 3: Leveraging the demand request history for all products, compute the demand share history of each product. Investigate whether the product demand share of each product is evolving through time or is rather stable. Analyze your results and provide key insights.

Task 4: Leveraging the all-product portfolio demand request history for all states, compute the demand share history of each state. Investigate whether the product demand share of each product is evolving through time or is rather stable. Analyze your results and provide key insights.

FruitSoul produces and ships all its products from its factory based in Stone Mountain, Georgia. All year long, the factory operates according to two 8-hour shifts per day, six days a week, being off on Sundays, the 4th of July, and Labor Day.

Delivery of the ordered products to customers all around the USA has been contracted to a single service provider that picks up at the factory the ready-to-ship packed orders around 18h00 each working day. The file "FruitSoul Expected Delivery Cost and Time" provides, as its name implies, expected delivery distance, cost and time from Stone Mountain, Georgia, to customers in each State.

Destination State	Approximate distance from Stone Mountain (miles)	Expected Delivery Cost From Stone Mountain (USD/ounce)	Expected Delivery Time From Stone Mountain (days)
Alabama	150	0.92	1
Alaska	3410	2.78	5
Arizona	1840	2.78	5
Arkansas	450	1.10	3
California	2170	2.78	5
Colorado	1210	1.76	5
Connecticut	870	1.41	5
Delaware	690	1.41	5
Florida	440	1.10	3
Georgia	-	0.91	1
Hawaii	4480	2.78	5
Idaho	2160	2.78	5
Illinois	720	1.41	5
Indiana	420	1.10	3
Iowa	870	1.41	5
Kansas	880	1.41	5
Kentucky	320	1.10	3
Louisiana	480	1.10	4
Maine	1280	1.76	5
Maryland	680	1.41	5
Massachusetts	1060	1.76	5
Michigan	780	1.41	5
Minnesota	1130	1.76	5
Mississippi	350	1.10	3
Missouri	690	1.41	5

Destination State	Approximate distance from Stone Mountain (miles)	Expected Delivery Cost From Stone Mountain (USD/ounce)	Expected Delivery Time From Stone Mountain (days)
Montana	2060	2.78	5
Nebraska	1050	1.76	5
Nevada	2080	2.78	5
New Hampshire	1100	1.76	5
New Jersey	770	1.41	5
New Mexico	1350	1.76	5
New York	870	1.41	5
North Carolina	360	1.10	3
North Dakota	1390	1.76	5
Ohio	550	1.10	4
Oklahoma	2170	2.78	5
Oregon	800	1.41	5
Pennsylvania	960	1.41	5
Rhode Island	300	0.98	2
South Carolina	1280	1.76	5
South Dakota	230	0.98	2
Tennessee	740	1.41	5
Texas	800	1.41	5
Utah	1740	2.22	5
Vermont	1030	1.76	5
Virginia	520	1.10	4
Washington	2180	2.78	5
West Virginia	500	1.10	4
Wisconsin	700	1.41	5
Wyoming	1550	2.22	5

Task 5: Extend FruitSoul Demand Log by adding three columns respectively providing the earliest acceptable, preferred, and latest acceptable shipping dates for each demand request, accounting for the customer state and the delivery times expressed in the table above. Then, further extend FruitSoul Demand Log by adding three other columns respectively providing the minimal, customer-preferred, and maximal order-to-ship times for each demand request. Finally, similarly as in task 1, compute estimations for the preferred, earliest, latest and smoothed shipping demand history. Analyze your results and provide key insights.

FruitSoul's factory is organized around three successive process centers respectively focused on mixing, bottling, and packing-and-shipping. The third process center is responsible for both packing and shipping as FruitSoul has a policy of only packing orders that are to be shipped at the next pickup time by the delivery service provider.

Each process center is composed of a set of parallel modular processing cells. Each cell can be operated by one to five workers. In order to control operational complexity, FruitSoul enforces that the number of workers active in a cell can be changed from one shift to the next, but not within a shift. The following Tables provide key information regarding each process center and its processing cells, including a brief description, input, output, cell dimensions, production capacity, one-time cell setup cost and daily cell cost (covering acquisition, maintenance, energy).

Process Center	Brief Description	Input	Output	Cell Dimensions
Mixing	Mixing raw materials and flavor ingredients to create the final mix	Nutrient and fruity ingredients	Mix container	12ft x 12ft
Bottling	Fill jars with final mix, seal, and label	Final mix, empty jars	Labelled jars ready to ship	12ft x 12ft
Packing	Fill boxes with labelled jars, place shipping label	Empty boxes, order labels	Shipment packages	12ft x 9ft

Process Center	8-hour shift capacity per production cell as a function of the number of					Units
	1	2	3	4	5	
Mixing	640	1664	2304	2816	3200	Ounces
Bottling	100	175	240	300	350	Jars
Packing	30	55	100	130	150	Jars

Process Center	Unit Cell Setup Cost	Unit Daily Cell Cost
Mixing	$15,000	$400
Bottling	$8,000	$350
Packing	$5,000	$600

The mixing center produces the nine mixes in standard 3-gallon mix containers of 12 inches long and wide and 9 inches high. Each bottling cell is equipped to always have up to 4-hour ahead of mix containers in line with its daily bottling plan.

In its factory, FruitSoul has three types of employes. P-workers have the skills only to work in packing. B-workers have the skills to work both in packing and bottling. M-workers have the skills to work in packing, bottling, and mixing. P-workers, B-workers, and M-workers respectively cost the enterprise $20, $25, and $30 per regular hour, and 1.5 times these rates in overtime past 40 hours a week, up to a maximum of 55 hours a week in total. Due to training and expertise preservation considerations, FruitSoul enforces that all B-workers and M-workers are full-time permanent employees. FruitSoul aims for a stable core group of full-time permanent P-workers combined to a pool of part-time P-workers that are called on demand, always on a full-shift basis. These on-demand P-workers are estimated by FruitSoul to cost the enterprise in average around 15% more expensive than the core ones due to the extra administrative efforts and to training and quality related costs. Furthermore, FruitSoul has learned that on-demand P-workers should never account for more than 30% of the total workforce active in a given day, and ideally no more than 15%, to avoid losing time training workers in peak times, and to avoid efficiency, quality, and team spirit deterioration.

A provided in the above Table, the setup cost for a processing cell covers the initial installation and activation of the cell in the factory while the daily cell cost covers its acquisition price (price of delivered equipment and tooling), and its preventive and corrective maintenance, as well as its energy costs. Relative to the building cost, consider a yearly cost of \$25/ft^2-year and assume the required space to be 1.5 times the sum of the total space required by operating cells.

Materials costs are approximated below on a per-jar basis.

Material Cost per Jar	8-Ounce Jar	16-Ounce Jar	32-Ounce Jar
Ingredients	\$ 4.80	\$ 9.60	\$ 19.20
Bottle and Label	\$ 1.50	\$ 2.00	\$ 2.50
Packing	\$ 0.25	\$ 0.55	\$ 1.20

All mentioned production and materials characteristics and costs are included in file "FruitSoul Production and Materials Characteristics and Costs.xlsx".

Although product pricing is highly dynamic overall and for each specific product due to the constant flow of a multiplicity of laser-focused short-term promotions, FruitSoul requires you to assume in this study that market prices for 8-ounce, 16-ounce, and 32-ounce jars are respectively \$39, \$59, and \$89.

Until now, FruitSoul has strictly operated according to a stockless production-to-order policy, never bottling and/or packing a jar of product that is not already assigned to a paid customer order, thus with absolutely no inventory of finished products. It also has enforced that there be no stock of ready-to-bottle mix containers, refusing to mix anything for which there is not an order to be bottled and ship in the forthcoming hours.

Task 6: *Based on the results of task 5 and the imposition of the* stockless production-to-order policy*, identify all demand requests from customers that are fundamentally impossible to satisfy and are thus lost sales. Remove these from the shipping demand to get an achievable shipping demand history. Compute the percentage of demand that is lost in this fashion. Discuss.*

Task 7: *Given FruitSoul stockless production-to-order policy and the shipping demand histories estimated in task 6, develop estimated preferred, earliest, latest and smoothed packing-and-shipping demand history, bottling demand history, and mixing demand history.*

Task 8: *Assuming full clairvoyance, indeed full look-ahead knowledge of current and forthcoming demands (which is impossible in reality and here will be used as an ideal best bound), develop an approach for generating an integrated packing-bottling-mixing capacity, production, and shipping plan that guarantees that a S% service level is achieved. This means that at maximum S% of the demands will not be delivered within their earliest and latest acceptable times (thus resulting in lost sales), doing so at minimized cost and aiming to deliver demands as near to their*

preferred date as possible. Capacity is here measured in terms of number of cells of each type to be implemented and used in each year and the required number of workers of each skill level. Cost should account for the building space costs, the cell costs, and the workforce cost over the overall horizon.

The plan is not required to be proven fully optimal. Heuristic algorithms may be used to generate plans for specific values of service level S.

Develop a daily-step simulator and the pertinent performance dashboards to validate that your plan is feasible given any value of service level S. Then perform an experiment demonstrating the impact of target service level S on capacity requirements and costs. Discuss your results.

Task 9: Develop a financial planning model encompassing all revenues and costs generated by your proposed service level dependent plans. Your model should allow to generate financial planning outcomes such as financial reports and plots of revenues, costs, net profits (before administrative, R&D, etc.), and profit margins, at weekly and annual granularity levels. It is suggested yet not imposed that this model be integrated with your simulator for convenience purposes.

Use this model to financially contrast and analyze the plans obtained for your various target service level scenarios in task 8.

FruitSoul is now ready to consider building stocks of finished product jars, ready to pack and shift. As the filled and sealed bottles can be stored at room temperature, these would be stocked in a finished product distribution center (FPDC) without refrigeration capability, located near the bottling and packing centers. In the bottling center, individual jars would be placed in 12-jar cases of length-width-height dimensions of 13x10x6 $inch^3$ for 8-ounce jar cases, 15x10x7 $inch^3$ for 16-ounce jar cases, and 17x13x9 $inch^3$ for 32-ounce jar cases. In the FPDC, the cases would be stocked on typical storage racks of dimensions of 96x36x120 $inch^3$ with 10-tier shelving. According to FruitSoul, a rack shelving must concurrently store only cases of same-size jars. For planning purposes, use an overall space requirement of 36 ft^2 per storage rack, including the rack itself and sufficient maneuvering aisle space.

Handling of cases of jars from the bottling center to racks in the FPDC and then from a rack in the FPDC to a cell in the packing center is to be performed in priority by P-workers, yet it may be performed by any B-worker or M-worker when deemed pertinent.

FruitSoul intends for product-specific jar cases to be stored together in a disciplined way facilitating first-in-first-out usage.

Task 10: Assess how many cases can be stored on a single shelving, depending on the jar size. Provide illustrative layouts to demonstrate your results. Develop and demonstrate an algorithm for estimating the number of racks needed to enable

concurrently storing a specific quantity of cases of 8, 16, and 32 inches (e.g. 8: 200, 16: 100, 32: 50).

Task 11: There is strong argumentation within FruitSoul about which of the following two operating practices should be used:

a. *All finished product bottles produced in the bottling center are directly sent to the FPDC to be stored. All finished product bottles requested from the packing center are picked from racks in the FPDC, always picking the oldest cases first.*
b. *All finished product bottles produced in the bottling center are sent directly to the packing center if this center still needs replenishment of this product in the next H hours (H is currently perceived to be around 2 to 4 working hours), otherwise they are directly sent to the FPDC to be stored. All finished product bottles requested by the packing center from the FPDC (rather than directly from the bottling center) are picked from racks in the FPDC, always picking the oldest cases first.*

Describe in further detail how each operating practice could work in daily operations, enabling to perceive well the differences between them and their relative advantages and disadvantages. Based on your analysis, express and justify your recommendations.

Task 12: Exploiting now the capability of bottling and storing finished products that are not yet ordered by customers, assuming full clairvoyance and leveraging the packing-and-shipping demand history developed in task 7, develop an approach for generating an integrated packing-bottling-mixing capacity, production, and shipping plan that guarantees that a S% service level is achieved while maximizing net profit and aiming to deliver demands as near to their preferred date as possible.

Capacity is here measured in terms of number of cells of each type to be implemented and used in each year, the number of storage racks to be implemented and used in the FPDC in each year, and the required number of workers of each skill level. Leveraging and enhancing your financial planning model, profit should account for the revenues from sales, the building space costs, the cell costs, the rack costs, the inventory holding costs, and the workforce costs over the overall horizon.

The plan is not required to be proven fully optimal. Well justified heuristic algorithms may be used to generate plans for specific values of service level S.

Enhance your daily-step simulator and the pertinent performance dashboards to validate that your plan is feasible and profitable given any value of service level S. Then perform an experiment (1) demonstrating the impact of target service level S on capacity requirements, revenues, costs, and profit; and (2) contrasting the

performance of the new bottle-to-stock operating strategy and the no-stock produce-to-order operating strategy. Analyze and discuss your results.

FruitSoul now wants to explore extending beyond the bottle-to-stock strategy, to now investigate the potential of also allowing to mix-to-stock to enable an integrated strategy allowing to smartly exploit both mix-to-stock and bottle-to-stock. This would open the potential of having stocks of any of the 27 products and of any of the nine mixes. The logic for this strategy according to FruitSoul is that it may allow for smoothly run the mixing center, building inventory of mix containers ahead of demand peaks associated with large FruitSoul initiated promotions, being always highly responsive to supply requests from the bottling center as it deals with demand bumps from the pack-&-ship center and to prepare finished product inventory to also deal with the large forthcoming promotions peaks, and hence succeeding to contain the stressful rush of rapidly fulfilling high-peak demands to the pack-&-ship center. Overall, it should reduce significantly the capacity requirements of the mixing and bottling centers. This is why FruitSoul wants to explore this strategy.

As the filled and sealed mix containers can be stored at room temperature, these would be stocked in a mix distribution center (Mix DC) without refrigeration capability, located near the mixing and bottling centers. In the Mix DC, the mix containers cases would be stocked on typical storage racks of dimensions of 96x36x120 inch^3 with 10-tier shelving. According to FruitSoul, a rack shelving must concurrently store only containers for the same mix. For planning purposes, use an overall space requirement of 36 ft^2 per storage rack, including the rack itself and sufficient maneuvering aisle space. FruitSoul intends for mix-specific containers to be stored together in a disciplined way facilitating first-in-first-out usage. Handling of mix containers from the mixing center to racks in the Mix DC and then from a rack in the Mix DC to a cell in the bottling center is to be performed in priority by P-workers, yet it may be performed by any B-worker or M-worker when deemed pertinent.

Task 13: Do as in task 10, now for mix containers.

Task 14: Based on your learning in task 11, now similarly address the alternative operating practice choice for mix containers.

Task 15: Exploiting now the capability of bottling and storing finished products that are not yet ordered by customers and of mixing and storing the nine mixes as desired, and assuming full clairvoyance and leveraging the packing-and-shipping demand history developed in task 7, develop an approach for generating an integrated packing-bottling-mixing capacity, production, and shipping plan that guarantees that a S% service level is achieved while maximizing net profit and aiming to deliver demands as near to their preferred date as possible.

Capacity is here measured in terms of number of cells of each type to be implemented and used in each year, the number of storage racks to be implemented and used in the FPDC and in the Mix DC in each year, and the required

number of workers of each skill level. Leveraging and enhancing your financial planning model, profit should account for the revenues from sales, the building space costs, the cell costs, the rack costs, the inventory holding costs, and the workforce costs over the overall horizon.

The plan is not required to be proven fully optimal. Well justified heuristic algorithms may be used to generate plans for specific values of service level S.

Enhance your daily-step simulator and the pertinent performance dashboards to validate that your plan is feasible and profitable given any value of service level S. Then perform an experiment (1) demonstrating the impact of target service level S on capacity requirements, revenues, costs, and profit; and (2) contrasting the performance of the explored mix-&-bottle-to-stock strategy, bottle-to-stock operating strategy, and the no-stock produce-to-order operating strategy. Analyze and discuss your results.

Task 16: Provide FruitSoul an Executive Summary highlighting your overall assessments, insights, and recommendations, in a up to two pages format and including compelling Figures and/or Tables.

Task 17: Synthesize your team's key learnings from performing this casework.