**2020 INFORMS O.R. & Analytics Student Team Competition**

**FINAL PROBLEM STATEMENT**

The 2020 Title Sponsor, Bayer, has provided a challenging and multi-faceted problem for Competition teams to solve.  In order to make the problem realistic, manageable, and instructive, the problem uses a fictitious company and product.  However, this type of production planning and logistics problem is a common challenge for many types of industries.

The problem asks students to design a distribution network that involves determining product flows in the presence of resource capacity constraints at manufacturing facilities.  Using realistic data, students will need to perform statistical analyses, develop simulation models and/or machine learning, design the distribution network using optimization, and conduct a quantitative assessment of their solution.

**The Problem: Network Design & Facility Operations Modeling**

Jelly Bean (JB) Manufacturing is headquartered in Chicago, IL with manufacturing facilities in five locations spread throughout the midwestern region of the United States as shown in Figure 1. These five manufacturing facilities supply both domestic and international orders for jelly beans. JB Manufacturing sells jelly beans in bulk that are of different colors, sizes, and flavors. JB Manufacturing locations operate each year from April 1st (8am) to September 30th (5 pm), to fulfill seasonal demand for Halloween. Any production after 5pm on September 30th, would be considered lost sales; the amount of lost sales should be quantified in the student report out.

A close up of a logo

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Figure 1: Locations of JB Manufacturing headquarters and manufacturing facilities.

The headquarters in Chicago, IL is home to the company’s administrative, supply chain (planning, manufacturing, and logistics), process engineering, and commercial organizations. Each year, the orders for jelly beans from the wholesale retailers are received by the commercial organization and are passed on to the supply chain planning team. Competition teams will be provided with data showing the order bank comprising all orders received by the commercial team, specifying the quantity of a given color, size, flavor, and desired packaging.

**Definition:** Stock Keeping Unit (SKU) - Jelly beans that are of the same color, size and flavor packaged either in a bag or in a box constitute one SKU.

The supply chain planning team processes these orders and creates internal work orders for each manufacturing location specifying the quantity of jelly beans of a given color, size, and flavor that need to be packaged in bags and boxes at each site based on the initial inventory levels at start of the season at each site.

Jelly bean manufacturing is split into two phases--color coating & flavoring. For the scope of this competition, we assume that the coloring steps have been completed and the colored jelly beans are stored in the Raw Material Inventory Store and will pass through a series of operations before they are packaged. Figures 2 & 3 depicts both the process flow and the product differentiation at each processing step. Though the processing steps and stages for jelly bean manufacturing are similar, each of the locations has unique infrastructure with varying numbers of machines with different processing capabilities.

**Process Steps & Product Flow:**

*Raw Material Inventory (RMI) Store*: At each manufacturing facility, several drums act as an inventory store for the Raw Material. The number of drums and their capacities varies by site and the details by site are provided in the ‘Facility Details’ section below. Individual drums can hold jelly beans with a same color, however, jelly beans of a given color can occupy more than one drum. Further, at any given time at each site, jelly beans from a single RMI drum are released into the classifier to avoid mixing of colors at the downstream operations.

Rules:

1. Order of release from the RMI drums is dictated by the internal workorder designed by the planning function.
2. If there are two RMI drums with the same color at a given location, empty the drum with lower equipment number.
3. Releasing jelly beans from the RMI drum is allowed only if there are at least five pre-finished inventory bins empty and available.

*Classifier*: While each drum at the RMI stage holds jelly beans with the same color, the sizes of these jelly beans within a drum may vary. As the individual drums at the RMI step are emptied for further processing at the Classifier operation, the colored jelly beans are separated into five different sizes. The percentage split for each of the sizes is derived based on the historical data, these percentage splits for each color are provided in the data set.

*Pre-Finish Inventory (PFI) Store*: Once the colored jelly beans are sized and segregated, the beans are then stored in the PFI drums. To ensure contamination is avoided, each of the jelly bean sizes is assigned to a set of drums and great care is taken to ensure that at any given point in time, each drum is filled with similar color and sized jelly beans. Prior to the release of the jelly beans from the RMI drums, at least five PFI drums need to be empty.

Site Specific Rules:

1. As jelly beans flow through the classifier, they are split simultaneously and proportionally to fill the PFI drums at the ratios provided in the “classifier split” table.
2. For simplicity, you may assume that at any given location PFI drum can be filled with any given size, however, once the size to PFI drum assignment is made for a given internal work order, this assignment can only be refreshed when a new work order is processed.
3. To avoid overflow situations, the PFI drums are filled up to 95% of their capacity.
4. A PFI bin cannot be filled up and emptied at the same time, in other words, a PFI drum is emptied into the pre-finish operation only after it is disengaged from the classifier.
5. When more than five PFI bins are empty and available to be filled, the lowest PFI drum number is filled up first. Remember, at any given time, at most 5 drums will be getting filled up simultaneously, assign lowest size number to lowest available drum.
6. Jelly bean sizes cannot be mixed in a given drum.
7. Release of sized jelly beans into the pre-finish operation is dictated by First-In-First-Out policy. If you are using any other dispatching policy, please state that explicitly.
8. Number of PFI bins that can be emptied into the Pre-finish operations simultaneously depends on the number of pieces of equipment at the Pre-finish operation.
9. The quantity of sized jelly beans released into the pre-finish operation will be determined by the internal work order, please specify how did you arrive at this policy.
10. At each location, based on the facility design, any PFI drum can be engaged with any equipment at the pre-finish operation.

The number of drums and their capacities varies by site and the details by site are provided in the ‘Facility Details’ section below.

*Pre-Finish Operation*: At the Pre-finish operation, the PFI drums are emptied into a tank where flavors are applied to the jelly beans. Currently, 12 flavors of jelly beans are offered and at a given time, jelly beans of a given color and size are processed in the tank. The number of tanks, tank capacity, and the processing rates are provided in the “pre-finish” reference table.

Site Specific Rules:

1. For sites with more than one equipment at the pre-finish operation, assume the rate for each piece of equipment is the same.
2. When flavors are changed, there is a change-over time requirement of 5 minutes.
3. When sizes are changed, but there is no change in flavor, there is no change-over time penalty.

*Pack Inventory (PI) Store*: Once the Pre-finish operation is complete, the flavored jelly beans are staged at the PI drums. Each PI drum holds jelly beans grouped by color, size, and flavor to avoid contamination. The number of drums and their capacities vary by site and the details by site are provided in the ‘Facility Details’ section below.

Site Specific Rules:

1. As stated above, release of sized jelly beans into the pre-finish operation is dictated by First-In-First-Out policy. If you are using any other dispatching policy, please state that explicitly.
2. The flow of jelly beans from the pre-finish inventory store through the pre-finish operation and into the pack inventory store is a continuous flow. At each location, you may assume that any pre-finish operation can feed any of the PI drums.
3. To avoid overflow situations, the PFI drums are filled up to 95% of their capacity.
4. A PI bin cannot be filled up and emptied at the same time, in other words, a PI drum is emptied into the Packaging operation only after it is disengaged from the Pre-Finish Operation.
5. The lowest PI drum number is filled up first.
6. Jelly bean colors, flavors, and sizes cannot be mixed in a given drum.
7. Only one PI drum can be emptied into the Packaging operation.
8. The quantity of sized jelly beans released into the Packaging operation will be determined by the internal work order, please specify how did you arrive at this policy.

*Packaging*: The PI drums are emptied for packaging **either** in a bag or a box. Typically, bags and boxes are processed at different packaging equipment; the number, capacity, and processing rate are provided later.

Site Specific Rules:

1. Packaging rules dictate that the bagging and the box line cannot run at the same time.
2. When a drum from Packaging Inventory is emptied and fed to Packaging, the box line takes precedence in run order over the bagging line.
3. Orders for boxes shall be fulfilled prior to bag orders.
4. Any excess material shall be stored in bags.

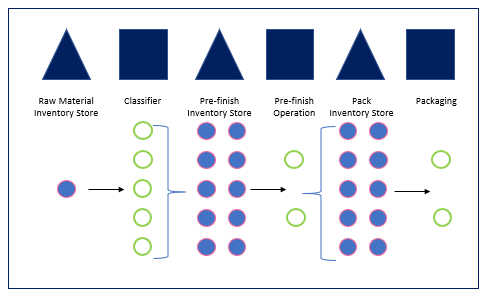


Figure 2: Process Flow

A close up of a map

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Flavor

Color

Size

Bag/Box

Figure 3: Product Differentiation

In order to provide some flexibility and efficient capacity utilization at the network level, the planning team may coordinate with the logistics team to move some jelly beans from one location to another provided sufficient storage drums are available at the other location’s RMI store. Due to fleet capacity restrictions, limits exist on the number of colored jelly beans and the total quantity that can be moved from one location to the other. These moves of jelly beans between facilities are made at the start of the season before classifier operations begin for the year. Once operations begin at the facility, raw materials cannot be transferred from one location to another. The raw material truck fleet at the beginning of the season becomes a dedicated fleet for moving the finished bags and boxes to the wholesalers. The move to the wholesalers is out of scope for this competition. The travel distances between facilities and the restrictions on the number of jelly bean varieties at RMI and the total quantity that can be transported from one site to the other are provided in the “distances matrix” and the “threshold – color” and the reference tables.

Manufacturing Costs:

Each manufacturing location produces material for a different cost of goods. The table below shows the cost of goods for both bags and boxes for each of the manufacturing locations. It should be assumed that there are 0.25 lb/bag and 2.5 lb/box.

Table 1: Cost break Down by site for bags and boxes.

|  |  |  |
| --- | --- | --- |
| Manufacturing cost by site | Cost/100 bags | Cost/100 boxes |
| Green Bay | $ 25.50 | $ 242.30 |
| Omaha | $ 25.00 | $ 238.50 |
| Springfield | $ 28.80 | $ 273.10 |
| Columbus | $ 27.50 | $ 261.30 |
| Detroit | $ 26.30 | $ 249.4 |

Transportation Specific Rules:

Due to the differences in manufacturing costs, it may be advantageous to move raw material inventory from one location to another to optimize the overall costs. Material movements between sites need to be completed prior to April 1st, the day when the operations begin.

Below are the distances to and from each manufacturing location. Truckloads of material cannot exceed 500,000 lbs subject to the condition that the receiving location has enough empty RMI drum capacity. Different colors will have the ability to be segregated during shipment. Shipment cost is assumed to be variable at the rate of $3.50/mile per 50,000 lbs and the cost is for one-way direction. Actual costs will be a function of number of miles and pounds moved between the sites. Further, only one color can be moved from one site to another.

Table 2: Distance Matrix with distances in miles.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Green Bay | Omaha | Springfield | Columbus | Detroit |
| Green Bay |  | 570 | 720 | 530 | 510 |
| Omaha | 570 |  | 630 | 780 | 730 |
| Springfield | 720 | 630 |  | 630 | 750 |
| Columbus | 530 | 780 | 630 |  | 210 |
| Detroit | 510 | 730 | 750 | 210 |  |

Table 3 below provides the number of drums at various inventory stores along with the amount of equipment available for the Pre-finish & Packaging operations. Each manufacturing location has a single classifier. The equipment and drum capacities and processing rates at various operations and inventory stores are provided. For sake of simplicity, assume the facility runs 24 hours a day, seven days a week (with no holidays). Shift changes and other breaks are out of scope of this problem as equipment operations are independent of these events.

Table 3: Amount of equipment and drums at each operation and inventory store.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Manufacturing Facility | Number of RMI Drums | Number of PF Drums | Number of Pre-finish operation equipment | Number of PI Drums | Number of Packaging Machines |
| Detroit, MI | 40 | 15 | 2 | 8 | 1 bag, 1 box |
| Columbus, OH | 30 | 32 | 3 | 10 | 2 bag, 1 box |
| Springfield, MO | 50 | 24 | 1 | 15 | 1 bag, 1 box |
| Green Bay, WI | 20 | 17 | 2 | 17 | 1 bag,1 box |
| Omaha, NE | 30 | 28 | 3 | 12 | 1 bag, 1 box |

JB Manufacturing Executive Leadership team has retained you as their Decision Science Solutions consultant for developing strategies to reduce the overall cost while still being able to meet the Halloween demand. There are two competing objectives JB Manufacturing is trying to balance: maximizing the demand that is fulfilled before the due date while minimizing the overall cost. In your solution, you should identify how you balance these objectives.

You have been asked to work with various organizations both at the headquarters and the manufacturing facilities to develop strategies for better planning and internal work order creation, establishing the current manufacturing capabilities, and balancing the work load across each of the manufacturing locations. These organizations along with their objectives are as follows:

Process Engineering Team:

1. Determine the statistical distribution of the processing rates for pre-finish and pack operations to establish current operational equipment capabilities at each manufacturing facility.
2. Work closely with the process engineers to develop simulation models for the five manufacturing facilities to establish manufacturing capabilities for each facility.

Planning Team:

1. Use the simulation models developed to evaluate the number of days it may take to process a given internal work order you will be designing in step c below.
2. Process the order bank obtained by the commercial team and create the internal work orders for each manufacturing facility. Each internal work order for a manufacturing facility will comprise the quantity of jelly beans to be manufactured for a specified list of SKUs. You may develop optimization models in conjunction with machine learning and simulation models.
3. Create a framework to analyze the complexity for each internal work order, in other words, develop a metric for comparing two internal work orders.

Logistics Team:

1. Determine the number of jelly bean varieties along with the quantities that will be moved between facilities at the start of the season to balance the work load across the five manufacturing facilities based on the internal work orders created.

Finance Team:

1. Determine the lowest overall cost while still meeting the Halloween demand. This includes the cost of manufacturing plus the cost of transportation movements.

VP Manufacturing:

1. Identify the bottleneck or rate-limiting steps at each of the manufacturing facilities.
2. Determine if it is possible to balance the material flow by adjusting and designing optimal internal work orders.

**Appendix**

Notes about the dataset:

* No outliers or missing values or ill-formatted values have been introduced in the dataset.
* Units are provided in the Variable values below for each of the tables below.

**Meta-table**

|  |  |
| --- | --- |
| Table Name | Explanation |
| Order Bank | A table that shows the quantity demanded for the color, size, flavor, and packaging type combinations. |
| RMI Inventory Level | The initial inventory of Jelly beans at RMI drums (and their capacities). |
| Classifier Split | The size percentages of each color, from the observations of historical data. |
| Pound to Bag and Pound to Box | The conversion factors between weight and packaging types. |
| Distance Matrix | The distance between each site. |
| Transportation Threshold | The transportation limit between sites |
| Pre-finish Inventory Drum | The capacity of pre-finish inventory drum. |
| Pack Inventory Drum | The capacity of pack inventory drum. |
| Classifier | The processing rate of each classifier. |
| Pre-finish | The historical pre-finish processing rates at each site. The data has been cleaned. |
| Packaging | The historical packaging processing rates at each site. The data has been cleaned. |
| Workorder Example | An example to show what an internal work order may look like |

**Below are detailed explanations for some of the more complex Tables.**

Table Name: Order Bank

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Customer Order Number | A string starts with a letter and followed by 7 digits | An id created by the system when an order is placed |
| Color | String. Coloring Agent 1-40 | The color of Jelly beans required by the order |
| Size | String. S1-S5 | The size of Jelly beans required by the order |
| Flavor | String. F1-F12 | The flavor of Jelly beans required by the order |
| Package Type | String. Either Bag or Box | The packaging type for an order |
| Qty (pack unit) | Positive integer | The number of packaging unit for a order |

Table Name: RMI Inventory Level

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Location Name | String | Facility location |
| RMI Drum | String | Name of the RMI drums |
| Color | String. Coloring Agent 1-40 | Jelly beans color in each RMI drum |
| Qty in Pounds | Numeric | Current inventory level in each RMI drum |
| Capacity | Numeric | The capacity of each RMI drum |

Table Name: Classifier Split

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Color | String | Jelly beans color |
| Size | String | Jelly beans size |
| Percentage | Non-negative numbers | The size percentages of a given color |

Table Name: Pre-finish Inventory Drum

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Site | String | Facility Location |
| Drum Number | String | Name of the PFI drums in the site |
| Capacity | Numeric | Total capacity of the drums (in pounds) |

Table Name: Pack Inventory Drum

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Site | String | Facility Location |
| Drum Number | String | Name of the PI drums in the site |
| Capacity | Numeric | Total capacity of the drums (in pounds) |

Table Name: Classifier

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Site | String | Facility Location |
| Classifier | String | Name of the Classifiers |
| Processing Rate | Numeric. Pounds per hour. | Historical processing rate of each classifier |

Table Name: Pre-finish

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Site | String | Facility Location |
| Size | String | Jelly beans size |
| Flavor | String | Jelly beans flavor |
| Processing Rate | Numeric. Pounds per hour. | Historical processing of each site-size-flavor combination |

Table Name: Packaging

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Site | String | Facility Location |
| Size | String | Jelly beans size |
| Packaging\_Type | String | Jelly beans packaging type |
| Processing Rate | Numeric. Pounds per hour. | Historical processing of each site-size-packaging\_type |

Table Name: Workorder Example. This is an output example of what a internal work order should look like,

|  |  |  |
| --- | --- | --- |
| Variable Name | Variable Values | Explanation |
| Plant Id | String | Facility Location |
| Internal Work Order Id | String | The id generated by the planning team |
| Color | String | The color of Jelly beans needed to be produced |
| Size | String | The size of Jelly beans needed to be produced |
| Flavor | String | The flavor of Jelly beans needed to be produced |
| Packaging Type | String | The package of Jelly beans needed to be produced |
| Qty | Non-negative numbers | The number of packaging unit needed to be produced |