Fall 2023 ISYE 580

Whey-Protein Line Simulation & Capacity-Expansion ROI Analysis

Group 8

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Executive Summary

The primary aim of this project is to evaluate a simulation model of a system in a whey protein production factory, delving into opportunities for system enhancement. The manager of this factory is looking for changes to improve their current system, the goal being to minimize waiting queues at different stations throughout the system. To ensure validation, data was provided by the manager to build a simulation of the current model. The research done throughout the project reveals different scenarios, ranging from the current system state to potential alternatives. Through examination of various factors influencing waiting queues within the system, the project seeks to find the root causes of inefficiencies and their ramifications for system performance.

The results obtained through simulation are significant, revealing specific changes that yield improvement in the system. These improvements are revealed in the form of reduced waiting queues and an upswing in profit. Building on these findings, a proposed model is identified. This proposed model comprises of strategic adjustments, such as reallocation of resources, capital investment and other process optimizations. The project involves offering recommendations to the factory manager and showing whether implementation of the proposed changes will enhance overall system efficiency.

1. Introduction

The aim of this project is to analyze a current system and to find methods that improve the system. In this case, the focus is on a whey protein factory that operates in two shifts per day, five days a week. The current model involves a series of stations: preparation, weighing, mixing, packaging, and shipping. For the current model, there is a mixer sanitation process in place depending on what flavors are currently being used and what flavors were last used. The proposed model is set up to avoid this condition for better efficiency. Additionally, more stations are added to further improve the model. Simulation will provide data for queuing analysis, which will be used to further understand the current state model and proposed model. This project will use Simio, a software used for simulation, to create data to analyze the results of these models.

2. Model Construction

The construction of the current simulation model is based on the following assumptions in **Table 1**. For all models, the entities used for the system are the following: orders and units. Orders are used to represent one customer order. Units are used to represent the number of whey protein products ordered, or the batch size of an order. Stations in the system can only take units, therefore it is necessary to convert an order to its batch size. These assumptions were provided by the manager and are also used for scenario analysis. Refer to **Table 1** for more details.

Table 1: Distributions of Operations

Operation	**Distribution**	**Parameters (in minutes)**
Orders Arrive	Exponential	Mean = 30
Preparation	Exponential	Mean = 1.1
Weighing Station	Normal	Mean = 2.6 Standard Deviation = 1.4
Mixing Station	Weibull (2-pound bags & jars)	Scale = 3.5 Shape = 3.2
	Normal (5- pound bags & jars)	Mean = 5 Standard Deviation = 3.2
Sanitation	Normal	Mean = 7.5 Standard Deviation = 1
Packaging	Exponential (2-pound products)	Mean = 0.85
	Normal (5-pound Products)	Mean = 1.2 Standard Deviation = 0.25

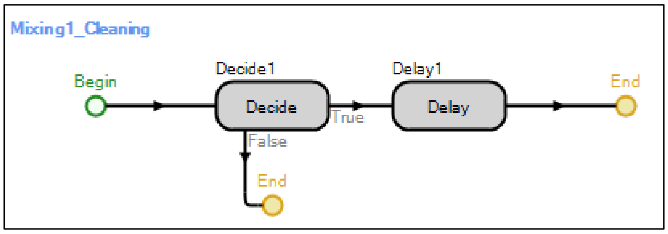
2.1 Current Model Construction

The current system begins with customer orders entering the system. Upon arrival, attributes such as container type, flavor, weight, and batch size are determined using a discrete distribution. After arrival, the batch size of a customer order is extracted, and the system therefore is split into two lanes, sending units to the preparation station. From the preparation system, units are put into bins and sent to the weighing station. After being weighed, units are ready to be mixed.

Before a unit can go into the mixing station, the station will undergo a sanitation process depending on the flavor of that unit. If the current flavor of a unit to be mixed is chocolate and the last flavor mixed was vanilla, then sanitation of the station is necessary which will delay the processing time of that mixing station. Otherwise, there is no sanitation necessary. This process can be seen in **Figure 1**.

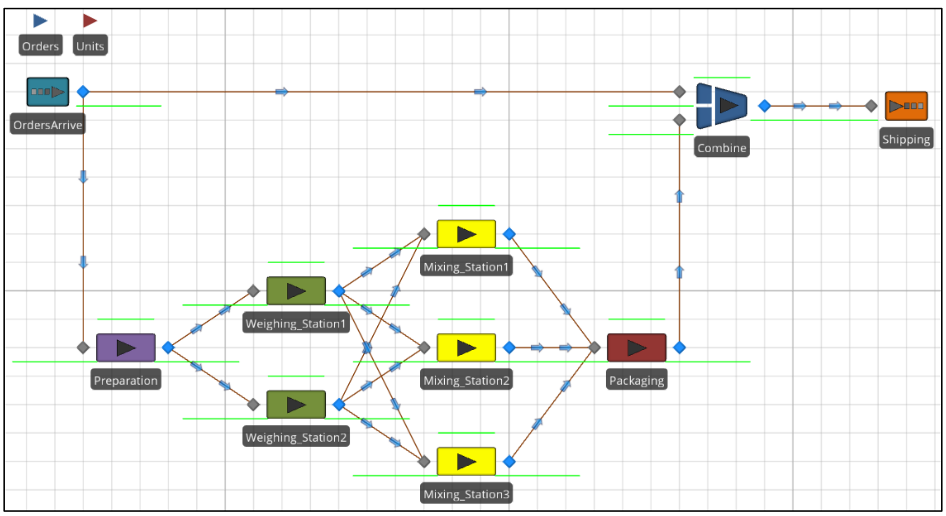
Commented [CN1]: Where is the rest? Need to describe that this is tracked for each mixing station and how the information is being kept and updated (i.e. state variables)

Figure 1: Sanitation Process



Once mixed, the unit will continue to the packaging station. After leaving the packaging station, units are allocated together to match their order number before being shipped out of the system. The current state model can be seen in **Figure 2.**

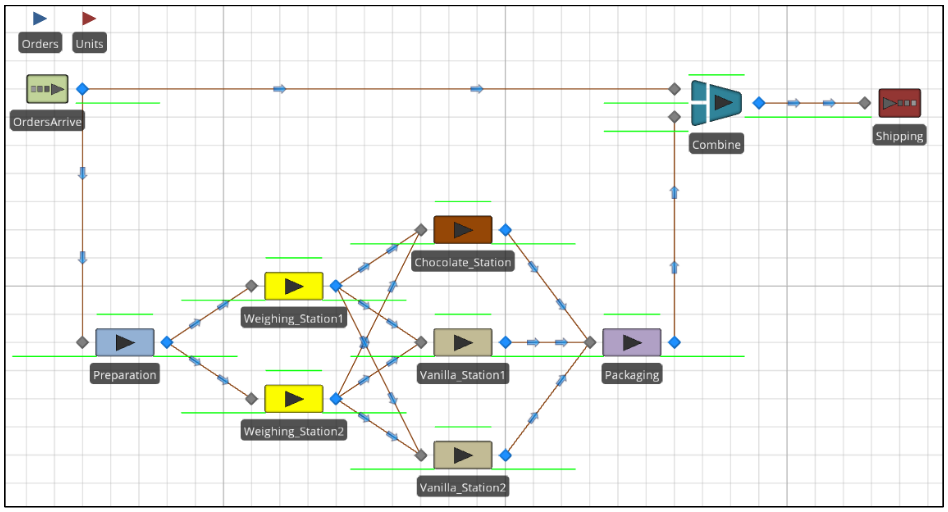
Figure 2: Current State Model



2.2 Current Model Construction with New Policy

The manager at the factory wants to introduce a new policy in the system that can eliminate the sanitation process. Our proposed idea for this policy was to dedicate one of the mixing stations for chocolate flavor units and the other remaining two would be dedicated to vanilla flavor units. This idea would then eliminate the sanitation process since the condition for the sanitation process would never be true. Refer to **Figure 3** for the completed model.

Figure 3: Current State Model with New Policy



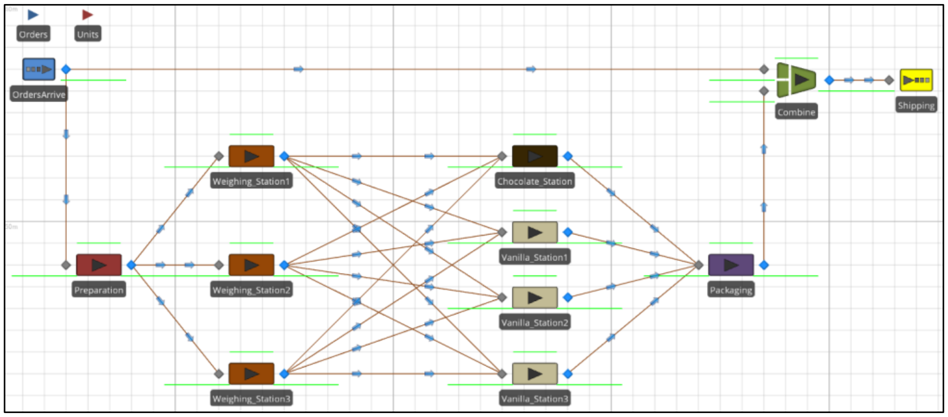
While the model appears to be like the current state model, the sanitation process referenced in **Figure 1** is eliminated. To ensure units would travel to their corresponding mixing station, logic was implemented where the system would check for the flavor of a unit and send that unit to the correct station.

While the proposed idea seemed to be a good solution for the new policy, through experimentation we found that the proposed idea did not work effectively for the current state. Our results will be further explained in our scenario analysis.

2.3 Proposed Model Construction

To find improvements to the current system, different tests were conducted, such as different number of workers at a station, adding more stations, as well as changing the sanitation process. For the proposed model, we found a model that is still like the current system, but just with a few changes. For the most part, the process for a unit is normal. Except for this proposed system, we kept the same number of workers at stations. Additionally, we added a new weighing machine and mixing machine. This lowered the number of units waiting in queues. However, despite our idea for the new policy not working for the current state model, we attempted to test our idea on this new model and saw positive results. For that reason, we decided to get rid of the sanitation process, by dedicating one mixer to chocolate flavor units and the rest to vanilla flavor units. Please refer to **Figure 4** for the completed model.

Figure 4: Proposed State Model



3. Model Validation

Model validation involved comparing the current state model to data provided by the factory manager for 3 weeks of operation. Since the factory operates on two 8-hour shifts for five days a week, 3 weeks of operation is equivalent to 240-hours. At the preparation station, there is no steady state attained and we are not able to get the warm from graph.

The data provided by the manager for a 240-hour operation period to validate is the following:

- Average number of units waiting at preparation is 30 units
- Average number of units waiting at weighing is 25 units

The data provided by the manager for an 80-hour operation period to validate is the following:

- Average throughput for units of 2-pound bags is 185
- Average throughput for units of 5-pound bags is 1465
- Average throughput for units of 2-pound jars is 845
- Average throughput for units of 5-pound jars is 535

For our confidence interval, we chose to conduct a one sample T-test because the number of replications ran was ten (n < 40). Refer to **Figure 5** for the formula used.

Commented [CN2]: What value of alpha was used?

Figure 5: Test Statistic Equation

$$-t_{n-1,\alpha/2} \leq \frac{\bar{x} - a}{\frac{s}{\sqrt{n}}} \leq t_{n-1,\alpha/2}$$

Using Simio, we were able to replicate and obtain averages for the corresponding stations for comparison. Our data collected, calculations, and conclusions are represented in **Table 2**.

Table 2: One Sample T-Test

	Preparation Station	Weigh Station 1	Weigh Station 2	Throughput of 2lb Bags	Throughput of 2lb Jars	Throughput of 5lb Bags	Throughput of 5lb Jars
Mean	24.72	18.4	23.9	155	1,456	773	526
Std. Dev.	6.69	13.3	14.1	34	161	112.8	116.9
n	10	10	10	10	10	10	10
a	30	25	25	185	1,465	845	535
$-2.26 \leq \frac{x - a}{\frac{s}{\sqrt{n}}} \leq 2.26$							
Test Statistic	-2.7	-1.5	-0.24	-2.82	-0.17	-2.02	-.025
Decision	**Reject**	**Fail to reject**	**Fail to reject**	**Reject**	**Fail to reject**	**Fail to reject**	**Fail to reject**
Half Width	4.78	9.5	10	24	115	80.6	83.6
Upper	29	28	34	179	1,571	853	609
Lower	19	9	14	130	1,340	692	442

We can see that our model validated most of the data within a 95% confidence interval. The test statistics for each data point were calculated and within the critical values, however, the test statistic for preparation and throughput for two-pound bags failed to lie within the desired region, therefore causing us to reject the data point. Despite this, we can see that our test statistic for the rejected data points lie very close to the boundary. We concluded that our current state model, albeit not fully validated, can be used as a close representation of the real system.

4. Scenario Analysis

As previously mentioned, the manager has tasked us to improve the current system. To create the proposed model, we had to conduct several scenarios to better understand what would improve. For this purpose, the project considers resource allocation, capital investment and changing processes in the system.

4.1 Capital Investment

The current state system can have many bins of units waiting for each station. Both the data given by the manager and the model prove this. Therefore, it is important to consider capital investment for methods that can improve the current system.

4.1.1 Current Representation Analysis

For the current system, we have only two weighing stations, and three mixing stations. We saw how many units wait in line to be weighed, so we thought of experimenting to see if it is worth the capital investment to add another weighing station and another mixing station to the system. **Table 3** below represents resource utilization of the mixing stations for the current system. This table will be cross-referenced for the proposed model.

Commented [CN3]: With or without the new policy?

Table 3: Current State Resource Utilization

Throughput	**Number of Bags & Jars**
2 Pound Bags	155
5 Pound Bags	773
2 Pound Jars	1,456
5 Pound Jars	526
	Resource Utilization (%)
Mixing Station 1	90.6
Mixing Station 2	91.25
Mixing Station 3	91.6
Total Profit: $8,047	

4.1.2 Proposed Representation Analysis

To begin improvement, we first wanted to test a scenario in which we add a third weighing station to the system and see if the number of units waiting at said station decreased. The results that we found are presented in **Table 4**.

Table 4: Scenario Analysis for Weighing Station

Average Number of Units Waiting	**Weighing Station 1**	**Weighing Station 2**	**Weighing Station 3**
With Two Stations	18.4	23.9	–
With Three Stations	1.22	0.91	1.47

Similar to **Table 2**, we conducted a two-sample T-test to confirm whether the difference between the two samples is great enough to consider the addition of a third station an improvement. Our calculation proved that this was the case.

In addition, we also experimented with adding another mixing station. We found the following results:

Commented [CN4]: Does this include adding the third weighing station or not?

These sections are hard to follow.

When adding other stations, you should also look at utilization of other stations, not just the one you added. You have to see how the entire model is changing with these additions

Table 5: Proposed State Resource Utilization

Throughput	**Number of Bags & Jars**
2 Pound Bags	150
5 Pound Bags	1,401
2 Pound Jars	1,135
5 Pound Jars	630
	Resource Utilization (%)
Mixing Station 1	63.33
Mixing Station 2	75.02
Mixing Station 3	71.65
Mixing Station 4	71.3
Total Profit: $9,986	

Comparing **Table 5** with **Table 3**, we can see a significant improvement in the system, increasing throughput and profit, while decreasing resource utilization. In the current system, profits made from one work week were a little over $8,000. Using this statistic, we can conclude profits made per year are equivalent to $416,000. Knowing that information, we considered whether this improvement would be worth the capital investment. The addition of one weighing and mixing station would be an investment of $135,000. This investment, however, will increase yearly profit by roughly 24%, or to a little over $519,000. Payback time would be about 13.5 weeks (about 3 months). We believe that this investment can be very beneficial to the system and the company.

4.2 Resource Allocation

In addition to capital investment, resource allocation can also be a method to improve a system and is worth testing.

4.2.1 Current Representation Analysis

For the current state system, the way resources are set up can be improved. Currently, there is only one worker for each station and different stations that handle the bulk of the process are being shared between all units, which causes problems to occur, such as long queues.

4.2.2 Proposed Representation Analysis

One way we believed could further improve the current state was to increase the number of workers at a station. During model validation, we noticed that the preparation station had a long queue, so we began testing by increasing the number of workers at the preparation station to see if this would decrease the queue. For the experiment, we ran three scenarios with ten replications. For each scenario, we changed the number of workers to be used at the preparation station. This is represented in **Table 6**, where we can see the number of units waiting at preparation with one worker, two workers, and three workers.

Table 6: Scenario Analysis for Preparation Station

	Scenario 1	Scenario 2	Scenario 3
Average Number of Units Waiting	29.59	4.75	2.47

While increasing the number of workers improved the number of units waiting, we noticed throughput for product types and profits decreased. For this reason, we decided to keep the number of workers at preparation to one. Additionally, we considered reallocating shared stations between units. Despite our idea for the new policy not working, we tested it to see if this made an improvement. Upon testing, we found that this time our idea to dedicate mixers to specific flavors worked for our proposed model. Through experimentation, we found it was best to dedicate one mixer to chocolate flavor units, and three mixers to vanilla.

5. Analysis of Results

Similar to the model validation, we chose to conduct a two-sample T-test since we were only running 10 replications for our proposed system. **Figure 6** shows the formula we will use for the test. **Table 7** presents our data collected, calculations, and conclusions for data collected for the weighing station.

Figure 6: T-Test Equation

$$-t_{v,\frac{\alpha}{2}} \leq \frac{(\bar{X}_1 - \bar{X}_2) - 0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \leq t_{v,\frac{\alpha}{2}}$$

Table 7: Two Sample T-Test

	Weigh Station 1	**New Weigh Station**
Mean	23.9	2.87
Std. Dev.	14.1	0.69
n	10	10
a	25	25
$-2.26 \leq \frac{(x1 - x2)}{\sqrt{\left(\frac{s1^2}{n1} + \frac{s2^2}{n2}\right)}} \leq 2.26$		
Test Statistic		4.71
Decision		**Reject**

Our decision is to reject the null hypothesis and therefore we know that the new sample data is an improvement, and we can conclude that the overall proposed model is an improvement to the current state model.

6. Conclusion and Recommendations

The results from this project have led our team to conclude that our proposed model is an improvement on the current model. During our analysis, we found that one change decreased profit, while also decreasing queue lines at a specific station. If maximizing efficiency is the priority, we would recommend using the changes that were implemented to obtain that result, but if maximizing profit is the priority, we recommend our proposed model. As of now, the current model makes an estimated yearly profit of $416,000. Our proposed model makes an estimated yearly profit of $519,000, a 24% increase from the current yearly profit. In addition, our proposed model becomes more efficient in certain stations compared to the current state, increasing efficiency in the overall system. We believe that with an investment of $135,000 and payback time of three months, the changes we made to the current model are worth implementing in the real system.

Appendix

Table 8: CI Calculation Preparation

Replications	Preparation
1	24.41
2	14.51
3	33.74
4	19.61
5	20.80
6	29.72
7	29.58
8	21.04
9	32.24
10	17.02
Mean	24.27
Standard Deviation	6.69
n	10
Test Statistics	-2.70
Provided Data (a)	30
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	4.78
Upper Bound	29
Lower Bound	19
Decision	Reject

Table 9: CI Calculation Weighing Station 1

Replications	**Weighing 1**
1	49.44
2	7.84
3	8.85
4	11.20
5	7.75
6	12.60
7	29.41
8	22.99
9	23.55
10	10.68
Mean	18.43
Standard Deviation	13.31
n	10
Test Statistics	-1.56
Provided Data (a)	25
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	9.51
Upper Bound	27.95
Lower Bound	8.9
Decision	Fail to Reject

Table 10: CI Calculation Weighing Station 2

Replications	Weighing 2
1	42.68
2	8.35
3	22.49
4	14.83
5	17.10
6	18.89
7	50.37
8	16.26
9	36.33
10	12.00
Mean	23.93
Standard Deviation	14.16
n	10
Test Statistics	-0.24
Provided Data (a)	25
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	10.13
Upper Bound	34.04
Lower Bound	13.78
Decision	Reject

Table 11: CI Calculation Throughput of 2 Pound Bags

Replications	Values
1	187
2	115
3	170
4	125
5	195
6	155
7	175
8	135
9	190
10	100
Mean	155
Standard Deviation	34.0
n	10
Test Statistics	-2.82
Provided Data (a)	185
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	24.315
Upper Bound	179.015
Lower Bound	130.385
Decision	Reject

Table 12: CI Calculation Throughput of 2 Pound Jars

Replications	Values
1	1614
2	1201
3	1368
4	1326
5	1623
6	1484
7	1450
8	1736
9	1409
10	1353
Mean	1456
Standard Deviation	161.4
n	10
Test Statistics	-0.17
Provided Data (a)	1465
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	115.4853818
Upper Bound	1571.885
Lower Bound	1340.915
Decision	Fail to Reject

Table 13: CI Calculation Throughput of 5 Pound Bags

Replications	Values
1	850
2	646
3	870
4	778
5	730
6	652
7	657
8	703
9	879
10	965
Mean	773
Standard Deviation	112.8
n	10
Test Statistics	-2.02
Provided Data (a)	845
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	80.67
Upper Bound	853.67
Lower Bound	692.34
Decision	Fail to Reject

Table 14: CI Calculation Throughput of 5 Pound Jars

Replications	Values
1	375
2	598
3	541
4	611
5	447
6	592
7	760
8	415
9	438
10	480
Mean	526
Standard Deviation	116.9
n	10
Test Statistics	-0.25
Provided Data (a)	535
Alpha (α)	0.05
df	9
T Distribution	-2.26 to 2.26
Half Width	83.62
Upper Bound	609.32
Lower Bound	442.08
Decision	Fail to Reject