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**SIMULATION MODELING AND ANALYSIS**

**ISYE 480/580**



**FINAL COURSE PROJECT (GROUP – 6)**

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# Executive Summary

The Whey Protein factory project is centered around enhancing the production line for Vanilla and Chocolate whey protein powder products, addressing specific variations in product attributes such as weight, container type, and batch size. The objective is to improve the system, as noted by the manager's concerns regarding the inefficient use of space due to bins waiting at each station and the lack of product flow to the shipping department, which is critical for meeting demand.

To tackle these inefficiencies, the project employs a simulation model that mirrors the actual factory operations, structured around a standard two-shift, sixteen-hour, five-day workweek. The model undergoes a rigorous validation process against current state data to ensure accuracy. Through a series of scenario analyses, the project explores different modifications, including staffing adjustments and equipment additions, to find the most profitable production setup.

The performance of each station is meticulously recorded, focusing on metrics such as average waiting time, throughput, queue length, station utilization, and WIP. These metrics guide iterative improvements to the model. The most significant enhancement involves adding an extra worker at the Preparation Station and additional stations at both the Weighing and Mixing stages, with an implementation cost of $135,000. A justification for this investment is presented through a cost-benefit analysis, showcasing the payback period to assure the manager of the financial viability. In essence, the project serves as an executive blueprint to streamline the factory’s operations, aiming to quicken the production line and improve product delivery to shipping, thus ensuring a leaner manufacturing process with optimized resource allocation.

# 1. Introduction

Simulation modeling involves creating an efficient simulation model which can reproduce close to real life observations and data for subsequent analysis. The input data, parameters and types of distributions followed have a huge effect on the final output data and how well the model will be close to realistic as possible. There are four different simulation modeling techniques that are mostly used namely: Discrete-Event System simulation, Monte Carlo simulation, Systems Dynamics simulation and Agent-based simulation.

Simulation modeling is an indispensable technique in modern manufacturing and operations management. It allows us to create a dynamic representation of a production system, like the one at the Whey Protein factory, to study and improve its processes. By simulating the intricate workings of the factory's operations, we gain insights into the flow of products from the initial customer order through to the final quality check before shipping. This virtual representation is crucial for decision-making, as it helps to identify bottlenecks, test the impact of potential changes, and determine the most effective strategies for enhancing productivity.

In this project, we utilize simulation modeling to investigate the current operational challenges faced by the Whey Protein factory, specifically targeting the production of Vanilla and Chocolate flavored powdered products. The focus is on improving the throughput and reducing the waiting time of bins at various production stages, thereby addressing space constraints and the consequent shortfall in the shipping department's output.

The process begins with a comprehensive collection and analysis of the factory's historical data and recent observations. This data serves as the foundation for building a base simulation model, which is meticulously validated against the actual performance of the factory to ensure its fidelity. Through scenario analyses, we examine the effects of introducing additional workers, machines, and dedicated resources on the production line's efficiency. We document the performance of each station, keeping a close eye on key metrics such as average waiting time, throughput, queue length, station utilization, and work in progress (WIP). Our pursuit of the most profitable production setup culminates in a model that includes strategic additions to the workforce and equipment.

The aim is to present a validated, optimized model that reflects the true state of the Whey Protein factory's production system, offering actionable insights for the manager to consider for implementation. This approach embodies the principles of lean manufacturing and operational excellence, striving to create a more agile, responsive, and efficient production line that can meet the demands of the market and the expectations of the customers.

2.Model Construction  
The flow of product from raw material to finished product in the whey protein powder factory can be described as a series of stages, each with its own specific tasks and processing times. Here's an overview of the process:

**Preparation:**

* At this stage, an employee reads the order and prints the recipe for the specific product type.
* The recipe and order are attached to a large bin, which can hold one unit.
* The processing time for each unit in the order at this station follows an exponential distribution with a mean of 1.1 minutes.

**Weighing Station:**

* There are two weighing stations in the factory.
* A worker scans the order and recipe, and an automated machine weighs all the ingredients and pours them into the empty bin.
* The machine then pushes the bin out of the machine.
* The processing time for each unit, regardless of bags or jars, follows a normal distribution with a mean of 2.6 minutes and a standard deviation of 1.4 minutes.

**Mixing Station:**

* There are three mixing stations operating in parallel.
* The powder in the bin is dumped into the mixer by a worker.
* The mixed powder is deposited back into the bin.
* The processing time at this station depends on the product type:
* For 2-pound bags and jars, the processing time follows a Weibull Distribution with Scale = 3.5 and Shape = 2.
* For 5-pound bags and jars, the processing time follows a Normal Distribution with Mean = 5 and Standard Deviation = 3.2.

If the current unit is vanilla flavor and the next product is chocolate flavor, the mixing station must be sanitized. Sanitization follows a normal distribution with a mean of 7.5 minutes and a standard deviation of 1 minute. No sanitization is needed if the current flavor is chocolate and the next is vanilla.

**Packaging:**

* Once the mixing is complete, the product is moved to the packaging station.
* The product is packaged into bags or jars, depending on the order's specifications (bag or jar, 2 pounds or 5 pounds).
* The attributes of container type, flavor, and batch size are determined based on the order specifications.
* The processing time for packaging likely depends on the specific packaging equipment used and can be calculated based on the characteristics of the equipment.

The Simio model was constructed using the following historical data from previous orders, and from three (3) weeks of observation of production activities, received from the factory manager. Table 1 lists all the assumptions, distributions, and statistical parameters used in creating the model.

|  |  |  |
| --- | --- | --- |
| Operation | Distribution | Parameters (in minutes) |
| Order | Exponential | 2 per hour (1 every 30 minutes) |
| Preparation Station | Exponential | Mean (1.1) |
| Weighing Station-1 | Normal | Mean (2.6), Standard Deviation (1.4) |
| Weighing Station-2 | Normal | Mean (2.6), Standard Deviation (1.4) |
| Mixing Station (2-Pound bags and 2-Pound jars) | Weibull | Scale (3.5), Shape (2) |
| Mixing Station (5-Pound bags and 5-Pound jars) | Normal | Mean (5), Standard Deviation (3.2) |
| Sanitation Process | Normal | Mean (7.5), Standard Deviation (1) |
| Packaging Station (2-pound bags and jars | Exponential | Mean (0.85) |
| Packaging 5pound products | Normal | Mean (1.2) |

Table 1: Distributions of Operations

## 2.1 Current Model Construction

The model was constructed in Simio and represented and modeled as shown in Figure 1..

Figure 1: Whey Protein Production Model

A screenshot of a computer

Description automatically generated

Figure 2: Process logic of assigning product attributes

A diagram of a system

Description automatically generated

Figure 3: Process Logic of sanitization process

A diagram of a decision

Description automatically generated

### 2.1Entity Creation and Attribute Assignment:

An entity named "ProteinBatch" was created to represent the product being processed. Attributes for the product type (2-pound bag, 2-pound jar, 5-pound bag, 5-pound jar) and flavor (vanilla and chocolate) were defined as state variables for the entity.

* **Attribute Assignment Process:**
* A process named "attribute assignment" was created to assign product type and flavor to the entity at the source.
* The source generates entities with the specified attributes based on the percentages mentioned in the connector.
* **Batch Size Determination:**
* To model batch size, the source was connected to 2 separator objects that make copies of the incoming entities into 15 and 20 copies, based on the specified percentages.
* This step ensures that each entity represents either a batch of 15 or 20 units.
* **Preparation Station:**
* The entity is then routed to the preparation station, which is represented by a server object.
* The processing time and capacity in the server properties to simulate the preparation process.
* **Weighing Stations:**
* After preparation, the entity moves to the weighing stations.
* The two weighing stations are represented by server objects working in parallel.
* The processing time and capacity for these stations in their respective server properties.
* **Mixing Stations:**
* The entity proceeds to one of the three mixing stations, represented by server objects operating in parallel.
* To determine the processing time based on the product type (2-pound bags/jars or 5-pound bags/jars), an “Math.If” logic was implemented and assigned the appropriate processing time accordingly.
* **Packaging Station:**
* After mixing, the entity moves to the packaging station, which is represented by a server object.
* The processing time and capacity for the packaging station were specified in its server properties.
* **Sink:**
* Finally, the entity is directed to the sink, which represents the end of the production simulation process.
* The sink collects statistics or records relevant data about the completed entities.

### 2.1.2Sanitization Logic:

* **State Variables Creation:**
* Two state variables, “CurrentFlavor” and “Previous Flavor”, were created at the model entity and model level respectively.
* “CurrentFlavor” tracks the flavor of the current product, while “PreviousFlavor” stores the flavor of the previously processed product.
* **State Assignment (Before Processing):**
* A state assignment operation was implemented at the "before processing" point of each mixing station.
* This operation assigns the value of “ModelEntity.Flavor” (the incoming product's flavor) to the “CurrentFlavor” state variable.
* **State Assignment (After Processing):**
* Another state assignment operation was utilized at the "after processing" point of each mixing station.
* This operation updates the “PreviousFlavor” state variable with the value stored in “CurrentFlavor” after processing.
* **Sanitization Process:**
* At the model level, a sanitization process was introduced.
* Within this process, a decision element was incorporated to evaluate the condition: (Model.CurrentFlavor == 'Chocolate' & PreviousFlavor == 'Vanilla').
* This condition checks whether the current product is chocolate and the previous product was vanilla, indicating a need for sanitization to prevent flavor mixing.
* **Delay for Sanitization:**
* If the condition in the decision element is met (i.e., vanilla followed by chocolate), it triggers a delay.
* This delay represents the required time for sanitization.
* During the delay, the mixing station is temporarily inactive to allow for proper cleaning or sanitization and prevent flavor contamination.

### 2.1.3 Integration with Mixing Stations:

* The sanitization process was added as an add-on process step in each of the mixing stations.
* Before a mixing station starts processing a product, it checks the flavor conditions and initiates sanitization, if necessary, based on the defined logic.

By following these steps, the simulation model incorporates a sanitization mechanism to ensure that when a chocolate-flavored product follows a vanilla-flavored product in a mixing station, the station undergoes sanitization to avoid flavor contamination, aligning with the real-world process.

# 3. Model Validation

Table 2 shows the current result observed by the manager and the simulated result. Based on the table, it can be inferred that the simulation model is valid and working correctly to mimic the real-life production process.



Table 2: Results for Current vs Simulated Model

## 3.1 Current State Analysis

Understanding the current state of a production system is essential for identifying areas of improvement, ensuring optimal performance, and laying the groundwork for future enhancements. Current state analysis provides a snapshot of how a factory operates under normal conditions. It serves as a benchmark against which any changes or interventions can be measured. Table 3 shows the current state data given by the manager using historical data and 3 weeks of observations.

| Station/Product | Average Number Waiting | **Average Weekly Throughput** |
| --- | --- | --- |
| Preparation Station | 30 | - |
| Weigh Station | 25 | - |
| 2 Pound Bags | - | 185 |
| 2 Pound Jars | - | 1465 |
| 5 Pound Bags | - | 845 |
| 5 Pound Jars | - | 535 |

Table 3 : Data of 3 weeks of observations

The table lists the average number of units waiting at the Preparation and Weigh Stations and the average weekly throughput for the different product types, providing a clear view of the system's current operational status.

To conduct a thorough current state analysis based on the current state metrics given by the manager, the methodology for this analysis employs statistical tests to compare the model's outputs with actual operational data given by the manager. Specifically, we use a t-test to examine whether the differences between the model's predictions and the observed data are statistically significant. The t-test provides test statistics that we compare against a critical value range, known as the t-distribution bounds. If the test statistic falls within this range, we fail to reject the null hypothesis, indicating that there is no significant difference and that the model is a faithful representation of the factory's operations.

This approach ensures that our simulation model is not only theoretically sound but also practically applicable, reflecting the true dynamics of the production system. Table 4 justifies the model's efficacy as a mirror of the current state, based on the statistical alignment with the factory's actual performance data.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Station/ Products** | **Average Number Waiting** | **Average Weekly Throughput** | **Test Statistic** | **T-Distribution Bounds** | **Decision** |
| Preparation Station | 30 | - | -1.11 | -2.685 to 2.685 | Fail to Reject Null |
| Weigh Station | 25 | - | -1.56 | -2.685 to 2.685 | Fail to Reject Null |
| 2 Pound Bags | - | 185 | 0.18 | -2.685 to 2.685 | Fail to Reject Null |
| 2 Pound Jars | - | 1465 | 0.44 | -2.685 to 2.685 | Fail to Reject Null |
| 5 Pound Bags | - | 845 | -0.02 | -2.685 to 2.685 | Fail to Reject Null |
| 5 Pound Jars | - | 535 | -0.09 | -2.685 to 2.685 | Fail to Reject Null |

Table 4: Hypothesis test of Simio model results against historical data from production

Based on the statistics provided in Table 4, the current state analysis table offers a comprehensive view of the performance metrics for various stations and products in the production system. For the Preparation Station and the Weigh Station, we observe an average number of 30 and 25 units waiting, respectively. The test statistics for these stations, -1.11 and -1.56, fall within the confidence interval bounds, leading us to fail to reject the null hypothesis. Similarly, for the product types – 2 Pound Bags, 2 Pound Jars, 5 Pound Bags, and 5 Pound Jars – with throughputs of 185, 1465, 845, and 535 respectively, their test statistics also fall within the confidence interval bounds, reinforcing the decision to fail to reject the null hypothesis.  
  
The simulation model does a good job of showing what's currently happening in the factory because it lines up with the factory's historical data and recent observations. The model's numbers are close to the real numbers we see in day-to-day operations, which means it's a reliable way to see how the factory is doing. We checked this by running statistical tests, and the results from the model matched the actual data from the factory floors closely. The model also accurately reports on the number of items waiting to be worked on and the number produced each week, just like the counts we have from the factory. All these factors confirm that our simulation is an accurate depiction of the factory's production process.

4. Scenario Analysis  
Several scenarios were explored to optimize key performance metrics such as Work in Progress (WIP), Time in System, and Throughput. These scenarios encompassed various strategies, including innovative approaches to managing workers and resources, adjustments to the number of workers assigned to stations, and significant capital investments in the form of additional stations or a combination of these approaches.

The purpose of these scenario analyses was to identify the most effective strategy for enhancing system performance while considering resource allocation and capital expenditure.

## 4.1 Scenario Results

Table-5 provides a summary of the Simio model results obtained based off the original historical data obtained from the factory manager. This result is also based on the original number of employees at each station (which is currently one each).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| STATION | Average Waiting Time | Throughput | Queue Length | Station Utilization | WIP |
| Preparation Station | 38.89 | 3182.7 | 26.33 | 72.33 | 13.8 |
| Weighing Station-1 | 58.38 | 1567.9 | 20.50 | 86.07 | 29.6 |
| Weighing Station-2 | 50.79 | 1558.1 | 15.27 | 84.72 | 27.1 |
| Mixing Station-1 | 55.82 | 1024.3 | 12.96 | 83.51 | 27.5 |
| Mixing Station-2 | 60.52 | 1010.2 | 14.10 | 82.45 | 35.5 |
| Mixing Station-3 | 53.01 | 1009.1 | 11.63 | 82.44 | 19.4 |
| Packaging Station | 1.53 | 3041.4 | 0.97 | 63.96 | 2.2 |

Table 5: Test Results for Original Model with given raw data

**Time in system**- 146.21 minutes (about 2 and a half hours)

**Total WIP** - 155.1

**Scenario-1**

Initially, to assess the impact on subsequent stations, a test was conducted where the number of workers at the Preparation Station was increased from one to three, considering that the cost of adding up to three workers there is negligible.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| STATION | Average Waiting Time | Throughput | Queue Length | Station Utilization | WIP |
| Preparation Station | 3.84 | 3100.1 | 2.49 | 24.06 | 1.4 |
| Weighing Station-1 | 67.67 | 1502.8 | 22.34 | 82.44 | 31 |
| Weighing Station-2 | 70.14 | 1533.2 | 23.52 | 83.92 | 33 |
| Mixing Station-1 | 51.87 | 1013.2 | 11.07 | 83.58 | 11 |
| Mixing Station-2 | 44.45 | 995.3 | 9.66 | 81.67 | 10 |
| Mixing Station-3 | 44.75 | 994.9 | 9.58 | 80.71 | 12 |
| Packaging Station | 1.52 | 3002.1 | 0.96 | 63.14 | 0.6 |

Table 6: Employees at the preparation station increased from one to three.

**Time in System** – , **WIP** - 79

Adding two additional workers at the Preparation Station boosted its efficiency but led to bottlenecks at the Weighing Stations, revealing the impact of changes in one production area on others.

**Scenario 2:**

To address this, reducing staff at the Preparation Station from three to two is proposed. This action aims to enhance worker utilization, currently at 23%, and balance the product flow, reducing the overload on the Weighing Stations and smoothing the overall production process.

Next Course of action- reduce workers at the preparation station from 3 to 2 and add an additional 1 machine with a cost of $65,000 at the weighing station.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| STATION | Average Waiting Time | Throughput | Queue Length | Station Utilization | WIP |
| Preparation Station | 7.37 | 3190 | 4.91 | 36 | 5 |
| Weighing Station-1 | 14.55 | 1054 | 3.18 | 57.33 | 3 |
| Weighing Station-2 | 15.01 | 1070 | 3.39 | 58 | 3 |
| Weighing Station-3 | 14.5 | 1065 | 3.27 | 58 | 2 |
| Mixing Station-1 | 79.8 | 1057 | 18.17 | 82 | 18 |
| Mixing Station-2 | 87.6 | 1055 | 19.9 | 74.5 | 17 |
| Mixing Station-3 | 79.28 | 1035 | 17.9 | 80 | 11 |
| Packaging Station | 1 | 3063 | 1.2 | 63 | 2 |

Table 7: Two Employees at the Preparation station and a third machine at the weighing station

**Time in System** – 108 minutes, **WIP** - 61

The adjustments at the Preparation and Weighing Stations (reducing workers from 3 to 2 and adding one additional weighing machine) have improved their output rates and reduced stress but have inadvertently shifted the bottleneck to the Mixing Stations, evident from high waiting times and near-capacity utilization. This calls for a targeted evaluation of the Mixing Stations to address the bottleneck and ensure a balanced, efficient production flow.

**Scenario-3:**

The observation that improvements in one station can create bottlenecks in subsequent stations has been a key learning from the recent changes. Specifically, enhancing the efficiency at the Preparation and Weighing Stations resulted in increased pressure on the Mixing Stations. However, a closer examination reveals that the subsequent Packaging Station, with an average waiting time of just 1 minute, appears to be underutilized. This suggests that increasing the capacity of the Mixing Stations is unlikely to overload the Packaging Station.

Consequently, the next course of action involves two strategic adjustments: returning the Weighing Stations to their original count of two and adding an additional machine or station to the Mixing Stations. The addition of a machine, costing $70,000, to the Mixing Stations is expected to alleviate the current bottleneck there without exerting undue pressure on the Packaging Station, which can handle increased throughput from the Mixing Stations. This approach aims to balance the production flow more effectively across the system.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| STATION | Average Waiting Time | Throughput | Queue Length | Station Utilization | WIP |
| Preparation Station | 7 | 3071 | 4 | 35 | 6 |
| Weighing Station-1 | 53 | 1506 | 17 | 82 | 26 |
| Weighing Station-2 | 53 | 1506 | 17 | 82 | 33 |
| Mixing Station-1 | 10 | 757 | 1 | 61 | 3 |
| Mixing Station-2 | 7 | 744 | 1 | 59 | 3 |
| Mixing Station-3 | 10 | 756 | 1 | 61 | 1 |
| Mixing Station-4 | 8 | 744 | 1 | 59 | 2 |
| Packaging Station | 1 | 3000 | 1 | 63 | 2 |

Table 8: Results after Installing a new machine in the Mixing Station

**Time in system** - 91 minutes

**Total WIP** - 76

After implementing the new strategy in the production system, significant changes were observed. The Preparation Station operates efficiently with a slight decrease in waiting time to 7 and a stable throughput. However, the Weighing Stations are now experiencing bottlenecks, shown by high waiting times of 53 and increased WIP. The addition of a fourth Mixing Station effectively eased its previous bottleneck, indicated by reduced waiting times and balanced throughput across all stations, with moderate utilization and controlled WIP.

The Packaging Station remains efficient, handling increased throughput from upstream stations without stress. The results suggest that while the Mixing Stations have been optimized, the focus should now shift to addressing the bottlenecks at the Weighing Stations, possibly through process improvements or resource reallocation, to maintain overall system efficiency.

**Scenario-4:**

The bottleneck at the weighing station can be further alleviated by adding a weighing station. Therefore, 2 workers at the preparation station, 3 weighing stations, and 4 mixing stations will cost $135,000 ($65,000 for 1 additional weigh station and $70,000 for one additional mixing station) for implementation.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| STATION | Average Waiting Time | Throughput | Queue Length | Station Utilization | WIP |
| Preparation Station | 8 | 3135 | 5 | 36 | 4 |
| Weighing Station-1 | 14 | 1037 | 3 | 57 | 3 |
| Weighing Station-2 | 14 | 1050 | 3 | 57 | 2 |
| Weighing Station-3 | 14 | 1036 | 3 | 57 | 4 |
| Mixing Station-1 | 18 | 781 | 3 | 61 | 3 |
| Mixing Station-2 | 19 | 785 | 3 | 60 | 3 |
| Mixing Station-3 | 21 | 772 | 3 | 61 | 4 |
| Mixing Station-4 | 18 | 764 | 3 | 60 | 2 |
| Packaging Station | 3.7 | 3101 | 2.4 | 64 | 3 |

Table 9: Results with 2 workers in preparation, 3 weighing stations and 4 mixing stations

**Time in system**- 51.55

**WIP**- 40

# **5.Analysis of Results**

**Improved Efficiency**

* Original Time in System: 146.21 minutes
* Best Model Time in System: 51.55 minutes
* Improvement: This is a reduction of approximately 64.7%. Such a significant decrease in the Time in System metric illustrates a substantial enhancement in the efficiency of the production line, indicating faster processing and reduced delays.

**Reduced Bottlenecks**

* Original WIP: 155.1 minutes
* Best Model WIP: 40 minutes
* Improvement: The WIP in the best model is reduced by about 74.2%. This substantial decrease points to effectively addressed bottlenecks, leading to a smoother flow of operations and less congestion within the system.

**Better Resource Utilization**

* The reduction in WIP by 74.2% suggests that resources (like machinery and labor) are being utilized more effectively in the best model. Lower WIP means that resources are not tied up managing excessive workloads, potentially leading to cost savings and more focused productivity.

**Queue length improvement**

* **Preparation Station**: Queue length reduced from 26.33 to 5, an 81% decrease, indicating improved workload handling and less congestion.
* **Weighing Stations**: Average queue length dropped from 17.89 to 3, an 83% reduction, thanks to the addition of a third station, leading to more efficient processing.
* **Mixing Stations**: Queue length decreased from an average of 12.52 to 3.25 (across four stations), a 74% decrease, showing effective management with the added station.
* **Packaging Station**: Minimal increase in queue length from 0.97 to 1, maintaining efficient operations despite upstream changes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Station** | **Original Model** | **Best Model** | **Improvement in Queue Length and WIP** | **Improvement in Time in System** |
| Preparation Station | Queue Length: 26.33  WIP: 13.8 | Queue Length: 5 WIP: 4 | Queue Length: -81%  WIP: -71% | N/A |
| Weighing Station-1 | Queue Length: 20.50  WIP: 29.6 | Queue Length: 3 WIP: 5 | Queue Length: -85%  WIP: -83% | N/A |
| Weighing Station-2 | Queue Length: 15.27  WIP: 27.1 | Queue Length: 3 WIP: 4 | Queue Length: -80%  WIP: -85% | N/A |
| Weighing Station-3 | N/A | Queue Length: 3 WIP: 4 | N/A | N/A |
| Mixing Station-1 | Queue Length: 12.96  WIP: 27.5 | Queue Length: 3 WIP: 7 | Queue Length: -77%  WIP: -75% | N/A |
| Mixing Station-2 | Queue Length: 12.96  WIP: 35.5 | Queue Length: 3 WIP: 4 | Queue Length: -77%  WIP: -89% | N/A |
| Mixing Station-3 | Queue Length: 11.63  WIP: 19.4 | Queue Length: 4 WIP: 5 | Queue Length: -66%  WIP: -74% | N/A |
| Mixing Station-4 | N/A |  | N/A | N/A |
| Packaging Station | Queue Length: 0.97  WIP: 2.2 | Queue Length:1 WIP: 3 | Queue Length: +3%  WIP: +36% | N/A |
| **Overall System** | Time in System: 146.21 minutes | Time in System: 51.55 minutes | N/A | -65% |

Table 10: Comparison between original model and proposed model

## 5.1Cost Justification

Cost of implementation = $135,00

|  |  |  |  |
| --- | --- | --- | --- |
| **Product Type** | **Throughput** | **Profit per Unit** | **Total Profit** |
| 2-pound bags | 190.1 | $1.20 | $228.12 |
| 2-pound jars | 1597.6 | $1.43 | $2284.57 |
| 5-pound bags | 812.3 | $4.21 | $3419.78 |
| 5-pound jars | 501.2 | $4.80 | $2405.76 |
| **Total** | 3101.2 |  | **$8338.23** |

Table 11: Cost Justification

**Annual Profit**: $8,338.23 (weekly profit) × 52 weeks = $433,588.96 annually.

**Payback Period**: $135,000 (cost of implementation) ÷ $433,588.96 (annual profit) ≈ 0.31 years.

Therefore, the payback period for the investment of $135,000, with a weekly profit of $8,338.23, is approximately 0.31 years, which is about 3.7 months.

5.2 New Policy (Improving Sanitization Process)

In the current setup, all units are directed to the next available machine at both the mixing and weighing stations. However, at the mixing station, an additional setup time is required for sanitization, specifically when mixing chocolate products. Given the product ratio of 1 chocolate to 3 vanillas, a strategic adjustment in the original model with 3 mixing stations can optimize the process.

The proposed strategy is to designate one of the three mixing stations exclusively for chocolate products. This specialization eliminates the need for frequent sanitization at this station, as it will consistently process only chocolate. The remaining three stations will be dedicated to processing vanilla products, which do not require the same level of sanitization. This approach not only streamlines the mixing process but also reduces the downtime associated with sanitization, thereby enhancing overall efficiency.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Original Model** | **New Sanitization Policy** | | |
| **Mixing** | **Average Waiting Time** | **Queue Length** | **Average Waiting Time (min)** | **Queue Length** |
| Mixing 1 | 38.45 | 11.74 | 55.82 | 12.96 |
| Mixing 2 | 18.00 | 4.76 | 60.52 | 14.10 |
| Mixing 3 | 21.00 | 10.27 | 53.01 | 11.63 |

Table 12: Comparison of original model to new sanitization policy

After implementing the sanitization strategy, significant efficiency improvements were observed across all mixing scenarios.

For Mixing Station 1, the average waiting time decreased by approximately 31.12% (from 55.82 to 38.45 minutes), and the queue length reduced by 9.41% (from 12.96 to 11.74). In Mixing Station 2, the waiting time saw a dramatic reduction of 70.26% (from 60.52 to 18 minutes), with the queue length decreasing by 66.24% (from 14.10 to 4.76). Mixing Station 3 also showed notable improvements, with a 60.38% decrease in waiting time (from 53.01 to 21 minutes) and a 11.69% reduction in queue length (from 11.63 to 10.27). In addition, the total time in the system was reduced from 146.21 minutes to 131.53 minutes which is nearly a 10% decrease.

These results indicate that the sanitization strategy not only maintained operational efficiency but significantly enhanced it, reducing waiting times and queue lengths considerably.

# 6. Conclusion and Recommendations

## 6.1 Conclusion

The Whey Protein factory project successfully optimized production processes and addressed operational inefficiencies. By employing simulation modeling and data analysis, the project enhanced resource allocation and improved key performance metrics.

Strategic enhancements, including additional workers and equipment, led to significant improvements. The project achieved a 64.7% reduction in Time in System and a 74.2% decrease in WIP. Resource utilization improved, and queue lengths were substantially reduced.

The cost of implementation was justified by an annual profit of $433,588.96, with a rapid payback period of approximately 3.7 months.

Overall, this project offers a blueprint for lean manufacturing, demonstrating the power of simulation modeling to enhance productivity, reduce costs, and meet market demands. It ensures customer satisfaction and long-term success for the factory.Top of Form

## 6.2 Recommendations

Based on the final model, which incorporates 2 workers at the Preparation Station, 2 Weighing Stations, and 3 Mixing Stations, along with the new sanitization policy, several key recommendations can be made to enhance the production process at the Whey Protein factory:

* Implement the Staffing Changes: The project results indicate that reallocating workers by reducing the number at the Preparation Station to 2 and maintaining 2 Weighing Stations greatly improves system efficiency. This change should be implemented as it optimizes worker utilization and product flow.
* Opting for Specialized Mixing Stations: The introduction of a dedicated Mixing Station for chocolate products, as per the new sanitization policy, has proven to significantly reduce waiting times and improve overall efficiency. This approach should be adopted to streamline the mixing process further.
* Monitor and Adjust: Continuously monitor key performance metrics such as Time in System, WIP, and queue lengths. Regularly evaluate system performance to identify any emerging bottlenecks or areas for improvement.
* Invest in Additional Resources: If demand increases beyond current capacity, consider investing in additional Mixing Stations or other resources to maintain efficiency and meet market demands while avoiding bottlenecks.

By implementing these recommendations, the Whey Protein factory can sustain and build upon the improvements achieved in the simulation model, ensuring a lean, efficient, and responsive production process that meets customer demands and drives long-term success.

# 7 Appendix

A – Sheet “Preparation Station” in Excel file “Summary of Results”

B – Sheet “Weighing Station” in Excel file “Summary of Results.”

C - Sheet “2 Pound Bags” in Excel file “Summary of Results.”

D - Sheet “2 Pound Jars” in Excel file “Summary of Results.”

D - Sheet “5 Pound Bags” in Excel file “Summary of Results.”

E - Sheet “5 Pound Jars” in Excel file “Summary of Results.”