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Design of Small-Scale Milk Processing Facility

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Design of Small-Scale Milk Processing Facility

BSEN 480: Senior Design Team #01
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University of Nebraska-Lincoln
Department of Biological Systems Engineering
Senior Design Team #01

Dr. Terry Howell, Jr.
Department Chair
Department of Biological & Agricultural Engineering
203 Engineering Hall
University of Arkansas
Fayetteville, AR 72701

Dear Dr. Howell,

We are writing today to submit our final report entitled *Design of Small-Scale Milk Processing Facility*.

The following report discusses a proposed modular dairy processing facility to be located on UNL's Innovation Campus. The report includes the challenges and advantages of a processing facility of this size, goals, objectives, criteria, constraints, and justification for the proposed design. The overarching goal of this project was to provide insight into the economics should this project move forward.

Itemized lists for equipment and costs are provided within the document. Final design elements covered are a weekly production schedule, shift schedules, wastewater treatment plans, and a proposed floor layout for the building.

We appreciate you trusting our team to research the feasibility and value of constructing a dairy processing facility on campus. We hope you find this report and our results satisfactory. Please reach out if you have any questions about our methods or findings.

Sincerely,

Date: 10May2024

Luke Bond

Date: 10May2024

Robert Stenzel

Date: 10May2024

Ry Steffen

Date: 10May2024

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Abstract
This project was intended to investigate the feasibility of a proposed modular dairy processing facility collocated with a small dairy on the University of Nebraska – Lincoln's Innovation Campus. Priority was placed upon cost savings for equipment to be used in processing. Process flow diagrams, floor plans, production schedules, risk assessments, and plans for wastewater treatment were all developed to address the needs of the plant should it be built. A Monte Carlo simulation was conducted to evaluate the timeline for breaking even financially, resulting in the potential for a payback period of 4.5 years. The 4.5-year payback period was based on simulations that assumed the plant uses some second-hand equipment and marked up the price for milk sold in retail stores.

Background Information
Client:
Dr. Terry Howell Jr. is the primary client with the dairy processing facility project. Dr. Howell is currently the Biological and Agricultural Engineering department head at the University of Arkansas. He previously served as the executive director of the Nebraska Food Processing Center, a position which he held for five years. Prior to his work in academia, he worked in industry as Senior Manager of Product Development with McKee Foods. His prior involvement in industry and with the Nebraska Food Processing Center make Dr. Howell's opinions and decisions key to the success of the dairy operation.

Context:
Nebraska's dairy industry is a vital component of the state's agricultural output. Renowned for its high-quality milk, Nebraska boasts a network of dairy farms that contribute to the state's economy and the nation's dairy supply. The products from these dairies are sold on shelves every day, but not every consumer understands how their products make it from farms to stores. A poll conducted by researchers at Michigan State University showed that nearly half of Americans never or rarely seek information about where their food comes from (Kirshenbaum & Buhler, 2018). The lack of knowledge of food production ultimately leads to a disconnect between consumers and producers of foods. Unfortunately, poor public knowledge is not the only issue plaguing the dairy industry in Nebraska.

Small dairy farmers often struggle to make ends meet, largely due to the unique challenges facing small dairy farms. A novel idea for the United States small dairy market, this processing facility will be collocated with the dairy farm. The cows will be milked by robotic milkers, after which the milk will be pumped directly to the processing facility. The idea is intended to reduce logistics costs and improve the efficiency of small dairies. Logistics costs are among the top priorities considered when building new dairies. It can be very expensive to haul raw milk from dairy farms to processing facilities. A 2023 testimony by Jeffery Sims of the National Milk Producers Federation put the costs at $4.50 per mile for a fully loaded milk truck to get from the dairy to the processor. This cost is paid by the farmer. As such, the closer a processor is to a dairy, the more profitable a dairy can be.

The number of dairies has been trending downward in recent decades, as small dairies have been consolidating into large, commercial dairy producers (MacDonald et al, 2020). The primary reason for this trend is the economics of size. As the number of cows increases on a farm, the relative total costs associated with each gallon of milk produced decrease (MacDonald et al, 2020). However, the consolidation of milk production into fewer and larger dairies has exposed the industry to the dangers of supply chain disruptions ranging from labor shortages to the unavailability of transportation (Federal Trade Commission, 2024). This project is intended in part to serve as an economic prototype for modular dairies. This is hoped to aid the reverse of the trend of consolidation and increase the diversity of sizes of dairies.

Purpose

The University of Nebraska Lincoln is applying for a grant to build a small dairy operation to both educate the public on the dairy industry and serve as an experiment on the profitability of small-scale dairy farming. The overall project will be holistic, containing contributions from almost every college; every discipline is involved, from marketing to animal health, from interior design to engineering. The dairy proposed is to house a minimum of sixty head of cattle. This report covers the design of the processing facility that takes in the raw milk from the dairy and outputs fully packaged, fully processed grade A milk.

This project has been attempted by previous teams. While previous work emphasized the educational aspects of the processing facility, this iteration focuses on the economics of the project.

Dairy Processing Basics

There are multiple steps and procedures necessary for a milk product to be safe to consume. The safe processing of dairy products includes collection, separation, pasteurization, homogenization, and packaging. Also included are equipment cleaning, safe handling of milk, and wastewater handling.

Collection

The collection of milk is where the processing of milk starts. In basic terms, collection is simply the milking of a cow and putting the raw milk into a cooled container. The collection method proposed for this dairy is a robotic milker that will feed the raw milk directly into the processing facility.

Separation

Raw milk has a relatively high-fat content, constituting anywhere from 3.0 to 5.0% of the raw milk’s weight (Tamime, 2009). This fat must be separated from the rest of the milk in order to produce different types of dairy products, such as 1% milk, skim milk, and heavy cream. The separation of the cream from the skim milk is also important during the pasteurization of the product. Higher fat contents require higher temperatures to ensure the reduction of the number of pathogenic bacteria in the product is satisfactory.

Pasteurization

The goal of pasteurization is to kill or deactivate harmful bacteria that can cause disease if consumed. In the dairy industry, this can be done in a couple of different ways: namely vat pasteurization, high-temperature/short-time, and ultra-high temperature. The chief differences between the types of pasteurization are the temperatures and the time spent within the pasteurization equipment. All methods of pasteurization achieve a similar reduction in harmful microorganisms. However, the method of pasteurization chosen can affect the properties of the produced milk, as higher temperatures can denature some proteins within the milk and change the overall flavor profile (Magar, 2023).

Homogenization

Homogenization is the last step in processing before packaging. During homogenization, the skim milk and cream are pushed together at high pressures to create a creamy-textured product that can be sold to the public. Homogenization also ensures a consistent texture throughout the product.

Packaging

Packaging can differ significantly depending on the intended products. Common packaging types include gallon and half-gallon jugs, single-serving pints, and quart cartons. Bulk packaging often comes in 5-gallon bags. The equipment needed for packaging depends on the products being produced. Common packaging equipment includes fillers, cappers labelers, metal detectors, and palletizers. Most equipment can be used for multiple different types of packaging; the equipment can be modified during production to make a different product in a process called a "changeover."

Cleaning, Safe Handling of Milk, and Wastewater Handling

The U.S. FDA has written rules within the Pasteurized Milk Ordinance (PMO) that detail metrics on how a dairy facility must be run. Included within the PMO is cleaning the facility, safe handling of milk, and wastewater handling.

Cleaning is imperative to prevent the buildup of harmful bacteria. All equipment needs to be cleaned after each shift, while raw holding tanks need to be cleaned after 72 hours (U.S. Food and Drug Administration, 2019). This 72-hour rule also has the effect that raw milk must be utilized within three days of milking.

Wastewater treatment plans need to be developed for any processing facility. A strong wastewater treatment plan is necessary to reduce the likelihood of contamination of the finished product and the environment surrounding the facility.

Stakeholder Analysis

- Dr. Terry Howell
- University of Nebraska – Lincoln
- Dairy Farmers
- Dairy Processors
- Consumers
- Federal and Local Regulators
- Staff Working the Plant
- Dr. Kievit and Dr. Brown-Brandl
- Manufacturers of Dairy Processing Equipment

- Logistics Companies
- Members of Team 1
- Cows
- Dr. Rossana Villa Rojas
- UNL Biological Systems Engineering Department

Dr. Terry Howell is one of the main stakeholders in this project. Although he is no longer the executive director of the Nebraska FPC, his knowledge about the project from his experience in industry, work with the previous year's group, and the FPC in general make his input on the project invaluable to a successful design. His advice was taken into account in developing every aspect of the project. His knowledge of the FPC from being its director for five years helped create a design that would fit into the operations at the FPC as well, which is crucial to getting the facility finished and operational.

This project is part of a larger, cross-disciplinary effort within the University of Nebraska-Lincoln. Stakeholders at UNL include the vendors of the milk produced, such as the Dairy Store and dining halls. Other stakeholders at UNL include the grant proposal team and the Nebraska Food Processing Center. The grant proposal team is instrumental in procuring funding for completing the project in the execution phase.

The ultimate goal is to support family farmers and Nebraska's dairy industry. If successful, this project could cause a wave that ripples throughout dairies in Nebraska, and even further beyond. This project is to serve as a prototype for farmers who may want to replicate the design in their own dairy operations. Having input from dairy farmers on this project is vital to ensure that this process could have broader impacts than at UNL alone.

Consumers are a major stakeholder in this project. Designing the dairy processing facility with a product in mind that will satisfy consumer needs and demands is key to the success of the facility.

Federal and local regulators have the final say in whether a dairy processor can operate or not. The FDA, USDA, and NDA set regulations and standards that the final design must meet. Following relevant government regulations, such as 21 CFR 1240.61: Mandatory pasteurization for all milk and milk products in final package form intended for direct human consumption, will result in a product that is satisfactory to government agencies and something that consumers can trust.

Manufacturers of dairy equipment are important stakeholders in this project. Lely, an equipment manufacturer based in the Netherlands, has plans to market its own version of a modular dairy processing facility called the Lely Orbiter. This is important to consider so that the team does not replicate the exact process and inadvertently infringe on any patents or copyrights. Dairy equipment manufacturers are also integral in supplying the needed pasteurizers, homogenizers, and holding tanks. They will affect both the availability and the cost of the equipment that would be needed for this project to be successful both functionally and economically.

Other than the university, farmers, consumers, regulators, and manufacturers, stakeholders in this project include dairy processors that could use this facility as a model for their own modularized practices; workers at the proposed plant; Dr. Forrest Kievit and Dr. Tami Brown-

Brandl; UNL's Biological Systems Engineering Department; Dr. Villa Rojas; the logistics companies to transport the processed milk; members of Team 1; and even the cows themselves.

Problem Statement

There is a need to design a milk processing plant that can take raw milk from a small dairy operation and output packaged pasteurized milk to improve the profitability of small milk production and dairy processing operations, helping to diversify the size of United States dairies.

Design Goals

The goal of this project is to design a milk processing plant that can process milk from a small dairy operation with sixty head of cattle into packaged milk that can be sold to the public.

Design Objectives

- Estimate heat and mass balances for the plant.
- Provide a design that adheres to federal and local regulations.
- Provide educational value to the public.
- Create factory layouts.
- Provide cost-benefit analysis.

Constraints

- The plant operates Monday through Friday from 8:00 AM – 7:15 PM with two 8-hour shifts overlapping.
- The plant process must be certifiable by applicable state and federal regulatory agencies such as the FDA, USDA, and NDA.
- Plant design must break even financially after 6 years of operation according to a Monte Carlo simulation.
- The plant will utilize a 3-A Standard for dairy product cleanliness and sterilization.

The plant will be a university entity. Due to this, this plant will not operate as it might in the dairy processing industry. As such, the process will not operate 24 hours a day, 7 days a week. It should also be noted that government holidays should also be accounted for, as many of these days are university days off.

Meeting FDA, USDA, and Nebraska Department of Agriculture (NDA) regulations is the number one priority in food production. These entities set regulations on pasteurization steps, holding tanks, microbe counts, and documentation. Following all relevant regulations ensures consumer safety.

The overall goal of the project is to increase profitability for small dairy operations in a market dominated by larger competitors. Thus, the processing plant must be profitable within 6 years of starting operations. This will not only show the design's economic practicality but the feasibility of future designs' success as well. Therefore, an important constraint for the project is its ability to "break-even" financially after this period by showing profitability after returning investments on all of the costs involved with designing, building, and operating the facility. This will be measurable using a Monte Carlo situation to evaluate the costs and profits involved with the operation.

The milk processing plant will utilize a 3-A standard for sterilization and overall cleanliness of the plant. Using equipment that is 3-A certified is common industry practice. This ensures that federal and local regulations are met by all processing equipment. The standard is set to mitigate the potential of food contamination from bacteria, viruses, and other contaminants.

Criteria

- The plant will utilize the most economical processing equipment.
- The plant should be capable of using a mix of packaging types that will maximize profit.
- Produces multiple types of packaged milk (Heavy cream, half-and-half, whole, 2%, and skim).
- Process design should be capable of processing raw milk from 60-240 head of cattle.
- The design should be as compact as is feasible for functionality.

Utilizing the most economical method of pasteurization will set the plant off on the right foot financially. The most economical method will be the technology that can pay off the fastest. Processing equipment downstream will also be evaluated with the lens of utilizing the most affordable technology, without sacrificing quality.

The criteria of utilizing a mix of packaging types that will maximize profit has been purposely left broad. This will leave the team the leeway to determine exactly what mix is most profitable to produce when executing the economic analysis of the project. A mixture of 5-gallon bulk bags, single-serving 12-ounce bottles, gallon, and half-gallon jugs will be considered. The mixture of milk types will be evaluated for maximizing returns using a Monte Carlo simulation.

Production of multiple types of milk (i.e., whole, 2%, 1%, skim) should be considered in the design. This would allow for the possibility of higher profits by reaching a wider population in the market. The addition of the ability to produce various types of milk will require extra steps at the end of the processing of whole milk. Flavoring additives will not be considered for this project due to the expensive equipment needed. Flavored milk is generally not more expensive at stores compared to unflavored milk and thus would not be economically feasible in a small dairy.

The given number of cattle for the proposed dairy is 60 head. As such, the process design shall be capable of processing the raw milk produced by 60 head of cattle over three days; storage will need to be addressed for the raw milk produced over weekends. However, the plant should be capable of storing and handling the milk produced by up to 240 head of cows. This is to accommodate any expansion that may happen at the dairy.

2300 square feet was the amount of space allocated for the processing facility by last year’s team. This number was given by the architecture team responsible for designing the building that the processing equipment will be installed within. This number is not necessarily a hard maximum restriction for the facility, but it should be used as guidance for the building.

Social, Global, Cultural, Economic, and Environmental Considerations

Identifying all social, global, cultural, economic, and environmental considerations associated with developing and implementing a dairy processing plant is essential to knowing how our design will integrate into the world at large. This allows us to determine what factors will impact our development of the design, as well as what impacts the implementation and operation of the facility would have.

Social Considerations

The regulations and the people involved with this project are major social considerations. This small dairy operation will have to abide by regulations and guidelines set by local, state, and federal entities. These agencies include the FDA, USDA, and NDA. The facility will also need to operate under conditions acceptable to OSHA. The workers of the dairy will likely be students who may or may not have a background in dairy processing, so there should be a form of standardized training. UNL could offer training programs to students wanting to go into dairy processing whether it is for the planned facility or a similar facility. This training program could be across all roles from worker to management. Additionally, training programs could be offered to dairy farmers looking to start processing facilities on their farms.

Global Considerations

This project has the potential to be groundbreaking for small dairies throughout the world. Many developing regions of the world remain agrarian societies that have economies that rely on agricultural practices. These regions also often lack adequate transportation systems to allow for large-scale, industrialized dairy processing. There then exists a need for small-scale, modular dairy processing like the approach taken in this project. For the dairy processing plant designed here to apply to developing regions globally, the plant must use widely available and affordable technologies.

Cultural Considerations

A facility that handles milk from smaller local dairies and outputs locally produced and processed milk has the potential to affect the local culture in towns across America. A greater sense of community and support could arise as communities in towns like Lincoln embrace self-sustainability. Consumers of the milk would be supporting other locals directly and connecting with them simply by buying milk that was produced and processed by their own neighbors. Furthermore, the fact that production and processing are kept local and visible is very helpful in keeping the facility in good standing in the public eye, since the milk is produced by cows in a smaller facility that is nearby as opposed to very larger facilities farther away, where it is harder to figure out how the cows or treated or what kind of processing methods are used. The implementation of this design would also give community members a better sense of control over their own local economy and food security (Ferguson & Thompson, 2020).

This design may not be implemented in different countries around the world, however. For example, in some countries, the main form of dairy production is on a large scale, similar to most dairy production in the United States. The design would likely not be as applicable in countries such as China or South Africa, in which dairy production facilities are modern and relatively large; in those areas, processing facilities must be equally as large to handle the volume. Furthermore, some countries have smaller dairy operations in which the families of producers consume a good amount of the milk, such as many operations in Kenya. Other countries like Pakistan have small dairy operations that produce high volumes of milk but cannot store or ship their product in a safe and timely manner (Tariq, 2023). These operations, although they would likely benefit from this kind of system, often lack the infrastructure, minimum production volume, and/or government assistance needed to justify the implementation of this design, so milk collection centers or transportation to large dairy processing facilities are more feasible than on-site processing at this point in time (Dolecheck & Bewley, 2023). Contrarily, India, for example, has great amounts of smaller dairy operations scattered around the country as well as strong government support for dairy farmers. Due to this, a model such as the one proposed in this project may be extremely useful for creating similar systems for small dairies, if it proves profitable (Invest India, 2024). Overall, before the implementation of this design, it is crucial to consider the given conditions of the production facility and determine whether or not it would be applicable.

Economic Considerations

The design of this dairy processing facility has large economic implications for not only the University of Nebraska – Lincoln, but also small, family-owned dairy operations. Many smaller dairy operations would see a boost in revenue if they could process the raw milk they produce on-site. This in turn reduces logistics costs, as well as costs associated with the storage of raw milk. It is important to consider the startup costs associated with buying the equipment as well. The target breakeven point for the project would be 6 years, so smaller dairy operations must account for whether or not this would be a feasible investment depending on their current financial situation and future outlook. How the funds are sourced for these costs will determine how feasible a project like this would be in industry. Logistics companies will be needed for the transportation of processed milk to local businesses. The shelf life of the processed milk will be determined by the pasteurization method and the cost of these methods should be weighed with the shelf life.

Environmental Considerations

As a dairy-processing facility, our design will be closely involved with local environmental practices along with proper handling of cattle in the associated barn. Our waste product management will follow proper regulations involving organic byproducts such as cream, as well as spoiled products. Sustainable practices are a potential point of improvement to our future design, as milk processing itself requires a considerable amount of water and electricity; an energy-efficient pasteurizer would be one way to reduce the energetic requirements and consequent environmental impact of the facility. Sourcing power from sustainable means would also enable this project to reduce associated carbon emissions. Sustainable power can be sourced through Lincoln Electric System, with the use of LES's renewable energy certificates (LES, n.d.).

Analysis of Alternatives

The main solution alternatives that are applicable to this project are mainly regarding the method of pasteurization, filtration, and separation used when processing raw milk. The three alternatives that will be explored for the pasteurization of milk at this facility are vat pasteurization, high-temperature/short-time pasteurization, and ultra-high-temperature pasteurization. Alternatives for filtration to be considered are no filtration, microfiltration, and ultrafiltration. The final processing alternatives to be considered will be cold separation and hot separation.

Alternatives for the mixture of bottled and bagged milk manufactured will also be considered. The output alternatives considered will be entirely bagged milk, entirely single-serving bottles of milk, and a mix of the two.

Figure 1: Vat pasteurization equipment example. Retrieved from https://www.ancoequipment.com/batch-pasteurizers.

Pasteurization Alternatives

Vat Pasteurization (Magar, 2023):

Vat (low temperature) pasteurization (Figure 1) is more commonly used in facilities that process a lower volume of milk, as the facility being designed would be. This method involves bringing the milk to a relatively lower pasteurization temperature for a longer period, and results in a shorter shelf-life of the final product. Heating and cooling costs for this method are relatively expensive as well, and it is a batch step in the process.

Fast Facts:

- Temperature brought to ~62-64°C for ~30 minutes.
- The shelf life of food when refrigerated is 2-3 weeks.
- Is a batch step in the process.
- Effective for low volumes.
- Heating and cooling are relatively expensive.

High Temperature/Short Time (HTST) Pasteurization (Magar, 2023):

High temperature/short time (HTST) (Figure 2) is currently a very popular pasteurization method in the dairy industry. This method is continuous. HTST involves heating the milk to around 74°C for only 15-30 seconds, followed by rapid cooling. Benefits of HTST include elimination of nearly all harmful bacteria, spoilage, yeast, or mold, a higher shelf life than vat pasteurized milk, and preservation of flavor and color for longer. However, this method is much more

Figure 2: HTST pasteurization equipment example. Retrieved from https://www.kossindustrial.com/Processing-Equipment/HTST-Pasteurizers.

expensive than vat pasteurization, and it works best when used to process higher volumes of milk than what this plant would be handling.

Fast Facts:

- Continuous method.
- Currently very popular.
- Heated to ~71.5-74°C for 15-30 seconds.
- Rapidly cooled to ~4-5.5°C
- The shelf life of food when refrigerated is 2-3 weeks.
- Color and flavor are well preserved.
- Expensive.

Ultra-High Temperature (UHT) Pasteurization (Magar, 2023):

The ultra-high temperature (UHT) (Figure 3) method has the shortest processing time of any other pasteurization technique. The main negative aspects of this method include the fact that flavor is changed, and the nutrient content is lower than milk processed using lower temperatures. Furthermore, it uses a very high amount of energy during operation and does not allow for biodegradable packing. However, the shelf life is extended greatly, and the final product can remain unrefrigerated for up to 6-9 months.

Figure 3: UHT Pasteurization equipment example. Retrieved from https://cedarstoneindustry.com/product-category/cleaning-pasteurization/uht-systems/.

Fast Facts:

- Milk is sterilized at 135°C for 2-5 seconds before packaging.
- Milk can be left out of the refrigerator for ~6-9 months.
- Reduces the nutritional value of the milk.
- Energetically costly.
- Changes the color and flavor of the milk.
- The packaging cannot be biodegradable.
- Expensive.

Filtration Alternatives

No Filtration

The no-filtration alternative is the simplest and cheapest of the filtration solutions. However, it does come at the cost of leaving undesirable particulates within the milk including bacteria, spores, and fat globules (Filter Holdings, 2023). The bacteria are however deactivated during pasteurization further downstream. Cost savings associated with no filtration are not only associated with capital costs, but also money saved long term from reduced maintenance and upkeep of the system.

Micro-Filtration

Micro-filtration is among the “leakiest” of the filtration methods available in dairy processing (Figure 4). This leakiness allows the majority of particulates to pass through the filter but stops bacteria, spores, and fat globules leading to a smoother taste profile (Filter Holdings, 2023). This also helps to extend the shelf life by a small margin (Filter Holdings, 2023).

Ultra-Filtration

Ultra-filtration is the most expensive of the three options but also offers the strongest filtering ability. This method removes a larger number of particulates from the milk as compared to micro-filtration, including casein, whey, and plant proteins present in the milk. This leads to a slightly changed flavor profile (Filter Holdings, 2023).

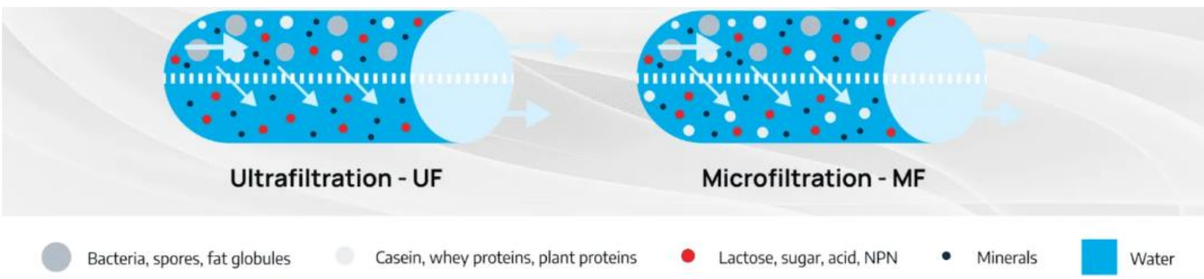

Figure 4: Differences in filtration alternatives. Retrieved from https://filterholdings.com/blog/membrane-filtration-of-milk/.

Separation Alternatives

Cold Separation

Cold separation is an effective method of separating butterfat from the milk stream during the processing of raw milk. This method is usually done around 10°C and has been gaining in popularity in industry in recent years. This is largely due to the reduced biological buildup due to the lower temperatures during processing (Tetra Pak, n.d.). The main drawbacks of cold separation come in during processing times. Due to the higher viscosity of the milk at colder temperatures, it flows more slowly through the separator and leads to longer processing times. Other drawbacks include that it can be more difficult to get the correct cream separation, but newer technologies have been somewhat successful in addressing this issue (Tetra Pak, n.d.).

Hot Separation

Hot separation generally is operated at around 50°C and is a faster process compared to cold separation. This efficiency does come at the cost of needing to clean the separator more often due to heat-induced biofouling (Tetra Pak, n.d.). This elevated temperature can also lead to thermoduric bacteria buildup that can survive the pasteurization process and cause contamination of the product (Tetra Pak, n.d.). The need for cleaning ultimately leads to more downtime in cleaning the process.

Output Alternatives

Entirely Bagged Milk

The bagged milk that would be made at the processing facility would be 5-gallon bulk bags intended for commercial clients, such as UNL's Dining Service. While having a single intended product simplifies the overall process and potentially reduces the amount of required equipment, bulk bags of milk are generally lower-margin items. Along with potential reduced returns, committing all of the milk to places like UNL's Dining Service creates issues when considering that the dining service works at reduced capacities during summer and winter breaks for students. This then creates problems for what the processing facility will do with the excess milk at this time. Additionally, places like the Dining Service will only use a certain amount of milk every week. This creates waste if too much milk is produced.

Entirely Bottled Milk

Single-serving bottled milk is a much higher margin product as compared to bulk bags. The bottles can be marketed at UNL's on-campus stores or local grocers for consumers to buy. The main disadvantage of using an entirely bottled line is that they are prone to suffer when consumer habits change. If consumers do not buy the bottles, the processor does not make money. This is opposed to the consistent cash flows that contractual supply agreements for supplying bulk bags would guarantee.

A Mixture of Bagged and Bottled Milk

A mixed output of bagged and bottled milk offers the advantages of both bagged and bottled milk. Supplying bagged milk guarantees consistent cash flows for the majority of the year, while bottled milk can be a higher-margin product and help to reduce any surplus of milk left over after the bags have been sold. There are a couple of disadvantages associated with outputting a mix of products. Chiefly is the increased equipment cost. Having two packaging types means there will be a need for separate equipment for both outputs. Two packaging types could also reduce the productivity of the plant, as there will be changeover times associated with switching between products. Finding the correct mixture of bagged and bottled milk to produce would be key to ensuring that having a mix would justify the increased capital costs.

Decision Matrices

A set of decision matrices was made to pick the best option according to weighted criteria (Tables 1-5).

Table 1: Decision matrix criteria weighting.

	Cost	Capability for multiple types of milk	Capability for processing different volumes	Equipment Size	Total
Cost	X	1	1	1	3
Capability for multiple types of milk	0	X	1	1	2
Capability for processing different volumes	0	0	X	0	0.5
Equipment Size	0	0	1	X	1

Table 2: Decision-making matrix for pasteurization alternatives.

		Design Alternatives - Pasteurization		
Criteria	Criteria Weight	A	B	C
Cost	3	3	2	1
Capability for multiple types of milk	2	3	1	1
Capability for processing different volumes	0.5	1	3	3
Equipment Size	1	2	3	1
	Score	17.5	12.5	7.5

KEY	
A	Vat Pastuerization
B	HTST Pastuerization
C	UHT Pasteurization

Table 3: Decision-making matrix for filtration alternatives.

		Design Alternatives - Filtration		
Criteria	Criteria Weight	A	B	C
Cost	3	3	2	1
Capability for multiple types of milk	2	X	X	X
Capability for processing different volumes	0.5	3	2	1
Equipment Size	1	3	2	1
	Score	13.5	9	4.5

KEY	
A	No Filtration
B	Micro-Filtration
C	Ultra-Filtration

Table 4: Decision-making matrix for separation alternatives.

		Design Alternatives - Separation	
Criteria	Criteria Weight	A	B
Cost	3	2	1
Capability for multiple types of milk	2	1	2
Capability for processing different volumes	0.5	1	2
Equipment Size	1	1	1
	Score	9.5	9

KEY	
A	Cold Separation
B	Hot Separation

Table 5: Decision-making matrix for outputs.

		Design Alternatives - Output Alternatives		
Criteria	Criteria Weight	A	B	C
Cost	3	1	2	3
Capability for multiple types of milk	2	1	2	3
Capability for processing different volumes	0.5	3	2	1
Equipment Size	1	3	2	1
	Score	9.5	13	16.5

KEY	
A	Entirely Bagged
B	Entirely Bottled
C	Mixed Output

Chosen Alternatives

Based upon the above decision matrices, the design will utilize vat pasteurization, no filtration will be done on the product, and butterfat will be separated using a cold separator.

Vat pasteurization is by far the most affordable of all of the pasteurization alternatives. It should also be noted that vat pasteurization is more versatile in its ability for the pasteurization of different milkfat profiles. The main drawback of vat pasteurization is its slower processing times. This should not be an issue in this project due to the low number of cattle to be housed in the dairy.

No filtration will be done within this process. This is due to the need for quicker processing times to make up for the slow vat pasteurization step. The products from this process will be sold locally, this reduces the need to remove as many spoilage bacteria as possible within the end product. The choice of no filtration also saves space within the facility. It also saves time and labor that would otherwise be spent on maintaining the filters.

Cold separation was chosen for this process due to the lower costs associated with the equipment over time. Hot separation requires more downtime for cleaning, while cold separation can run multiple batches before requiring cleaning. Moreover, the dairy industry is moving toward using cold separation and it is appropriate to follow the trends for this facility.

A mixed output will be used for this process. The approach to ranking the alternatives was taken slightly differently than in the other decision matrices. The cost for the output alternatives was defined as the potential for making money, rather than the equipment cost itself. The startup costs for the mixed output option will certainly be more than the other two options, but it opens up the facility to a larger market to sell to. As the facility begins production, it is best to have a diverse customer base and without producing multiple packaging types, the customer base would be severely limited.

Risk Analysis

Risk analysis was performed for equipment used within the facility (Tables 6 and 7). Table 6 includes the identification of potential failures, consequences, likelihood of failure, risk control measures, and rationales for controls. Table 7 shows the rating scale for the risk assessments. The main controls identified for ensuring risks have been minimized within the design are Good Engineering Practices (GEPs) and procedural controls. Qualification and validation of equipment fall under the purview of GEP. Qualification and validation plans should be developed in accordance with current industry standards and practices. Qualification and validation protocols were not written for this report and should be written in case of further developments toward building this facility. Procedural controls include standard operating procedures (SOPs) and are the gold standard for quality in manufacturing. SOPs should be written according to industry standards to meet federal guidelines. This will help ensure a safe, consistent, high-quality product for the end consumer.

Table 6: Risk analysis for equipment used in the facility.

TRANSFER PUMPS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of the pump	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept

Transfer of Milk	*Business Risk*: pump housing leaks either processed or raw milk.	2	Surrounding area would be contaminated in the event of a leak.	Environment al/Biological	During the transfer of raw milk, a possible leak can occur due to wear on parts.	3	Without proper maintenance , it is sure that leakage will occur in the pumps. Regular maintenance is necessary for proper function.	6	Good Engineering Practice	Regular maintenance will be conducted on pumps.
	Consumer Risk: The pump leaks lubricant into the product.	3	Potential sickness or hospitalization could occur if a motor lubricant is ingested should the milk pass through all inspections.	Chemical	Old gaskets can wear out over time and cause the motor to leak lubricants into the product.	3	Regular maintenance should be done on all equipment within the plant. These should include inspections and regular replacement of critical parts.	9	Good Engineering Practice	Regular maintenance will be conducted on pumps.

RAW STORAGE TANKS - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of storage tank	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Transfer of Raw Milk	*Business Risk*: Effluent from tank contaminates the surrounding area in the event of a spill.	2	Surrounding area would be contaminated in the event of a raw milk spill.	Environment al/Biological	During the transfer of raw milk, a possible spill can occur. A puncture of the tank is also possible.	1	It is unlikely that a tank is punctured. The tank is unlikely to spill as the tank is only in use when inlet/outlets are fully secure.	2	Procedural Control	Opening of tank valves shall only be done when the transfer piping is fully connected.

Refrigeration of Raw Milk	*Consumer Risk*: Refrigeration temperature is above 4°C.	3	Inadequate refrigeration temperatures leads to elevated microbial levels.	Biological	Glycol is not delivered at correct temperature /rate.	1	Continuous monitoring of the temperature inside the storage tanks ensures no milk that has not been refrigerated properly will reach the public.	3	Good Engineering Practice	Installation/Operational/Performance Validation will be undertaken to ensure that all components of the system are performing as defined.

VAT PASTEURIZATION TANKS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of pasteurization tank	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Pasteurization of Milk	*Consumer Risk*: Milk does not sit at pasteurization temperature for the requisite amount of time.	5	There are elevated microbial levels in milk that have not been properly pasteurized leading to an increased risk of illness.	Biological	It is possible that the temperature is not met due to the hot water not providing enough energy. It is also possible that the milk is not held for a long enough time due to operator error.	2	It is unlikely that the vat not reach temperature because of the controlled water temperature used to heat the vat. The residence time will be controlled via HMI and will have no operator override.	10	Procedural Control	Training will be utilized to ensure operators are capable of using the HMI of the pasteurizers. Residence times will be programmed directly into the vat pasteurizer HMI. Batch logs will be kept as evidence of compliance.

HEAT EXCHANGERS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description

Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of heat exchanger	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
Cooling of Milk Fluid	*Consumer Risk*: heat exchanger fails to drop the temperature of fluid below 4°C.	3	Failing to drop the temperature below 4°C could result in higher microbial loads within the storage tanks. However, the storage tanks themselves are cooled and can cool the milk to a lower temperature if not already below 4°C.	Biological	Glycol is not circulating through the heat exchanger efficiently. There could be a buildup of material on the walls of the heat exchanger thereby lowering its efficiency.	2	CIP can properly clean the walls of the heat exchanger and maintain effective levels of heat exchange.	6	Procedural Control and Good Engineering Practice.	Cleaning batch records will be kept as well as records of the efficiency of the heat exchanger. Installation/Operational/Performance Qualification will be carried out to confirm all requirements are met for the heat exchanger.
Maintenance	*Business Risk:* contents under pressure are not properly handled leading to improper release during maintenance.	5	Failing to relieve pressure when doing maintenance can result in a powerful stream that can result in serious harm.	Physical	A worker could be preparing to do maintenance on the exchanger and isolating the system. The glycol is under some pressure. Improper handling of potential energy can lead to injury or death.	4	Workers not properly trained or negligent to follow procedures can result in the event occurring.	20	Procedural Control and Good Engineering Practice.	Lock-Out/Tag-Out procedures will be utilized to isolate all systems under pressure. Pressure relief valves will be used to ensure the system does not reach dangerous pressures.

CREAM METERED PUMP - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of the pump	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
Transfer of Cream	*Business Risk*: pump housing leaks cream.	2	Surrounding area would be contaminated in the event of a leak.	Environmental/Biological	During the transfer of cream a possible leak can occur due to wear on parts.	3	Without proper maintenance, it is sure that leakage will occur in the pumps. Regular maintenance	6	Good Engineering Practice	Regular maintenance will be conducted on pumps.

							is necessary for proper function.			
	Consumer Risk: The pump leaks lubricant into the product.	3	Potential sickness or hospitalization could occur if a motor lubricant is ingested should the milk pass through all inspections.	Chemical	Old gaskets can wear out over time and cause the motor to leak lubricants into the product.	3	Regular maintenance should be done on all equipment within the plant. These should include inspections and regular replacement of critical parts.	9	Good Engineering Practice	Regular maintenance will be conducted on pumps.
	Business Risk: inaccurate amount of cream is transferred during metering.	4	No injuries result. The cream is wasted and the product is out of specification leading to a recall of the product.	Physical	Calibration is out of specification .	5	It is difficult to meter to the precision needed for this project.	20	Good Engineering Practice and Technical Control	Regular calibrations will be required as well as batch testing to confirm specifications of the product have been met.

FINISHED STORAGE TANKS - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of storage tank	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
Clean-in-Place	*Business Risk*: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Transfer of Processed Milk	*Business Risk*: Effluent from tank contaminates the surrounding area in the event of a spill.	2	Surrounding area would be contaminated in the event of a raw milk spill.	Environmental/Biological	During the transfer of raw milk, a possible spill can occur. A puncture of the tank is also possible.	1	It is unlikely that a tank is punctured. The tank is unlikely to spill as the tank is only in use when inlet/outlets are fully secure.	2	Procedural Control	Opening of tank valves shall only be done when the transfer piping is fully connected.

Refrigeration of Processed Milk	*Consumer Risk*: Refrigeration temperature is above 4°C.	4	Inadequate refrigeration temperatures leads to elevated microbial levels.	Biological	Glycol is not delivered at correct temperature /rate.	1	Continuous monitoring of the temperature inside the storage tanks ensures no milk that has not been refrigerated properly will reach the public.	4	Good Engineering Practice	Installation/Operational/Performance Validation will be undertaken to ensure that all components of the system are performing as defined.

PACKAGING - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Packaging - General	*Consumer Risk:* Clean-in-Place fails to sanitize equipment.	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Fail to release stored energy from equipment during maintenance.	5	Improper release of energy during maintenance of packaging equipment can lead to serious injury or death.	Physical	Lock-Out/Tag-Out procedures were not followed either from a lack of training or negligence.	4	Untrained personnel are more likely to not follow Lock-Out/Tag-Out procedures. There is a large amount of student workers planned for this plant.	20	Procedural Control and Good Engineering Practice	Lock-Out/Tag-Out procedures will be followed. Training strategies will be employed to ensure that maintenance workers are capable of working on systems independently. Physical guards will be placed to prevent unauthorized access to machinery.
Filling	*Business Risk:* Inaccurate filling amounts.	5	No injuries associated. This risk is associated with elevated cost to the business either through over filled products or discarded product that does not meet specifications.	Physical	Calibration is not correct.	2	Calibrations are adequate to prevent incorrect filling of bottles.	10	Procedural Control and Good Engineering Practice	Calibrations and Qualifications will be adequate to ensure proper amounts of milk are dispensed into respective bottles.
Capper	*Consumer Risk:* Plastic inside product.	5	Plastic inside of the product has potential to be ingest which can then cause damage to internal organs.	Physical	Calibration is not correct, or timing is misaligned.	3	It is possible that the capper becomes misaligned with the necessary timing.	15	Good Engineering Practice	Installation/Operational/Performance Qualification will be carried out to ensure that the equipment is operating correctly.
Sealer	*Consumer Risk*: inadequate sealing.	4	Seal is not on the final product and leaves the product open to contamination.	Biological	Sealer does not meet required temperature or length of time.	1	Calibration and maintenance are adequate to ensure that the	4	Procedural Control	Calibrations and Qualifications will be adequate to ensure seal of product from

							product is meeting specifications for its seal.			external environment.
Labeler	*Consumer Risk*: Lot labeling is incorrect	5	Incorrect lot labeling can lead to illness in the event of a product recall.	Biological	Corruption of software in the event of a power loss and restart.	4	Power losses are likely to happen but can be mitigated with the use of a site generator.	20	Good Engineering Practice	Utilize backup and restore to capture lot numbers and times.
	Business Risk: Illegible labels.	2	Labeler could cut off labeling at incorrect lengths.	Physical	Incorrect timing of labeler.	2	It is unlikely to occur with proper qualification and validation.	4	Good Engineering Practice	Installation/Operational/Performance Qualification will be carried out to ensure that the equipment is operating correctly.

Table 7: Risk Analysis scoring matrix.

Consquences

Score	1	2	3	4	5
Description	Insignificant	Minor	Moderate	Major	Catastrophic
Example	Minor injury, no first aid required	Harmful injury (first aid required, under 3 days recovery time)	Serious injury, medical assistance required. Injury must be reported.	Major injury, urgent medical assistance required.	Fatality

Likelihood

Score	1	2	3	4	5
Description	Rare	Unlikely	Possible	Likely	Almost certain

Rating Matrix

Consequences							
	Catastrophic	5	5	10	15	20	25
	Major	4	4	8	12	16	20
	Moderate	3	3	6	9	12	15
	Minor	2	2	4	6	8	10
	Insignificant	1	1	2	3	4	5
			1	2	3	4	5
			Rare	Unlikely	Possible	Likely	Almost Certain
			Likelihood				

Engineering Analysis

Raw Milk Inputs

Input calculations are necessary to inform what the dairy can produce and sell to consumers. Input numbers are dictated by the number of cows used within the dairy, as well as the assumed amount of milk produced each day by each cow. According to the USDA, a dairy cow produces 8 gallons of milk on average every day. With this assumption, raw milk inputs were calculated per day and year for different numbers of cows (Table 8).

Cream is another limiting factor in how much of a product can be made. Mass balances of cream were calculated using an assumed butterfat composition of 3.5% and 4.0% (Table 9). Depending on the breed of cow, this butterfat percentage could be higher or lower than the assumed amounts. Cream mass balances were calculated in metric units for ease in sizing equipment and were based on an assumed 2% loss of raw milk during the separation step.

Table 8: Raw milk inputs every day and year from different numbers of cows.

Raw Milk Inputs		
Number of Cows	**Daily Milk (gallons)**	**Yearly Milk (gallons)**
60	480	175,000
180	1,440	525,600
240	1,920	700,800

Table 9: Cream mass balances after the separation step.

Assuming 3.5% Fat Milk		
	Volume (Liters)	**Fat %**
Whole Milk In	1781	3.5%
Raw Skim	1655	0.02%
Raw Cream	125	50%
Assuming 4% Fat Milk		
	Volume (Liters)	**Fat %**
Raw Whole Milk In	1781	4.0%
Raw Skim	1638	0.02%
Raw Cream	143	50%

Process Flow Diagram (PFD)

The PFD document is used as a conceptual diagram to map out the entire process for the diary processing plant (Figure 5). This document spells out the unit operations involved with the process of taking in raw milk and outputting processed milk. The PFD was also used to inform what equipment needed to be priced out as well as the plant layout. Equipment sizes were based on mass balances calculated.

The description of the process is as follows:

Product manufacturing steps:

1. Cows are milked with a robot milker.
2. Raw milk is temporarily deposited into a 75L intermediate storage tank.
3. Raw milk is pulled from the 75L tank through a heat exchanger to drop the raw milk temperature to 4°C.
4. Raw milk is placed into one of two 7500L jacketed – storage tanks.
    a. The tank that is deposited into switches every two days.

5. Raw milk is pumped into a cold separation step.
    a. Milk is separated into two streams.
        i. Skim stream with 0.02% fat content.
        ii. Cream stream with 50% fat content.
6. Raw skim milk is pumped into a 2000L tank. Raw cream is pumped directly to 200L vat pasteurizer.
7. Raw skim milk is transferred to a 2000L vat pasteurizer.
8. Vat pasteurizers are heated with hot water flowing through the jacketed vats to 66°C and 63°C for cream and skim pasteurization respectively.
9. Vat pasteurizers are held at temperature for 30 minutes.
10. Following pasteurization, milk components are transferred to a 2000L blending tank at rates according to what product is being made.
11. The prepared mix is pumped into a homogenizer.
12. Homogenized milk product flows through a heat exchanger to drop the temperature to 4°C.
13. The product is placed into a product tank.
14. The product is bottled or bagged.

Wastewater Component:

1. Wastewater is fed into drains on the floor.
    a. Wastewater could constitute routine cleaning wastes, spilled product, or other aqueous wastes.
2. Floor drains lead to a 7,500L storage tank.
3. Storage tank is monitored for pH and temperature and adjustments are made from auxiliary storage tanks.
4. Waste contents are released through a metered flow pump to Lincoln municipal wastewater.

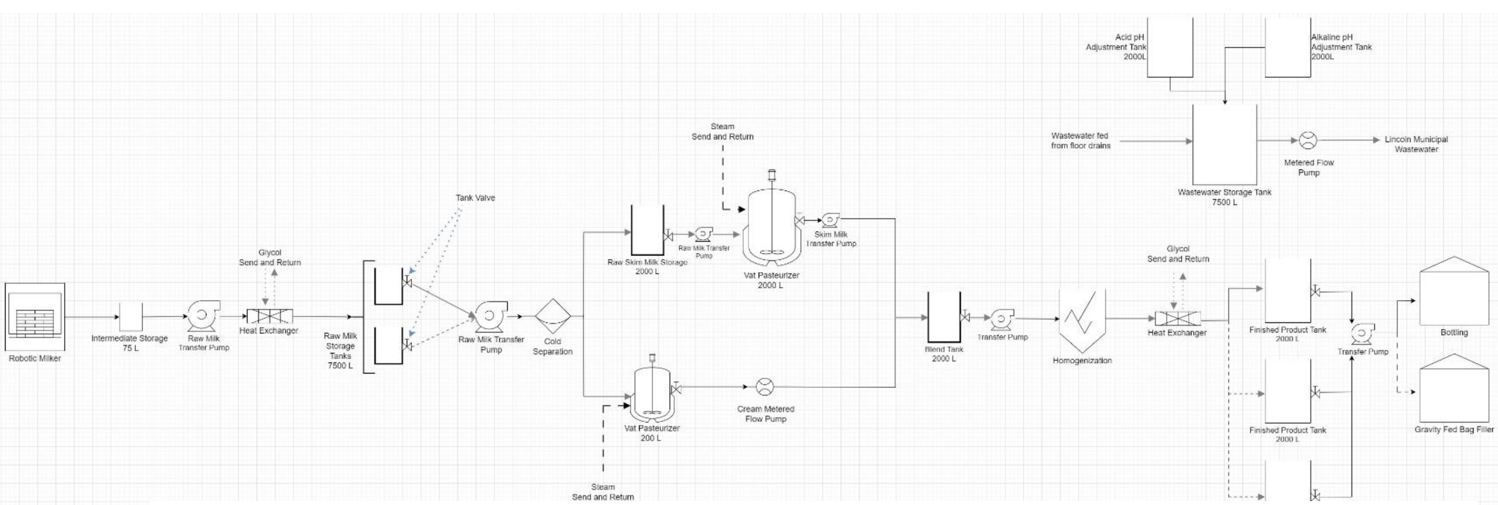

Figure 5: Process Flow Diagram of milk processing facility.

Wastewater Calculations

Calculations for the wastewater effluent total output volume are necessary for the Lincoln municipal wastewater treatment facility. Wastewater effluent will be stored in a 7,500L tank outside of the processing area. BOD is Biological Oxygen Demand and is the deciding factor in how much oxygen is needed for the breakdown of the material. BOD content is how the dissolved oxygen content is utilized by microorganisms during the oxidation of organic compounds in the effluent (USDA). A higher BOD value indicates more organic matter is in the effluent. The BOD value associated with milk is 1300 mg/L (Slavov, 2017). BOD Calculations can be found below.

Total daily Effluent Calculations

$$528\,\frac{gallons\ processed\ milk}{day}\cdot\frac{2\ gallons\ wastewater}{1\ gallon\ processed\ milk}=1056\,\frac{gallons\ wastewater}{day}$$

$$1056\,\frac{gallons\ processed\ milk}{day}\cdot\frac{2\ gallons\ wastewater}{1\ gallon\ processed\ milk}=2112\,\frac{gallons\ wastewater}{day}$$

BOD Calculations

Pounds of BOD = gallons of effluent divided by 1,000,000 x 8.34 x mg/l BOD5

$$\frac{1056\ gallons}{1{,}000{,}000\cdot day}\cdot 8.34\cdot 1300\,\frac{mg}{L}=11.45\ \frac{lbs}{day}$$

$$\frac{2112\ gallons}{1{,}000{,}000\cdot day}\cdot 8.34\cdot 1300\,\frac{mg}{L}=22.90\ \frac{lbs}{day}$$

Economic Analysis

Equipment Costs

Equipment costs were estimated with assistance from Walter Powell of Dairy Engineers (Table 10). It should be noted that some equipment quoted is slightly larger than the sizes specified in the PFD; equipment is not always made in the sizes specified and the closest size up was chosen. Regardless, this extra capacity will not affect the process's efficacy.

Table 10: Equipment costs for dairy processing plant.

Equipment Costs		
Equipment	**Units**	**Total Price**
700 gallon Vat Pasteurizer w/ PMO Appliances	1	$ 115,500.00
10 gallon Vat Pasteurizer w/ PMO Appliances	1	$ 26,223.75

APV Gaulin G90 Homogenizer	1	$ 102,112.50
FPX-711 pump with 1 hp motor	1	$ 3,863.48
500-gal blend tank	1	$ 84,000.00
W61-T-S-15-4AR-000-00-00- TF-E-32-00 Valve	1	$ 2,000.09
2000 gal bulk storage	2	$ 90,300.00
W61-T-S-20-4AR-000-00-00-TF-E-32-00 Valve	2	$ 2,259.81
FPX-711 pump with 1 hp motor	1	$ 3,863.48
W68-T-S-15(10)-4AREP-000- 00-00-TR-V-32-00 Valve	1	$ 4,746.32
90 GALLON PMO BALANCE TANK	1	$ 6,825.00
2000 gal single shell storage tank	1	$ 57,750.00
FPX-711 pump with 1 hp motor	2	$ 7,726.95
500 gallon finished storage tank	4	$ 222,600.00
200 gallon COP tank	1	$ 6,825.00
SPXFlow SE20X-Q3P2 Separator	1	$ 115,500.00
Automation controls in Stainless steel panel with PLC, HMI, motor starters, etc	1	$ 36,750.00
Aluminum Food Grade Tilt & Roll Ladder	1	$ 1,279.43
Stainless Steel Worktable	1	$ 393.75
Easy-Count Scale - 60 lbs x .002 lb	1	$ 341.25
FOSS MilkoScan™ Mars	1	$ 38,165.69
550 GALLON TOTE TANK. TRANSTORE MODEL	2	$ 8,820.00
Mariner Peristaltic Filler	1	$ 136,500.00
Capper + elevator	1	$ 84,000.00
Induction sealer	1	$ 14,700.00
Labeler + lot coder	1	$ 58,800.00
Metal Detector	1	$ 31,500.00
Conveyance	1	$ 42,000.00
Gravity Filling System for 5-gal bags	1	$ 8,400.00
Single Tank, Single Pump, Portable CIP Skid	2	$ 189,000.00
Total Cost		$ 1,502,746.50

Installation Costs

Table 11 below shows the estimated installation costs for the equipment in the processing facility. This estimate was developed by the team with the guidance of industry professionals. It should be noted that the installation cost estimated provided is an underestimate; it does not include any overtime hours, project manager hours, or travel time pay. This also does not include costs associated with the construction of the building or integration with Innovation Campus utilities. With this in mind, the total installation cost estimated for this project is approximately $190,000.

The estimation segments the installation process into crating/uncrating activities, installation activities, and costs from materials. Installation and labor hours were added as bulk estimates within each step. Labor was estimated to cost $110 per hour. There was an assumed no markup for the cost of materials.

Table 11: Installation cost estimates. Costs are broken down on a step-by-step basis.

Line #												
1	Project:	UNL Small-Scale Dairy Processing										
2	Date:	5/10/2024										
3												
4				Dollars	Hours	Hours		Dollars	Dollars	Dollars		
5	**Step/Operation**	**Component**	**Multiples**	**Materials**	**Crate/ Uncrate**	**Installation**		**Total Materials**	**Unload/ Uncrate**	**Installation**	**Total Dollars**	**Total On-site hours**
6	**Floor installation**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
7		Surface prep	-	$ -	-	90		$ -	$ -	$ 9,900.00	$ 9,900.00	90
8		spray with grit	-	$ -	-	-		$ -	$ -	$ -	$ -	-
9		clean area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
10		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
11		Site prep	-	$ -	-	-		$ -	$ -	$ -	$ -	-
12		Move into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
13		Uncrate and unwrap	-	$ -	2	-		$ -	$ 220.00	$ -	$ -	-
14		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
15		Install piping (4") - 240 ft	-	$ 2,712.00	-	50		$ 2,712.00	$ -	$ 5,500.00	$ 8,212.00	50
16		Bond pipes	-	$ 100.00	-	-		$ 100.00	$ -	$ -	$ 100.00	-
17		Grout over piping	-	$ -	-	-		$ -	$ -	$ -	$ -	-
18		Install grates	-	$ 52.00	-	-		$ 52.00	$ -	$ -	$ 272.00	2
19		Mortar cover bed	-	$ 775.45	-	-		$ 775.45	$ -	$ -	$ 775.45	-
20		Install dairy brick - roughly 1780 sq ft	-	$ 25,551.90	-	-		$ 25,551.90	$ -	$ -	$ 25,551.90	-
21		Stage in area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
22		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
23		lay dairy brick	-	$ -	-	-		$ -	$ -	$ -	$ -	-
24		forklift rental	-	$ -	-	-		$ -	$ -	$ -	$ -	-
25		fit and finish walk through	-	$ -	-	-		$ -	$ -	$ -	$ -	-
26			-	$ -	-	-		$ -	$ -	$ -	$ -	-
27	**Install Storage Tanks**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
28		forklift rental	-	$ -	-	-		$ -	$ -	$ -	$ -	-
29		site prep	10	$ -	60	-		$ -	$ 6,600.00	$ -	$ 6,600.00	60
30		Move tank into area	10	$ -	-	-		$ -	$ -	$ -	$ -	-
31		unwrap and dispose of waste	10	$ -	-	-		$ -	$ -	$ -	$ -	-
32		tip tank up	10	$ -	-	-		$ -	$ -	$ -	$ -	-
33		drill holes for leveling legs	10	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
34		Clean holes	10	$ -	-	-		$ -	$ -	$ -	$ -	-
35		Install bolts for legs - epoxy	10	$ -	-	-		$ -	$ -	$ -	$ -	-
36		Install tank	10	$ -	-	-		$ -	$ -	$ -	$ -	-
37		Level tank	10	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20

38		make form for grout	10	$ -	-	100		$ -	$ -	$ 11,000.00	$ 11,000.00	100
39		grout	10	$ -	-	-		$ -	$ -	$ -	$ -	-
40		remove grout form	10	$ -	-	-		$ -	$ -	$ -	$ -	-
41		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
42		7 - W61-T-S-20-4AR-000-00-00-TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
43			-	$ -	-	-		$ -	$ -	$ -	$ -	-
44	**Install pasteurizers**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
45		1 semi trip	-	$ -	-	-		$ -	$ -	$ -	$ -	-
46		site prep	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
47		Move 2000L Vat pasteurizer into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
48		unwrap and dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
49		tip vat up	-	$ -	-	-		$ -	$ -	$ -	$ -	-
50		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
51		make form for grout	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
52		grout	-	$ -	-	-		$ -	$ -	$ -	$ -	-
53		remove grout form	-	$ -	-	-		$ -	$ -	$ -	$ -	-
54		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
55		W61-T-S-20-4AR-000-00-00- TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
56		HMI	-	$ -	-	-		$ -	$ -	$ -	$ -	-
57		site prep	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
58		Move 200L Vat pasteurizer into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
59		unwrap and dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
60		tip vat up	-	$ -	-	-		$ -	$ -	$ -	$ -	-
61		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
62		Grout steps (grout steps for tanks)	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
63		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
64		W61-T-S-20-4AR-000-00-00- TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
65		HMI	-	$ -	-	-		$ -	$ -	$ -	$ -	-
66			-	$ -	-	-		$ -	$ -	$ -	$ -	-
67			-	$ -	-	-		$ -	$ -	$ -	$ -	-
68			-	$ -	-	-		$ -	$ -	$ -	$ -	-
69	**Install Gaulin M3 Homogenizer 2-stg**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
70		1 skid	-	$ -	-	-		$ -	$ -	$ -	$ -	-
71		Site prep (See lines 18-20)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
72		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
73		Grout steps (grout steps for tanks)	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
74		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
75			-	$ -	-	-		$ -	$ -	$ -	$ -	-
76			-	$ -	-	-		$ -	$ -	$ -	$ -	-
77			-	$ -	-	-		$ -	$ -	$ -	$ -	-
78			-	$ -	-	-		$ -	$ -	$ -	$ -	-
79			-	$ -	-	-		$ -	$ -	$ -	$ -	-

80	**Install SPXFlow SE20X-Q3P2 Separator**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
81		1 skid	-	$ -	-	-		$ -	$ -	$ -	$ -	-
82		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
83		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
84		Anchoring	-	$ -	-	4		$ -	$ -	$ 440.00	$ 440.00	4
85		electrical - 400V 3 phase	-	$ -	-	-		$ -	$ -	$ -	$ -	-
86			-	$ -	-	-		$ -	$ -	$ -	$ -	-
87			-	$ -	-	-		$ -	$ -	$ -	$ -	-
88			-	$ -	-	-		$ -	$ -	$ -	$ -	-
89	**Install heat exchangers AGC Model Pro21-M Frame**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
90		Site prep (See lines 12-14)	2	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
91		Rough placement frame	2	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
92		Level	2	$ -	-	1		$ -	$ -	$ 110.00	$ 110.00	1
93		Final placement	2	$ -	-	6		$ -	$ -	$ 660.00	$ 660.00	6
94		Assemble heat exchanger	2	$ -	-	8		$ -	$ -	$ 880.00	$ 880.00	8
95			-	$ -	-	-		$ -	$ -	$ -	$ -	-
96			-	$ -	-	-		$ -	$ -	$ -	$ -	-
97			-	$ -	-	-		$ -	$ -	$ -	$ -	-
98			-	$ -	-	-		$ -	$ -	$ -	$ -	-
99			-	$ -	-	-		$ -	$ -	$ -	$ -	-
100			-	$ -	-	-		$ -	$ -	$ -	$ -	-
101			-	$ -	-	-		$ -	$ -	$ -	$ -	-
102	**Install FPX-711 pump with 1 hp motor**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
103		Site prep (See lines 12-14)	6	$ -	3	-		$ -	$ 330.00	$ -	$ 330.00	3
104		Grout steps (grout steps for tanks)	6	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
105			-	$ -	-	-		$ -	$ -	$ -	$ -	-
106			-	$ -	-	-		$ -	$ -	$ -	$ -	-
107			-	$ -	-	-		$ -	$ -	$ -	$ -	-
108			-	$ -	-	-		$ -	$ -	$ -	$ -	-
109			-	$ -	-	-		$ -	$ -	$ -	$ -	-
110			-	$ -	-	-		$ -	$ -	$ -	$ -	-
111	**Install Anderson 1.5" flow meter with display**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
112		Site prep (See lines 12-14)	-	$ -	1	-		$ -	$ 110.00	$ -	$ 110.00	1
113			-	$ -	-	-		$ -	$ -	$ -	$ -	-
114			-	$ -	-	-		$ -	$ -	$ -	$ -	-
115			-	$ -	-	-		$ -	$ -	$ -	$ -	-
116			-	$ -	-	-		$ -	$ -	$ -	$ -	-
117			-	$ -	-	-		$ -	$ -	$ -	$ -	-
118			-	$ -	-	-		$ -	$ -	$ -	$ -	-
119			-	$ -	-	-		$ -	$ -	$ -	$ -	-
120	**Install Mariner Peristalic Filler**		-	$ -	-	-		$ -	$ -	$ -	$ -	-

121		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
122		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
123		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
124		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
125		Assemble Filler	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
126			-	$ -	-	-		$ -	$ -	$ -	$ -	-
127			-	$ -	-	-		$ -	$ -	$ -	$ -	-
128			-	$ -	-	-		$ -	$ -	$ -	$ -	-
129	**Capper+elevator**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
130		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
131		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
132		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
133		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
134		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
135			-	$ -	-	-		$ -	$ -	$ -	$ -	-
136	**induction sealer**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
137		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
138		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
139		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
140		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
141		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
142			-	$ -	-	-		$ -	$ -	$ -	$ -	-
143			-	$ -	-	-		$ -	$ -	$ -	$ -	-
144	**labeler+lot coder**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
145		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
146		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
147		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
148		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
149		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
150			-	$ -	-	-		$ -	$ -	$ -	$ -	-
151	**metal detector**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
152		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
153		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
154		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
155		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
156		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
157			-	$ -	-	-		$ -	$ -	$ -	$ -	-
158	**gravity fill system - 5-gallon bag**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
159		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
160		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
161		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
162		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2

163		Assemble	-	$ -	-	20	$ -	$ -	$ 2,200.00	$ 2,200.00	20
164			-	$ -	-	-	$ -	$ -	$ -	$ -	-
165			-	$ -	-	-	$ -	$ -	$ -	$ -	-
166	**Conveyance (12 ft estimated)**	Site prep (See lines 12-14)	-	$ -	6	-	$ -	$ 660.00	$ -	$ 660.00	6
167		Rough placement frame	-	$ -	-	2	$ -	$ -	$ 220.00	$ 220.00	2
168		Level	-	$ -	-	2	$ -	$ -	$ 220.00	$ 220.00	2
169		Final placement	-	$ -	-	2	$ -	$ -	$ 220.00	$ 220.00	2
170		Assemble	-	$ -	-	20	$ -	$ -	$ 2,200.00	$ 2,200.00	20
171		Guard rails	-	$ -	-	50	$ -	$ -	$ 5,500.00	$ 5,500.00	50
172	**Packaging Electrical**		-	$ -	-	-	$ -	$ -	$ -	$ -	-
173		conduit	-	$ -	6	100	$ -	$ 660.00	$ 11,000.00	$ 11,660.00	106
174		HMIs	-	$ -	20	100	$ -	$ 2,200.00	$ 11,000.00	$ 13,200.00	120
175			-	$ -	-	-	$ -	$ -	$ -	$ -	-
176			-	$ -	-	-	$ -	$ -	$ -	$ -	-
177	**Piping and intermediate tank install**		-	$ -	-	-	$ -	$ -	$ -	$ -	-
178		2" Type 304 steel pipe - About 200 feet total length	-	$ 5,000.00	6	200	$ 5,000.00	$ 660.00	$ 22,000.00	$ 27,660.00	206
179		75L intermediate storage	-	$ -	6	2	$ -	$ 660.00	$ 220.00	$ 880.00	8
180		pipe hangers (1 for every 10 ft, 1 for every vertical connection)	40	$ 4,400.00	6	80	$ 4,400.00	$ 660.00	$ 8,800.00	$ 13,860.00	86
181		Likely ISO Clamp Unions where needed, CIP fittings preferred where possible	-	$ -	2	-	$ -	$ 220.00	$ -	$ 220.00	2
182		elbow joints	50	$ 850.00	2	-	$ 850.00	$ 220.00	$ -	$ 1,070.00	2
183			-	$ -	-	-	$ -	$ -	$ -	$ -	-
184	**Install Coolers**		-	$ -	-	-	$ -	$ -	$ -	$ -	-
185		Site prep (See lines 12-14)	-	$ -	18	-	$ -	$ 1,980.00	$ -	$ 1,980.00	18
186		assemble construction materials	-	$ -	-	10	$ -	$ -	$ 1,100.00	$ 1,100.00	10
187		construct cooler walls	-	$ -	-	50	$ -	$ -	$ 5,500.00	$ 5,500.00	50
188		install refrigeration systems	-	$ -	-	20	$ -	$ -	$ 2,200.00	$ 2,200.00	20
189		Electrical	-	$ -	-	20	$ -	$ -	$ 2,200.00	$ 2,200.00	20
190											
191	Layout	$ 5,750.00									
192	Rentals	$ 10,400.00									
193	**Totals:**			**$39,441**	**204**	**1163**	**$39,441**	**$22,440**	**$127,930**	**$189,811**	**1367**
194	**Total Cost:**	**$189,811**									

Monte Carlo Simulation

For the analysis of the project's economic viability, it was decided that a Monte Carlo simulation would be used. The basic principle behind the Monte Carlo method is the use of repeat random sampling on the entire range of values relevant to the scenario. A guiding equation is established using these randomized variables; in this case, the equation takes the aggregate costs accrued in a year against the profits generated from milk sales in a year to determine the number of years required for the operation to begin profiting.

Four simulations were run with different parameters at 10,000 trials each; the outcome of each simulation is shown in Table 12 below. "Full Cost" refers to the use of newer pieces of equipment, whereas "Reduced Cost" considers the use of restored equipment (such as the homogenizer) and one fewer CIP skid. "No Markup" refers to selling the milk products at the same rate to both UNL dining services and in retail grocers or convenience stores. "15% Markup" means the products sold in grocery and convenience stores will be sold with a 15% markup, but the milk sold to UNL directly with still receive no markup. In every simulation, all values (with the exception of employee salaries) were given a baseline 10% fluctuation to account for shifts in market stability, milk output, etc. over the course of operation.

As advised by Dr. Howell, a university entity like this project can afford to break even in 6 years or fewer and be considered a financial success. In a traditional industry scenario, however, 2-3 years is the expectation for financial success. As seen in Table 12, the "Reduced Cost, 15% Markup" scenario is the best option for potential implementation and successfully begins to turn a profit after roughly 4.5 years. However, this apparent success is not without caveats. This simulation is only for the processing portion of the facility, so no attention was paid to the operations or costs outside of the scope of our project. These likely come with hefty additional economic considerations and will impact the economic viability of the project, but the processing portion as a standalone is successful. A link to the full Monte Carlo simulation document can be found in the appendix section at the end of the report.

Table 12: Monte Carlo simulation summary. Reduced cost is assuming lower costs due to buying used equipment.

Monte Carlo Simulation Summary Table				
Return on Investment	**Full Cost, No Markup**	**Reduced cost, No Markup**	**Full Cost, 15% Markup**	**Reduced Cost, 15% Markup**
Mean (Years)	7.68	6.87	4.97	4.43
Standard Deviation (Years)	1.15	1.01	0.87	0.76

Description of Final Design

Floor Layout

A drawing of the floor layout for the dairy processing plant is necessary to show how the necessary equipment and facilities for a dairy plant can fit into the allotted space given for the project. The below figures (Figures 6 and 7) are images of the floor layout created in AutoCAD.

Equipment

The equipment sizes shown are based on research done on specific equipment models provided by Dairy Engineering, as well as other equipment models that would be appropriate for the plant's needs. Included are all storage vessels, two pasteurizers, a separator, a homogenizer, a packaging station, a CIP system, a COP station, an equipment cleaning station, and handwashing stations. Equipment is spaced so that the CIP system can be maneuvered between equipment easily. All equipment is arranged in a way that follows the PFD closely so as to minimize piping needs for connections and confusion of crossing connections.

Rooms/Facilities

Included outside of the equipment needed for processing are two separate restroom/locker rooms for employees, a cleaning supply closet, a maintenance closet, a conference room, an office/control room, extra storage, and cold storage for finished product. These were added based on the needs of the client, as well as general standards in the industry. The cold product storage has been sized to fit at least two days' worth of bottled product on pallets (at least four batches) with extra room for shelves and maneuverability as needed.

Miscellaneous Information

The assumed minimum target area for the building was 2300 square feet, and the final design ended up being 2800 square feet. The area of just the processing floor is about 1800 square feet. All exterior walls are 10 inches thick based on the standard for exterior walls, and all interior walls are 4.5 inches thick to account for a 2"x4" and a quarter inch of drywall on either side. All swinging exterior doors are 36" wide, and all swinging interior doors at 30" wide besides the bathroom stall doors which are 24" wide. The only employee entrance is located at the far South side of the building as it is shown, and it leads into a hallway where employees can go into locker rooms to ensure that all proper PPE and clothing is worn before entering the process room. Two overhead doors for shipping needs are located by the cold storage room, sized to fit a standard shipping dock. An overhead door is also located behind the raw storage for installation and maintenance purposes as well as easy access to this equipment when needed.

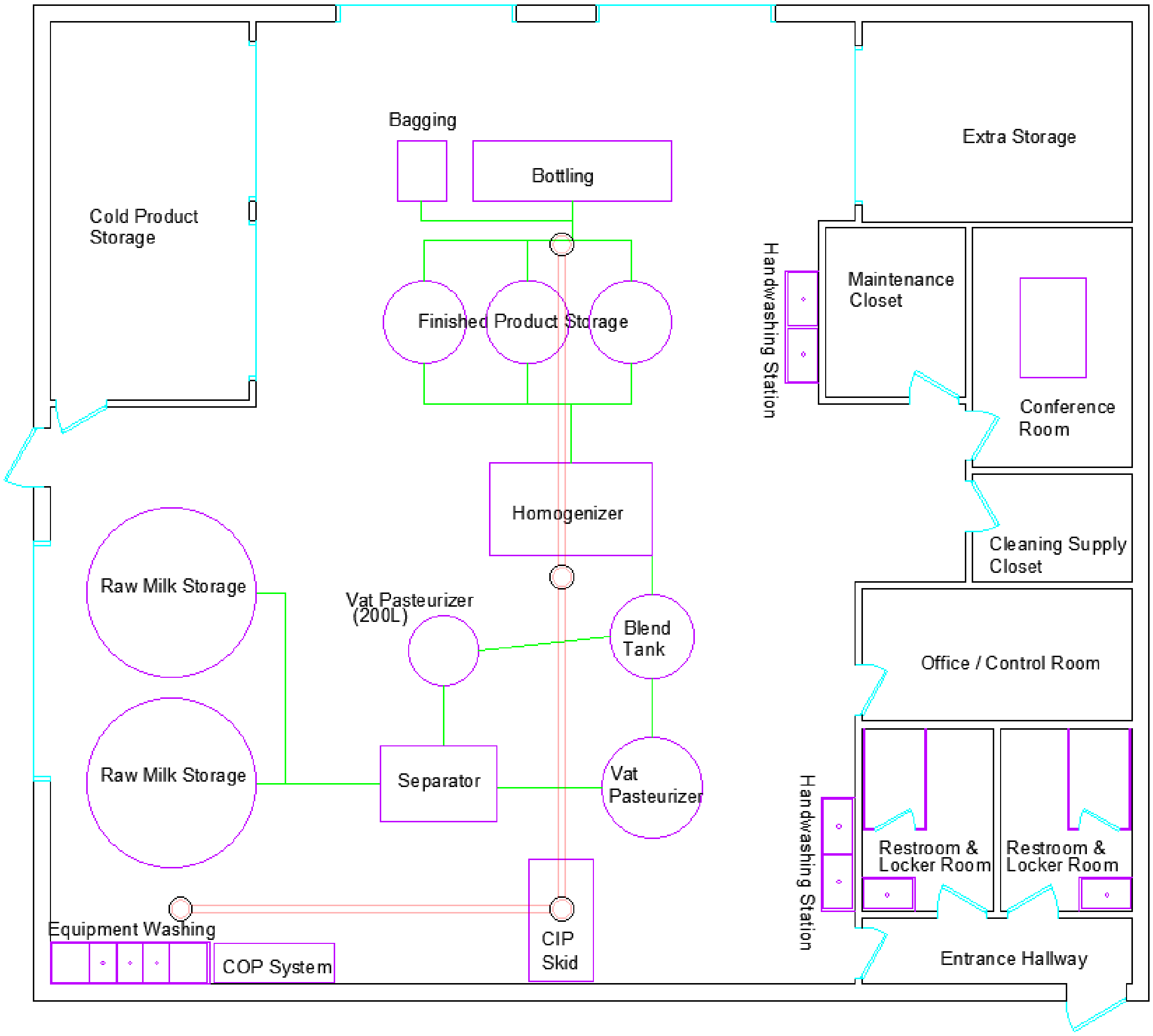

Figure 6: View of the Dairy Processing Plant Floor Layout without dimensions.

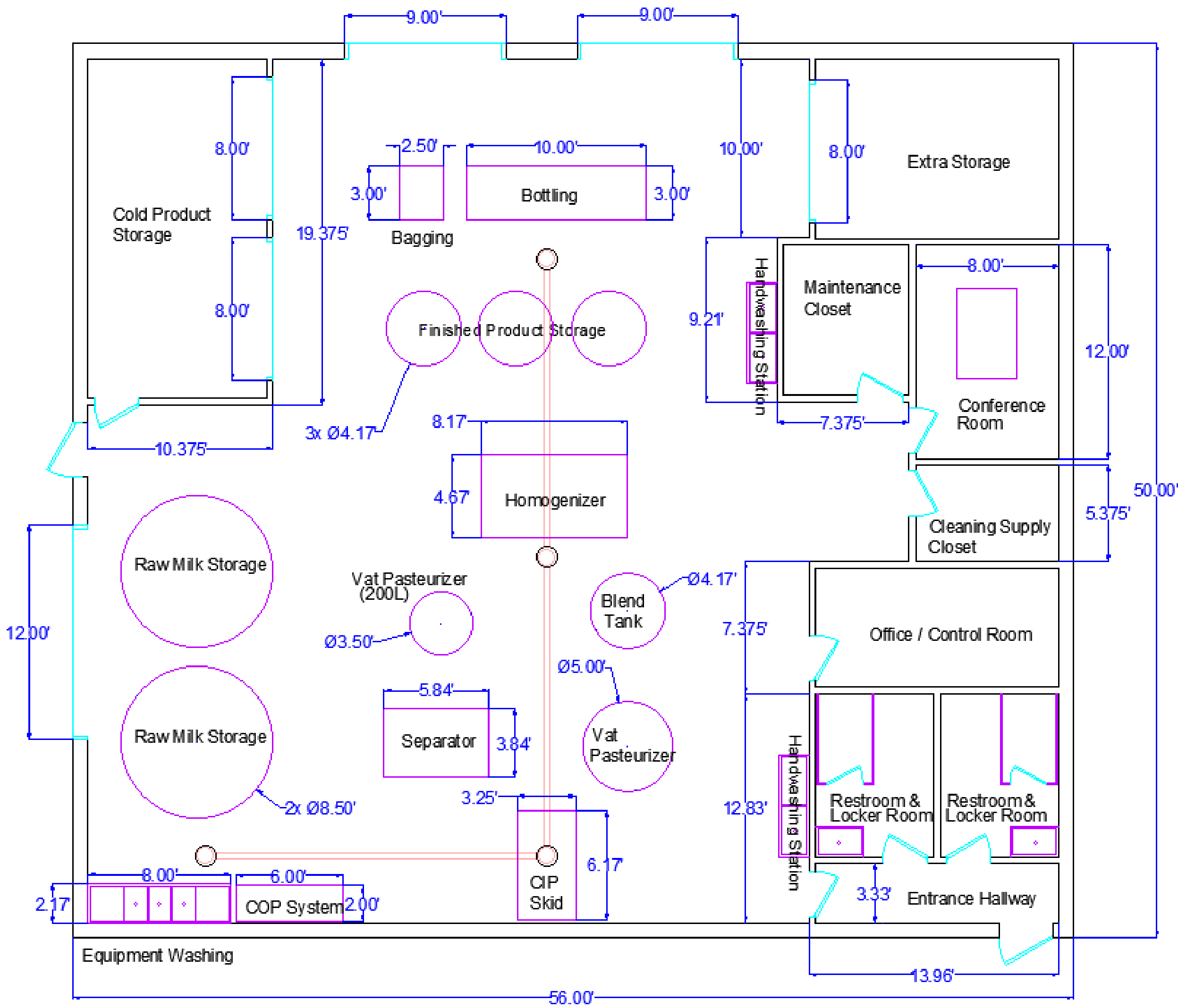

Figure 7: Dimensioned View of the Dairy Processing Plant Floor Layout

Wastewater Treatment Plan

The plan for the wastewater treatment is to have all CIP, COP, and milk waste flow down the four-floor drains into a 7,500L holding tank. This holding tank will be located outside of the processing area and will have two additional tanks attached to it. These additional tanks will be for the pH treatment of the wastewater with one being an alkaline treatment and the other being an acidic treatment. The industry standard for wastewater pH is between 6 and 9 pH. Once the wastewater is treated and is able to maintain the appropriate pH values, the wastewater will be released to the municipal wastewater stream via a metered flow pump. The wastewater will then be treated by the Theresa Street Water Resource Recovery Facility. Should an entire storage tank need to be discarded, waste haulers will be enlisted instead of releasing the large volume of milk to the public utility.

Wastewater flow to the Publicly Owned Treated Works (POTW) will be controlled and pumped out over the course of the day. In order to pump wastewater to the POTW, a permit will be required. This permit called an “NPDES Permit to Discharge Wastewater” can be found on the Nebraska Department of Environment and Energy website. Based on the BOD calculations from above, this treatment plan is under the daily allotment of 52 lbs./day of BOD material per state law.

Clean-in-Place (CIP) Protocol

The following is a general procedure that would be used for cleaning the processing facility. The main concern of the protocol is cleaning the process equipment and tanks to minimize the possibility of harming public health and safety.

Beginning of the Day

1. Disinfect with hot water by running hot water (90-95°C) through all equipment for 5-10 minutes.

General Cleaning Procedure

The general cleaning procedure should be followed after production is finished for the day.

Visual Inspection

1. Inspect each piece of equipment to check for dry solids that may have built up.
2. Scrape any dry solids.
    a. Different scrapers, brushes, etc. that come into direct contact with processing equipment should be different for raw-handling and finished product-handling equipment.
3. Rinse and drain all equipment with clean water.
    a. Run clean water through the system until water runs clear out of equipment drains.
    b. This will be ~3 minutes for cold equipment and ~10 minutes for hot equipment.
    c. This water should be at or near 50-55°C to successfully clean out the fats without coagulating proteins.

Cleaning Circuits

Cleaning of equipment is broken up into three separate circuits to prevent the spread of contaminating bacteria. The circuits are as follows:

Circuit #1 – Raw Milk Storage Tanks to Cream/Raw skim milk storage tanks – all cold, raw product, all same treatment.

Circuit #2 – Piping after Homogenization Heat Exchanger to End – all cold, finished product, all same treatment.

Circuit #3 - Piping before Vat Pasteurization to Homogenization Heat Exchanger – all hot product, all same treatment.

Circuits 1 and 2 will utilize the following cleaning protocol:

1. Circulate alkaline detergent solution (.5-1.5%) for 10 minutes at 75°C.
    - Alkali detergent will be NaOH (.15-5%) at 70-80°C.
    - A surfactant will be included with the solution in order to decrease liquid surface tension and ensure full contact between the NaOH and the particles left in the equipment.
2. Rinse of equipment with warm water (50-55°C) for 3 minutes.
3. Disinfect equipment with hot water (90-95°C) for 5 minutes.

Tanks do not need to follow steps 4 and 5.

4. Run cool water through for ~8 minutes.
5. The CIP system should be inspected and disinfected again when switching from equipment that handles raw product to equipment that handled pasteurized product to prevent cross-contamination.

Circuit 3 will utilize the following protocol after steps 1-3:

1. Circulate alkaline detergent solution used in other circuits for 30 minutes at 75°C.
2. Rinsing of alkaline detergent solution with warm water (50-55°C) for ~5 minutes.
3. Circulation of acidic detergent solution for 20 minutes at ~70°C.
    - Acidic detergent solution will be Nitric acid concentrated at 0.5-1%
4. Rinse with warm water for ~8 minutes.
5. Disinfect equipment with hot water (90-95°C) for 5 minutes.
6. Equipment besides tanks will have cool water run through after this step for ~8 minutes.

COP (cleaning out of place) will occur before the CIP procedure is conducted for the necessary pieces. This will include disassembling and extracting various pieces of equipment from different processing equipment and cleaning them in the COP tank as well as the equipment washing sink if deemed necessary. This will be done for all parts of equipment that are not compatible or efficiently cleaned using the CIP protocol.

Production Schedule

The processing schedule for the facility was developed in accordance with all necessary processing steps per the Process Flow Diagram. The below figure shows the schedule for processing one batch of milk each day, including relevant unit operation processing times for each piece of equipment as well as ample time for cleaning (Figure 8). Monday and Tuesday are different from the rest of the week since milk from the weekend will need to be processed on those days.

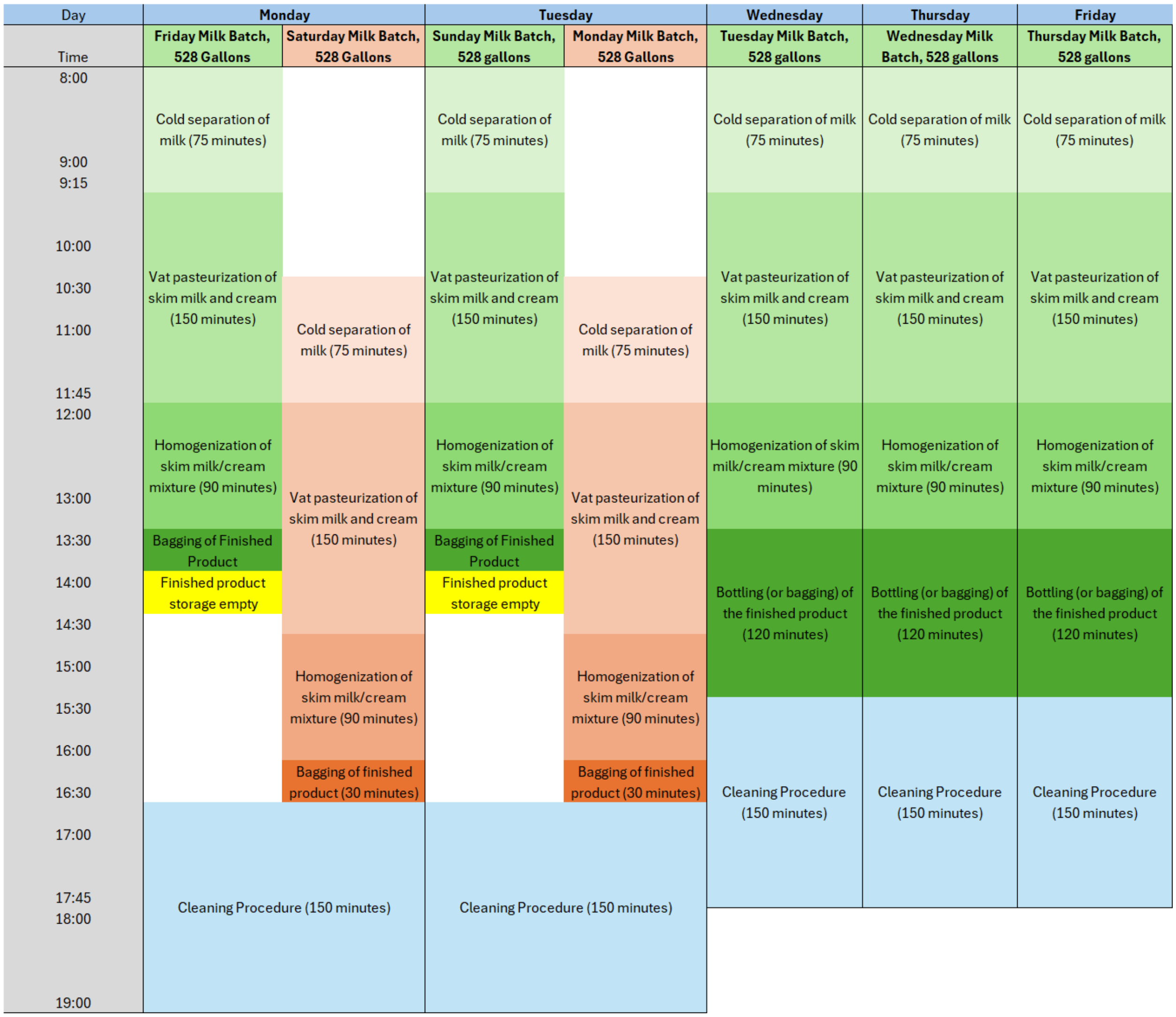

Figure 8: Timeline of daily production schedule.

Below is a schedule showing labor requirements for each day of the week (Figure 9). This plan proposes the utilization of two full-time employees each day, one to start the day and one to end the day, with overlap in the middle of the day during busy times for the plant. These employees will be supported by four student workers that will come in during different parts of the day to supplement. Student shifts are not longer than 4 hours each, but these shifts may be split up between more students if necessary to work with student schedules.

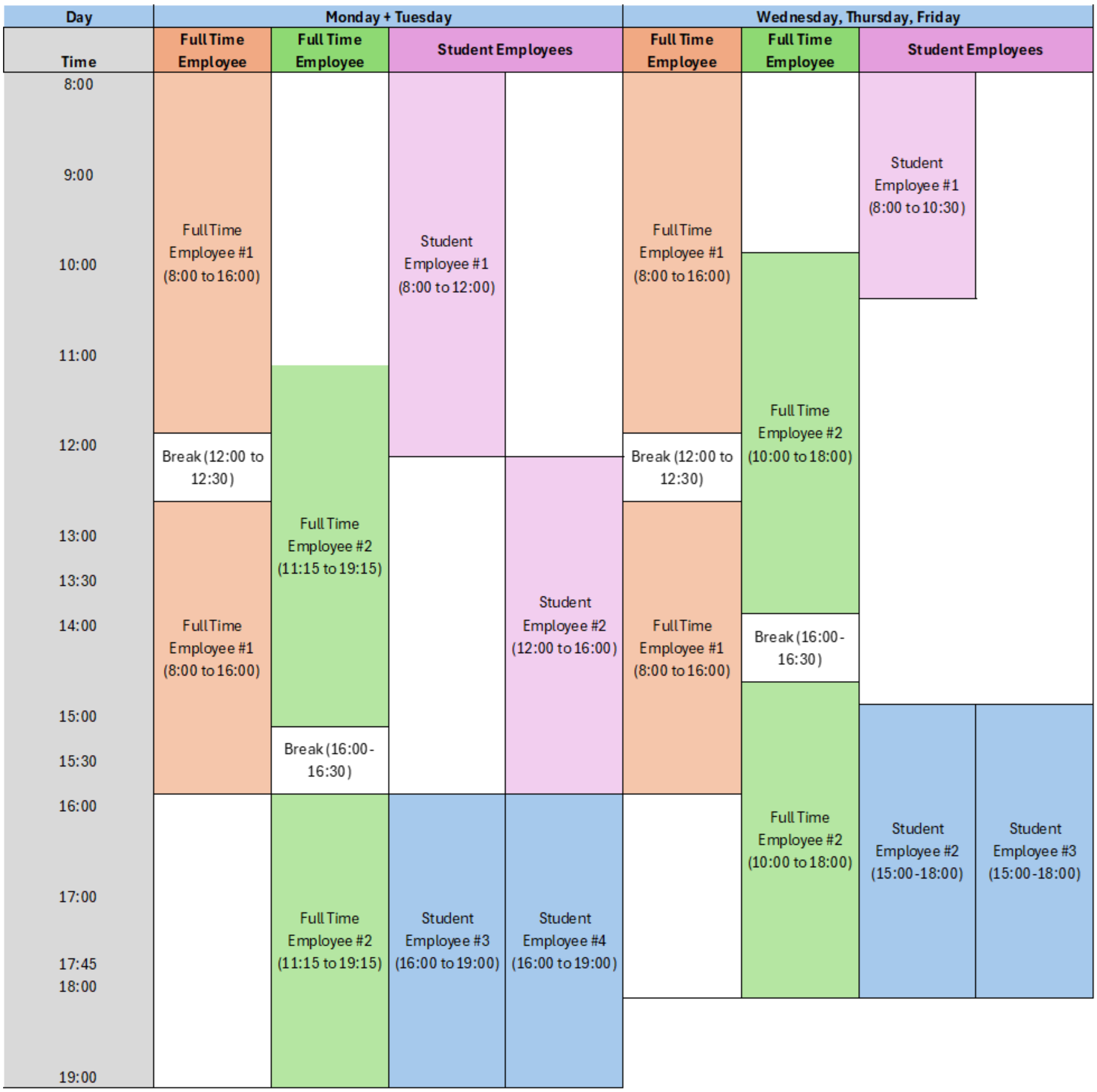

Figure 9: Employee shift schedule.

Shown below is a table outlining production output volumes and specific products for each day of the week (Table 13). Gallon Jugs were preferred over pints, as gallon jugs can be sold with a wider margin of profit. Packaging costs also limit the number of products that can be manufactured at this small scale. Skim milk will only be produced once a month and in bagged form only. It will be produced during the second batch on the first Tuesday of every month. Excess cream will also be retained, packaged, and sold.

Table 13: Daily production outputs broken down into exact products made each day.

Monday			
Batch 1		**Batch 2**	
Whole Milk 5-gal bag	90 bags	**2% Milk 5-gal bag**	89 bags
Cream	18.2 gallons	**Cream**	24.8 gallons

Tuesday							
Batch 1				**Batch 2***			
	Units	**Milk (gallons)**	**Totals (gallons)**		**Units**	**Milk (gallons)**	**Totals (gallons)**
2% Milk 5-gal bag	89	5	445	**2% Milk 5-gal bag**	89	5	445
Cream	1	24.8	24.8	**Cream**	1	24.8	24.8
			469.8				469.8

Alternate skim milk bags once a month for batch 2

Wednesday			
	Units	**Milk (gallons)**	**Totals (gallons)**
2% Gallon Jugs	325	1	325
2% Half Gallon Jugs	100	0.5	50
2% Pints	400	0.125	50
2% Half Pints	320	0.0625	20
Cream	1	24.8	24.8
			469.8

Thursday			
	Units	**Milk (gallons)**	**Totals (gallons)**
Whole Milk Gallon Jugs	330	1	330
Whole Milk Half Gallon Jugs	100	0.5	50
Whole Milk Pints	400	0.125	50
Whole Milk Half Pints	340	0.0625	21
Cream	1	18.2	18.2
			469.2

Friday			
	Units	**Milk (gallons)**	**Totals (gallons)**
2% Gallon Jugs	325	1	325
2% Half Gallon Jugs	100	0.5	50
2% Pints	400	0.125	50
2% Half Pints	320	0.0625	20
Cream	1	24.8	24.8
			469.8

Budget

The budget developed breaks down costs associated with equipment, engineering, and installation into different categories. A summary budget can be found in Table 14. Each category is listed separately below, and costs are broken down by line item. The total cost for the project, if executed, would be $1,707,982.49. As mentioned before, this number is an underestimate of the true cost. This number does not include project management costs, construction of the building, or the costs to run portions of the building beyond the processing section.

Table 14: Budget breakdown for the dairy processing facility. This includes engineering hours, equipment, and installation costs.

Item	Cost
Administrative Hours	168 hours ($50/hour) = $8,400
Design Hours	140.5 hours ($50/hour) = $7,025
Equipment Cost Range	$1,502,746.49
Installation Estimation	$189,811
Total	**$1,707,982.49**

Conclusion

The final design met all constraints and nearly all criteria put forth at the beginning of this report. The facility's processing floor will occupy less than 2300 ft^2, it can run with two 8-hour shifts during the day, it has the beginnings for the path to regulatory certifications, and is capable of producing multiple different types of milk. It should be noted that with the design as it stands, it would not be feasible to process milk from 240 cows. It would be most comfortable processing between the ranges of milk from 60-180 cows. Adding an extra 7500L raw milk holding tank as well as increasing the number of shifts to three per day could potentially serve as a solution to be able to process milk produced by 240 cows.

Student Roles

Jack

Jack completed the floor layout, cleaning protocol, and production and employee schedules for the project. He used equipment sizes and client recommendations and requirements to develop the floor layout in AutoCAD. This along with the creation of a cleaning protocol and schedule compiling process times and labor needed to support the facility have contributed to the team's assembly of a final design solution that meets the needs of the client.

Luke

Luke completed the calculations for the daily effluent and daily BOD values for the project. He also completed the wastewater treatment plan along with the permitting needed for wastewater treatment. This and the creation of a daily estimated product output helped to design the solution that has been presented.

Robert

Robert completed the Monte Carlo simulation, budget considerations, and equipment selection for the project. He used Excel to run the economic simulation needed to determine project viability. He also consulted with industry professionals, including those at UNL's Food Processing Center for guidance on specific pieces of equipment and their associated costs. These factors allowed for the resulting economic analysis of the project to be as accurate as possible.

Ry

Ry completed the unit operations calculations, process flow diagram, and risk assessment portions of this project. He also reached out to industry professionals to get input and guidance for the project. This helped contribute to a more holistic solution. Ry also helped with other aspects of the project including installation estimates and report writing.

Gantt Chart

The Gantt chart below (Table 15) shows the scheduling and owner of each task completed for this project. The Gantt chart further breaks the project into two separate phases: project planning and prototype development. Project planning was mostly the problem definition phase of the project which had to be done before any prototype development could begin.

Table 15: Gantt chart for Modular Dairy Processing Facility project.

1	**Project Planning**	**Owner**	**Start Date**	**End Date**	**Pct Done**
1.1	Background	Ry S.	10/2/2023	10/20/2023	100%
1.2	Problem Definition	Jack V.	10/2/2023	12/8/2023	100%
1.3	Goals	Robert S.	10/25/2023	12/8/2023	100%
1.4	Objectives	Luke B.	10/25/2023	12/8/2023	100%
1.5	Criteria	Luke B.	10/10/2023	11/25/2023	100%
1.6	Constraints	Robert S.	10/10/2023	11/25/2023	100%
1.7	Standards & Regulations	Ry S.	10/31/2023	11/2/2023	100%
1.8	Decision Matrix	Team	1/22/2024	2/15/2024	100%
2	**Prototype Development**	**Owner**	**Start Date**	**End Date**	**Pct Done**
2.1	Process Flow Diagram	Ry S.	1/24/2024	2/27/2024	100%
2.2	Product Output Mix	Luke B.	1/24/2024	4/11/2024	100%
2.3	Cleaning Strategy	Jack V.	1/30/2024	2/27/2024	100%
2.3.1	Production Schedule	Jack V.	2/7/2024	4/3/2024	100%
2.4	Unit Operation Calculations	Ry S.	2/27/2024	4/3/2024	100%
2.5	Waste Water Treatment	Luke B.	2/5/2024	3/27/2024	100%
2.6	Equipment Selection	Robert S.	2/27/2024	4/11/2024	100%
2.7	Monte Carlo Simulation	Robert S.	1/25/2024	4/11/2024	100%
2.8	Floor Layout	Jack V.	2/27/2024	3/25/2024	100%
2.9	Risk Assessment	Ry S.	2/7/2024	4/11/2024	100%

Acknowledgments

Thank you to the staff at Dairy Engineering and Tuttle, Inc. for their guidance and help in pricing out equipment and installation costs for this project.

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Appendix

Links

Link to Monte Carlo Simulation

Figures

Figure 1: Vat pasteurization equipment example. Retrieved from https://www.ancoequipment.com/batch-pasteurizers.

Figure 2: HTST pasteurization equipment example. Retrieved from https://www.kossindustrial.com/Processing-Equipment/HTST-Pasteurizers.

Figure 3: UHT Pasteurization equipment example. Retrieved from https://cedarstoneindustry.com/product-category/cleaning-pasteurization/uht-systems/.

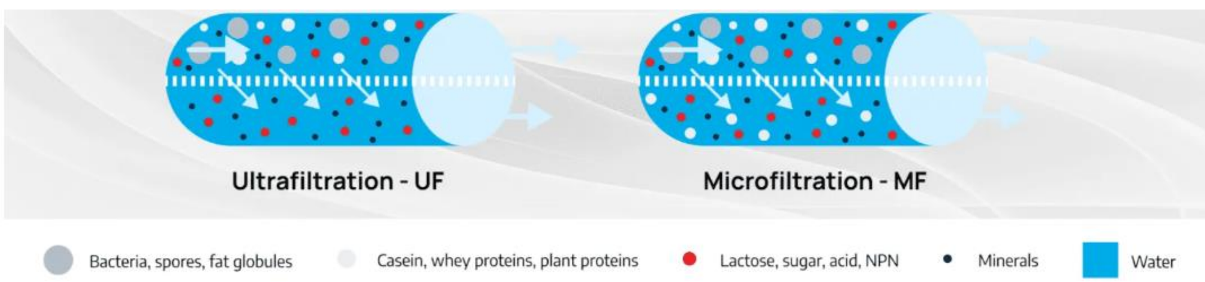

Figure 4: Differences in filtration alternatives. Retrieved from https://filterholdings.com/blog/membrane-filtration-of-milk/.

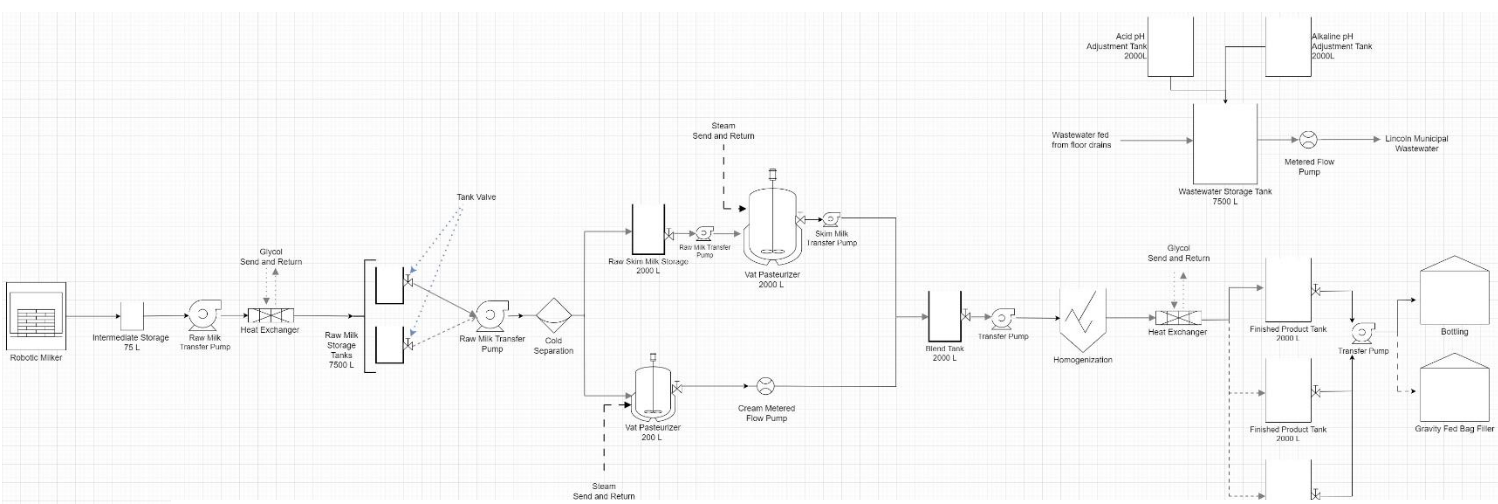

Figure 5: Process Flow Diagram of milk processing facility.

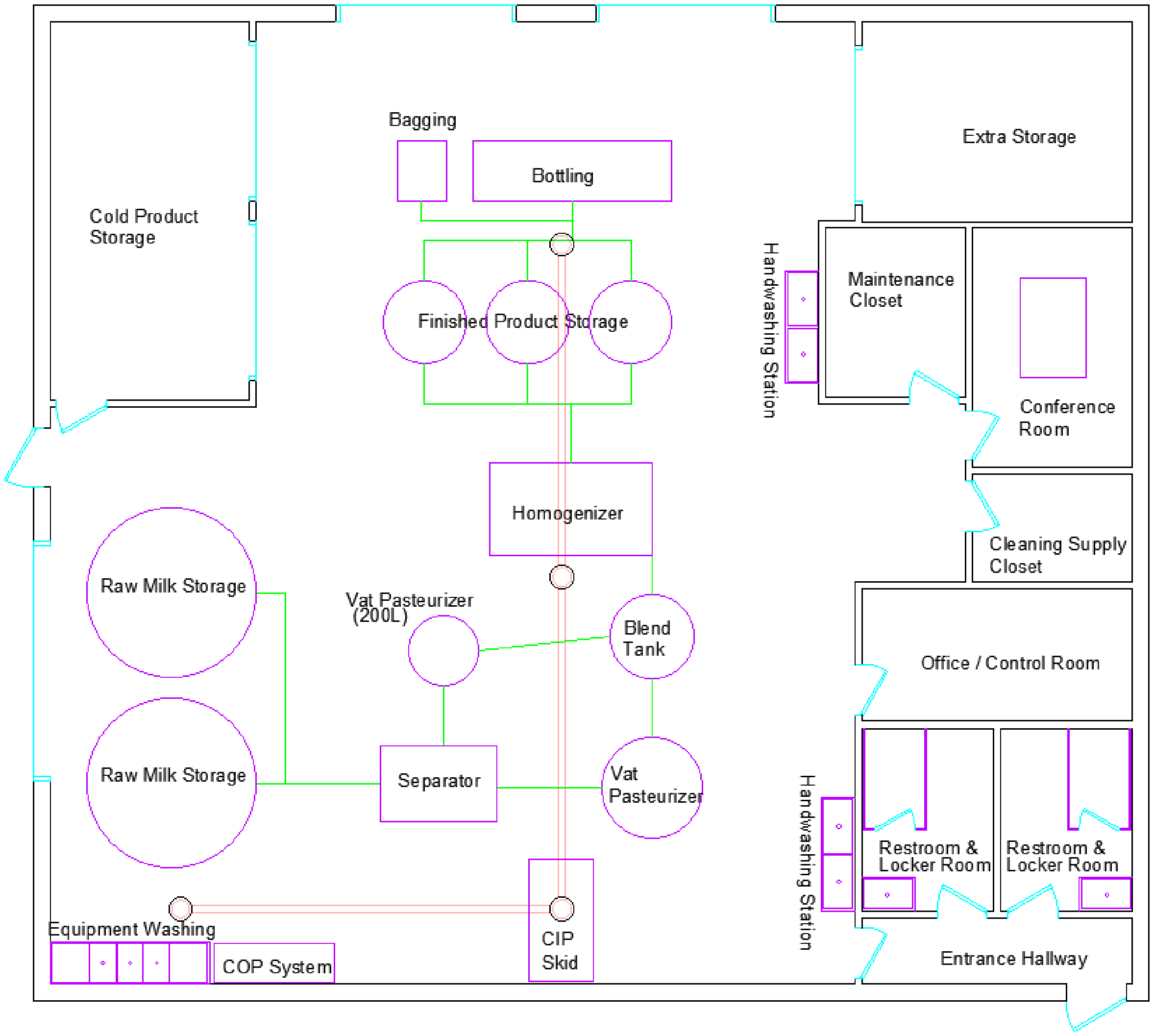

Figure 6: View of the Dairy Processing Plant Floor Layout without dimensions.

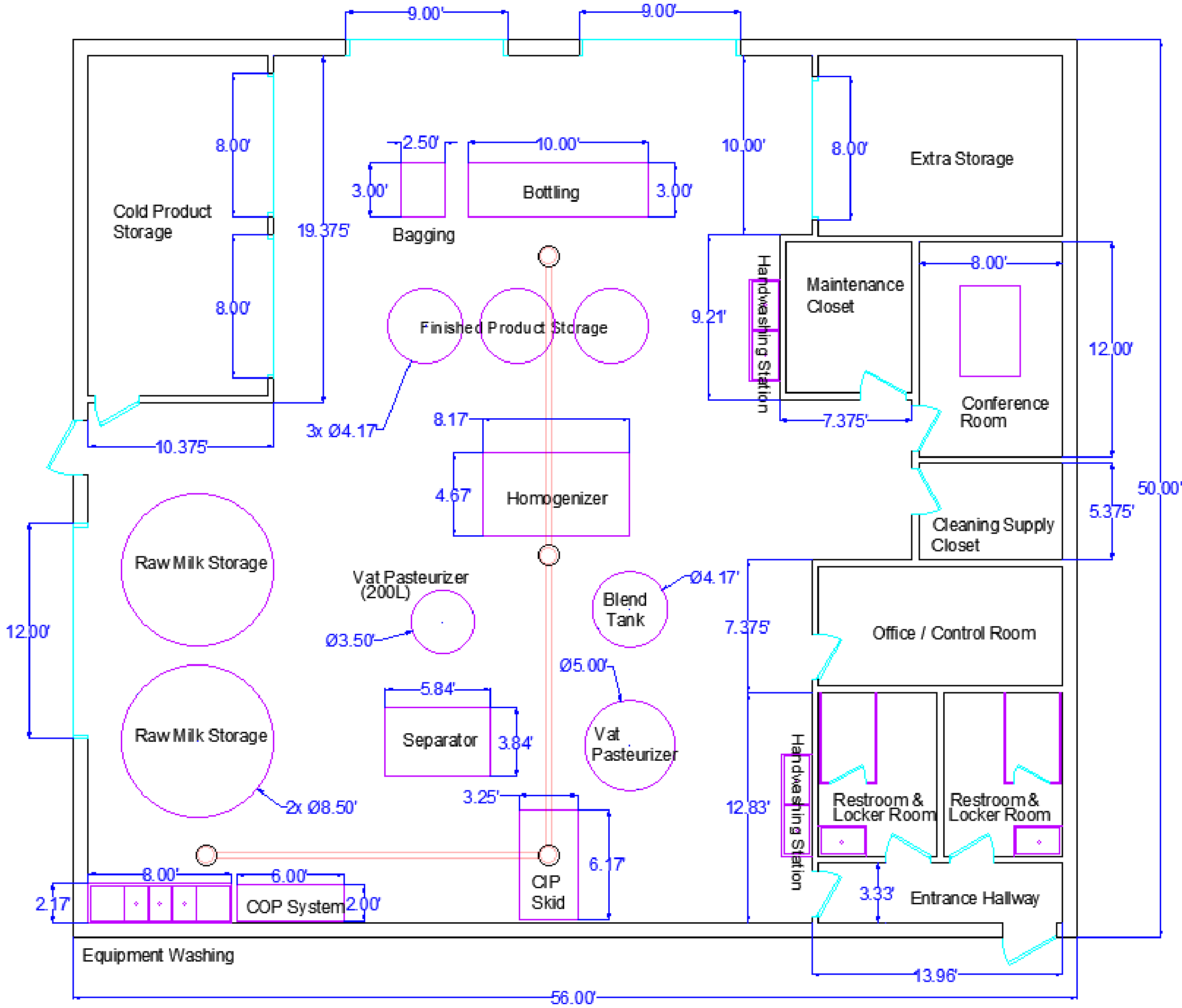

Figure 7: Dimensioned View of the Dairy Processing Plant Floor Layout

Day / Time	Monday: Friday Milk Batch, 528 Gallons	Monday: Saturday Milk Batch, 528 Gallons	Tuesday: Sunday Milk Batch, 528 gallons	Tuesday: Monday Milk Batch, 528 Gallons	Wednesday: Tuesday Milk Batch, 528 gallons	Thursday: Wednesday Milk Batch, 528 gallons	Friday: Thursday Milk Batch, 528 gallons
8:00	Cold separation of milk (75 minutes)		Cold separation of milk (75 minutes)		Cold separation of milk (75 minutes)	Cold separation of milk (75 minutes)	Cold separation of milk (75 minutes)
9:00							
9:15	Vat pasteurization of skim milk and cream (150 minutes)		Vat pasteurization of skim milk and cream (150 minutes)		Vat pasteurization of skim milk and cream (150 minutes)	Vat pasteurization of skim milk and cream (150 minutes)	Vat pasteurization of skim milk and cream (150 minutes)
10:00							
10:30		Cold separation of milk (75 minutes)		Cold separation of milk (75 minutes)			
11:00							
11:45	Homogenization of skim milk/cream mixture (90 minutes)	Vat pasteurization of skim milk and cream (150 minutes)	Homogenization of skim milk/cream mixture (90 minutes)	Vat pasteurization of skim milk and cream (150 minutes)	Homogenization of skim milk/cream mixture (90 minutes)	Homogenization of skim milk/cream mixture (90 minutes)	Homogenization of skim milk/cream mixture (90 minutes)
12:00							
13:00							
13:30	Bagging of Finished Product		Bagging of Finished Product		Bottling (or bagging) of the finished product (120 minutes)	Bottling (or bagging) of the finished product (120 minutes)	Bottling (or bagging) of the finished product (120 minutes)
14:00	Finished product storage empty		Finished product storage empty				
14:30		Homogenization of skim milk/cream mixture (90 minutes)		Homogenization of skim milk/cream mixture (90 minutes)			
15:00							
15:30					Cleaning Procedure (150 minutes)	Cleaning Procedure (150 minutes)	Cleaning Procedure (150 minutes)
16:00		Bagging of finished product (30 minutes)		Bagging of finished product (30 minutes)			
16:30	Cleaning Procedure (150 minutes)		Cleaning Procedure (150 minutes)				
17:00							
17:45							
18:00							
19:00							

Figure 8: Timeline of daily production schedule.

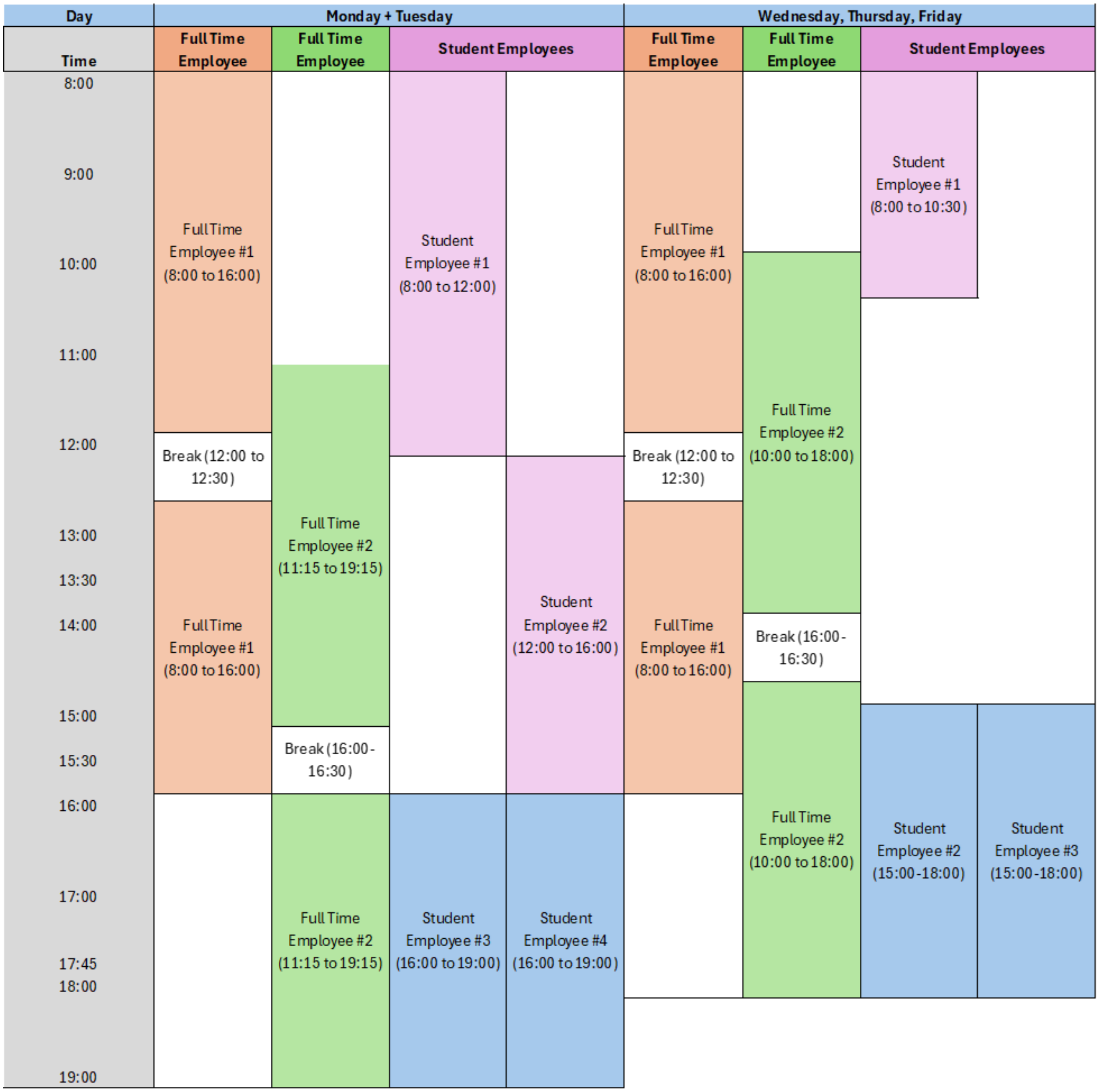

Figure 9: Employee shift schedule.

Tables

Table 1: Decision matrix criteria weighting.

	Cost	Capability for multiple types of milk	Capability for processing different volumes	Equipment Size	Total
Cost	X	1	1	1	3
Capability for multiple types of milk	0	X	1	1	2
Capability for processing different volumes	0	0	X	0	0.5
Equipment Size	0	0	1	X	1

Table 2: Decision-making matrix for pasteurization alternatives.

Criteria	Criteria Weight	Design Alternatives - Pasteurization A	B	C
Cost	3	3	2	1
Capability for multiple types of milk	2	3	1	1
Capability for processing different volumes	0.5	1	3	3
Equipment Size	1	2	3	1
	Score	17.5	12.5	7.5

KEY	
A	Vat Pastuerization
B	HTST Pastuerization
C	UHT Pasteurization

Table 3: Decision-making matrix for filtration alternatives.

Criteria	Criteria Weight	Design Alternatives - Filtration A	B	C
Cost	3	3	2	1
Capability for multiple types of milk	2	X	X	X
Capability for processing different volumes	0.5	3	2	1
Equipment Size	1	3	2	1
	Score	13.5	9	4.5

KEY	
A	No Filtration
B	Micro-Filtration
C	Ultra-Filtration

Table 4: Decision-making matrix for separation alternatives.

Criteria	Criteria Weight	Design Alternatives - Separation A	B
Cost	3	2	1
Capability for multiple types of milk	2	1	2
Capability for processing different volumes	0.5	1	2
Equipment Size	1	1	1
	Score	9.5	9

KEY	
A	Cold Separation
B	Hot Separation

Table 5: Decision-making matrix for outputs.

Criteria	Criteria Weight	Design Alternatives - Output Alternatives A	B	C
Cost	3	1	2	3
Capability for multiple types of milk	2	1	2	3
Capability for processing different volumes	0.5	3	2	1
Equipment Size	1	3	2	1
	Score	9.5	13	16.5

KEY	
A	Entirely Bagged
B	Entirely Bottled
C	Mixed Output

Table 6: Risk analysis for equipment used in the facility.

TRANSFER PUMPS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence: Rating	Consequence: Rationale	Likelihood of Failure: Cause Type	Likelihood of Failure: Possible Cause Description	Likelihood of Failure: Rating	Likelihood of Failure: Rationale	Risk Level: Rating	Risk Control Strategy: Risk Controls	Risk Control Strategy: Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of the pump	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept

							during all cleaning activities.			
Transfer of Milk	*Business Risk*: pump housing leaks either processed or raw milk.	2	Surrounding area would be contaminated in the event of a leak.	Environmental/Biological	During the transfer of raw milk, a possible leak can occur due to wear on parts.	3	Without proper maintenance, it is sure that leakage will occur in the pumps. Regular maintenance is necessary for proper function.	6	Good Engineering Practice	Regular maintenance will be conducted on pumps.
	Consumer Risk: The pump leaks lubricant into the product.	3	Potential sickness or hospitalization could occur if a motor lubricant is ingested should the milk pass through all inspections.	Chemical	Old gaskets can wear out over time and cause the motor to leak lubricants into the product.	3	Regular maintenance should be done on all equipment within the plant. These should include inspections and regular replacement of critical parts.	9	Good Engineering Practice	Regular maintenance will be conducted on pumps.
RAW STORAGE TANKS - RISK ASSESSMENT										
Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk*: Clean-in-Place fails to sanitize inside of storage tank	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Transfer of Raw Milk	*Business Risk*: Effluent from tank contaminates the surrounding area in the event of a spill.	2	Surrounding area would be contaminated in the event of a raw milk spill.	Environmental/Biological	During the transfer of raw milk, a possible spill can occur. A puncture of the tank is	1	It is unlikely that a tank is punctured. The tank is unlikely to spill as the tank is only in use when	2	Procedural Control	Opening of tank valves shall only be done when the transfer piping is fully connected.

					also possible.		inlet/outlets are fully secure.			
Refrigeration of Raw Milk	*Consumer Risk*: Refrigeration temperature is above 4°C.	3	Inadequate refrigeration temperatures leads to elevated microbial levels.	Biological	Glycol is not delivered at correct temperature /rate.	1	Continuous monitoring of the temperature inside the storage tanks ensures no milk that has not been refrigerated properly will reach the public.	3	Good Engineering Practice	Installation/Operational/Performance Validation will be undertaken to ensure that all components of the system are performing as defined.

VAT PASTEURIZATION TANKS - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of pasteurization tank	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Pasteurization of Milk	*Consumer Risk*: Milk does not sit at pasteurization temperature for the requisite amount of time.	5	There are elevated microbial levels in milk that have not been properly pasteurized leading to an increased risk of illness.	Biological	It is possible that the temperature is not met due to the hot water not providing enough energy. It is also possible that the milk is not held for a long enough time due to operator error.	2	It is unlikely that the vat not reach temperature because of the controlled water temperature used to heat the vat. The residence time will be controlled via HMI and will have no operator override.	10	Procedural Control	Training will be utilized to ensure operators are capable of using the HMI of the pasteurizers. Residence times will be programmed directly into the vat pasteurizer HMI. Batch logs will be kept as evidence of compliance.

HEAT EXCHANGERS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of heat exchanger	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
Cooling of Milk Fluid	*Consumer Risk*: heat exchanger fails to drop the temperature of fluid below 4°C.	3	Failing to drop the temperature below 4°C could result in higher microbial loads within the storage tanks. However, the storage tanks themselves are cooled and can cool the milk to a lower temperature if not already below 4°C.	Biological	Glycol is not circulating through the heat exchanger efficiently. There could be a buildup of material on the walls of the heat exchanger thereby lowering its efficiency.	2	CIP can properly clean the walls of the heat exchanger and maintain effective levels of heat exchange.	6	Procedural Control and Good Engineering Practice.	Cleaning batch records will be kept as well as records of the efficiency of the heat exchanger. Installation/Operational/Performance Qualification will be carried out to confirm all requirements are met for the heat exchanger.
Maintenance	*Business Risk:* contents under pressure are not properly handled leading to improper release during maintenance.	5	Failing to relieve pressure when doing maintenance can result in a powerful stream that can result in serious harm.	Physical	A worker could be preparing to do maintenance on the exchanger and isolating the system. The glycol is under some pressure. Improper handling of potential energy can lead to injury or death.	4	Workers not properly trained or negligent to follow procedures can result in the event occurring.	20	Procedural Control and Good Engineering Practice.	Lock-Out/Tag-Out procedures will be utilized to isolate all systems under pressure. Pressure relief valves will be used to ensure the system does not reach dangerous pressures.

CREAM METERED PUMP - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of the pump	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept

Transfer of Cream	*Business Risk*: pump housing leaks cream.	2	Surrounding area would be contaminated in the event of a leak.	Environmental/Biological	During the transfer of cream a possible leak can occur due to wear on parts.	3	Without proper maintenance, it is sure that leakage will occur in the pumps. Regular maintenance is necessary for proper function.	6	Good Engineering Practice	Regular maintenance will be conducted on pumps.
	Consumer Risk: The pump leaks lubricant into the product.	3	Potential sickness or hospitalization could occur if a motor lubricant is ingested should the milk pass through all inspections.	Chemical	Old gaskets can wear out over time and cause the motor to leak lubricants into the product.	3	Regular maintenance should be done on all equipment within the plant. These should include inspections and regular replacement of critical parts.	9	Good Engineering Practice	Regular maintenance will be conducted on pumps.
	Business Risk: inaccurate amount of cream is transferred during metering.	4	No injuries result. The cream is wasted and the product is out of specification leading to a recall of the product.	Physical	Calibration is out of specification.	5	It is difficult to meter to the precision needed for this project.	20	Good Engineering Practice and Technical Control	Regular calibrations will be required as well as batch testing to confirm specifications of the product have been met.

FINISHED STORAGE TANKS - RISK ASSESSMENT

Manufacturing Business Process	Potential Failure	Consequence		Likelihood of Failure				Risk Level	Risk Control Strategy	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Clean-in-Place	*Consumer Risk:* Clean-in-Place fails to sanitize inside of storage tank	3	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	6	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Potential pinch hazard while opening and closing tank for cleaning.	3	It is possible to be caught between a closing lid and the tank while cleaning the equipment.	Physical	Cleaning the tank involves spraying out the inside with water following CIP. A person could be leaning into the tank while the lid begins to close.	4	A quickly closing lid could result in serious bodily harm.	12	Technical Control	Slow close lids will be utilized on all tanks within the plant.
Transfer of Processed Milk	*Business Risk*: Effluent from tank contaminates the surrounding area in the event of a spill.	2	Surrounding area would be contaminated in the event of a raw milk spill.	Environmental/Biological	During the transfer of raw milk, a possible spill can occur. A puncture of the tank is also possible.	1	It is unlikely that a tank is punctured. The tank is unlikely to spill as the tank is only in use when inlet/outlets	2	Procedural Control	Opening of tank valves shall only be done when the transfer piping is fully connected.

							are fully secure.			
Refrigeration of Processed Milk	*Consumer Risk*: Refrigeration temperature is above 4°C.	4	Inadequate refrigeration temperatures leads to elevated microbial levels.	Biological	Glycol is not delivered at correct temperature /rate.	1	Continuous monitoring of the temperature inside the storage tanks ensures no milk that has not been refrigerated properly will reach the public.	4	Good Engineering Practice	Installation/Operational/Performance Validation will be undertaken to ensure that all components of the system are performing as defined.

PACKAGING - RISK ASSESSMENT

Manufacturing Business Process	**Potential Failure**	**Consequence**		**Likelihood of Failure**				**Risk Level**	**Risk Control Strategy**	
		Rating	Rationale	Cause Type	Possible Cause Description	Rating	Rationale	Rating	Risk Controls	Additional Description
Packaging - General	*Consumer Risk:* Clean-in-Place fails to sanitize equipment.	5	Without adequate cleaning there is an increased risk of microbial level buildup leading to elevated risk of sickness and or fatalities.	Chemical	CIP did not have sufficient residence time.	2	CIP protocol addresses necessary residence times to sanitize equipment within the plant. CIP protocol must be followed during all cleaning activities.	10	Procedural Control	CIP protocol will be written to explicitly state how long the CIP system should be used. Cleaning batch records will be kept
	Business Risk: Fail to release stored energy from equipment during maintenance.	5	Improper release of energy during maintenance of packaging equipment can lead to serious injury or death.	Physical	Lock-Out/Tag-Out procedures were not followed either from a lack of training or negligence.	4	Untrained personnel are more likely to not follow Lock-Out/Tag-Out procedures. There is a large amount of student workers planned for this plant.	20	Procedural Control and Good Engineering Practice	Lock-Out/Tag-Out procedures will be followed. Training strategies will be employed to ensure that maintenance workers are capable of working on systems independently. Physical guards will be placed to prevent unauthorized access to machinery.
Filling	*Business Risk:* Inaccurate filling amounts.	5	No injuries associated. This risk is associated with elevated cost to the business either through over filled products or discarded product that does not meet specifications.	Physical	Calibration is not correct.	2	Calibrations are adequate to prevent incorrect filling of bottles.	10	Procedural Control and Good Engineering Practice	Calibrations and Qualifications will be adequate to ensure proper amounts of milk are dispensed into respective bottles.
Capper	*Consumer Risk:* Plastic inside product.	5	Plastic inside of the product has potential to be ingest which can then cause damage to internal organs.	Physical	Calibration is not correct, or timing is misaligned.	3	It is possible that the capper becomes misaligned with the	15	Good Engineering Practice	Installation/Operational/Performance Qualification will be carried out to ensure that the equipment is

							necessary timing.			operating correctly.
Sealer	*Consumer Risk*: inadequate sealing.	4	Seal is not on the final product and leaves the product open to contamination.	Biological	Sealer does not meet required temperature or length of time.	1	Calibration and maintenance are adequate to ensure that the product is meeting specifications for its seal.	4	Procedural Control	Calibrations and Qualifications will be adequate to ensure seal of product from external environment.
Labeler	*Consumer Risk*: Lot labeling is incorrect	5	Incorrect lot labeling can lead to illness in the event of a product recall.	Biological	Corruption of software in the event of a power loss and restart.	4	Power losses are likely to happen but can be mitigated with the use of a site generator.	20	Good Engineering Practice	Utilize backup and restore to capture lot numbers and times.
	Business Risk: Illegible labels.	2	Labeler could cut off labeling at incorrect lengths.	Physical	Incorrect timing of labeler.	2	It is unlikely to occur with proper qualification and validation.	4	Good Engineering Practice	Installation/Operational/Performance Qualification will be carried out to ensure that the equipment is operating correctly.

Table 7: Risk Analysis scoring matrix.

Consquences					
Score	1	2	3	4	5
Description	Insignificant	Minor	Moderate	Major	Catastrophic
Example	Minor injury, no first aid required	Harmful injury (first aid required, under 3 days recovery time)	Serious injury, medical assistance required. Injury must be reported.	Major injury, urgent medical assistance required.	Fatality

Likelihood					
Score	1	2	3	4	5
Description	Rare	Unlikely	Possible	Likely	Almost certain

Rating Matrix							
Consequences	Catastrophic	5	5	10	15	20	25
	Major	4	4	8	12	16	20
	Moderate	3	3	6	9	12	15
	Minor	2	2	4	6	8	10
	Insignificant	1	1	2	3	4	5
			1	2	3	4	5
			Rare	Unlikely	Possible	Likely	Almost Certain
			Likelihood				

Table 8: Raw milk inputs every day and year from different numbers of cows.

Raw Milk Inputs		
Number of Cows	**Daily Milk (gallons)**	**Yearly Milk (gallons)**
60	480	175,000
180	1,440	525,600
240	1,920	700,800

Table 9: Cream mass balances after the separation step.

Assuming 3.5% Fat Milk		
	Volume (Liters)	**Fat %**
Whole Milk In	1781	3.5%
Raw Skim	1655	0.02%
Raw Cream	125	50%
Assuming 4% Fat Milk		
	Volume (Liters)	**Fat %**
Raw Whole Milk In	1781	4.0%
Raw Skim	1638	0.02%
Raw Cream	143	50%

Table 10: Equipment costs for dairy processing plant.

Equipment Costs		
Equipment	**Units**	**Total Price**
700 gallon Vat Pasteurizer w/ PMO Appliances	1	$ 115,500.00
10 gallon Vat Pasteurizer w/ PMO Appliances	1	$ 26,223.75
APV Gaulin G90 Homogenizer	1	$ 102,112.50
FPX-711 pump with 1 hp motor	1	$ 3,863.48
500-gal blend tank	1	$ 84,000.00
W61-T-S-15-4AR-000-00-00- TF-E-32-00 Valve	1	$ 2,000.09
2000 gal bulk storage	2	$ 90,300.00
W61-T-S-20-4AR-000-00-00-TF-E-32-00 Valve	2	$ 2,259.81
FPX-711 pump with 1 hp motor	1	$ 3,863.48
W68-T-S-15(10)-4AREP-000- 00-00-TR-V-32-00 Valve	1	$ 4,746.32
90 GALLON PMO BALANCE TANK	1	$ 6,825.00
2000 gal single shell storage tank	1	$ 57,750.00
FPX-711 pump with 1 hp motor	2	$ 7,726.95

500 gallon finished storage tank	4	$ 222,600.00
200 gallon COP tank	1	$ 6,825.00
SPXFlow SE20X-Q3P2 Separator	1	$ 115,500.00
Automation controls in Stainless steel panel with PLC, HMI, motor starters, etc	1	$ 36,750.00
Aluminum Food Grade Tilt & Roll Ladder	1	$ 1,279.43
Stainless Steel Worktable	1	$ 393.75
Easy-Count Scale - 60 lbs x .002 lb	1	$ 341.25
FOSS MilkoScan™ Mars	1	$ 38,165.69
550 GALLON TOTE TANK. TRANSTORE MODEL	2	$ 8,820.00
Mariner Peristaltic Filler	1	$ 136,500.00
Capper + elevator	1	$ 84,000.00
Induction sealer	1	$ 14,700.00
Labeler + lot coder	1	$ 58,800.00
Metal Detector	1	$ 31,500.00
Conveyance	1	$ 42,000.00
Gravity Filling System for 5-gal bags	1	$ 8,400.00
Single Tank, Single Pump, Portable CIP Skid	2	$ 189,000.00
Total Cost		**$ 1,502,746.50**

Table 11: Installation cost estimates. Costs are broken down on a step-by-step basis.

Line #												
1	Project:	UNL Small-Scale Dairy Processing										
2	Date:	5/10/2024										
3												
4				Dollars	Hours	Hours		Dollars	Dollars	Dollars		
5	**Step/Operation**	**Component**	**Multiples**	**Materials**	**Crate/ Uncrate**	**Installation**		**Total Materials**	**Unload/ Uncrate**	**Installation**	**Total Dollars**	**Total On-site hours**
6	**Floor installation**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
7		Surface prep	-	$ -	-	90		$ -	$ -	$ 9,900.00	$ 9,900.00	90
8		spray with grit	-	$ -	-	-		$ -	$ -	$ -	$ -	-
9		clean area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
10		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
11		Site prep	-	$ -	-	-		$ -	$ -	$ -	$ -	-
12		Move into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
13		Uncrate and unwrap	-	$ -	2	-		$ -	$ 220.00	$ -	$ -	-
14		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
15		Install piping (4") - 240 ft	-	$ 2,712.00	-	50		$ 2,712.00	$ -	$ 5,500.00	$ 8,212.00	50
16		Bond pipes	-	$ 100.00	-	-		$ 100.00	$ -	$ -	$ 100.00	-
17		Grout over piping	-	$ -	-	-		$ -	$ -	$ -	$ -	-
18		Install grates	-	$ 52.00	-	-		$ 52.00	$ -	$ -	$ 272.00	2
19		Mortar cover bed	-	$ 775.45	-	-		$ 775.45	$ -	$ -	$ 775.45	-
20		Install dairy brick - roughly 1780 sq ft	-	$ 25,551.90	-	-		$ 25,551.90	$ -	$ -	$ 25,551.90	-
21		Stage in area	-	$ -	-	-		$ -	$ -	$ -	$ -	-

22		dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
23		lay dairy brick	-	$ -	-	-		$ -	$ -	$ -	$ -	-
24		forklift rental	-	$ -	-	-		$ -	$ -	$ -	$ -	-
25		fit and finish walk through	-	$ -	-	-		$ -	$ -	$ -	$ -	-
26			-	$ -	-	-		$ -	$ -	$ -	$ -	-
27	**Install Storage Tanks**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
28		forklift rental	-	$ -	-	-		$ -	$ -	$ -	$ -	-
29		site prep	10	$ -	60	-		$ -	$ 6,600.00	$ -	$ 6,600.00	60
30		Move tank into area	10	$ -	-	-		$ -	$ -	$ -	$ -	-
31		unwrap and dispose of waste	10	$ -	-	-		$ -	$ -	$ -	$ -	-
32		tip tank up	10	$ -	-	-		$ -	$ -	$ -	$ -	-
33		drill holes for leveling legs	10	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
34		Clean holes	10	$ -	-	-		$ -	$ -	$ -	$ -	-
35		Install bolts for legs - epoxy	10	$ -	-	-		$ -	$ -	$ -	$ -	-
36		Install tank	10	$ -	-	-		$ -	$ -	$ -	$ -	-
37		Level tank	10	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
38		make form for grout	10	$ -	-	100		$ -	$ -	$ 11,000.00	$ 11,000.00	100
39		grout	10	$ -	-	-		$ -	$ -	$ -	$ -	-
40		remove grout form	10	$ -	-	-		$ -	$ -	$ -	$ -	-
41		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
42		7 - W61-T-S-20-4AR-000-00-00-TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
43			-	$ -	-	-		$ -	$ -	$ -	$ -	-
44	**Install pasteurizers**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
45		1 semi trip	-	$ -	-	-		$ -	$ -	$ -	$ -	-
46		site prep	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
47		Move 2000L Vat pasteurizer into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
48		unwrap and dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
49		tip vat up	-	$ -	-	-		$ -	$ -	$ -	$ -	-
50		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
51		make form for grout	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
52		grout	-	$ -	-	-		$ -	$ -	$ -	$ -	-
53		remove grout form	-	$ -	-	-		$ -	$ -	$ -	$ -	-
54		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
55		W61-T-S-20-4AR-000-00-00- TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
56		HMI	-	$ -	-	-		$ -	$ -	$ -	$ -	-
57		site prep	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
58		Move 200L Vat pasteurizer into area	-	$ -	-	-		$ -	$ -	$ -	$ -	-
59		unwrap and dispose of waste	-	$ -	-	-		$ -	$ -	$ -	$ -	-
60		tip vat up	-	$ -	-	-		$ -	$ -	$ -	$ -	-
61		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
62		Grout steps (grout steps for tanks)	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
63		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-

64		W61-T-S-20-4AR-000-00-00- TF-E-32-00 Valve	-	$ -	-	-		$ -	$ -	$ -	$ -	-
65		HMI	-	$ -	-	-		$ -	$ -	$ -	$ -	-
66			-	$ -	-	-		$ -	$ -	$ -	$ -	-
67			-	$ -	-	-		$ -	$ -	$ -	$ -	-
68			-	$ -	-	-		$ -	$ -	$ -	$ -	-
69	**Install Gaulin M3 Homogenizer 2-stg**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
70		1 skid	-	$ -	-	-		$ -	$ -	$ -	$ -	-
71		Site prep (See lines 18-20)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
72		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
73		Grout steps (grout steps for tanks)	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
74		electrical	-	$ -	-	-		$ -	$ -	$ -	$ -	-
75			-	$ -	-	-		$ -	$ -	$ -	$ -	-
76			-	$ -	-	-		$ -	$ -	$ -	$ -	-
77			-	$ -	-	-		$ -	$ -	$ -	$ -	-
78			-	$ -	-	-		$ -	$ -	$ -	$ -	-
79			-	$ -	-	-		$ -	$ -	$ -	$ -	-
80	**Install SPXFlow SE20X-Q3P2 Separator**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
81		1 skid	-	$ -	-	-		$ -	$ -	$ -	$ -	-
82		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
83		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
84		Anchoring	-	$ -	-	4		$ -	$ -	$ 440.00	$ 440.00	4
85		electrical - 400V 3 phase	-	$ -	-	-		$ -	$ -	$ -	$ -	-
86			-	$ -	-	-		$ -	$ -	$ -	$ -	-
87			-	$ -	-	-		$ -	$ -	$ -	$ -	-
88			-	$ -	-	-		$ -	$ -	$ -	$ -	-
89	**Install heat exchangers AGC Model Pro21-M Frame**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
90		Site prep (See lines 12-14)	2	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
91		Rough placement frame	2	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
92		Level	2	$ -	-	1		$ -	$ -	$ 110.00	$ 110.00	1
93		Final placement	2	$ -	-	6		$ -	$ -	$ 660.00	$ 660.00	6
94		Assemble heat exchanger	2	$ -	-	8		$ -	$ -	$ 880.00	$ 880.00	8
95			-	$ -	-	-		$ -	$ -	$ -	$ -	-
96			-	$ -	-	-		$ -	$ -	$ -	$ -	-
97			-	$ -	-	-		$ -	$ -	$ -	$ -	-
98			-	$ -	-	-		$ -	$ -	$ -	$ -	-
99			-	$ -	-	-		$ -	$ -	$ -	$ -	-
100			-	$ -	-	-		$ -	$ -	$ -	$ -	-
101			-	$ -	-	-		$ -	$ -	$ -	$ -	-
102	**Install FPX-711 pump with 1 hp motor**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
103		Site prep (See lines 12-14)	6	$ -	3	-		$ -	$ 330.00	$ -	$ 330.00	3
104		Grout steps (grout steps for tanks)	6	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10

105			-	$ -	-	-		$ -	$ -	$ -	$ -	-
106			-	$ -	-	-		$ -	$ -	$ -	$ -	-
107			-	$ -	-	-		$ -	$ -	$ -	$ -	-
108			-	$ -	-	-		$ -	$ -	$ -	$ -	-
109			-	$ -	-	-		$ -	$ -	$ -	$ -	-
110			-	$ -	-	-		$ -	$ -	$ -	$ -	-
111	**Install Anderson 1.5" flow meter with display**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
112		Site prep (See lines 12-14)	-	$ -	1	-		$ -	$ 110.00	$ -	$ 110.00	1
113			-	$ -	-	-		$ -	$ -	$ -	$ -	-
114			-	$ -	-	-		$ -	$ -	$ -	$ -	-
115			-	$ -	-	-		$ -	$ -	$ -	$ -	-
116			-	$ -	-	-		$ -	$ -	$ -	$ -	-
117			-	$ -	-	-		$ -	$ -	$ -	$ -	-
118			-	$ -	-	-		$ -	$ -	$ -	$ -	-
119			-	$ -	-	-		$ -	$ -	$ -	$ -	-
120	**Install Mariner Peristalic Filler**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
121		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
122		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
123		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
124		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
125		Assemble Filler	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
126			-	$ -	-	-		$ -	$ -	$ -	$ -	-
127			-	$ -	-	-		$ -	$ -	$ -	$ -	-
128			-	$ -	-	-		$ -	$ -	$ -	$ -	-
129	**Capper+elevator**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
130		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
131		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
132		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
133		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
134		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
135			-	$ -	-	-		$ -	$ -	$ -	$ -	-
136	**induction sealer**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
137		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
138		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
139		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
140		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
141		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
142			-	$ -	-	-		$ -	$ -	$ -	$ -	-
143			-	$ -	-	-		$ -	$ -	$ -	$ -	-
144	**labeler+lot coder**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
145		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
146		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2

147		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
148		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
149		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
150			-	$ -	-	-		$ -	$ -	$ -	$ -	-
151	**metal detector**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
152		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
153		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
154		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
155		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
156		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
157			-	$ -	-	-		$ -	$ -	$ -	$ -	-
158	**gravity fill system - 5-gallon bag**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
159		Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
160		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
161		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
162		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
163		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
164			-	$ -	-	-		$ -	$ -	$ -	$ -	-
165			-	$ -	-	-		$ -	$ -	$ -	$ -	-
166	**Conveyance (12 ft estimated)**	Site prep (See lines 12-14)	-	$ -	6	-		$ -	$ 660.00	$ -	$ 660.00	6
167		Rough placement frame	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
168		Level	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
169		Final placement	-	$ -	-	2		$ -	$ -	$ 220.00	$ 220.00	2
170		Assemble	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
171		Guard rails	-	$ -	-	50		$ -	$ -	$ 5,500.00	$ 5,500.00	50
172	**Packaging Electrical**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
173		conduit	-	$ -	6	100		$ -	$ 660.00	$ 11,000.00	$ 11,660.00	106
174		HMIs	-	$ -	20	100		$ -	$ 2,200.00	$ 11,000.00	$ 13,200.00	120
175			-	$ -	-	-		$ -	$ -	$ -	$ -	-
176			-	$ -	-	-		$ -	$ -	$ -	$ -	-
177	**Piping and intermediate tank install**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
178		2" Type 304 steel pipe - About 200 feet total length	-	$ 5,000.00	6	200		$ 5,000.00	$ 660.00	$ 22,000.00	$ 27,660.00	206
179		75L intermediate storage	-	$ -	6	2		$ -	$ 660.00	$ 220.00	$ 880.00	8
180		pipe hangers (1 for every 10 ft, 1 for every vertical connection)	40	$ 4,400.00	6	80		$ 4,400.00	$ 660.00	$ 8,800.00	$ 13,860.00	86
181		Likely ISO Clamp Unions where needed, CIP fittings preferred where possible	-	$ -	2	-		$ -	$ 220.00	$ -	$ 220.00	2
182		elbow joints	50	$ 850.00	2	-		$ 850.00	$ 220.00	$ -	$ 1,070.00	2
183			-	$ -	-	-		$ -	$ -	$ -	$ -	-
184	**Install Coolers**		-	$ -	-	-		$ -	$ -	$ -	$ -	-
185		Site prep (See lines 12-14)	-	$ -	18	-		$ -	$ 1,980.00	$ -	$ 1,980.00	18
186		assemble construction materials	-	$ -	-	10		$ -	$ -	$ 1,100.00	$ 1,100.00	10
187		construct cooler walls	-	$ -	-	50		$ -	$ -	$ 5,500.00	$ 5,500.00	50

188		install refrigeration systems	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
189		Electrical	-	$ -	-	20		$ -	$ -	$ 2,200.00	$ 2,200.00	20
190												
191	Layout	$ 5,750.00										
192	Rentals	$ 10,400.00										
193	**Totals:**			**$39,441**	**204**	**1163**		**$39,441**	**$22,440**	**$127,930**	**$189,811**	**1367**
194	**Total Cost:**	**$189,811**										

Table 12: Monte Carlo simulation summary. Reduced cost is assuming lower costs due to buying used equipment.

Monte Carlo Simulation Summary Table				
Return on Investment	**Full Cost, No Markup**	**Reduced cost, No Markup**	**Full Cost, 15% Markup**	**Reduced Cost, 15% Markup**
Mean (Years)	7.68	6.87	4.97	4.43
Standard Deviation (Years)	1.15	1.01	0.87	0.76

Table 13: Daily production outputs broken down into exact products made each day.

Monday				**Tuesday**							
Batch 1		**Batch 2**		**Batch 1**				**Batch 2***			
Whole Milk 5-gal bag	90 bags	**2% Milk 5-gal bag**	89 bags		**Units**	**Milk (gallons)**	**Totals (gallons)**		**Units**	**Milk (gallons)**	**Totals (gallons)**
Cream	18.2 gallons	**Cream**	24.8 gallons	**2% Milk 5-gal bag**	89	5	445	**2% Milk 5-gal bag**	89	5	445
				Cream	1	24.8	24.8	**Cream**	1	24.8	24.8
							469.8				469.8

*Alternate skim milk bags once a month for batch 2

Wednesday				**Thursday**				**Friday**			
	Units	**Milk (gallons)**	**Totals (gallons)**		**Units**	**Milk (gallons)**	**Totals (gallons)**		**Units**	**Milk (gallons)**	**Totals (gallons)**
2% Gallon Jugs	325	1	325	**Whole Milk Gallon Jugs**	330	1	330	**2% Gallon Jugs**	325	1	325
2% Half Gallon Jugs	100	0.5	50	**Whole Milk Half Gallon Jugs**	100	0.5	50	**2% Half Gallon Jugs**	100	0.5	50
2% Pints	400	0.125	50	**Whole Milk Pints**	400	0.125	50	**2% Pints**	400	0.125	50
2% Half Pints	320	0.0625	20	**Whole Milk Half Pints**	340	0.0625	21	**2% Half Pints**	320	0.0625	20
Cream	1	24.8	24.8	**Cream**	1	18.2	18.2	**Cream**	1	24.8	24.8
			469.8				469.2				469.8

Table 14: Budget breakdown for the dairy processing facility. This includes engineering hours, equipment, and installation costs.

Item	**Cost**
Administrative Hours	168 hours ($50/hour) = $8,400

Design Hours	140.5 hours ($50/hour) = $7,025
Equipment Cost Range	$1,502,746.49
Installation Estimation	$189,811
Total	**$1,707,982.49**

Table 15: Gantt chart for Modular Dairy Processing Facility project.

1	**Project Planning**	**Owner**	**Start Date**	**End Date**	**Pct Done**
1.1	Background	Ry S.	10/2/2023	10/20/2023	100%
1.2	Problem Definition	Jack V.	10/2/2023	12/8/2023	100%
1.3	Goals	Robert S.	10/25/2023	12/8/2023	100%
1.4	Objectives	Luke B.	10/25/2023	12/8/2023	100%
1.5	Criteria	Luke B.	10/10/2023	11/25/2023	100%
1.6	Constraints	Robert S.	10/10/2023	11/25/2023	100%
1.7	Standards & Regulations	Ry S.	10/31/2023	11/2/2023	100%
1.8	Decision Matrix	Team	1/22/2024	2/15/2024	100%
2	**Prototype Development**	**Owner**	**Start Date**	**End Date**	**Pct Done**
2.1	Process Flow Diagram	Ry S.	1/24/2024	2/27/2024	100%
2.2	Product Output Mix	Luke B.	1/24/2024	4/11/2024	100%
2.3	Cleaning Strategy	Jack V.	1/30/2024	2/27/2024	100%
2.3.1	Production Schedule	Jack V.	2/7/2024	4/3/2024	100%
2.4	Unit Operation Calculations	Ry S.	2/27/2024	4/3/2024	100%
2.5	Waste Water Treatment	Luke B.	2/5/2024	3/27/2024	100%
2.6	Equipment Selection	Robert S.	2/27/2024	4/11/2024	100%
2.7	Monte Carlo Simulation	Robert S.	1/25/2024	4/11/2024	100%
2.8	Floor Layout	Jack V.	2/27/2024	3/25/2024	100%
2.9	Risk Assessment	Ry S.	2/7/2024	4/11/2024	100%