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DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

IMPROVING BUSINESS EFFICIENCY THROUGH MODERNIZATION AT THE BERKEY CREAMERY

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ABSTRACT

It is often considered a difficult task for small businesses to acquire and implement the right information systems which improve efficiency and further profits due to the high cost and high variation of modern software. However, this should not deter business owners as affordable software and simple self-built programs can be utilized to help businesses grow. This paper examines a real-world business in the Pennsylvania State University Berkey Creamery and evaluates potential solutions to help the Creamery improve efficiency and further profits. Specifically, this paper analyzes why ERPNext, an innovative and modern open-source ERP software alternative for small businesses, is a feasible solution for the Creamery due to its low cost and basic functionality. Additionally, this paper examines a MS Excel solver-based program that solves the allergen constraint sequence optimization problem to help improve manufacturing efficiency.

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Chapter 1

Introduction

1.1 Background and Motivation

Businesses should always be striving to maximize profits. This paper aims to analyze current processes at the Berkey Creamery and recommend potential ways to help increase efficiency as well as profits using 21st-century technology. One of the most popular tools that companies are utilizing presently is Enterprise Resource Planning (ERP) systems. These systems are a form of software that on the surface, allows companies to gather more insights about their business. ERP systems combine multiple business functions such as manufacturing, sales, human resources, and much more into one integrated platform. This platform helps management make better decisions by organizing important information about one's business, often in real-time and using this information to generate key insights.

Top companies like SAP and Oracle dominate the ERP software market and develop essential software that top businesses in the world use. However, because of the high cost of software from these top ERP companies, many small businesses have never integrated ERP software into their businesses and are missing out on ways to increase business efficiency as well as profits (Seethamraju, 2015). The Penn State Berkey Creamery is an ice cream manufacturer/retailer and makes for a fantastic example of a small business still operating without an ERP system. Without an ERP system, the Creamery spends time (as well as money) doing things that an ERP system could do for them, such as manually counting inventory, maintaining purchases/sales, tracking finances, and much more.

ERP systems typically have multiple modules built into them which helps business leaders make better decisions, however, ERP systems cannot help business leaders make every single decision. One important decision that the Berkey Creamery is tasked with that an ERP system could not help with is production scheduling. While ERP systems can create and maintain production schedules, it is up to the supply chain master of any organization to physically develop a production schedule in the most optimal way possible.

For a business such as the Creamery whose main focus is ice cream manufacturing, the difference in efficiency between the optimal production schedule order and a randomized production schedule order is very sizeable. The machinery that is used to make ice cream must comply with health and safety standards, meaning, certain flavors with certain allergens cannot be manufactured before other flavors with different allergens. Being able to optimize such a sequence is essential for a business like the Creamery because non-optimal sequences will result in wasted hours of clean-up every day.

To optimize this sequencing of production, this paper later discusses the creation of a mixed-integer linear program (MILP) that solves this problem using the built-in solver tool in Microsoft Excel. This program considers different sets of allergen constraints per flavor and produces an optimal production sequence that the supply chain master can use (with or without an ERP system) in the scheduling of production.

1.2 History of the Berkey Creamery

The Creamery was first built in 1865 on the Pennsylvania State University campus. In 1892 the university began offering short dairy courses making the Creamery the first academic facility in the world which offered courses on ice cream making. In 1904 the Creamery began its retail services offering pasteurized milk as well as cream. The next few decades consisted of ice cream research as well as consistent demand growth, especially once ice cream consumption became a tradition on Penn State Football game days.

In the 1940s the logistics of the business began to form with the introduction of a delivery fleet to sell milk in the local area. By 1960 the first public retail space opened on Curtain road with 24 flavors of ice cream. In the next coming years, retail demand continued to see constant growth with refrigeration becoming more available in supermarkets and homes. In 1968 the Berkeys helped Penn Staters gain an important foothold in the industry and their help later turns to the official naming of the Berkey Creamery. The creation of the food science department came in 1975 which quickly became one of the most prestigious collegiate programs in the country with the help of the thriving Creamery. In 1978 two graduates of this program created Ben & Jerry's, one of the largest ice cream manufacturing companies in the world today (The Berkey Creamery Story, n.d.).

With the Creamery being a unique business over the years that also holds academic importance, business growth often has become overlooked. Specifically, in recent years the lack of 21st-century technology utilized in their business scheme has held the business back from continued growth. Today, the Creamery produces and sells milk, yogurt, cheese, and ice cream, with ice cream being the highest selling product by a wide margin. This paper focuses solely on possible implementation software/techniques to help regain that constant growth the Creamery is known for in ice cream production and sales.

1.3 Thesis Overview

Chapter 2 consists of a literature review on the corresponding subject matter. The literature review holds importance as it illustrates past research in similar subject areas. Particularly, in ERP analysis/implementation as well as MS Excel solver/sequence optimization methods.

Chapter 3 examines operations at the Creamery which are essential to understanding key components in the following chapters. This includes all processes from manufacturing to retail.

Chapter 4 introduces ERP vetting techniques and dives into a potential software for the Creamery – ERPNext. This chapter expands upon ERPNext in detail and sheds light on some key modules built into the software which make it a viable solution.

Chapter 5 examines a sequence optimization tool built for the Creamery. This tool was built on MS Excel's built-in solver and requires demand data (flavors to be manufactured in one week) and allergen constraints per flavor as the program's input data. The output of this program is an optimal sequence of flavors to be manufactured in one day.

Chapter 6 concludes the paper and examines future work to be done in this subject area.

Chapter 2

Literature Review

2.1 Why ERP?

With the booming rise of technology in the 1990s, the development of enterprise resource planning (ERP) systems came along (Harreld, 2001). ERP systems gave companies a new way to look to further maximize profits by combining key functional areas of a business into one system that could be tracked, often in real-time. These systems primarily helped companies by improving business insights which in turn could help lead to an increase in efficiency and collaboration while a decrease in operational costs and risks (What is ERP?, n.d.). With the many advantages of ERP systems, the boom of ERP implementation began between the 1990s and the turn of the twenty-first century.

As the market for ERP software continued to grow, so did the number of companies that specialized in a unique version of the software. While the market of ERP was expanding, so was the definition of ERP, with each software specializing in something different. This made the concept of vetting ERP systems extremely important as companies began asking the question, "Which system is **best** for our business?" This question has grown more complex over the years and will only continue to become more complicated in the future. The current value of ERP and related services has an approximate global market of $41.69 billion with a compound annual growth rate of 7.2% in 2020 (Kirmizi & Kocaoglu, 2019). This market will only continue to grow and is expected to be valued around $70.3 Billion per year by 2025 (ERP Software Market to Reach a Market Size of $70.3 Billion by 2025 - KBV Research, 2019).

All companies vetting through this large market of software for a premier ERP system for themselves are all searching for remarkably equivalent benefits. According to (Kirmizi & Kocaoglu, 2019), the most frequent benefits companies are looking for in an ERP system are:

1. Improved Planning
2. Reduced costs throughout the supply chain
3. Reduced throughput time
4. Just in time manufacturing
5. Improved delivery times
6. Better service and product quality.
7. Reliable data and standardized reporting, therefore
8. Improved communication and coordination throughout supply chain
9. Improved productivity and efficiency.

However, because all companies have extremely variable desires and constraints, selecting the right system must be looked at on a case-by-case basis. For the case of the Creamery and other small businesses, the most common constraint is cost (especially considering the extremely high cost of the top software in the world). Therefore, smaller companies that sell ERP software at a smaller cost must be considered. This paper analyzes a potential solution that can bring a company like the Creamery all nine of the above-listed benefits at an extremely low cost.

2.2 Preparing for Implementation

Even for well-designed systems, the failure rate of ERP implementation is extremely high (Lee, 2017) making the preparation for implementation crucial to ensure successful adoption. An ERP readiness assessment model compiles a list of key factors and sub-factors as the requirements for a business to be prepared to begin ERP implementation (Kirmizi & Kocaoglu, 2019). This readiness assessment model cites top management, project management, people, change management, and technical requirements as the top key factors in assessing a company's readiness for ERP implementation. The complete list of factors, sub-factors, and descriptions can be found in Chapter 7, the Appendix.

A company such as the Creamery who has not begun to prepare for ERP implementation has a considerable amount of planning/work before even giving thought to implementing a system (regardless of the system chosen). This is because an ERP system requires significant changeover in everyday operations in order to ensure everything desired is being recorded properly and accurately in the system. Thus, all required factors in the readiness model must be met before considering implementation.

2.3 Sequence Optimization & The Traveling Salesman Problem

Sequence optimization refers to the specific, optimal order in which events follow one another to maximize efficiency. One of the most famous sequence optimization problems in the world is the traveling salesman problem (TSP). The TSP is a problem that asks, "given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city and returns to the origin city?" It is one of the most closely studied problems in the field of optimization research, especially because there is not one concrete algorithm that can be applied to all variations of the problem. There are multiple algorithms out there that are designed to solve different varieties of this problem, all of which are extremely computationally intense.

Mike C. Patterson & Bob Harmel, in their paper, developed an algorithm that solves the TSP using mixed-integer linear programming (MILP) in MS Excel solver (Harmel & Patterson, 2003). The algorithm is modeled by inputting the distance between cities through a set of constraints, with the solution being an optimal travel sequence. This same algorithm can be modified to fit other sequence optimization problems, similar to the one which is shown in Chapter 5 to assist with the Creamery's production schedule sequencing.

Chapter 3

Operations at the Berkey Creamery

Understanding the operations at the Creamery is essential to the research demonstrated in later chapters. The following figures depict the processes that occur within the Creamery concerning the manufacturing and sales of ice cream. All figures were taken and modified from the six-sigma case study on the Berkey Creamery (Sundararaman, 2019). Any comments within the figures are analyzed in Sundararaman's paper – a case study that influenced the research conducted in this paper.

Figure 1 describes the progression of ice cream making, starting at the source with milk production, and ending at the three main areas of sales: retail, wholesale, and e-commerce. This figure also references processes A and E which are later expanded upon in Figures 2 and 6, respectively.

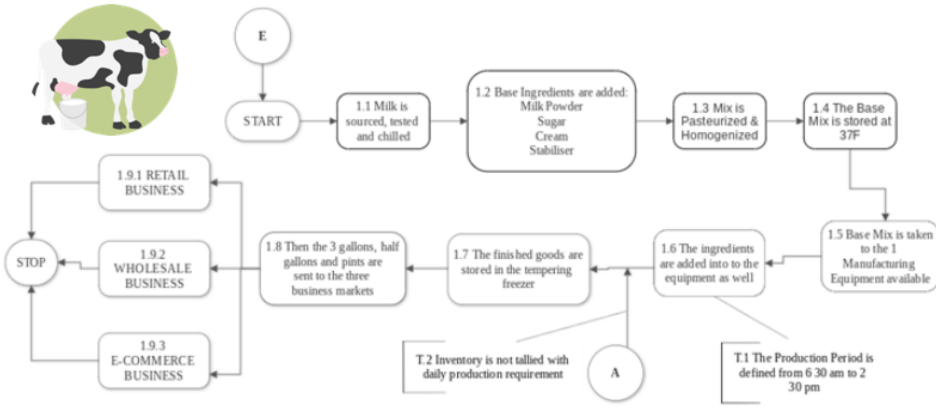

Figure 1 – Ice cream making process

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Figure 2 shows the bi-weekly production schedule creation process, ending with subset A. This figure also references subsets, B, C, D, and F which are each expanded upon in Figures 3, 4, 5, and 7, respectively.

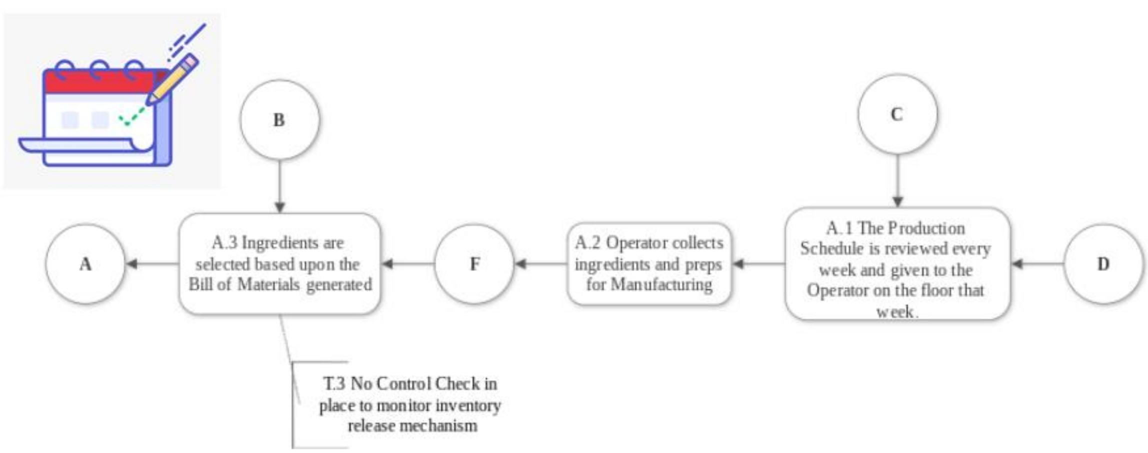

Figure 2 - Production schedule creation

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

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Figure 3 expands upon subset B and shows the process for the creation of a new flavor.

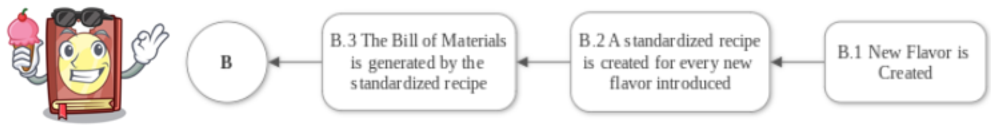

Figure 3 – Creation of a new flavor

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Figure 4 displays how the supply chain master decides what flavors to produce for the upcoming weeks.

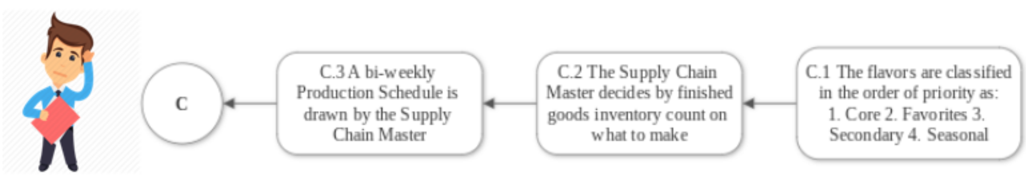

Figure 4 – Finalizing production scheduling

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Figure 5 represents how a re-order is triggered in their current system when inventory is running low. The comments of T.4, T.5, and T.6 raise red flags in the system which are root causes of low productivity.

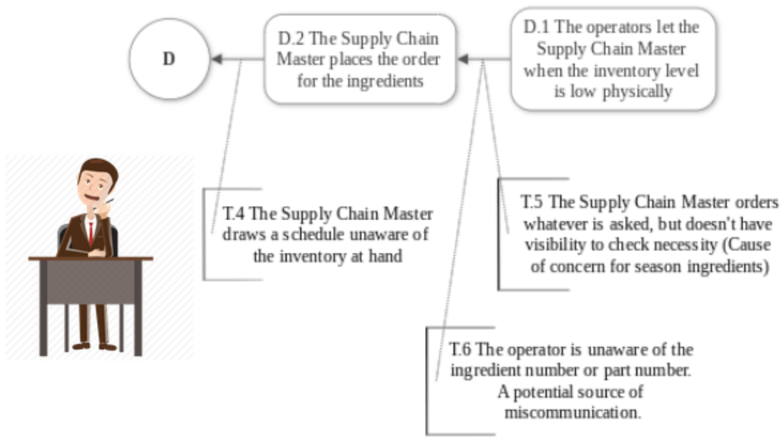

Figure 5 – Re-order process

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Figure 6 elaborates on the current lack of waste documentation which also raises a red flag (see comment T.7) in the current business model. This helps highlight inefficiencies caused in inventory planning and control as well as manufacturing and production management.

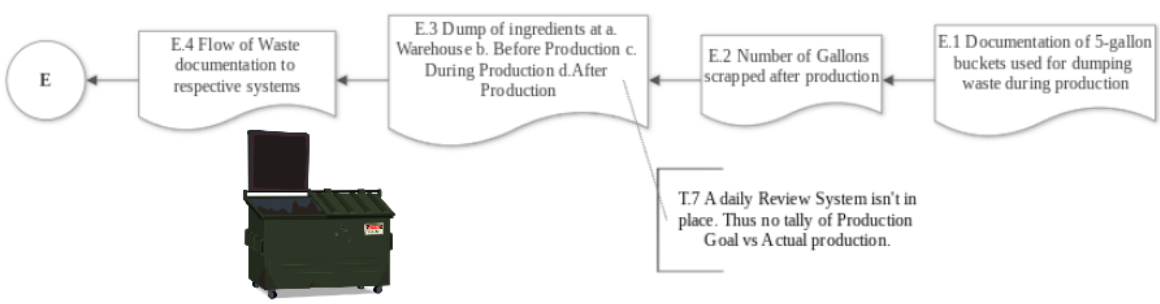

Figure 6 – Waste documentation

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Figure 7 shows essential data gathered during Madhumitha's work and time study. It contains the current rate of production of ice cream, the distribution of workforce and utilization, and the inconsistency in setup and changeover times.

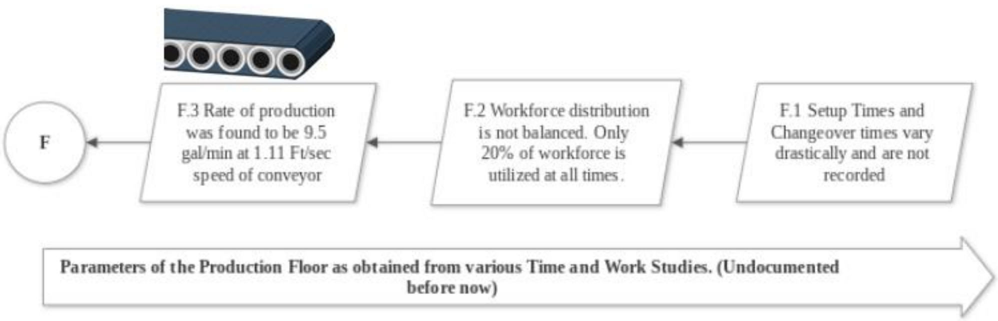

Figure 7 – Production flow parameters

**Figure adopted from six-sigma case study on the Berkey Creamery (Sundararaman, 2019)*

Overall, these current processes are crucial to understanding the current state of the Creamery. In order to ever consider implementing an ERP system, a laid-out business model must be in place. Some of the figures in this chapter highlighted inconsistencies and lack of documentation which must be improved upon before beginning ERP system implementation. Chapter 4.1 expands upon the exact requirements the Creamery must follow before ERP implementation.

Chapter 4

ERP Software Analysis

4.1 Prerequisite to ERP implementation

Before beginning to even consider the implementation of an ERP system, several requirements must be followed to ensure successful implementation. The ERP readiness model as shown in the Appendix as Table 3 is a key resource for preparing for ERP implementation. This table is a culmination of key ERP readiness dimensions from multiple scholarly articles. It represents essential factors of a business that must be met before attempting to implement an ERP system. Missing dimensions will likely result in a failed implementation as well as a loss of both time and money. While ERP readiness is not analyzed for the Creamery in this paper, it is clear that the Creamery is missing multiple dimensions of this table. ERP implementation is not an easy task, and therefore, the Creamery needs to modify its processes accordingly before beginning the implementation phase.

4.2 Introduction to ERPNext

One ERP system was selected to analyze closely in an attempt to showcase the capabilities of ERP and the potential benefits a system could bring to the Creamery. When vetting potential ERP systems for the Creamery, low cost and basic functionality were the top factors in choosing one system. This led to the discovery of ERPNext, an extremely inexpensive ERP alternative for small businesses. Table 1 shows the cost comparison of two top ERP software systems compared to ERPNext.

Table 1 - ERP Cost Comparison

ORACLE vs. SAP vs. ERPNext

Fees per month per user		Total Price	
Oracle	$80-$175	Oracle	$15k-$400k
SAP	$150-$220	SAP	$25k-$2M
ERPNext	$10	ERPNext	$120 per user per year

**Information retrieved from (Ostroverkh, 2019)*

ERPNext is an open-source system with different modules for key business functions. While open-source software is not a necessary component in a system for the Creamery, it brings an extra beneficial dimension that other software does not necessarily have. Open-source software is simply shared source code that allows the software's code to be modified to better fit the specific needs of the user. In other words, the program can easily be changed to best match the operations at the Creamery. Non-open-source software would require the Creamery to tweak its operations to best match the software.

ERPNext is also a web application, meaning that the program is run entirely online. Therefore, anyone with access to the company profile as well as a device that can access a web browser can work in the ERP system. Additionally, the layout of the software is exceptionally simple, making the knowledge of basic computer functionality the only real requirement for a majority of employees when working with the software.

Table 2 illustrates key functionality included in ERPNext.

Table 2 - ERPNext functionality

Accounting Get a real time view of your cash flow. Full-fledged accounting module covering every aspect of book keeping.	**HR & Payroll** Manage full employee life cycle right from onboarding, payroll, attendance, expense claims, assets to separation.	**Manufacturing** Effectively maintain and manage multilevel bill of materials, production planning, job cards & inventory.
Sales & Purchase Increase productivity and lower costs by managing your sales and purchase cycles, from purchase to sales orders	**CRM** Win and retain more customers by optimizing sales process. Track leads, opportunities and send the quotes on the go.	**Projects** Deliver both internal and external projects on time, budget and profitability. Track tasks, timesheets and issues by project.
Helpdesk Deliver a better service experience with an intuitive issue tracker and integrated knowledge base	**Asset Management** Maintain and Manage details of assets, their movement, value adjustment and depreciation.	**Website** ERPNext comes with a fully featured content management with blogs, web pages and forms.

**Information obtained from (ERPNext, n.d.)*

While all of these modules could be of value to the Creamery, the one that could immediately make the most drastic improvement is the manufacturing module. As shown in Chapter 3, the Creamery's current business model contains the most obvious red flags regarding inventory control, production scheduling, and waste management. Better management of these areas in the manufacturing module could immediately improve inventory management which, in turn, could help with production scheduling and help better manage/reduce waste generated.

4.3 Building ERPNext for the Creamery

While the Creamery is not yet ready for ERP implementation as shown by the lack of ERP readiness sub-factors in Chapter 3 and section 4.1, a sample profile for the Creamery was created and built simply to show system capabilities and benefits. Because this was built as a sample profile, modules related to finances and employee management were not altered. Rather, the profile was created to highlight the ease of use as well as the potential advantages related to inventory management and production scheduling. Figure 8 illustrates the high-level processes that went into building this sample profile.

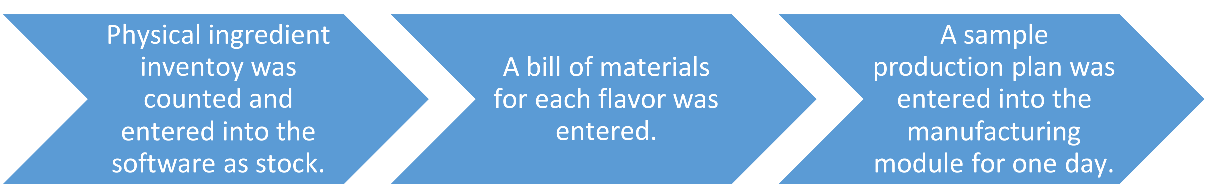

Figure 8 – Building an ERPNext profile for the Creamery

Production planning was the one tool examined within the manufacturing module with significant variety. ERPNext is only able to serve as a tool to manage production plans, not to create them. The optimized creation of production plans is examined outside of ERPNext in Chapter 5. However, ERPNext allows for a variety of ways to manage production schedules. Production schedules are uploaded to the system by filling out the information shown in Figure 9.

	Include Exploded It...	Item Code	BOM No	Planned Qty	For Warehouse	
1		Vanilla Bean Ice Cre...	BOM-Vanilla Bean-...	100	Finished Goods - PSBC	
2		Alumni Swirl Ice Cr...	BOM-Alumni Swirl I...	110	Finished Goods - PSBC	
3		Death By Chocolate...	BOM-Death By Cho...	110	Finished Goods - PSBC	
4		Peachy Paterno Ice ...	BOM-Peachy Pater...	110	Finished Goods - PSBC	
5		Cookies-N-Cream I...	BOM-Cookies-N-Cr...	110	Finished Goods - PSBC	
6		Bittersweet Mint Ic...	BOM-Bittersweet M...	110	Finished Goods - PSBC	

Figure 9 – Production schedule creation

After filling out the information in Figure 9 with flavors to be manufactured, the bill of materials is automatically uploaded and all that is left to be filled out is the planned quantity as well as the final warehouse that the ice cream will be stored. After this is complete, the production schedule can be tracked in a variety of ways, from high-level to extremely detailed.

The given source code of ERPNext currently allows for three main ways for production schedules to be tracked. They can be tracked by the completion of the entire schedule, where the entire production schedule is simply marked as complete when finished. Production schedules can also be tracked by the completion of individual work orders, or by the completion of one individual flavor at a time. While this would track inventory in a more real-time fashion compared to tracking the entire schedule, it would also require more employee time marking work orders as complete in the system. Finally, production schedules can be tracked by job card, or by each manufacturing process. This means the time of each manufacturing process can be tracked, also allowing for management to ensure employees are working at appropriate speeds. Overall, it would be up to the manager to decide what needs to be tracked and how much employee time can be designated to working in the software. If the manager decides more, less, or different information is needed when tracking a production schedule, the open source code can be rewritten to best fit the company's needs.

At the completion of any work order or production schedule, inventory is automatically adjusted in the system. That means that ingredient inventory is automatically backflushed (subtracted) while ice cream stock is automatically added. If more or less of a flavor is manufactured than originally inputted, if the bill of materials is not followed precisely, or if there is any other variation in the production schedule, the exact ingredient/ice cream totals can easily be adjusted in the system. If there is a lack of ingredient inventory, the system will notify the user before the production schedule can even be posted.

Another important piece of ERPNext's software is assigning employee roles and permissions. Employees/users can be added under the users and permissions module as shown in Figure 10 with just their name and email address.

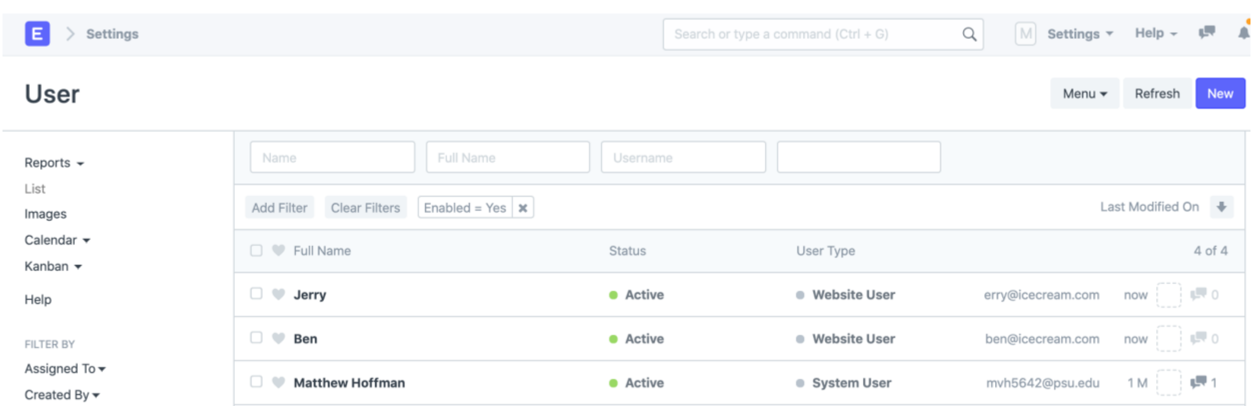

Figure 10 – Adding users to ERPNext profile

Users will be invited to set up their account in order to sign in and access the web application. After sending the invite, personal profiles will not have access to any modules. Therefore, each profile must be granted appropriate permissions. For the example of the employee Jerry who will only need to access stock/inventory and manufacturing, the following roles will be checked under his profile as shown in Figure 11.

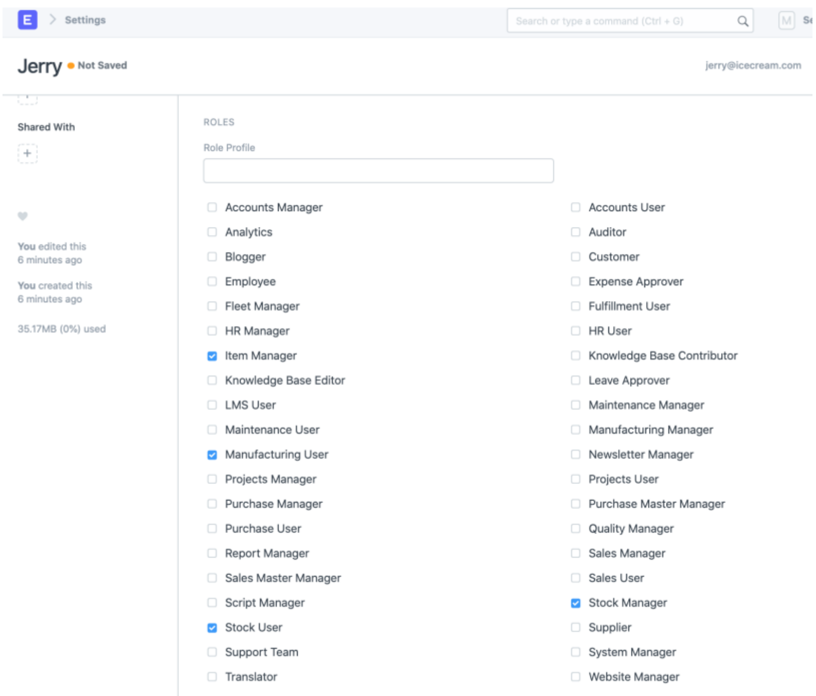

Figure 11 – Assigning user permissions

Once again, because the software is open source, the meaning of each of these roles and their corresponding permissions can be adjusted. Overall, granting correct access to particular employees to work out of the web application is an especially swift and simple process.

4.4 Expected Immediate and Long-Term Benefits

While a very straightforward task such as entering current stock is a seemingly effortless chore on ERPNext, its importance cannot be understated. The ability to have an accurate count of real-time stock on one platform is the first step to making the Creamery a more efficient and profitable business. Every year, approximately 1,500 person-hours are lost in inventory counting (about 4 hours/week) which would be immediately eliminated with an accurate system in place. Exact inventory counts could be checked anytime through random cycle counts to ensure accurate inventory levels. Additionally, inventory could be better managed with a concrete waste management system in place. Currently, as shown in Chapter 3, there is no waste management system in place, meaning that as ingredients and manufactured ice cream flavors perish, there is no record of it. Without a record of it, there is no way to minimize it. With ERPNext’s software in place, all waste would have to be managed to keep an accurate, live count of stock on the company's profile. This, in itself, would serve as a waste management system for the Creamery and help the supply chain leader more efficiently order ingredients and schedule production plans.

After the immediate benefits described above, as the Creamery would continue to use ERPNext, data would continue to be stored. This combination of manufacturing and waste data over time would eventually turn into an additional data set to help forecast future demand. Additionally, if the Creamery were to decide to import sales data into the ERP system as well, this too could be used for forecasting. Because demand for a business like the Creamery is not constant, but rather dependent on a set of variables such as the time of year, current events on campus, the temperature outside, and so much more, past demand data is crucial for forecasting.

Outside of modules related to manufacturing/sales, the Creamery could significantly reduce paper usage by recording everything on the one ERP system. Employee profiles and anything else related to HR, quality management, purchasing, customer relationship management, accounting, assets, side projects, and so much more could be of use to the

Creamery. Besides reducing paper, the system would reduce employee-spent time managing these modules in the company’s current state (on paper, organized independently), compared to the ability to organize everything together on one universal system.

Overall, all long-term benefits would focus on improving efficiency and therefore improving profitability. These long-term benefits would continue to gain clarity as time goes on and more data is recorded.

Chapter 5

Sequence Optimization

5.1 Introduction

While any ERP system can manage production schedules, it is always up to the user to ultimately create any production schedule. Currently, flavors to be manufactured are decided by the supply chain master and the order of production which *appears* most efficient is chosen. Regarding the Creamery, the top constraint which most significantly effects efficiency is the set of allergens assigned per flavor.

Each ice cream flavor that is manufactured at the Creamery has its own set of allergens, such as peanuts or pecans. A full clean-in-place (CIP) is required when manufacturing a flavor with fewer allergen constraints than the one prior to it. For example, a full CIP will be required if vanilla (no allergens) needs to be manufactured directly after peanut butter cup (peanut allergen). A full CIP requires approximately 2-4 hours depending on the ice cream flavors which can have a significant cost on an 8-hour production day. Therefore, it is of paramount importance to schedule flavors in a manner that minimizes the number of CIP's in a day.

5.2 Setting up the MILP

The sequence optimization MILP designed in this chapter was based on the TSP formulation created by (Harmel & Patterson, 2003). Figure 12 illustrates the input data for TSP formulation, where the distances between each city are shown.

TABLE 1. Road Mileage Distances Between Cities

	To	Boston	Cleveland	Detroit	Indianapolis	New York	Philadelphia	Washington, D.C.
From	Boston	0	628	695	906	206	296	429
	Cleveland	628	0	170	294	473	413	346
	Detroit	695	170	0	278	637	576	506
	Indianapolis	906	294	278	0	713	633	558
	New York	206	473	637	713	0	100	233
	Philadelphia	296	413	576	633	100	0	133
	Washington, D.C.	429	346	506	558	233	133	0

Figure 12 - TSP Formulation

**Figure from An Algorithm for Using Excel Solver for the Traveling Salesman Problem (Harmel & Patterson, 2003)*

In Figure 12, the TSP formulation is shown where "From" cities can be represented as the *i* variable while "To" cities can be represented as the *j* variable. Here, the distance from *i* to *j* = the distance from *j* to *i*, thus paralleling the problem. The way the MILP is able to solve this as a TSP problem is through a series of inputted constraints (not shown in Figure 12) which cover the necessary sequence-dependent setups. In this specific problem, a sequence-dependent setup would refer to the need to start at the origin city and return to that city as the last stop.

Figure 13 represents part of the sequence optimization MILP and is constructed similarly to Figure 12, with X's used to mark allergens assigned to corresponding flavors. The figure also illustrates a problem for a random day, specifically, seven flavors that must be manufactured in one day. Obviously, the number and type of flavors will change on a day-to-day basis. In Figure

13, each ice cream flavor is assigned a corresponding row of allergen constraints. Flavors are then organized into classes that represent unique allergen constraints. For example, Chocolate Chip Cookie Dough and Cookies-n-Cream both have identical allergen constraints – milk, wheat, and soy. Therefore, when the two flavors are compared to one another, the order in which they are manufactured is not of importance because no CIP will ever be required between the two flavors.

Ice Cream Flavors	Almond	Coconut	Peanut	Pecan	Pistachio	Walnut	Soy	Wheat	Egg	Milk	Class
Vanilla Bean	0	0	0	0	0	0	0	0	0	X	1
Peanut Butter Swirl	0	0	X	0	0	0	0	0	0	X	2
Monkey Business	0	0	X	0	0	0	X	0	0	X	3
Chocolate Chip Cookie Dough	0	0	0	0	0	0	X	X	0	X	4
Cookies-n-Cream	0	0	0	0	0	0	X	X	0	X	4
Grilled Stickies	0	0	0	0	0	0	X	X	0	X	4
Lion Tracks	0	0	X	0	0	0	X	0	0	X	3
4 Unique Classes											
1	0	0	0	0	0	0	0	0	0	X	
2	0	0	X	0	0	0	0	0	0	X	
3	0	0	X	0	0	0	X	0	0	X	
4	0	0	0	0	0	0	X	X	0	X	

Figure 13 - MILP input data & creating classes

After the list of unique classes is created, the table in Figure 14 is created which compares classes to one another. The table represents the variable a_{ij} with rows representing the *i* classes and columns representing the *j* classes. While moving from class *i* to class *j*, a 0 is inserted if flavor *i* can be manufactured before flavor *j* without requiring a CIP. For example, the variable $a_{1,2}$ (cell (1,2)) has a value of 0 because any class 2 flavor can be manufactured after any class 1 flavor without having to perform a full CIP. Similarly, while moving from class *i* to class *j*, a 0 is inserted if flavor *i* cannot be manufactured before flavor *j* without requiring a full CIP. For example, the variable $a_{2,1}$ (cell (2,1)) has a value of 1 because any class 1 flavor cannot be manufactured after any class 2 flavor without requiring a full CIP. Additionally, a value of 1 is entered in cells where i=j arbitrarily, but ultimately does not affect the formulation as it is impossible to move between identical classes. This constraint is later shown in Figure 15, which lists all the constraints entered into the MILP.

Class Comparison				
i,j	**1**	**2**	**3**	**4**
1	1	0	0	0
2	1	1	0	1
3	1	1	1	1
4	1	1	1	1

Figure 14 - Class comparison

5.3 Formulation and Results

After the MILP is setup, the formulation must be created. The next step is creating the $b_{i,j}$ table as shown in Figure 15. The $b_{i,j}$ variables represent the final solution which will ultimately be used to communicate the optimal solution to the user. This table is empty before the program is run and will be full (and represent the solution) after it is run. The highlighted objective cell represents the sum of the products between the a_{ij} and b_{ij} table minus 1. It also represents the number of full CIP's required. Therefore, the entire goal of the MILP is to minimize the value in the objective cell. Specifically, the objective cell is:

$= a_{11}b_{11}+a_{12}b_{12}+a_{13}b_{13}+\ldots\ldots -1.$

This value is shown as -1 before the program is run as the $b_{i,j}$ table is empty and therefore all b_{ij} cells have a value of 0. There is a minus one at the end of that objective cell to account for the fact that the optimal solution will always contain a loop. This means that the first manufactured flavor will be the same as the last manufactured flavor in the optimal solution, however, this flavor will not be manufactured a second time at the end in real-world production. This can be seen later in the chapter after understanding the optimal solution in Figure 17.

Prod Schedule						
i,j	1	2	3	4		
1					0	
2					0	
3					0	
4					0	Obj
	0	0	0	0		-1

Figure 15 – Objective & empty production schedule table

Next, the MS Excel solver add-in can be opened, and the formulation can be entered. The highlighted "Obj" cell is listed as the objective, and the variable cells are listed as the entire $b_{i,j}$ table. Finally, all the necessary constraints must be entered as shown in Figure 16.

Constraints	
Meaning	**Variable Formulation**
Can only enter each class once (sum of each column in $b_{i,j}$ table is 1)	$b_{11}+b_{21}+b_{31}+\ldots..=1\ \forall\ j$
Can only leave each class once (sum of each row in $b_{i,j}$ table is 1)	$b_{11}+b_{12}+b_{13}+\ldots.=1\ \forall\ i$
All $b_{i,j}$ variables are binary	$b_{i,j}=0,1\ \forall\ i,j$
Can't move between identical classes	$b_{11}=0,\ b_{22}=0,\ b_{33}=0,\ldots\ldots\ \forall\ i=j$

Figure 16 - Assigning variable constraints

Once all the constraints are entered, the solving method must be changed to Simplex LP and then the MILP is ready to run. Hitting solve will prompt MS Excel solver to search for a solution. Once a solution is found, the $b_{i,j}$ table will be populated with 1's and 0's as shown in Figure 17.

Prod Schedule						
i,j	**1**	**2**	**3**	**4**		
1	0	0	0	1	1	
2	0	0	1	0	1	
3	1	0	0	0	1	
4	0	1	0	0	1	Obj
	1	1	1	1		1

Figure 17 – Production schedule table with results

The populated table is read similarly to the $a_{i,j}$ and $b_{i,j}$ tables. Starting by first manufacturing class 1, the next class to be manufactured will be class 4 because $b_{1,4}$ is the only cell in the first row with a value of 1. Moving to the fourth row, it can be seen that class 2 will be manufactured after class 4 because $b_{4,2}$ is the only cell in the fourth row with a value of 1. Finally, after manufacturing class 2, class 3 will be manufactured as $b_{2,3}$ is the only cell in the second row with a value of 1. It can also be seen that $b_{3,1}$ has a value of 1, however, we have already manufactured class 1 and thus, this value can be ignored. The production order solution will always loop back to class 1, which is the sole reason why the objective cell formula contains a subtraction of 1 after the sum of products between $a_{i,j}$ and $b_{i,j}$. In this particular problem, the objective cell has a value of 1, meaning that only one full CIP will be required in this day of production.

Finally, the production order can be put together in the optimal order of class 1, class 4, class 2, and then class 3. A sample solution with actual flavors is shown in Figure 18. Note that the order of production within classes does not affect the number of CIP's.

Key
Order within class does not matter

1st Class Produced
2nd Class Produced
3rd Class Produced
4th Class Produced

Optimal Production Order:	**Class Solution**
Vanilla Bean	1
Chocolate Chip Cookie Dough	4
Cookies-n-Cream	
Grilled Stickies	
Peanut Butter Swirl	2
Monkey Business	3
Lion Tracks	

Figure 18 - MILP results

These same steps can be taken to formulate different problems with a different number of flavors and/or classes. Using this same formulation will constantly ensure the minimal number of CIP's in one day of ice cream production, consequently improving the Creamery's manufacturing efficiency. Typically, 2-4 classes are currently being manufactured throughout one day of production, and it is recommended that this program be used on days when the number of classes being manufactured is greater than or equal to 4. Otherwise, when there at 3 or fewer classes, the program may not be needed as the optimal order can easily be self-discovered without running this program.

The exact improvement this program makes on the Creamery's manufacturing efficiency depends on the optimal solution compared to the sequence currently being arbitrarily chosen. For example, if classes were arbitrarily chosen to be manufactured in the order of class 1, class 4, class 3, and then class 2, two full CIP's would be required on that day compared to one in the optimal sequence. Therefore, running the program on that day would save the Creamery approximately 2-4 hours of cleanup.

Chapter 6

Conclusions and Future Work

Changes such as ERP implementation into a business model are extremely complex and take a great deal of preparation. While the Creamery is not quite ready for an ERP implementation, it is only a matter of time until it becomes necessary to find new ways to increase company growth and profits. When that time comes, an ERP system should be the first addition that management decides to implement.

This paper does not shed much light on preparation for ERP implementation, however, the ERP readiness model in Table 3 in the Appendix contains key sub-factors that the Creamery will need to strive towards when it comes time to preparing to implement an ERP system. A majority of these are management based and can be achieved in a short amount of time. For example, the sub-factor Project Manager (PM) can be accomplished by adding PM to an employee's job title who can assist other employees during implementation.

When the time comes where management decides an ERP system is necessary and the Creamery is properly prepared for the ERP implementation phase, ERPNext should be an extremely logical choice at an exceptionally low cost with all basic functionality. Implementation of such a system should not affect the physical manufacturing process, but rather, increase efficiency regarding the ingredient ordering process, waste management process, and ice cream production process.

The MS Excel solver sequence optimization tool can be used with or without an ERP system in place to minimize time wasted performing unnecessary CIP's. On production days when the number of classes is less than or equal to 3, the tool may not be necessary as the optimal order can easily be self-discovered without the tool. On production days when the number of classes is 4 or greater, the tool should be used 100% of the time to avoid spending hours on one or more unnecessary CIP.

Overall, there is a lot of work to be done, starting with change management, but improving business growth and profits is not far away. When the decision to purchase and adopt an ERP system finally does come into the Creamery's everyday business model, a majority of their processes will change and slowly but surely, the Creamery will become a much better entity from a business standpoint.

Appendix

Table 3 – ERP readiness model

Factor	Sub-factor
Top Management	**Clear Roles and Responsibilities (CRR):** The roles and responsibilities of project stakeholders (project manager, senior management, employees, customers, and suppliers, etc.) within the current organization should be clearly defined, fully documented and understood by all.
	Top Management Commitment (TMC): The inclusion of the ERP project in the strategic plan of the company by the senior management, the concrete determination of general objectives of ERP and what the managers and employees understand from the ERP system is crucial for success of the project.
	Cross-Functional Support (CFS): The support of the unit employees and the unit managers within the organization to the ERP project is very useful for the project manager to manage the relevant processes successfully.
Project Management	**Project Manager (PM):** It is imperative to have a project manager who is assigned at a higher level within the organisation with the knowledge, experience, and ability to successfully execute and coordinate all the processes of the ERP Project.
	ERP Vision, Goals and Objectives (VGO): The vision of ERP Project, the identification of measurable goals for the project, the understanding of these goals by the project stakeholders, the creation of the project organisation and the definition of the motivation and task back-ups of the project team are essential success factors.
	Project Planning (PP) (Scope, Time, Budget, Risk, other resources): It is crucial to determine the expectations and the scope of the ERP project, to prepare the project organisation structure, to prepare the project plan (Budget, Time, Scope, Human Resources, Risk, etc.), to determine the key users, to define the motivation of the project team.

People	**Training (TR):** During the ERP project, employees' adaptation to the new process increases the success of the project when go-live is underway. Therefore, training and related activities become an important aspect.
	Competency of IT Staff (CIT): It is a critical success factor that IT personnel who have an important role in the implementation of ERP projects must have technical expertise, business processes, and ERP processes knowledge, ERP project experience.
Change Management	**Business Processes and Organisation (BPO):** It is crucial that the organisation is committed to change, to take decisions in a participatory environment, to support the learning and development of employees, and to address the concerns of the ERP project on employees. In addition, professional support in readiness, software selection, and implementation phases should be carefully considered. Another aspect is the fact that the organisational chart and business process are realistic, standardised, documented, and understood by the employees.
Technical Requirements	**IT Infrastructure (ITI):** It is important to determine the software, hardware, and network infrastructure that will be needed for the ERP system to operate successfully and to overcome the deficiencies in these issues.
	Data Management (DM): It is crucial that the master data (Material Master and Customer Master), BOM, Route and Procurement times, etc.) are formed correctly, and the necessary procedures for data creation are determined.

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