Operational Decision Support for a Dairy Manufacturing Industry Using Simulation Modelling.

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Declaration of Authorship

I, Barbara Emanuelle Minardi-Kwiatkowksa, hereby declare that this thesis titled, "Operational Decision Support for a Dairy Manufacturing Industry Using Simulation Modelling" and the work presented in it, which I now submit for assessment on the programme of study leading to the award of Master of Engineering is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Acknowledgments

"If I have seen further than others, it is by standing upon the shoulders of giant"
Isaac Newton

And from that sentence I commend my immense thanks to Professor John Geraghty for the opportunity to participate in this project that will undoubtedly be a milestone in my academic, professional and personal life. Your support was instrumental in giving me confidence in me at one of the times I needed it most.

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Abstract

The Dairy Industry has to deal with complexities compared to other sectors such as perishability and seasonality. The opportunity to properly process milk during the peak season is the most important issue for any dairy company otherwise not only tangible values such as sales are lost but also intangible values such as the credibility can be damaged.

The purpose of this research is to describe the use of a milk industry model and to study the best scenario for the demand on manufacturing performance of Irish dairy co-operative society. The model, developed in ExtendSim®, dynamic simulation software, is a framework that provides a what-if analysis considering changes in different scenarios in order to illustrate potential benefits to managers for a successful demand planning.

The discrete-rate simulation model was built according to an SME Company and the operational decisions are made after the customer's orders. An analysis correlating the bottleneck and profitability of dairy ingredients such as Casein/ Caseinate evaluating the impact on the factory capacity. Considering that both products currently are competing for the utilization of a common piece of equipment, a planned sequencing process must be followed, thus this will guarantee that there will be no delay in the production and the specific demand is achieved.

The key features of the proposed approach are combined of the shutdowns, breakdowns and capacities in the actual flow behaviour, collect the results of adjustments from future demands profile and identify the opportunities of value-adding activities to the enterprise via simulation. Moreover, this research also proposes a different approach to Caseinate production comparing the current process to the proposed solution to increase the output.

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List of Abbreviations

ANOVA	Analysis of Variance
CCM	Change Constrained Model
CIP	Cleaning-In-Place
DES	Discrete Event Simulation
ERP	Enterprise Resource Planning
FGI	Finished Goods Inventory
FSC	Food Supply Chain
GATT	General Agreement on Tariffs and Trade
GrSCM	Green Supply Chain
LCA	Life Cycle Assessment
MCDM	Multi-criteria Decision-making
MTO	Make to Order
MTS	Make to Stock
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SD	System Dynamics
WIP	Work in Process

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Chapter 1

INTRODUCTION

The dairy sector is, in many countries, a major contributor to the manufacturing capacity of the food sector, and as more components of milk are utilised in processed foods, so this importance is likely to grow. This competitive, commercial position, together with the fact that the general public has a high regard for dairy products, is an indication of the extent to which milk producers and processors have combined to ensure that retail products are both nutritious and hygienically acceptable. Achievement of these aims, and at a reasonable cost, has depended to a large measure on the advancements that have been made in the handling of large volumes of milk.

In some instances, the increased capacity has arisen simply from an expansion of a traditional method, but in others a totally new approach has had to be adopted either for manufacturing process per se, or for utilisation of the end products. Success has also depended on the derivation of accurate process controls, both through automation, and through improved procedures for quality control.

The European Commission, in 1984, introduced the Milk Quota Regulation in order to try and address the oversupply of milk on the European Union. In pursuance of positioning Ireland as a world leader in dairy innovation and helping to maximise the long-term growth opportunities after the end of milk quota, the Irish Government in partnership with private industry has been investing €25 million. The Dairy Processing Technology Centre (DPTC) which is hosted by the University of Limerick, is a collaboration of 8 companies and 9 Research Performing Organisations (RPO's). The main objective of this centre is to create 52 new jobs for highly-skilled researchers over the 05 year term of the centre anticipating the increase of 50% in the Irish milk pool by 2020.

The centre is funded by Enterprise Ireland and the Dairy Industry Partners and it has been established as a centre of excellence for dairy processing research and innovation. The Centre helps to fuel growth in the Irish dairy sector by performing research focused on cost-efficient processing, facilitating a step-change in environmental sustainability and creating, validating and commercialising a pipeline of science and technology-based manufacturing platforms for dairy ingredients. The foundation of the DPTC is a strong, long-term industry–academic collaborative partnership that develops, builds and translates the knowledge and capabilities in dairy processing that are needed today and for the long-term growth development of the sector.

The industrial partner in this research is a medium-sized company and it was founded following the merger of two Co-ops in 2001. They produce a wide array of dairy consumer products such as milk, butter, cream; dairy ingredients such as Casein, skimmed milk powder, whole milk powder, whey and animal feed products. Each of the three divisions within company is focused on ensuring commitment to the highest standards of quality, efficiency, competitiveness and customer satisfaction to all stakeholders.

The company operates through three divisions.

- Dairy Ingredient manufacturing: Working with freshly assembled milk, the division offers a comprehensive portfolio of high quality functional food ingredients with proteins, milk powders and dairy fats.
- Dairies: Liquid milk manufacturing and sales distribution fleet, supplying all the major supermarket groups, convenience stores and independents in the region.
- Agribusiness: operates 13 retail stores and a feed manufacturing facility.

The field of this study is the manufacturing process at Dairy Industrial Partner, specifically in two products: Casein/ Caseinate due to the market value. Highlighting that the whey is the core product of the company, but the most profitable is the Casein/Caseinate.

To support the operational decision system a simulation tool was used to create different scenarios and provide a similar environment for the production. Through simulation model the real world uncertainties can be incorporated in the production process in order enhance the decision-making process.

The model and simulation tool used was ExtenSim®, which was not only the first "drag and drop" simulation program, it was the first graphical simulation tool to embody the concept of modelling components as objects. ExtendSim® provides libraries of blocks containing their own behaviour, responses to messages, interface, and data. This creates a very flexible modelling architecture. Complex processes can be modelled by combining existing blocks together. Once a process has been defined it can be encapsulated into a hierarchical block and saved in a library for reuse.

This research is divided into three main sections. Section 2 presents the literature overview for understanding the contribution of the dairy sector and the decision-making process previously researched. Section 3 describes the process of the partner company by specifying details regarding the modelling approach and simulator architecture. Section 4 explores the simulation results and Section 5 presents the conclusion and the discussion of the future work.

Chapter 2

LITERATURE REVIEW

2.1. Introduction

Supply chain management is a set of methods that are used to provide better integration and better management to all network parameters: transport, inventory, costs, etc. These parameters are present in the suppliers, in their own company and finally in the clients. The proper management of the network allows an optimized production to offer to the final customer the right product, in the right quantity. The main goal is to reduce costs along the chain, taking into account customer requirements - after all, this is quality: deliver what the customer wants, at the price and conditions he expects.

This management can be complicated, especially for a system that does not have control over the whole chain. For example, a company that outsources a portion of production or logistics has no more control over an important part of the process. It is also difficult to manage because customer demand is mostly unknown and varies substantially from one month to the next, which implies more complex production planning. The products to be manufactured can also change (new season, fashion, models, improvements), which will highlight the need for a new strategy for prices and calculations of costs of supply and inventory.

Decision levels are largely dependent, although distinct, working in an integrated way to achieve results within the organization. It is possible to visualize 3 levels: strategic, tactical and operational. Each level unfolds in different responsibilities and focuses. It is of utmost importance for the professional to know his/her position within this decision structure so that he/she performs his/her activities according to the expectations attributed to them.

Dairy products are milk products, such as cheese, yogurt, butter, sour cream, among others. Its consumption is extremely important for a maintenance of human health, acting alongside passive immunology, modulation of the immune system, protection against hypertension, protection against osteoporosis, cancer prevention, among others. Some important functional foods are also derived from milk, such as fermented milks, yogurts and other fermented dairy products. They are nutritious foods, natural or enriched with food additives that reduce the risk of diseases, besides offering several health benefits, inherent to their chemical composition. The management of the supply chain in the dairy industry should be based on planning which support decision making and thus minimize risks and maximize results, which in this area is of the utmost importance due to the amount of material and financial resources consumed by it. Computer simulation allows managers to experiment with reality through a model and thus evaluate how the variables will behave in the idealized system.

2.2. Supply Chain Management

When trade was incorporated into human activities, originally in the form of barter, the movement of goods and commodities became an important task for the genesis of a socially and economically more dynamic life. According to (Moura, 2006), logistics areas have grown in importance in many business management sectors; however, it had originated when the exchange among communities and transportation of goods was required throughout distances.

The concept of Logistics and Supply Chain is normally interchanged in the literature selected; however, it was observed that Logistics is related to the movement of material and information, while the Supply Chain is defined as a global network by involving collaboration between companies.

2.2.1. Logistics Definition

From French origin, the meaning of the word logistics was initially restricted to the military field, as a strategy of movement and lodgement of troops and their supplies, only later expanding its use to the market field (Filho, 2006) when the companies, influenced by the success of these strategies, began to reproduce them in their commercial practices (Costa, Dias and Godinho, 2010)

The law of supply and demand, presented in many sectors is more complex than they initially believed. Competition and a higher level of consumer demand meant that these companies had to adapt to this reality, striving to achieve the sale of what was produced, using resources such as market research, advertising and strategies that ensure an efficient flow of these products to their customers (Moura, 2006).

The Logistics efficiency of a company depends on its ability to plan, implement and control the flow and storage of goods, services and information that involve its relationship with its suppliers and customers, from end to end process that involves this relationship, in a collaborative movement (Costa, Dias and Godinho, 2010).

The logistics efficiency would be possible with the cadenced action of all those involved in the process from the initial point of production to the final product and its consumer, thus forming a supply chain that, according to (Pierreval, Bruniaux and Caux, 2007) ***apud*** (Fuentes *et al.*, 2016) "represents a network of organizations through two-way links of different processes and activities that produce value in the form of products and services that are placed in the hands of the end consumer." It is a logistics network composed of Suppliers, production centres, warehouses, and distribution centres, retailers, in addition to raw materials, inventories of products in process and finished products that move between the facilities" (Kaminsky, Simshi-levi and Simchi-levi, 2010).

2.2.2. Supply Chain Definition

According to (Ballou, 2006), the Supply Chain is defined as a set of functional activities such as transportation, inventory management which are constantly repeated along the channel whereby raw materials are converted into final products. Through this definition, it is possible to observe that Supply Chain Management creates an inter-relation between companies while Logistics creates an intra-relation inbound operation.

The Supply Chain Management is presented by (Magalhães, 2013) as an effort to coordinate and control all the processes that involve the management of a product, from the raw material to the presentation of the product to the final consumer, processes that must be efficiently managed and controlled by each involved in the activity of meeting the needs of the market and its efficiency is crucial to the success of a company in the marketplace, ensuring superior service to customers by adding value to the final products and minimizing total operating costs.

(Bowersox, 2014) presents SCM from a management point of view and states that SCM is a business-to-business collaboration driving strategic decision-makers by efficiently improving operational tasks where each company echoes its own strategic decision from suppliers to final customers.

Kaminsky, Simshi-levi and Simchi-levi (2010) states that each chain consists of three different levels: (i) Strategic, which is responsible for the company's structural decisions, the product design of the company, the selection of its suppliers and formation of strategic alliances; (ii) Tactical, dedicated to decisions that are taken once or twice a year in the company, which relate to purchasing, production, inventory policies and transport strategies; (iii) Operational, that is dedicated to the daily decisions of the company, like programming and production management and definition of routes and loading of trucks.

2.3. The Decision-Making Process

The decision-making process is a daily practice of the human being and at the business level this subject must follow crucial steps until the decision is made and its results are perceived, such as the definition of the problem, identification of the criteria relevant to the decision, evaluation and hierarchy of those criteria by priority of each of them, listing of possible alternatives of success in solving the problem, classification of each of these alternatives listed, and, finally, the calculation of the optimal decision, which is defined from the allocation of an estimated monetary value to the likely consequences resulting from the choice of these alternatives (Robbins, 2000). Furthermore, the planning process is a vital part of the decision-making process in order to establish and support the achievement of global strategy goals.

Chiavenato (1982, 1999) states decision-making as a process to be carefully followed regarding its results, in response to a problem that requires to be solved, need to be satisfied or a goal to be achieved. However, in addition to policies and time, as limiting factors, there are other factors that prevent the administrator from making an accurate assessment of the factors that involve a problem situation, even in the case of long-term planning, thus not guaranteeing any effective prediction success. Subsequently, decision-making in a company will always require planning that will define the actions which must be performed in order to achieve the goal outlined in that decision

The decision levels are subdivided into three different hierarchies as shown in Table 2.1; defined by the nature of the actions to be implemented, as well as the time horizon that involves the execution of each of these actions. In this sense, the literature presents a hierarchy formed, respectively, by the strategic planning, with objectives and execution of long-term actions, elaborated by the institutional level of the company, represented by the management; medium-term managerial responsibility of the intermediate level of the company, represented by managers, supervisors, coordinators, and; operational, with short-term objectives, and implementation at the operational level (Chiavenato, 1999).

Table 2.1
Decision levels hierarchy

Operational Level	***Planning Type***	***Content***	***Term***	***Scope***
Institutional	Strategic	Generic and synthetic	Long	Macro-oriented. It addresses the organization as a whole.
Intermediate	Tactical	Less generic and more detailed	Medium	It addresses each separate organizational unit.
Operational	Operational	Less generic and more detailed	Short	Micro oriented. Addresses each operation separately.

2.3.1. Strategic level

Strategic level, always involves extensive time horizons and implies consequences for the company as a whole, originated from the definition of global objectives and respective implementation of actions for its accomplishment, consisting of a "managerial process that enables the executive to establish the course to be followed by the company, with a view to obtaining a level of optimization in the relationship of the company with its environment ", taking into consideration," basic premises that the company as a whole must respect for that the strategic process has coherence and decision support (Oliveira, 1992).

Long-term plans are those whose execution is carried out over a period of time that exceeds the period of one year, although these plans are less efficient than the short-term ones that are fundamental to the company because they involve decisions about capital expenditure, development of the enterprise and research programs (Albers, 1977).

However, long-term goals are only realized from the accomplishment of other objectives, of lesser scope, whose actions for their realization are given immediately, or in a term of less than one year, in the experience of routines that permeate daily business. In this sense, it is necessary to materialize the tactical and operational planning, capable of accounting for the achievement of the objectives contained in the strategic planning of the company. In this way, strategic planning will be the basis for the formulation of a tactical plan that, in turn, will generate an operational plan, with activities and actions executable in the business routine.

2.3.2. Tactical Level

The Tactical level involves organizational units separately, such as a department or division. It extends into the medium term and is developed by the intermediate level. Chiavenato (1982, 1999) states this level is formed, therefore, by the unfolding of a strategic planning, and its unfolding, in turn, forms operational planning consisting of a set of deliberate and systematic decisions involving more limited enterprises, shorter deadlines, areas less broad and lower levels of the organization's hierarchy.

The Tactical planning level, according to Oliveira (1992), has the purpose of guarantying the efficiency of resource application in order to achieve the strategic objectives and policies previously defined. Therefore, the objectives contained in the strategic planning are broken down into other objectives that are defined as departmental responsibilities in the company, forming the tactical planning, which aims to optimise a specific sector and not the company as a whole.

2.3.3. Operational Level

At the Operational level, (Chiavenato, 1982; Oliveira, 1992) states this level is responsible for the execution. The formalization, mainly through written documents, of established development and deployment methodologies, corresponds to the set of individual action plans to be executed enhancing the efficiency, in the routines that permeate the operational level of the organizations, aiming at the promotion of the maximization of results that realize short-term objectives, in order to ensure the effectiveness of results of the intermediary and institutional levels of the company.

Chiavenato (1982, 1999) also complements the operational planning can be viewed as a feedback system where the input set by tactical level is detailed providing means and favourable conditions for optimising and maximising profitability. At the operational level, the routine administration must be executed in order to guarantee that all the tasks will be performed according to the objectives previously established by the strategic and tactical levels.

The relationship among the three different decision levels previously detailed is demonstrated though the Manufacturing Resource Plan (MRPII) structure shown in Figure 2.1, where the inputs required and the outputs provided throughout the activities in each planning process can be observed. In each stage the resources required are evaluated in order to guarantee the flow of each activity.

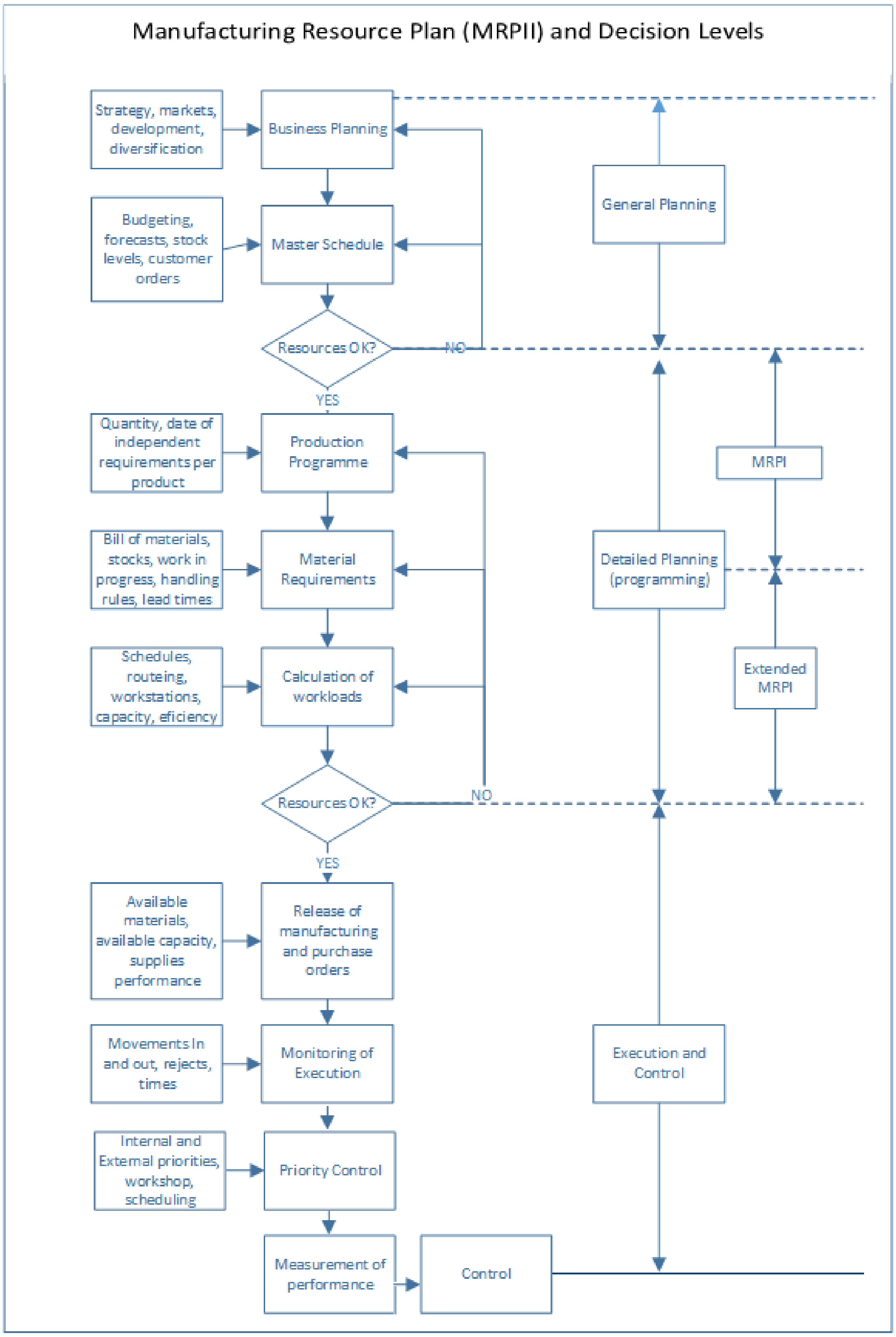

Figure 2.1 – Manufacturing Resource Plan (MRPII) and the Decision Levels

According to (Albers, 1977; Oliveira, 1992; Faria, 1996), in the business sphere each level of the planning process is essential for organizations not only to set future goals, but also to visualise possible issues that could be addressed from different contexts, as well as a visualisation of the very impacts that a planning can cause.

2.4. Dairy Supply Chain

Dairy Supply Chain is composed of mainly farms, equipment suppliers, processers, retailers and distribution channels. Prepared foods can also be considered part of the dairy supply chain once products such as bakery require milk and processed milk as a raw material. In this case, the milk itself is not the final product but is part of another chain. The Dairy Supply Industry is based not only on milk as mainly raw material but on equipment and technology to support logistics strategies and operations. Increase in Dairy production can also indirectly contribute to other industrial sectors once more material flow results in more warehouses, equipment, transportation, information, business and investment.

This sector faces many challenging activities from the milk reception to the availability of end products to the final customers. Firstly, the fresh milk, is a raw material with a high level of sensibility and due to the high perishability it must be processed immediately. Secondly, the commodity resulted by production process is controlled by market prices. Consequently, operation costs must stay at the minimum level to assure profitable results for manufactures.

Milk is the main raw material in Dairy Supply Chain and is strongly present in the human diet because of the high level of nutrients and vitamins and it therefore plays an important role in the body's development. The milk extraction can be manual or automatized through pumps and vessels which is increasing among farmers in order to guarantee finished products quality avoiding microorganism's contamination due to extra manipulation and the milking is the most time-consuming activity in dairy farming (*Dairy Processing Handbook*, 2017).

The milk extracted can be divided into many end products and to reach high levels of quality the main characteristic relies on the milk composition, which is composed of vitamins, minerals, fat and mainly by proteins classified according to chemical or physical properties. Regarding to market strategy the milk can be classified as (i) dairy commodities which are more income sensitive than bulk markets and compete with local processors or multinationals, and (ii) commodities which compete in price and quality low-cost exporters (Slack N., Brandon-Jones A., 2013). (See Appendix A for a list of dairy commodities provided by OECD and its quantities produced in the world).

Basically, the concentration of milk proteins is divided into Casein and Serum protein known as Whey protein and is broadly applied in the food industry. Despite the Casein structure being dynamic and responding to environmental factors such as temperature, pH and pressure; those elements are essential to be considered in production process. Furthermore, the concentration of components is known as “total solids” or dry matter (DM) which is left when water is removed from the milk. This measure is extremely important in dairy industrialization due to the nature of the end-products. For example, a raw material concentrated on higher levels of fat can be applied to different product processes (*Dairy Processing Handbook*, 2017).

2.4.1. Dairy Market in Ireland

According to (*Board Bia - Irish Food Board*, 2015), the value of Irish food & drink exports reached 10.8 billion and the concentration in the UK and EU added up to 7.8 billion Euro during 2015. Dairy accounted around 3.24 billion worth of exports to the International markets and represents 30% of the total market of Drink and Food exports. The category accounts for 35% of total dairy exports with trade estimated at 1.15 billion in 2015 shown in Figure 2.2.

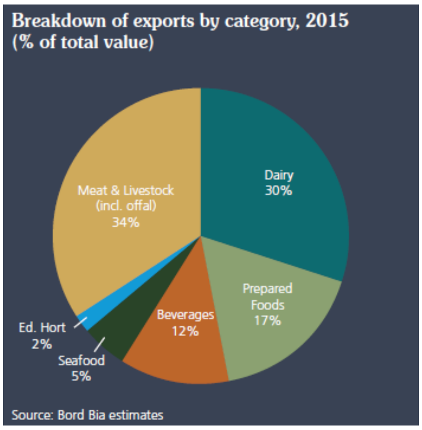

Figure 2.2 - Breakdown of exports by category, 2015

However, this increase in volumes might not reflect the increase in value. According to (*Food and Agriculture Organization of the United Nations*, 2015) Global agricultural commodity prices as measured by the FAO Food Price Index registered a reduction of 19% between January and December of 2015. A decrease in Dairy Prices Index can be observed between 2014 and 2016 in Table 2.2 where the prices during a 10 year period is demonstrated.

The price is market controlled and due to 41% of exports going to the UK and 28% to markets that predominantly trade in US dollars, any slight change in exchange rates affects the competitiveness of the entire sector. The competiveness of the Irish industrial sector is measured by Ireland’s Competitiveness Scorecard, where the ability of enterprises to compete successfully in international markets is measured (*National Competitiveness Council*, 2017). The challenges in improving the quantity and quality of labour, productive capital, and enhancing total factor productivity (through technological change, innovation and the application of competition policy) are significant.

Table 2.2
The Food Price Index and its composition

Date	Food Price Index	Meat Price Index	Dairy Price Index
2006	127.2	120.9	129.7
2007	161.4	130.8	219.1
2008	201.4	160.7	223.1
2009	160.3	141.3	148.6
2010	188.0	158.3	206.6
2011	229.9	183.3	229.5
2012	213.3	182.0	193.6
2013	209.8	184.1	242.7
2014	201.8	198.3	224.1
2015	164.0	168.1	160.3
2016	161.5	156.2	153.8
2017	175.1	159.8	193.6

The dairy supply faces several challenges not only on the volume of raw material, but the quality and milk composition due to the cow's diet, which directly increases the final cost. Moreover, the temperature required to keep milk safe is 4ºC, implying additional costs in refrigeration, especially in transportation (Quinlan *et al.*, 2012). Economic order strategy is difficult to apply due to the nature of the product, for this reason dairy supply relies on contracts between processors and farms. The schedule is established according to the processor's necessity and normally the milk collection occurs daily. The process starts when the raw milk arrives in insulated road tankers in order to keep it chilled, the intake volume is measured for recording and a reception quality test is required to guarantee the property of the milk. This operation can be manual or automatic and depends on the volume of the tankers to be controlled (*Dairy Processing Handbook*, 2017).

2.4.2. The storage of raw material

Raw milk is also known as a whole milk and is stored in large vertical tanks where the capacity depends on the manufacturer. There are two different categories of tanks (i) storage tanks and (ii) process tanks. Storage tanks are normally used in reception to provide the right flow to the production line. Silos are one type of storage tank, normally located outdoors to reduce impact on building and infrastructure costs. Intermediate storage to support the operation or WIP are used through smaller tanks, known as intermediate tanks or balance tanks, in order to create buffers between processes. The aim of these tanks is to balance the flow throughout the line and even guarantee the production flow during downtimes, for example (*Dairy Processing Handbook*, 2017).

Contrasting from grain silos, in dairy storage the silos must be equipped by level indicators and an agitator in order to prevent separation of milk components by gravity (*Dairy Processing Handbook*, 2017). Decisions regarding equipment will be determined by the volume desired to be processed and the financial resources available to justify the investment.

2.4.3. Industrialization Process

There are some aspects to be considered when a milk process line is designed according to different product requirements. The first step is the pasteurising and testing raw milk to assure it has been properly heated. The trade-off between time and temperature is an important issue within industries once higher temperature reduces time, and cycle-time, but can damage the structure of the milk. However, in companies where the pasteurization is not possible straightaway as soon as the milk is received, a process called thermization is applied to avoid bacterial growth (*Dairy Processing Handbook*, 2017). In terms of temperature the majority of equipment is manufactured using stainless steel due to heat transfer characteristics.

According to (*Dairy Processing Handbook*, 2017).There are three types of heat exchangers:

- Plate Heat Exchanger: Widely used in dairy process, the PHE consists of a pack of stainless steel plates clamped in a frame. The plates are corrugated in a patter designed to optimise temperature.
- Tubular heat exchanger: Has no contact points in the product channel and the fluid can have higher size particles compared to PHE and some types are suited to high pressure and temperature.
- Scraped-surface heat exchanger: Especially designed for products with higher viscosity and crystallization of products such as jams, dressing and chocolate.

In the past sedimentation by gravity technique was used to separate fat from milk. However, to increase productivity the use of separation by centrifugal force is essential in dairy process in order to separate solids from liquid. The milk enters into separated channels at the external edge of the disk and flows through the channels toward the axis of rotation leaving the vessel at the top (Spreer, 1998). The solids are separated and sent back along the undersides of the discs to the boundary of the clarifier bowl. This process is depicted in Figure 2.3.

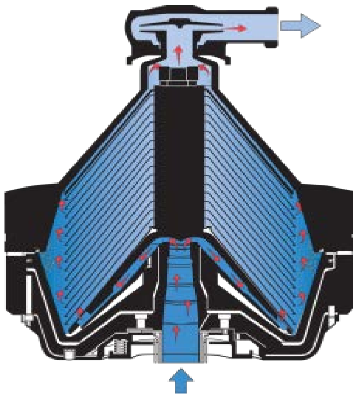

Figure 2.3 - Clarifier used for separation process

The main difference between a centrifugal clarifier and a separator is the design of the disk stack and the number of outlets, a clarifier has one and a separator has two there are differences in outlet performance of hermetic and paring-disc separators. The first one is able to create high pressure which increases the fat content to around 72% of globular fat (*Dairy Processing Handbook*, 2017).

After the separation of fat and proteins through a centrifugal separator, the standardization process is required to correct the level of fat in the milk, by addition of cream or skim milk in order to reach a given fat content (Spreer, 1998). This process is shown in Figure 2.4. Computerized systems combined with control valves are applied to correct the fat content to required levels.

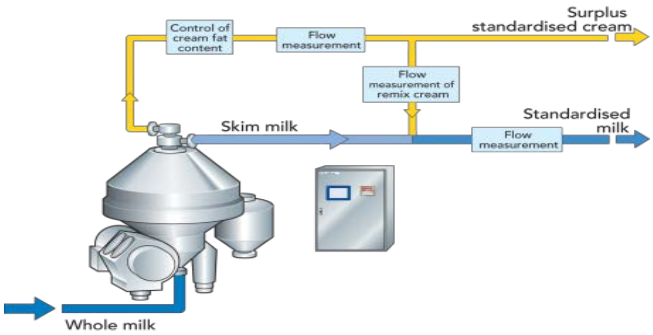

Figure 2.4 - Standardization process

The discharge system of a separator can be triggered automatically or manually and the sediment is removed though gravity or pumps.

Flow transmitters combined to control circuit are extensively used to control the flow of fluids. The flow control contains a microprocessor keeping a stable magnetic field, the voltage is amplified and transmitted to the control panel. Furthermore, there are specific types of products such as cheese, where the standardization must be done in order to control the proteins content and fat obtaining the perfect combination between fat low-high levels and proteins with different levels of concentration.

Decanters are another type of centrifuges applied especially to Casein, crystallized lactose and milk extracted from soybeans for example, due to the solid content. Additionally, it continuously operates to suspend solids from liquids through centrifugal force where the solid phase discharge (by gravity) (3) and the liquid phase discharge (2) followed by feed suspension (1), are shown in Figure 2.5.

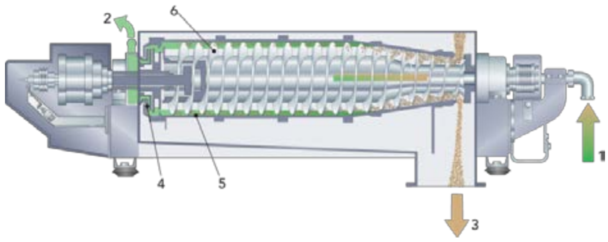

Figure 2.5 - Suspension of solids from liquids by decanting process

Homogenization breaks fat globes into smaller pieces diminishing creaming of the milk. The fluid passes through a small passage at high velocity where the globes are split. This process can enhance the milk's physical structure once the sensitivity to fat oxidation is reduced. Conversely, this process is not suitable for certain types of cheese. A homogenizer combined with high-pressure pumps is the equipment needed to operate when high-efficiency homogenization is required(Spreer, 1998). In the processing milk line, the homogenizer is normally positioned after the first regenerative section. Moreover, despite the high cost involved in this process, some companies homogenize part of the milk (*Dairy Processing Handbook*, 2017).

In the dairy processing, the separation of the milk is the most important process to obtain different types of products and in specific cases, the separation at molecular and ionic level has to be achieved. This separation is known as membrane technology and it relies on the particle size and molecular weight (Trevor Britz, 2008) :

- Reverse Osmosis (RO): the concentration is obtained through water removal, generally applied to dehydration of milk, such as whey and condensate.
- Nanofiltration (NF): Also known as partial demineralization, the concentration is obtained through removal of chlorine and sodium, UF permeate, for example.
- Ultrafiltration(UF): the concentration of large molecules, such as proteins, widely applied to the yoghurt and cheese separation process
- Microfiltration (MF): removal of bacteria, widely applied to skimmed milk, such as whey and brine.

The capacity of separation is impacted by the membrane resistance when a formation of layer increases the resistance of the flow. The fouling effect is a common consequence of gradual accumulation of components over the surface reducing the output capacity. After reaching a perfect level of separation, evaporation process is required for some specific products such as whole milk and whey, in order to improve the dryer's efficiency.

The energy consumption required to remove water from a solution is high and to minimize this effect, the evaporators are designed to operate with multiple-effects which can reduce the consumption of vapour in this process. There are different types of evaporators applied to different processes:

- Circulation evaporators, for example, are used when a low degree of concentration is required or when small quantities of product are processed. It is most common in yoghurt processing where part of the product is recirculated by a centrifugal pump to a heat exchanger in order to adjust the temperature, and return to another evaporation cycle, this process is continually repeated until the desired level of concentration is achieved.
- Plate-type evaporators use pipes along the plate pack where the product is sprayed in the thin surface. The water is evaporated and the vapour is separated from the concentrated liquid through a cyclone separator.
- Tubular evaporators are the most common used in dairy process. Vertical tubes are normally found where the product flows downward on the inner surface of the tubes and the heating steam condenses on the outer surface of the tubes.

In pre-concentrators systems, the calandria is divided between 4 and 6 sections where the product is pumped and distributed into internal tubes. The volume of the product is reduced by the evaporation of water during the down flow. At the bottom end of the section, the vapour evolved is removed and the product is collected and sent to the next section of the calandria. The concentration is increased once the product passes through each transfer. This structure allows substances such as whey, to be concentrated from 6% to 32% of solids.

Multiple-effect evaporators are widely used due to the fact that two evaporators in the series are much more efficient because of the second effect is able to operate at a higher vacuum condition and at a lower temperature. The total volume of product in the evaporator system increases due to the number of effects connected in the series (A. Varnam, 2001).

Thermal vapour recompression (TVR) is a system where the vapour from the process is compressed and recycled as a heating medium. The compressor uses the high steam pressure to increase the Kinect energy and the steam is ejected at high speed from the nozzle. A thermocompressor combined with a multiple-effect unit optimizes the energy balance (A. Varnam, 2001).

The mechanical vapour recompression (MVR) sends all the vapour out of the evaporator and compresses it before returning it to the heating side of the evaporator. Using an evaporator with mechanical vapour recompression can halve the operating costs compared to a conventional six-effect evaporator with a thermocompressor (A. Varnam, 2001) (*Dairy Processing Handbook*, 2017). A process for a tubular falling-film evaporator with mechanical recompression is shown in Figure 2.6 where the balance tank (1) sends the milk to a PHE(2) followed by tubular heaters (3). The milk heated is sent to the calandria (4) where the vapour and the condensed substance are separated (5) the MVR (6) combined with circulation pumps (7) and vacuum pumps (8) complement the evaporation system.

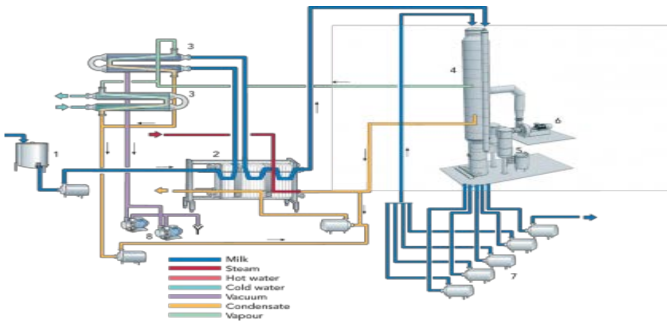

Figure 2.6 - Evaporation process

In order to control de fluid flow throughout the line the use of pumps is essential considering the fact that is more productive compared to a plant operating by gravity. Furthermore, the balance between equipment is no longer achieve without pumps and valve controls. Additionally, high pressure flow also must be controlled. The types of pumps and valves rely on flow characteristic such as: viscosity, density, temperature, pressure and the flow rate. The most common pumps are centrifugal, positive displacement pumps, and liquid-ring. The last one is widely applied to the cleaning process (*Dairy Processing Handbook*, 2017).

Air is an important issue to be addressed in milk production, especially because of its impact of the evaporation process. The presence of the air in milk is 6% approximately and can lead to different causes such as: inaccuracy in volumetric measurement, fouling, reduction efficiency in separators. To reduce the impact of the air in milk deaerators are required to remove the air from the process line. (*Dairy Processing Handbook*, 2017).

2.4.4. Dairy Products

Milk and dairy products have been consumed for thousands of years as a wholesome staple diet in many cultures around the world. They provide the necessary nutritional, functional and physiological values to maintain health and wellbeing of the human body.

Apart from their health benefits, dairy products are also recognised economically as an agricultural commodity and an essential commercial driver, especially in industrialised developed countries. The dairy industry is an important sector within the food industry, the most dynamic and with the highest gross input. Milk is composed of water, fat, proteins (mainly Casein micelles and whey proteins), carbohydrates (mainly lactose) and quantitatively minor bioactive components: minerals, vitamins and enzymes (Jesen, 1995). It contains two major protein types: Casein and Whey Protein. Milk proteins have received increasing attention as potential ingredients of health-promoting functional foods targeted at diet-related chronic diseases such as cardiovascular disease, diabetes type 2 and obesity.

i. Whey: Apart from their health benefits, dairy products are also recognised economically as an agricultural commodity and an essential commercial driver, especially in industrialised developed countries. The dairy industry is an important sector within the food industry, the most dynamic and with the highest gross input. Milk is composed of water, fat, proteins (mainly Casein micelles and whey proteins), carbohydrates (mainly lactose) and quantitatively minor bioactive components: minerals, vitamins and enzymes (Jesen, 1995). It contains two major protein types: Casein and Whey Protein. Milk proteins have received increasing attention as potential ingredients of health-promoting functional foods targeted at diet-related chronic diseases such as cardiovascular disease, diabetes type 2 and obesity.

ii. Casein: Casein (from the Latin word caseus for cheese) is the main proteinaceous component of milk, where it accounts for 80% of the total protein inventory. The amount of Casein in cow's whole milk varies according to the breed of cow and stage of lactation, but is generally in the range 24 – 29 gr per litre. Casein may therefore be considered as a highly nutritious protein.

iii. Caseinate: Caseinate may be produced from Acid Casein curd or from dry Acid Casein by reaction under aqueous conditions with anyone of several different dilute alkalis, as outlined in Figure 2.7. The resulting homogeneous Caseinate solution may be dried by the spray or roller process to produce a Caseinate powder having a moisture content of 3-8 per cent, depending on the manufacturer and customer requirements. Raw materials in Casein manufacturing countries, it is common practice to prepare sodium Caseinate from fresh Acid Casein curd since it is considered to be blander in flavour than sodium Caseinate made from dried Casein (Cayen, M. N. and Baker, 1963) (Burston, D.O., Muller, L. L. and Hayes, 1967). Sodium Caseinate prepared from dry Casein will also incur the additional manufacturing costs associated with drying, dry processing, bagging and storage of the Casein before its conversion to sodium Caseinate. The most common alkali used in the production of sodium Caseinate is sodium hydroxide solution, with strength of 2.5M.

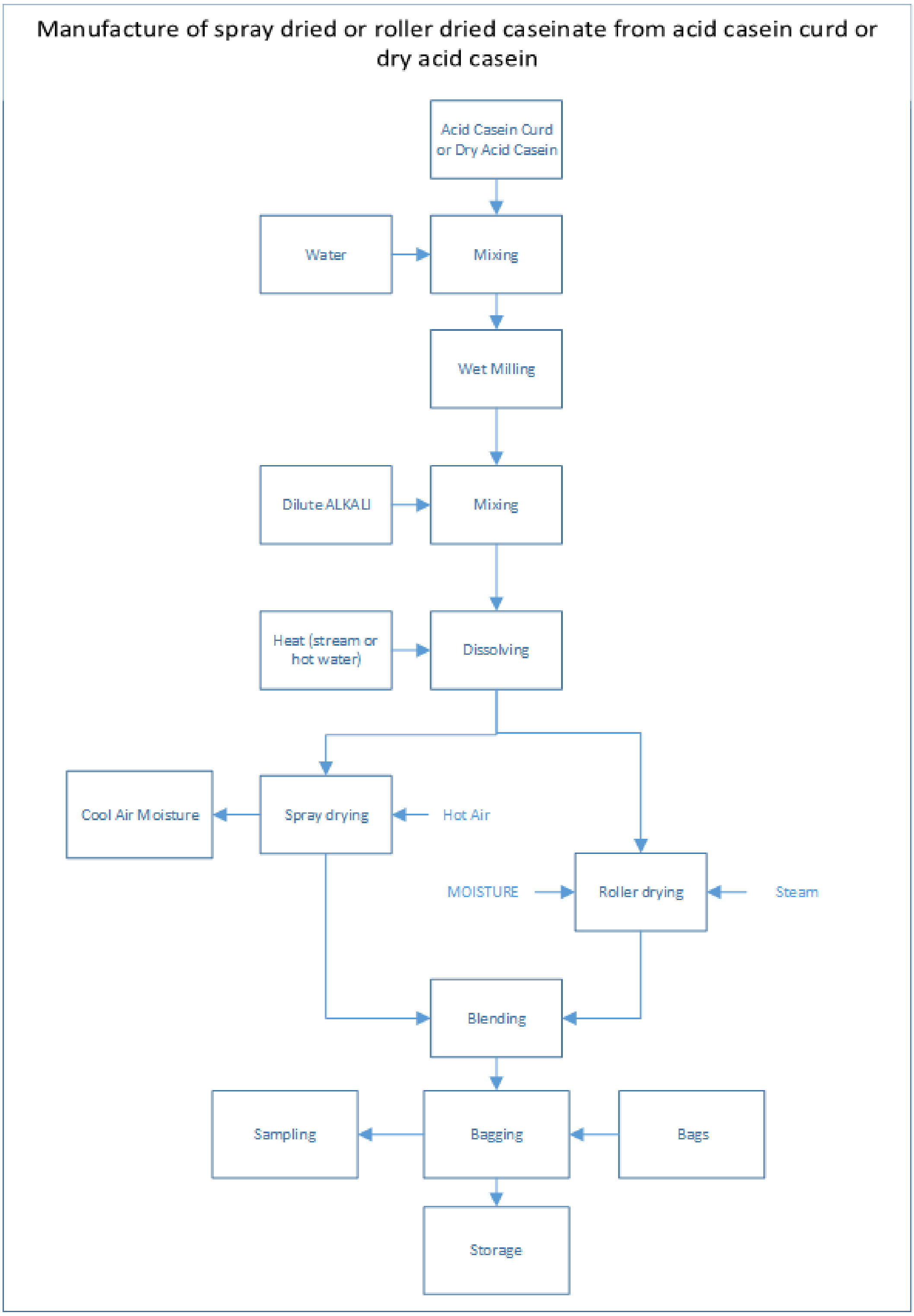

Figure 2.7 – Manufacture of spray dried or roller dried Caseinate from Acid Casein curd or dry Acid Casein

Apart from their health benefits, dairy products are also recognised economically as an agricultural commodity and an essential commercial driver, especially in industrialised developed countries. The dairy industry is an important sector within the food industry, the most dynamic and with the highest gross input. Milk is composed of water, fat, proteins (mainly Casein micelles and whey proteins), carbohydrates (mainly lactose) and quantitatively minor bioactive components: minerals, vitamins and enzymes (Jesen, 1995). It contains two major protein types: Casein and Whey Protein. Milk proteins have received increasing attention as potential ingredients of health-promoting functional foods targeted at diet-related chronic diseases such as cardiovascular disease, diabetes type 2 and obesity.

2.5. Modelling and Simulation

Simulation is defined by (Law and Kelton, 1991) as a model created to represent a system at a specific moment according to the objectives of a given study in order to interact in an indirect and simplified way simulating the operations process in the real world through a computer. Complementing this concept (Kheir, 1996) defines as a process which the understanding of the behaviour of a physical existed system is attained through the representative model.

In the field of operational research, the simulation of systems is an important tool that allows performing experiments that, for different reasons, are not feasible in a real system where the solution of problems is not possible from analytical means (Costa, 2002). This assertion finds ratification (Law and Kelton, 1991), which confirm that "as a technique, simulation is one of the most widely used in operational research and management science".

An analytical solution is possible when the use of mathematical methods (algebra, calculus, probability) is sufficient to obtain accurate information in system models whose relations that compose them are very simple. However, the real system models are usually very complex, which makes the need for simulation emerge, considering the impossibility of analytical solution for these systems, since the mathematical models valid for this complexity are also complex (Law and Kelton, 1991) .

Additionally, (Kheir, 1996) also states that the model development involves the construction of a logical-mathematical representation of the system and the preparation of a specialized computer program allowing the system imitation behaviour. Once the model is validated the next step relies on the experimentation phase evaluating the response according to the inputs provided.

The role of computer simulation for systems analysis is stated by (Zeigler, Praehofer and Kim, 2000), in a context of modelling and simulation, since it allows the generation of data resulting from indications presented by a model, which may present peculiarities previously unknown, even not bringing forth any new knowledge.

A model, however, no matter how complex or whatever the situation may be, is merely a representation of reality, "a reflection of the modeller’s understanding of reality, its components, and its interrelations" (Kheir, 1996) and should never be confused with it. In this sense, the system modeller has complete freedom to determine the way in which data will circulate through the channels that make up that system, which data can be presented in the form of information, physical forces and fields, material flows and/or (Zeigler, Praehofer and Kim, 2000).

According to (Law and Kelton, 1991; Kheir, 1996), systems can be categorized as discrete or continuous, and a discrete system is one in which the variables involved in the study undergo instantaneous changes at specific times of time, whereas in a continuous system these variables undergo continuous changes over time. However, there are systems that are not completely discrete or continuous, raising the need for the formulation of a discrete-continuous simulation model, in which there is a combination of aspects of both systems.

In this sense, Computational Simulation can be characterized, according to (PIDD, 1998), by three different types of approaches; simulation by discrete events, continuous simulation and a combination of the two.

As (Kheir, 1996) states, "in a discrete-time system, the variables change only in distinct (finite) instants of time (such as per hour, daily or quarterly)." In this model, it is possible to have state transition functions that allow the use of information from a next state, from a current state, observed at the input (Zeigler, Praehofer and Kim, 2000). Concerning continuous simulation, (Law and Kelton, 1991) reiterate that the state variables change continuously according to time. Involving differential equations related to state change rates, varying over time.

With this, despite the presentation of some disadvantages - the costs and the time expenditure for the formulation of a simulation model; the need for several simulations for each set of parameters to be analysed; the analysts' overestimation of the numbers presented in each simulation process; the consequent need for specialized training and skill of the modeller, so that the study presents effective results, since a model presents only results from the parameters previously defined by the modeller (Torga, 2007).

Simulation is a process that allows the visualization of probable results in different environments and contexts incorporating uncertainties defined by probabilities and it is being popular in the decision-making process. It has widely been applied in different sectors presenting itself as an important tool for the administrators in their companies. In the specific case of this work, the combination between continuous and discrete events will be explored.

2.6. SCOR model

The Supply Chain Operations Reference (SCOR) was introduced in 1996 and has been endorsed by the Supply Chain Council (SCC), a global organisation interested in SCM. This model is being adopted by many business companies throughout the world in order to standardize supply chain process. The SCOR model is based on five general processes: Plan, Source, Make, Deliver and Return. The SCOR modelling approach relies on the assumption that any supply chain can be represented by 5 basic processes (APICS, 2017):

- Plan: it balances the demand and supply to best meet the sourcing, production, and delivery requirements.
- Source: procures goods and services to meet planned or actual demand.
- Process: includes functions that transform goods to a finished state to meet planned or actual demand.
- Deliver: provides finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.
- Return: is associated with returning or receiving returned products.

Figure 2.8 depicts SCOR management processes and the relationship between Suppliers and Customers.

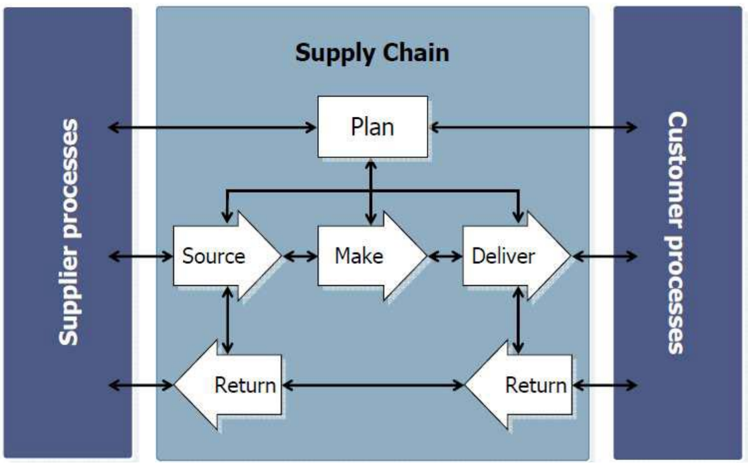

Figure 2.8 - SCOR management processes

Despite the fact that the SCOR model supports static supply chain operations, the application of simulation is useful in order to incorporate dynamic effects that might represent real conditions. In (Persson *et al.*, 2012) an integration between SCOR and discrete event simulation (DES) was developed using the enterprise package Arena®. An object-oriented process model using e-SCOR was developed based on SCOR and layered upon a discrete event simulator in (Longo and Mirabelli, 2008) where the elimination of one distributor in the supply chain was required due to the introduction of the web channel. A model based on SCOR representing the dynamics of market networks in a single auction and bidding strategy environment was designed by (Rabelo *et al.*, 2007) and the main objective was to calculate the equilibrium price in every market of an SC where the companies were represented as agents and a simulation was performed comparing the result between one and two markets. In (Pierreval, Bruniaux and Caux, 2007) an integration of continuous simulation models combined with SCOR was conducted by a hybrid simulation framework to support decision makers incorporating qualitative criteria such as political issues.

2.7. Modelling and Simulation applied to Dairy Supply Chain

In this section, the application of Modelling and Simulation to Dairy Supply Chain will be described. Even though in the literature several applications in operational level were found, the findings are significantly applicable as insights for strategic decisions.

The concentration of researches regarding simulation applied to the Dairy Supply Chain is distributed from 2003 and 2016 where 20 papers were selected as shown in Figure 2.9. From 2012 to 2014 the concentration of papers are related to sequencing of production lines in the Dairy environment.

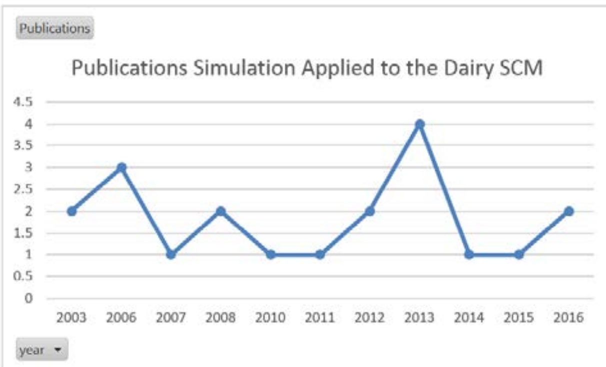

Figure 2.9 - Researches concentrated on Simulation applied to the Dairy Supply Chain

A Case Study was conducted by (ABED, 2008) where a discrete-event simulation (DES) model was developed through Arena® package to analyse the effects of each activity in the dairy process such as the mixing of raw material throughout the packing of the final product. Additionally, seven scenarios were produced and compared in order to propose an optimum solution. A simulation and optimisation-based decision support tool was developed between two factories and the integration of a large quantity of milk suppliers and the uncertainty in demand (Li, Zhang and Jiang, 2008).

The incorporation of sustainable aspects of SCM is adopted by (Sonesson and Analysis, 2001) through Life Cycle Assessment (LCA) and five approaches were explored in the flow of material. The model consists of the integration of transportation among farms, dairies, distributors, retails and households and aspects of packing, energy utilization, water and waste. Furthermore, the use of resources such as wood for paper production and pallets; and oil for plastic packaging production was explored. LCA was also explored by (Nutter *et al.*, 2013) to evaluate the global warming potential related to USA milk processing. The model evaluated the GHG emission per kg of packaged milk. However, the results are not considering other products in the dairy industry such as milk powder or Casein where the electricity required processing these products is high.

The application of Modelling and Simulation to evaluate specific energy consumption (SEC) and greenhouse gas emission was used in the fluid milk process combining capital cost assessment of different types of heat treatment such as: HTST Pasteurization, UHT Processing, Crossflow MF without Pasteurization, Crossflow MF followed by HSTS Pasteurisation, Partial Homogenisation and their impact on sustainability was conducted by (Tomasula *et al.*, 2014).

Quality-control and moral hazard were modelled by (Yun-xian and Xian-glin, 2010) considering the quality approach of the milk's depots and the processors. Effects such as additional compensation for customers, incoming inspection and independent investigation systems were evaluated in order to increase their quality to the final customers.

A centralized management optimisation in (Bei, Jie and Jian, 2006) proposes a simulation method using General Algebraic Modelling System (GAMS) comparing strategic decisions about centralization and decentralization and its impact on the supply chain network. An optimisation model applying (GAMS) combined with Microsoft Excel® to evaluate the cost of seasonality in Ireland was proposed by (Heinschink, Shalloo and Wallace, 2016). Due to the fact that milk production relies mainly on grass-based and the effect of extra processing capacities required during the peak season is high. A financial analysis suggested changes in supply from a seasonal to a smother patter.

An optimisation model was conducted considering the supply chain design for agricultural and fresh products was conducted by (Yu-Chung, 2013). Even though the model do is not designed for dairy, fresh food are challenging and risky operations due to the perishable nature of this products and must be kept at low temperature similar to the majority of dairy products. The model calculates the components of the total network composed for farmers, agricultural produce-marketing corporations and retailers.

Freshness in explored also by (Amorim, Günther and Almada-Lobo, 2012) applying mixed-integer linear programing in products (MILP) with fixed shelf-life and loose shelf-live. A multi-objective integrated production and distribution planned of perishable product was modelled considering maximizing the freshness of the products delivered to the distributors' centres and minimizing the costs related to the supply chain operation. Risk in production planning of perishable good was also studied by (Fioroni *et al.*, 2013) in a model to minimize risk of spoilage and revenue losses at the operational level. Sequencing applying MILP to optimising the production scheduling of fresh yoghurt was conducted by (Doganis and Sarimveis, 2007) minimizing the cost of production in different lines of production and also by (Bilgen and Çelebi, 2013)combining MILP and simulation in a hybrid model using Arena® package.

An economic approach was studied in (Guan and Philpott, 2011) describing the effects of contracts arranged several months in anticipation, especially the price-demand curve. A multistage stochastic programming model in a Dairy Company was conducted in this research. A payment system to compensate farmers for delivering quality goods dairy is proposed by (Fuentes *et al.*, 2016) where a spreadsheet decision support tool was designed to calculate the profit based on suppliers' milk quality.

A model to represent the current condition between dairy companies and rural producers was conducted using System Dynamics (SD) by (Bijman and Hendrikse, 2003). The model proposed a reduction of cost over time through better performance in quality and quantity metrics. Therefore, costs that are not value-added activities should be minimized to increase the performance of the total system. SD was also applied by (Reiner, Gold and Hahn, 2015) through a model to explore the effects of appropriated pricing strategy for wealth generation and health improvement at the Base of Pyramid (BoP). The research proposed insights to find the best price and decisions regarding distributions of dairy products in Bangladesh.

In addition, a simulation model applied to the dairy supply chain decisions was conducted by (Prost, González and Urbicain, 2006) comparing single effect vertical falling film evaporator in order to obtain a general correlation for the calculation of the liquid side heat transfer coefficient previously studied. Multiple effect evaporator is widely applied and in dairy industrial process and the variables applied in thermodynamic of juice evaporation process referred in this paper is also applied in milk evaporation due to the similar physical condition and objective, removing the water from the fluid promoting its concentration.

A study to estimate the milk transport costs and carbon emissions from milk transport associated with alternative milk supply patterns and output levels in Ireland was conducted by (Quinlan *et al.*, 2012) whereby a milk transport simulation model was used to simulate three alternative milk supply patterns and its effect on carbon emissions.

The papers are classified into three decision levels as depicted in Table 2.3. Simulation models are widely applied at the operational and the tactical levels. Operational simulation approach is used for sequencing activities, understand the variability of each operation and its impact on the entire process. At the tactical most research are concentrated on planning activities considering external elements in their model such as suppliers and demand behaviour in order to minimise the impact in their process. At the strategic level, two researches explore the effects of sustainability and long-term decision.

Table 2.3
Research concentrated on Simulation applied to the Dairy Supply Chain

Authors	Decision Level	Total
(Tomasula *et al.*, 2014) (Doganis and Sarimveis, 2007)(Fioroni *et al.*, 2013)(Quinlan *et al.*, 2012)(ABED, 2008)(Prost, González and Urbicain, 2006)(Amorim, Günther and Almada-Lobo, 2012)	Operational	7
(Bei, Jie and Jian, 2006; Xue, Wang and Shen, 2007; Guan and Philpott, 2011; Bilgen and Çelebi, 2013; Yu-Chung, 2013; Fuentes *et al.*, 2016)(Li and Jiang, 2012) [105]	Tactical	8
(Sonesson and Analysis, 2001; Hovelaque, Cordier and Rennes, 2006; Reiner, Gold and Hahn, 2015; Heinschink, Shalloo and Wallace, 2016)(Nutter *et al.*, 2013)	Strategic	5

Chapter 3

METHODOLOGY

3.1. Research Methodology

The challenge in the Dairy Industry is to synchronise aspects of pull and push methodology. Even though pull system is followed in the long-term period, once the production is based on contracts previously established by customers, in the short-term period, aspects of push system are more common and visible due to the fact that the raw material must be processed as soon as it arrives in the reception area.

Conversely from assembly lines where different products can be processed by multi routings, in the dairy environment the raw milk received starts a continuous process until the final product is produced.

Moreover, the increasing in capacity in an assembly line can be achieved through the bottlenecks management, in the dairy process, the whole line must be changed in order to support final yield increased. Equipment in general requires a high level of capital investment and in many cases collaboration between companies is used as strategy to temporary increase the capacity.

To achieve the research aim, two different models were built to support the decision-making process regarding Casein and Caseinate production. The proposed solution applied Discrete Event Simulation to evaluate potential improvements for the current scenario, Data Analysis and Design of Experiments (DOE) to compare all the results from each experiment conducted. Furthermore, the aspects of CONWIP to support the work authorisation and flow of material were also described in detail. A comparison between assembly lines methods applied do manufacturing process and the particularities of dairy industry are highlighted combined with an overview to the applied research tools is detailed in the following sections.

3.2. Dairy Industry Case Study

3.2.1. Industrial Partner Case Study

In this case study, the industrial partner is an intermediate milk processor in the Dairy Supply Chain, and the final product is used as a raw material for other companies and processors.

Most of their products are negotiated by contracts which are arranged in advance of production. After the contracts have been made, the production in the months may be lower than what has been forecast compromising their deliveries.

The company faces many challenge including the ERP gap and a lack of business planning software to optimise their operations. The records available refer to the output produced and temperature registered provided by equipment and due to government requirements. Through this output it was possible to compare and validate records of the designed model. Another challenge faced was with regard to the unplanned breakdowns which are controlled in spreadsheets and the level of possible misguided accuracy.

The structure of the dairy case presented is validated by means of: (i) interviewing the operator to understand the production of Acid Casein / Caseinate and Whey in a dairy processor in Ireland, (ii) mapping the process, (iii) visiting the production line, (iv) validating the strategy with the strategic board (v) using company profiles, technical reports available from dairy, (vi) researching lasted outcomes literature focused on dairy SC, (vii) evaluating documentaries related to dairy available on the internet, and extending researches to SC text books.

The production flow is depicted through Figure 3.1. The raw material is received and separated into other branches of processing, the processes are aggregated in order to simplify the current production structure. Process 1.1 is responsible for generate a by-product of Acid Casein referred as Whey. Special attention to Process 2.2 where the waste is generated and is processed by the effluent treatment plant and packaging area responsible for finished goods unitisation and palletisation.

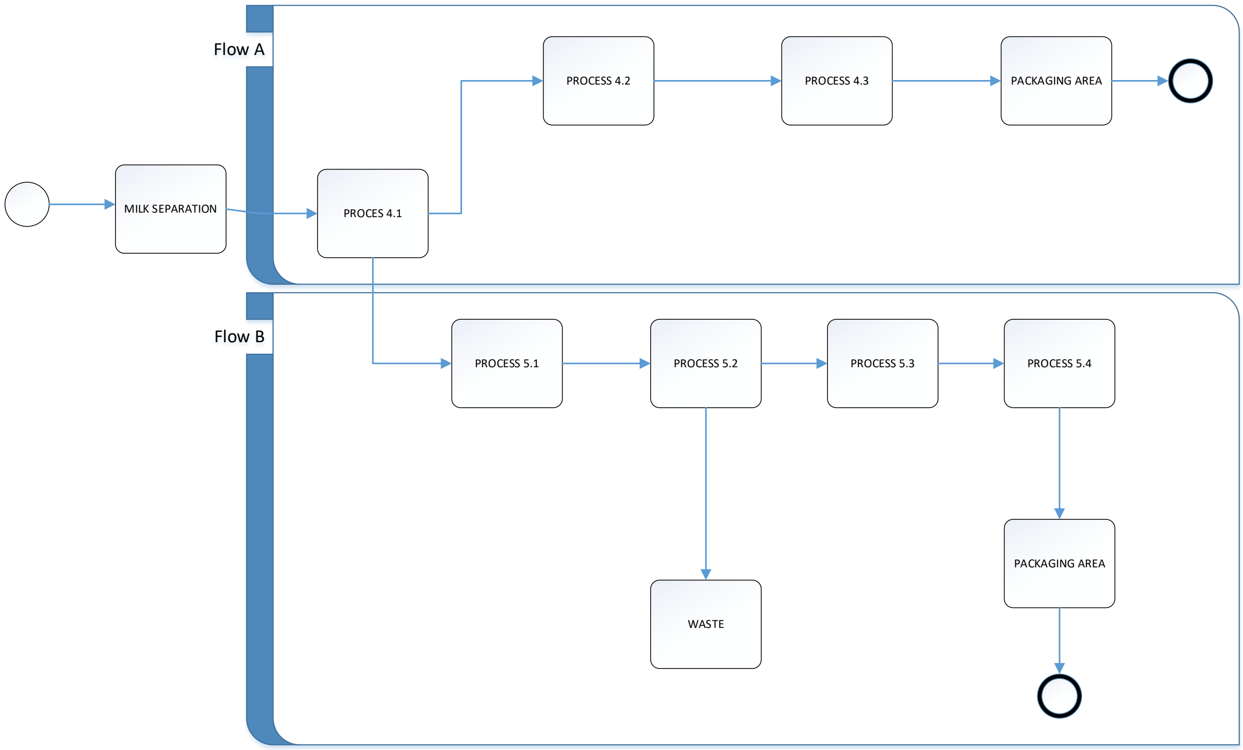

Figure 3.1 – Industrial Partner – Process Mapping

The flow A can be divided into two branches called Casein and Caseinate. According to (Sarode *et al.*, 2016), the Caseinate is widely applied in food products as a source of protein and can be manufactured in two ways:

(i) Precipitated Acid Casein curd where the curd can be divided into two branches: Casein and/or Caseinate immediately after the separation and clarification process;

(ii) From dried Acid Casein where before the Caseinate manufacture, the Casein can be storage in silos;

The flow B represents the by-product from Acid Casein which is Whey. Whey is not involve at the data analyse of this present thesis.

3.2.2. Simulation Model Developed

Discrete Event Simulation (DES) is widely applied to decision-making processes providing insights through what-if analyses to evaluate different strategies and scenarios, permitting the comparison of various operational alternatives to support better strategic decisions.

A discrete rate simulation combined with DES model was developed to represent the real process in the industrial partner. Process such as milk reception for example where the reception and separation of the milk occurs daily in order to produce different branches of products were considered.

The initial objective was to identify the bottlenecks and increase the capacity of Casein / Caseinate maximising the profitability in Dairy Supply chain in addition to satisfying the customer's demand. Thus, an increase in the Casein / Caseinate production was explored as experimental methodology; however, some important issues were considered due to direct impact on the product output.

Due to the high level of WIP in the middle of the process, the model built followed by unplanned breakdowns and the current rate and flow in each process. Despite the fact that Whey is a by-product of Casein / Caseinate, the model had to consider both products and their impact on each other.

In order to provide a good approximation of produced and simulated quantities, the model was built do consider the level of uncertainty required in the real world. There are three main causes of disruptions identified in the production line: (i) planned CIP process, (ii) unplanned downtimes, and (iii) excess of WIP. For this reason, this three causes were modelled using stochastics and deterministic models based on real data previously collected:

(i) Because of the fact that CIP times ranges are known, a triangular distribution was applied to simulate the CIP times with limited ranges based on real process;
(ii) Different causes of unplanned breakdowns were evaluated and could occur in different part of the production process. Thus, to deal with this range of possibilities, the unplanned downtimes were placed in three main areas. Moreover, the historical data was analysed using the StatFit® tool to identify which distribution would best represent these stops. Weibull and Exponential distributions were applied to deal with these type of disruptions;
(iii) To identify the stops caused by excess of WIP, the silos level were modelled with indicators and the flow may have been interrupted due to an excess of product. In this case, a deterministic model was applied to identity the possibility of a disruption and a signal was sent to the initial operations.

In the first version, the model was designed to deal with two branches of products carrying different production flows. Casein / Caseinate and Whey were developed first in order to guarantee the model accuracy and its results. The Appendix C depicts the model developed through the commercial package ExtendSim® and the two branches represent the industrial partner process.

The model was designed to simulate the same operation in the Industrial Partner processing which means that the milk is supplied hourly during the peak seasonality period. Additionally, after the transformation both products are packaged to be delivered. The efficiency in the packaging area is directly impacts the production flow. For instance, if any long unplanned breakdowns occur, the end product inside the silos cannot be removed disrupting the production flow.

ExtendSim® was performed to conduct the simulation experiments according to the designed flow. For all conducted experiments: (i) simulation run-length was 5040 period representing the peak season in the dairy industrial partner, (ii) the warm-up period was not required due to nature of the process which starts on March are extends to October , (iii) an average of 20 replications were considered.

3.2.3.Model Validation

After the execution of one complete period of production, the average of the all replications of Casein / Caseinate and Whey were calculated and compared to samples took from the existent records. Through IBM SPSS®, RStudio and Microsoft Excel the yield produced monthly recorded in the dataset created by ExtendSim® were examined. The comparison and the results produced by the model create will be explore as follows.

3.2.3.1. Time series

The real and simulation quantities demonstrated in a time-series graph in order to visually compare the data produced over an extended period of time. Through Figure 3.2 the time-series simulation and real production can be easily observed in the Casein / Caseinate pattern. Even though the variability and uncertainties were incorporated in the model, the simulated output produced a small range of disparity compared to the real production. The use of other tools is required to investigate the impact of this result.

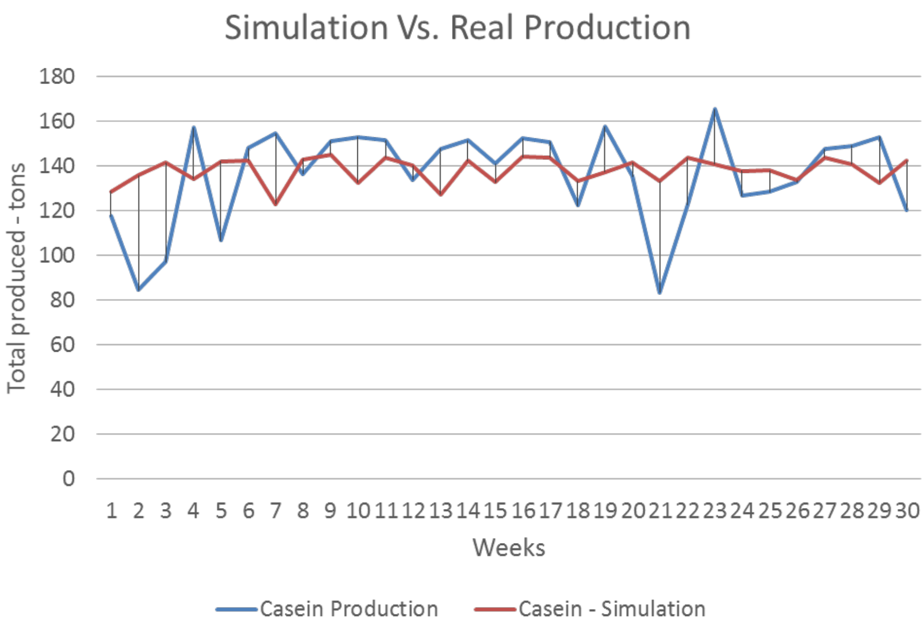

Figure 3.2 – Time-series graph - Comparison between Production and Simulation

3.2.3.2. Boxplot Whiskers

The graph presented in Figure 3.3 depicts the behaviour of Casein / Caseinate and Whey comparing the production and simulation results through boxplot which are an important data representation of central value. It is possible to observe the records or points which are clustered around the simulated mean in Casein / Caseinate and followed by two outliers. The discrepancy between lowest and highest limits is minor compared to Casein / Caseinate real production. On the other hand, Whey represents similar behaviour compared to Whey real production. To evaluate significant differences between these one measure T-test will be described in the next topic.

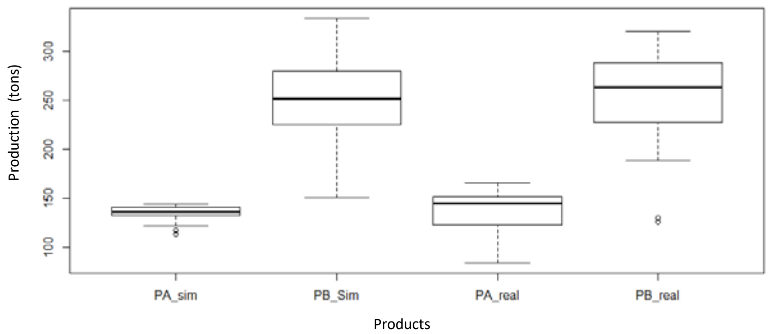

Figure 3.3 – Boxplot Whiskers - Comparison between Production and Simulation

3.2.3.3. Independent-samples t-test

The independent-samples t-test was conducted to compare the two unrelated groups of variables (real produced and simulated). For Casein, there was not a significant difference in the scores for real produced (M= 136.11 SD=21.48) and simulated (M=137.78, SD=5.92) conditions; t (30) =-0.441, p =0.683. In this case the value of t (30) is negative, because the average of total production simulated is higher than the average of total real production. Considering the null hypothesis where both means for simulated and real should be the same. At the 0.05 level of significance, there is no strong evidence to conclude that the two samples are different. Because p-value exceeds 0.05 the null hypothesis cannot be reject.

For Whey, considering the correlation between Casein production, there was not a significant difference in the scores for real produced (M= 252.66 SD=47.68) and simulated (M=247.91, SD=34.88) conditions; t (30) =0.441, p =0.661. In this case the value of t (30) is positive, because the average of total real production is higher than the average of total production simulated. Also considering the null hypothesis where both means for simulated and real should be the same. At the 0.05 level of significance, there is no strong evidence to conclude that the two samples are different. Because p-value exceeds 0.05 the null hypothesis cannot be reject.

Considering Whey is the by-product of Casein the values of p are the same (p=0.661) and they are higher than α (α=0.05). The conclusion is, in both testes for the real production of whey and casein, there were not significant difference for simulated production (p> α) validating the model.

3.2.3.4. Histogram of disruptions

A histogram is a reasonable measure of frequency and followed by a normal bell shape suggests a good visualisation of the data distribution and concentration around the mean. Considering that all the statistical analysis to compare the output of real production and simulation were satisfied a histogram depicts through Figure 3.4 the distribution of waste produced with a positive skewness and the total disruption caused by excess of WIP with a negative skewness. The experiments conducted in the next section considered the possibility to reduce the disruption caused by excess of production flow.

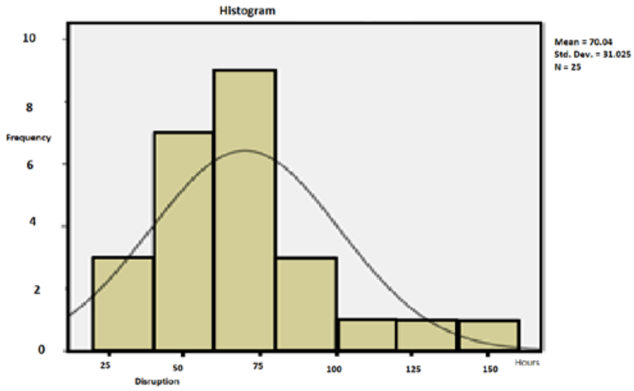

Figure 3.4 – Histogram of Disruptions

3.2.4. Description of the Changed Models

In this first version only two products are being produced and no improvements were made. The model was previously validated considering the real conditions of the current production. In the real world capital investment to increase the production is required. For this reason, the model was extended into two new versions in order to support the decision making process through what-if analysis.

Two different versions were created to compare the performance in the Casein and Caseinate process. In both versions the disruption in the by-product processed was minimized due to the fact the main products (Casein and Caseinate) are most valuable and profitable during the peak season.

According to (*Dairy Processing Handbook*, 2017), the sodium Caseinate is composed by sodium hydroxide (NaOH) due to the cost compared to other types such as sodium phosphates for example. (Sarode *et al.*, 2016) states the Caseinate can be produced from freshly precipitated Acid Casein curd or from dried Acid Casein. Both processes will be described and compared as follows.

3.2.4.1. Caseinate processed from curd production

(Sarode *et al.*, 2016) states that this process is widely applied in the dairy environment due to the fact that the curd, which is a production in process, is the raw material for Caseinate. As soon as the milk processed reacts with the acid, the curd is can be transformed into Casein or Caseinate according to the production plan previously defined. This process is mostly used due to the fact that no additional cost of drying is required once the Caseinate that is produced can be stored in silos to be packaged. In this process, production plan certainty is essential for products that are manufactured to supply a known demand normally established by contracts.

The Caseinate produced from curd is given in Figure 3.5 where the fresh curd is sent to a second branch to be processed, dried and further bagged.

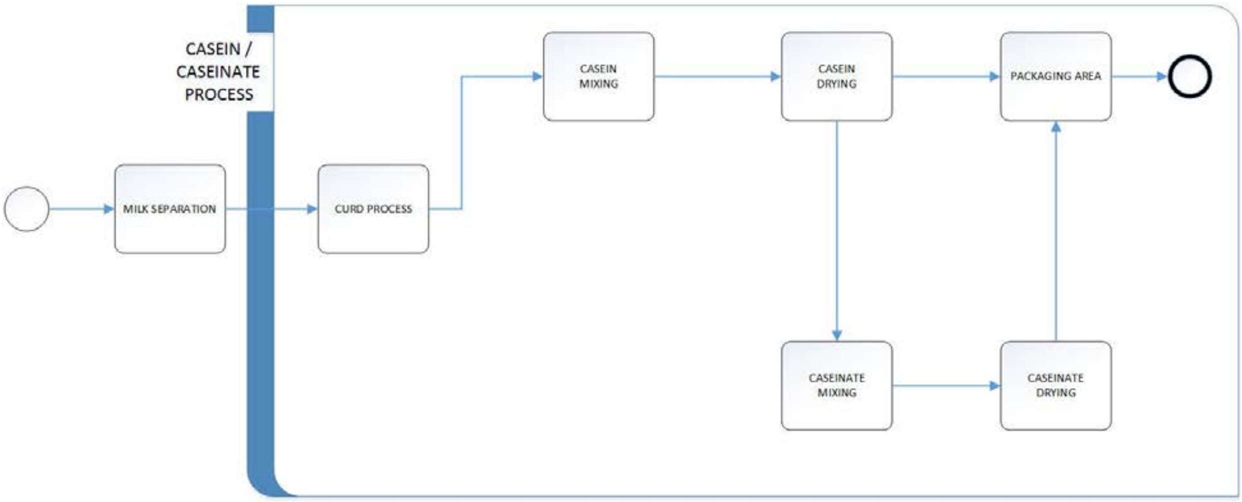

Figure 3.5 – Caseinate production from fresh curd

The Caseinate produced from curd is washed and dewatered to concentrate around 50% of the total solids before being processed by a colloid mill with controlled temperature and PH in order to reduce the viscosity dissolution resistance. The viscosity can highly affect the production flow of Caseinate and because of that, a precautious procedure to keep Caseinate solution stable is essential.

The drying process is the most expensive activity in the Caseinate production and all the requirements regarding viscosity, temperature can affect the time and energy required to produce the final product.

Dedicated silos are required to separately store Casein and Caseinate and the packaging area could be dedicated or shared between both products. The model developed to reproduce the behaviour of Caseinate produced from curd is given in Figure 3.6.

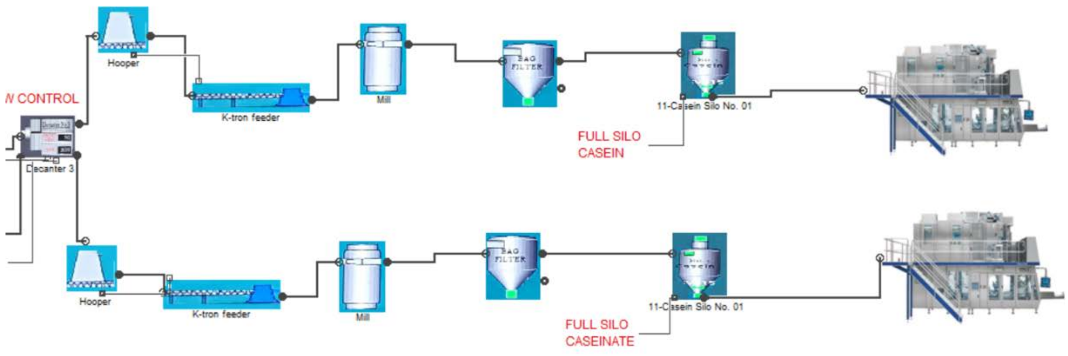

Figure 3.6 – Simulation Model - Caseinate production curd

3.2.4.2. Caseinate processed from dried Casein production

The Caseinate originated from dried Casein is the method currently applied in Industrial Partner; the dried Casein is stored in silos to be posterior processed. The reaction required to transform Caseinate into Casein follows a similar flow to processing Caseinate from fresh curd, the main difference is the drying process which is applied twice, incurring additional manufacturing costs associated with this operation.

In the current scenario Caseinate is being produced according to the required demand while Casein is constantly produced and stored in silos. Furthermore, packaged occurs daily. The Caseinate produced from dried Casein is given in Figure 3.7 where the powder Casein is previously stored in its silos and the Caseinate can be produced as requested by a known/unknown demand.

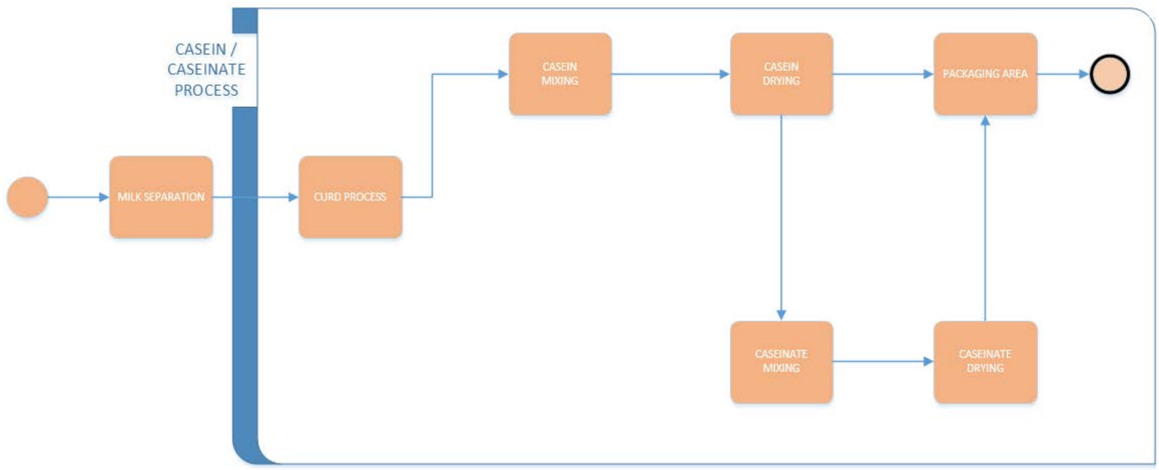

Figure 3.7 – Caseinate production from dried Casein

The disadvantage in the current scenario is all the operational costs associated with the Casein production are incorporated into the Caseinate. However, this disadvantage can be overcome through the flexibility created to transform Caseinate into specific periods of times, followed by the oscillation in the dairy market price.

Less storage space or silos are required to separately store Casein and Caseinate, due to the fact that Casein is the current production and Caseinate is produced according to an MTO (Make to order) policy and the packaging area most commonly shared between both products.

The model developed to reproduce the current behaviour of Caseinate produced from dried Casein is given in Figure 3.8. Through Table 3.1 initial advantages and disadvantages of both process are compared and briefly described. The exploration of the best method will be fully described in the section 4.

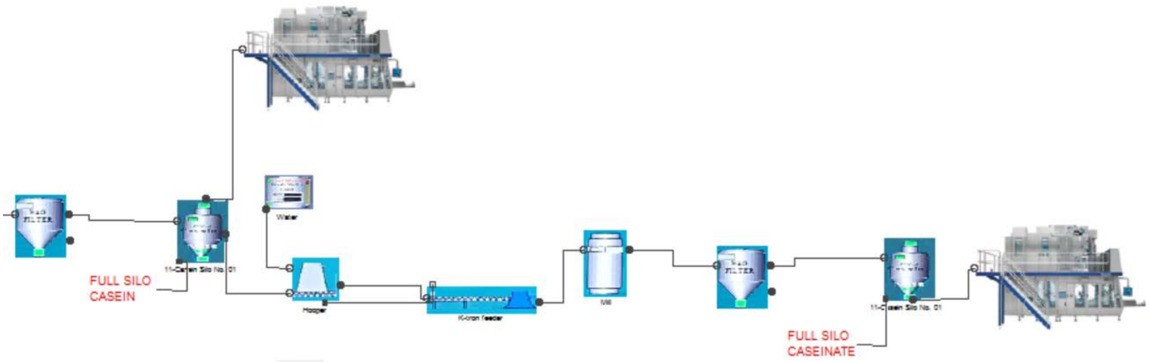

Figure 3.8 – Simulation Model - Caseinate production from dried Casein

Table 3.1
Comparison between two methods of Casein Production

Production	Advantage	Disadvantage
Caseinate from curd	Less operational cost	Dedicated silos
Caseinate from dried Casein	High flexibility	High operational cost

3.2.5. Analysis in the current flow

An analysis in the current WIP flow was conducted in this section and is demonstrated in a histogram and a Normal Q-Q Plot of 214 days of peak season production through Figure 3.9. Even though QQ-Plot are widely used to compare two samples come from population with a common distribution, the application of QQ-Plot is valuable to identify the normality of the current flow and its distribution. SPSS® was used to conduct this analysis.

In both graphs it is possible to observe that the flow of material have reached maximum capacity few times while the majority of the flow is concentrated below the mean which might depicts a high variability in the flow of milk designed to produce Casein/Caseinate. The records are standardized in order to maintain the confidentiality.

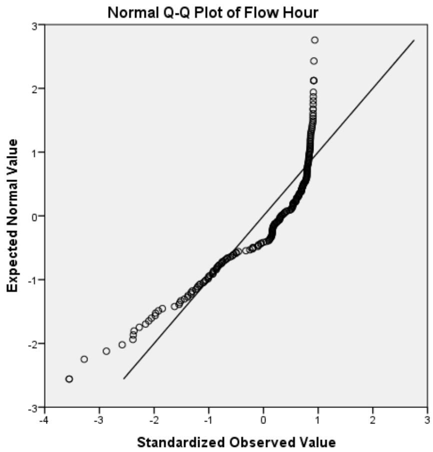

Figure 3.9 – Milk Flow in the Casein/Caseinate process

With respect to Casein, a similar analysis was conducted. Even though the 214 days of production was recorded, 168 entry values were considered due to the fact that there are days where only Caseinate is produced. Through the histogram and QQ-Plot presented in Figure 3.10 it is possible to observe that Casein slightly follows a normal distribution; however, some outliers are evident. In some days the production reached the maximum capacity while some days where the production operated at the minimum level.

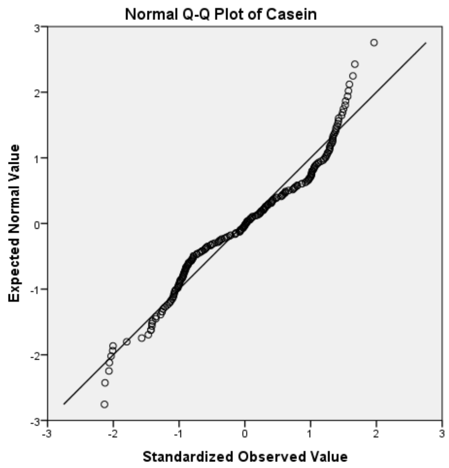

Figure 3.10 – Production Flow of Casein

With respect to Caseinate, a similar analysis was conducted. Even though the 214 days of production was recorded, 121 entry values were considered due to the fact that there are days where only Casein is produced. Through the histogram and QQ-Plot presented in Figure 3.11 it is possible to observe that Caseinate have more variability in the process and the production result does not follow a normal distribution highly impacted by its outliers.

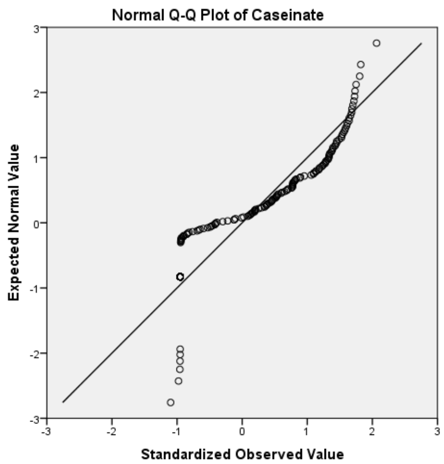

Figure 3.11 – Production Flow of Caseinate

In order to understand the variability demonstrated previously in the WIP, Casein and Caseinate flow, the downtime records were analysed. Part of the variability might be connected to the shutdowns and identify a method to evaluate the impact of downtimes in the whole production while could enhance the model.

In the current process, downtimes occurred 71 times and presented an average of 6.58 hours with 5 hours of standard deviation. In special case, a downtime could take more than 20 hours and the impact in the WIP flow and the Casein/Caseinate is inevitable due to the fact that is a continuous process and the milk cannot be storage more than 70 hours. The frequency and distribution of downtimes are depicted through Figure 3.12.

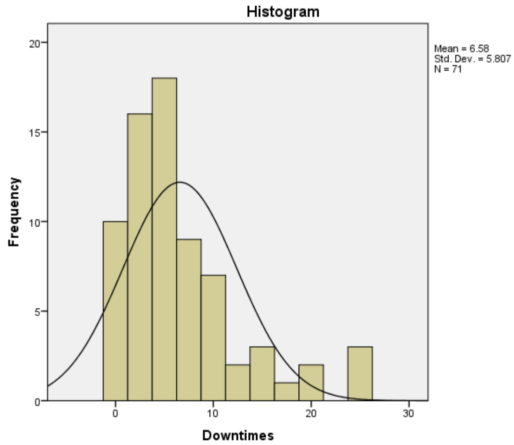

Figure 3.12 – Production Flow of Casein - histogram

3.2.6.Production Plan and COWIP in Dairy Industry

In any manufacturing environment, a previous schedule must be provided by the Production Plan department anticipating any sort of disruption and reducing uncertainties. In the dairy sector the production plan must consider the milk composition due to the seasonality impact in the final product. In the Industrial Partner, both products manufactured in this study, follow different planning policies. Caseinate is an MTO (Make-to-order product) produced according to the established contracts while Casein can be considered as an MTS (Make-to-stock) due to the fact that the production is constant.

According to (Hopp and Spearman, 2008), some specific alternatives are applied to avoid drastic swings in the production line such as : (i) Varying the number of shifts, (ii) Varying the number of days per week, (iii) Varying the number of hours per day, (iv) Varying staffing levels, (v) Using outside vendors. These strategies are applied to increase the capacity smoothing the WIP and production flow. However, in the Industrial partner, most part of these strategies are already being applied. The plant operates 24/7 during 7 days per week. Cleaning process are carefully planned and predicted maintenances stop each year due to the lack of appropriate raw material for production. Shutdowns can be minimized in order to increase the production smooth and the cost of shutdowns should be calculated considering the market price instead of labour costs.

In a basic CONWIP system purposed by (Hopp and Spearman, 2008), the simplest manufacturing is composed by a single-routing and a single-family production line. In this system all releases are coordinated with completions to maintain the WIP level constant. In the dairy reality, the production follows a continuous process and the progression is viewed as a linear flow. The author suggests the raw materials arrive to the line but are only released into the line if there is an available CONWIP authorisation. However, even though this implementation would work well in the assembly lines environment, in a continuous flow, the raw material must be processed as soon as it arrives in the reception due to perishable conditions. In this specific point the cards must be extended to the farmers in order to coordinate the arrivals.

Furthermore, in an effective assembly COWIP system, the variability must be constant. A multi-level of priority in order to maintain the WIP constant is called passing points. These passing points are buffers along the line where the job priority can be changed. Once the line is stabilized the chasing in the workstation for persistent queues is applied. In comparison to the dairy process, the flow is constant and the equipment is dedicated to produce certain types of products. Especially in the Casein process, the bottlenecks can be easily identified due to the level of utilization in the production line.

According to (Hopp and Spearman, 2008), different CONWIP breakdowns in each workstations as a loop are identical to one-card Kanban and the more CONWIP loops we break the line into, the closer its behaviour will be to Kanban.

Figure 3.13 demonstrates this relationship between Kanban and CONWIP cards.

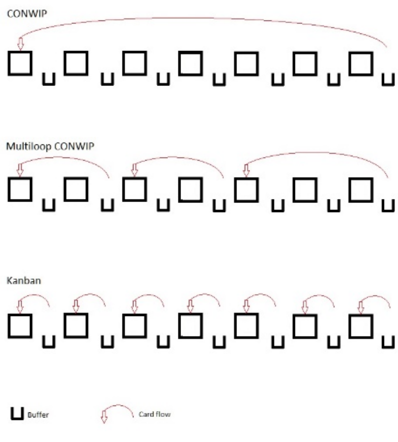

Figure 3.13 – CONWIP loops

3.2.7.Mathematical model and notations

The optimisation model was applied using simple Linear Programming in a spreadsheet file of Microsoft Excel ® Solver and will be further explained in the next section. In the optimisation model, there are two products being considered and in the current process and the resources are not shared. However, in the proposed model to produce Caseinate from curd process, one branch will be dedicated to Casein while the other branch can be shared between Casein/Caseinate demands.

In the current scenario, the demand is higher than the supply capacity in the Industrial Partner estimated at around 10% greater. All the backlogs are not being considered as a sales loss, but a future order fulfilment due to the fact that can be posterior negotiated among other customers.

A Linear Program was proposed to obtain the optimum quantity in both products. In order to establish a relationship among variables and its measurements some notations were defined and will be explored as follows.

w	Time periods in weeks - where w = 1 refers to weeks in the planning horizon
i	Product Index (Casein, Caseinate, Whey) (Product 1, Product 2, Product 3)
$dmax_t^i$	Max demand in period *t,* in units
$dmin_t^i$	Min demand in period *t,* in units
a_t^i	Time required to produce *i,* in the bottleneck
cap_t^i	Capacity in period t, in units or Litres according to the equipment
$cost_t^i$	Total cost of production of *i*
TP_t^i	Profitability product *i* according to the Sales Price
TQ_t^i	Total produced of *i*
IQ_t^i	Inventory remained at the end of period t of product *i*
S_t^i	Quantity sold at the end of period t of product *i*

In this notation, TP_t^i,and TQ_t^i are decision variables and the optimisation model is responsible for maximize the objective function according to the constrains defined, variable such as d, a, c and t are constants and will supply the model. The quantity produced TQ is considered as sold once the company works above the demand required and the demand will be estimated based on the current capacity.

The demand has to consider lower and upper limits due to long-term contracts that must to be fulfil. The industry partner must to produce certain minimum of both products. To optimise the profitability, the production has to follow the upper limits according to the capacity.

The objective is to maximise the profit considering both products subtracting the cost of production subject to capacity as follows:

$$\text{Maximize} \quad \sum_{t=1}^{t}((TP_t^i) - (cost_t^i))(TQ_t^i) \tag{3-1}$$

Subject to:

$$d_{mint}^i \leq S_t^i \leq d_{maxt}^i \tag{3-2}$$

$$TQ_t^i \leq c_t^i \tag{3-3}$$

$$I_t^i \leq I_{t-1}^i + TQ_t^i - S_t^i \tag{3-4}$$

$$I_t^i, TQ_t^i, S_t^i \geq 0 \tag{3-5}$$

In this notation, the objective function computes the profitability according to the produced units and sales quantity in the period t, subtracting the costs of production. Constraints (3-2) are limiting sales to the available demand while (3-3) are limiting the production to the capacity at the bottleneck. The constraints (3-4) are considering the remained inventory in the previous period adding the production in the current period and subtracting the current unit sales. Finally, constraints (3-5) guarantees that no quantity will be negative.

Important criterion must be considered by the model developed:

(i) Contracts fulfilment: The model might be able to evaluate if the demand is capacity-feasible according to the constraint $d_{mint}^i \leq S_t^i \leq d_{maxt}^i$

(ii) Bottleneck management: A piece of equipment showing a high level of utilization requires special attention in the production line.

(iii) Best Production Mix: Considering the fact that the maximum demand is not feasible, the model must consider decrease the yield according to the product profit.

Chapter 4

RESULTS

4.1. Introduction

In this section the results and considerations regarding the experiments are fully explored and divided into 3 subsections: (i) Analysis of Impact and Cost of Downtimes in the current production flow, (iii) Optimising the current process in the Industry Partner through MILP, and (iii) Analysis of the proposed model of Casein production.

4.2. Analysis of Impact of Downtime in the current production flow

Downtimes in any production environment are responsible for decreasing both capacity and yield. A relationship between downtimes that occurred in the Industry Partner was explored to provide a better understanding of the real impact in the current production flow.

All the production records during the peak season were added up in months and for each month the total number of downtimes was collected and it is shown in Table 4.1

However, in order to maintain the confidentiality in the operation, the values given were reflected the margin in total produced in units.

Table 4.1
Margin of Total Production of each product (units) and Total downtime per month (hrs)

Months	Sum of Casein produced units	Sum of Caseinate produced units	Sum of total casein / Caseinate	Sum of operational DT (hrs)
1	0.174	- 0.419	- 0.363	37
2	- 0.631	1.212	0.724	32
3	- 0.269	0.261	- 0.179	82
4	0.950	- 0.992	0.503	68
5	1.762	- 1.409	1.720	7
6	- 0.483	- 0.166	- 1.525	124
7	- 1.503	1.513	- 0.880	118
Total				467

Despite knowing that the partner company's mode of production is a pulled production, that is, the production carried out according to the customer's request and the variation of the total production may be different between the months, for academic purposes the research assumes that the production ratio for each product will follow the same pattern for all the months that the data was collected.

Considering the values from Table 4.1, the proportion of each product based on the total production is given in Table 4.2.

Table 4.2
The proportion of each product based on the total production

% of Casein	62%
% of Caseinate	38%

Considering the weighted arithmetic average calculated in the Table 4.2 we were able to relate the amount of downtime hours to each product per month. Table 4.3

Table 4.3
Calculus of downtime of each product related weight arithmetic average per month

Months	Sum of operational DT (hrs)	Casein (62%) - hrs	Caseinate (38%) - hrs
1	37	23	14
2	32	20	12
3	82	51	31
4	68	42	26
5	7	4	3
6	124	77	47
7	118	73	45
Total	467	290	177

The production records during the peak season were added up into months and for each month the total downtimes number were computed. A regression line to visualize the relationship between monthly downtimes and production is demonstrated in Figure 4.1.

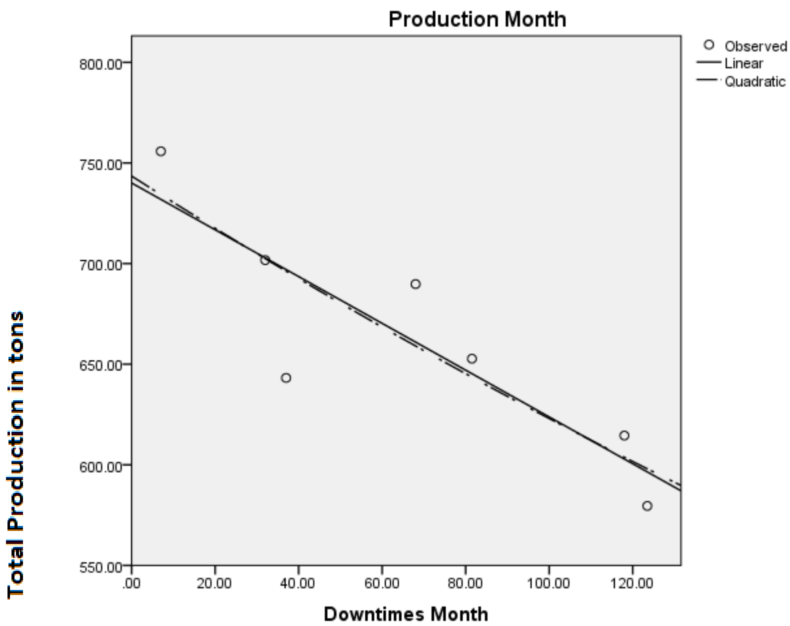

Figure 4.1 – Relationship between Monthly Production and Downtimes

To estimate how each downtime affects the Casein/Caseinate production system a linear regression model was built to identify if there is any strong relationship to justify the increase/decrease in the total production. Thus, for each production hour at the factory, 1.51 units of Casein or Caseinate is produced. Considering the information from Table 4.3, which shows the estimation downtime for each product per month, we applied the ratio 1.51 and showed the results in Table 4.4.

Table 4.4
Quantity of each product related the total DT

Months	Casein - units	Caseinate - units
1	34	21
2	30	18
3	76	46
4	63	39
5	7	4
6	115	70
7	110	67
Total	434	266

As a market strategy of the company, the Caseinate's sales price was not disclosed. However, according to (Understanding Dairy Markets, 2017), we obtained an average sales value of € 5,500.00 per unit of Casein as established in Appendix B.

Thus, the company did not produce 700 units of product during the seven months analysed due to the downtimes.

4.3. Optimising the current process

The current process could be optimised in terms of profitability, considering the cost of storage and market price of Casein/Caseinate. General solutions of MILP by means of exploring capacity as a constraint, leading to produce below capacity highlighting that producing at full capacity may not provide an optimal solution due to the fact that the costs involved in storage/warehouse can compromise high profitability.

However, most MILP models do not consider downtimes in their set of decision variables and the model might not provide a good response compared to the daily basis reality. In spite of this, the total cost of inventory impacts the final profitability, the trade-off between total downtimes cost and inventory must be considered due to the fact the production at the full capacity could be changed. The impact of downtimes was previously described and has been incorporated into the optimising process.

By adding a new production branch in the current model in order to consider two products will increase the possibility of a "floating bottleneck" effect. This occurs due to the fact that different products require different amounts of processing time throughout workstations, so the workstation that is most heavily loaded during a period may well depend on the mix of products run during that period. If flexibility in the mix is possible, we can use the Aggregate Planning model to adjust the mix according to the current capacity by means of managing bottlenecks.

Considering the current situation where two products (Casein/Caseinate) require the same process flow but present a slight difference in their process and associated costs the data required do evaluate the results produced is presented in Table 4.5.

Generally in analysis exploring the profitability to find the best mix the cost is subtracted from the sales price as used. However, in order to maintain the confidentiality in the operation, the values given are reflected the margin in the market price, costs associated were not presented in detail. Indirect costs such as labour costs and head costs were not considered in this calculation.

Table 4.5
Data comparison between two products

Description	Casein	Caseinate
Margin in the Market Price	10 %	15 %
Time required Process1	15 sec	15 sec
Time required Process2	15 sec	15 sec
Time required Process 3	55 min	60 min
Time required Process 4	0	5 min
Maximum weekly sales	170 units	70 units
Minimum contract sales	80 units	50 units

In addition to the data provided in Table 4.5, the 10,080 minutes is the availability of production time in this scenario considering 7 days per week and 24 hours per day. One week corresponds to 168 hours of production x (times) 60 minutes.

From the theoretical capacity the CIP average time has been discarded and an average of 9,600 minutes per week resulting in the production of Casein and Caseinate, before considering the impact of downtimes in the final production. The inventory build is not necessary due to the fact that the current demand is greater than the total production and is sent to the customers daily.

4.3.1.Analysis based on Profitability of Production

The initial analysis consists of evaluating the trade-off between the two products through the cost approach. For Casein the profitability reflects 10% while Caseinate represents 15%. The maximum production could be achieved to meet the demand. However, the constraints shown in process 3 highlight the potential for a bottleneck. The ideal condition must consider the minimum quantities of each product. For Caseinate which has a higher profitability the optimum quantity would be the 130 units (the maximum number of sales); however, the capacity is a constraint and Caseinate has to be produced to meet the minimum quantity of 80 units in order to meet the contracts previously established. However, this quantity is totally dependent on the capacity of each piece of equipment in the production line. Since Caseinate requires extra time to reach the desirable finished goods combined with the time required by process 2, this is managed as a potential bottleneck.

Table 4.6 demonstrates an ideal production mix based on cost/profitability approach where the availability of hours is considered as a constraint to determine the output of each product. Initially 80 units of Casein were considered in order to meet the minimum demand and the remaining time is applied in Caseinate production (more profitable). When the total variability decreases by 4,400, the remaining 5,160 minutes is used in order to produce Caseinate. The total profitability represented in units produced is given through Table 4.6.

Table 4.6
Production based on availability and profitability per week

Description	Casein	Caseinate	Total
Quantity	80 units	86 units	166 units
Time required	55 min	60 min	-
Total Hours Required	4400	5160	9560
Profitability (%)	10	15	-
Cost Proportion (€)	100	100	
Estimated Sales*	110	115	-
Total Profitability	8,800	9,890	18,690

*Estimated sales correspond to the total cost involved in the operation added to the profitability margin

4.3.2.Analysis based on the Bottleneck

In this evaluation, the profitability combined with capacity was considered. Basically the ideal condition might compute the profitability per minute in the bottleneck consumed by each product. Through this approach it is paramount to identify the bottleneck and the time required for each operation. Table 4.7 demonstrates the total time at the bottleneck (Process 3) for both products; Casein and Caseinate and the total time required to produce both products to meet the maximum demand.

Table 4.7
Production based on bottlenecks per week

Description	Casein	Caseinate	Total
Maximum Demand	170 units	70 units	240 units
Time Required	55 min	60 min	-
TOTAL Minutes	9,350	4,200	13,550

To evaluate the most profitable use of the limited time at the bottleneck, the next step consists of calculating the proportion of profitability spent in each product as demonstrated in Table 4.8.

Table 4.8
Production based on bottlenecks

Description	Casein	Caseinate
Estimated Sales*	110	115
Time Required on the BN	55 min	60 min
Proportion	2	1.91666667

*Estimated sales correspond to the total cost involved in the operation added to the profitability

Caseinate has a proportion of 1.92 while Caseinhas a proportion of 2. Therefore, the ratio of net profit shows that Casein should be given special attention compared to the cost approach. By producing 170 units, reaching the maximum demand required of Casein and the remainder of capacity for Caseinate, the total profitability has slightly increased at 3% of value compared to the previous analysis as presented in Table 4.9.

Table 4.9
Production based on BN and the Profitability per week

Description	Casein	Caseinate	Total
Quantity	170 units	4 units	240 units
Time required	55 min	60 min	-
Total Minutes	9,350	240	9,590
Estimated Sales*	110	115	-
TOTAL Profitability	18,700	460	19,160

*Estimated sales correspond to the total cost involved in the operation added to the profitability

The time constraint required to produce both products was considered to reach a higher profitability. However, the restriction regarding minimum quantity required to meet contracts is not reflected in this new approach. Moreover, the production of only 4 units of Caseinate would further increase the final costs due to processing time such as dryer and energy required to produce this minimum quantity, changing the current profitability calculated.

A method of optimising this combination is essential in order to calculate the best mix of product considering all the trade-offs presented in this environment. An optimisation model was applied using simple Linear Programming in a spreadsheet file of Microsoft Excel ® Solver and will be further explained in the next section 4.3.3.

4.3.3.Analysis based on Linear Programming Approach

The application of MILP considering the example of a product mix problem is widely applied in maximization business problems. The model proposed by section 3.2.7 has decreased the CIP average time from the theoretical capacity followed by the downtimes index. The downtimes highly impact the total production and must be incorporated into the capacity restriction model. The problem is explored algebraically and through optimal solution with Solver in Microsoft Excel®.

Maximize	$110\ x1 + 115x2$	(4-1)
Subject to:	$55x1\ + 60x2 \leq\ 9.600$	(4-2)
	$x1 \geq 80$	(4-3)
	$x2 \geq 50$	(4-4)
	$x1, x2 \geq 0$	(4-5)
	$x1 \leq 170$	(4-6)
	$x2 \leq 70$	(4-7)

In the model, the objective function increases the profitability combining both products. Each profit margin is computed by the total production in formula (4-1). In the first constraint the total capacity was reduced by CIP times restricting the total production in formula (4-2). Concerns regarding minimum production to reach specific contracts are defined through formulas (4-3 and 4-4). Formula (4-5) could be supressed due to the fact that the minimum quantities must be achieved. However, we must emphasise that both products resulted from the chemical reaction in the milk process and are continuously receiving raw material and must be processed as soon it arrives in the whole milk reception. Finally, formulas (4-6 and 4-7) restrict the maximum produced. This restriction is not totally related to the lack of demand, because in the current scenario the Industry Partner works with Backorder. However, the increased production could lead to an excess of inventory and storage costs, this analysis is not covered in the model presented. In Table 4.10 the optimum production is presented.

Table 4.10
Optimum production considering Excel MILP Solver per week

	Casein	Caseinate	
Estimated Sales*	110	115	
Time Demand (Production/Packaging/Transportation)	55 min	60 min	
Optimised Demand	120 units	50 units	
Maximum Sales/ week	170	70	
Minimum Sales/ week	80	50	
Constraints	Time Required		Time Available
	9,600 min		9,600 min
Net Profit	Casein	Caseinate	Total
	132.00	57.50	189.50

4.4. Analysis of the current production simulated

The first step in the analysis of the proposed system is to evaluate the effect of downtimes in the current simulation model. The variation in production was replicated 24 times and its variability is given in Figure 4.2 where the production is totally concentrated on the mean with a weak dispersion. The data collected from the simulation model is demonstrated in Appendix A. Furthermore, as demonstrated by the distribution the current variability is reflected by variations from production processes such as dryer efficiency and milk quality. Casein has a mean of 95 units of production and Caseinate is concentrated on 67 units of production with a negative skewness.

The best mix proposed by item 4.3 was not incorporated into the model due to the fact that the strategy assumed by the Industry Partner is to produce Caseinate as much as possible due to the profitability return and also due to the high impact supporting the actual market share. The optimum quantity is explored in the next section.

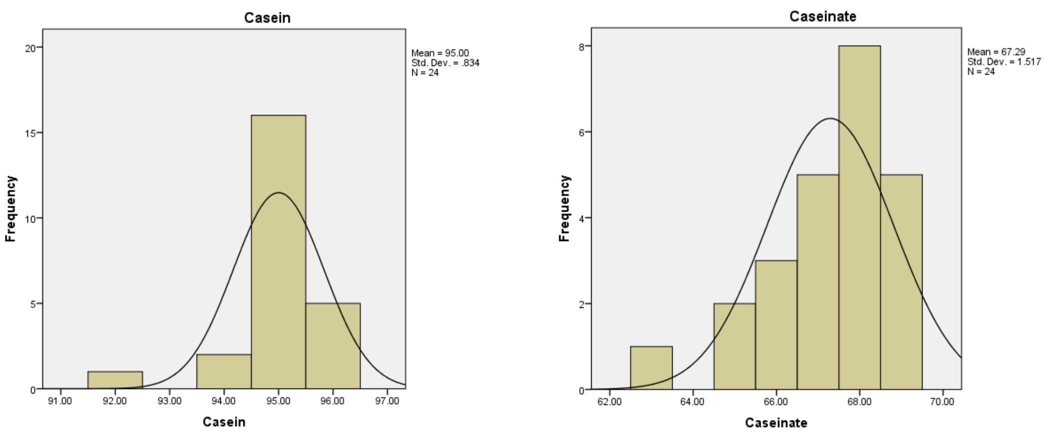

Figure 4.2 – Current Production in the Simulation Model – No Downtimes

When the shutdown time is incorporated in the model it is possible to notice a decrease in the output production and also the variability is increased. The variation in production was replicated 24 times and its variability is shown in Figure 4.3. Casein has a mean of 92 production units where it is possible to visualise the negative skewness while Caseinate is concentrated on 65 units of production. Both products have increased their variability as shown through the standard deviation presented.

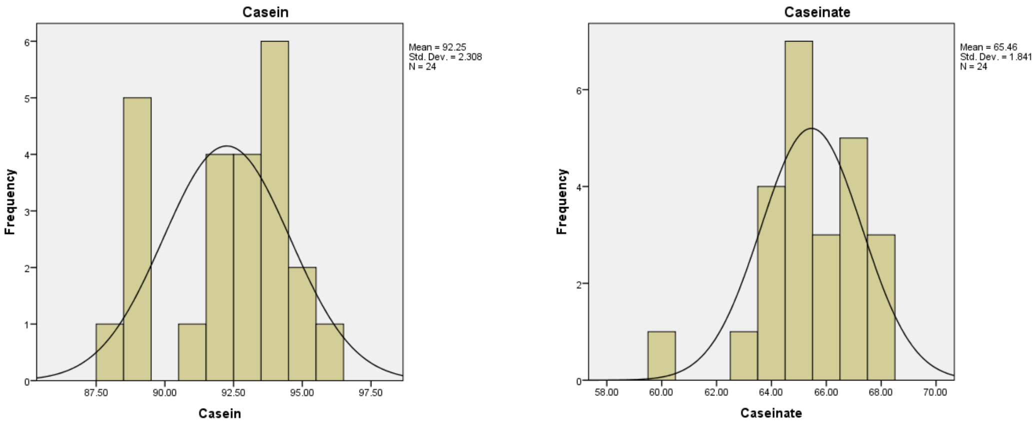

Figure 4.3 – Current Production in the Simulation Model – Downtimes Incorporated

A complementary test was performed to understand how significant the impact of downtimes is in the current process. A t-test through SPSS® was conducted and the two groups of data were compared. Group 1 is the level of production without downtimes and the Group 2 is the total production simulated considering the downtimes. The performed test is given through Table 4.11.

This study found that downtimes in production, had statistically significantly lower levels of yield (92.25 ± 2.30 units) per week compared to the simulation with no downtime effect (95 ± 0.834 units), t (46) = 5.490, *p* = 0.000.

Table 4.11
T-test performed by SPSS® comparing the impact of downtimes in the production

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Qt Produced	Equal variances assumed	25.123	.000	5.490	46	.000	2.75000	.50090	1.74173	3.75827
	Equal variances not assumed			5.490	28.907	.000	2.75000	.50090	1.72539	3.77461

4.5. Analysis of the proposed production simulated

The current process previously explained the Casein and Caseinate process produced in a serial line. After powder Casein is stored in silos, the product is sent to a similar process to produce casein. However, the proposed model of both products is produced in a parallel line, producing Caseinate from the curd process, one branch will be dedicated to Casein while the other branch can be shared between Casein/Caseinate demands.

The graph given in Figure 4.4 depicts the highest production of Casein and Caseinate in the current serial process. However, to reach a better performance in production increasing the milk flow and in specific bottlenecks are required. The data processed is presented in Appendix A where 36 scenarios were created through DOE in ExtendSim® a full factory analysis was conducted to visualize the production obtained. The data is standardized in order to protect the Industrial Partner confidentiality.

The scatter plotter is shown in different factors, the first factors have a better performance in quantity produced and are concentrated at the top of the graph where one standard deviation was increased.

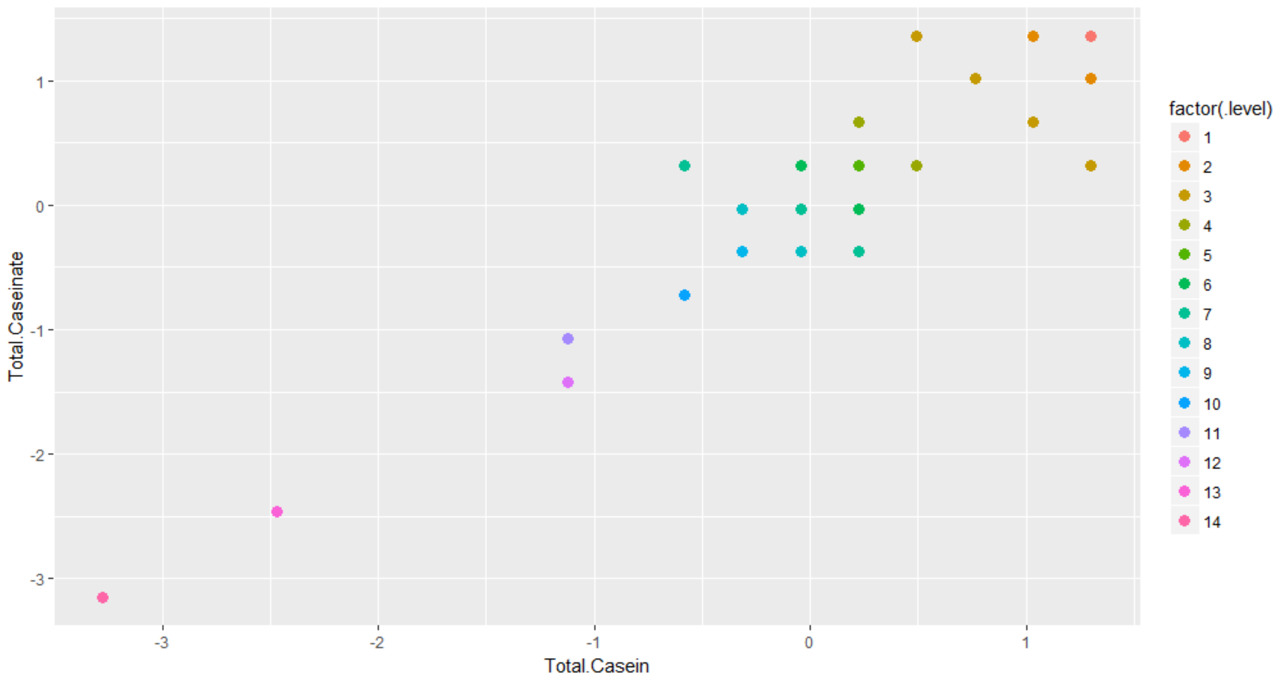

Figure 4.4 – Performance in the serial production

The proposed change in the process was measured though 6 scenarios due to the fact that no increase in the bottleneck would be required. The new branch would increase the total production reducing the bottleneck time as presented in Appendix A. A t-test using SPSS® was conducted to test the new production averages and the results are presented in Table 4.12 and 4.13. Six scenarios were selected from the current production where no increase or improvements were made and compared to the six scenarios where only an increase in the milk flow was required.

In Table 4.12 the difference between means and standard deviation from Group 1 (Serial production from Dried Casein) and Group 2 (Parallel production form Curd) where shown while Table 4.13 gives the t-test comparing both means and standard deviation.

Table 4.12
Group Statistic SPSS® comparing the new production from the serial and parallel

Group Statistics

	VAR00001	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	1.00	6	92.1667	3.76386	1.53659
	2.00	6	107.8333	1.32916	.54263

Table 4.13
T-test performed by SPSS® comparing the new production from the serial and parallel

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	1.465	.254	-9.614	10	.000	-15.66667	1.62959	-19.29761	-12.03572
	Equal variances not assumed			-9.614	6.228	.000	-15.66667	1.62959	-19.61901	-11.71432

The performed t-test shows that there are significant changes in the proposed model. A parallel production, where the Casein and Caseinate are processed into separated branches, had a statistically significantly higher levels of yield (107 ± 1.32 units) per week compared to those simulated in a serial production, where the Caseinate is processed after the Casein, (92 ± 3.76 units), t (10) = 6.228, p = 0.000.

Chapter 5

DISCUSSION AND FUTURE WORK

5.1. Introduction

In this section, the discussion regarding the proposed model to increase the production in a dairy industry is explored. The contributions of the research presented in this thesis have been threefold. Firstly, in section 5.2, the understanding of the impact of downtimes in the company's performance, resulting in delays in meeting customer's demand. Furthermore, the analysis of an optimum product mix combining profitability and the bottleneck and finally, the most important contribution, a proposal for improvement in the production process through a simulation model. In section 5.3 the recommendation for future work is explored.

5.2. Summary of Contributions to theory

During the mapping process in the Dairy Industry Partner, some average quantities were always widely used to justify the numbers of production. However, during the data exploration, some quantities did not fully reflect the company's reality. One point to highlight is that the amount of downtime not treated by the company causes not only delays to the delivery of goods, reducing the reliability between supplier and customer, but rather increases the cost of those downtimes thus causing the company to have a lack of production during the period analysed.

A further analysis combining important decision variables such as profitability and bottleneck to reach the best production mix was also explored through MILP. This analysis was necessary in order to understand how the process could be slightly optimised in turn impacting the current operation. All the results were statistically tested and validated by the proposed simulation model. Moreover, a proposed change in the current process was suggested. It is also important to highlight that the contribution for practical purposes in the Industrial Partner pointed to a different approach and gave different insights into a potential change in the current flow if any capital investment would be made in the future.

5.3. Recommendations for further research

The Dairy Industry plays an important role in the Irish Food Industry and the interaction between academia and industry could enhance the discovery of new opportunities for improvement in this sector. Some avenues for further research are apparent. Firstly, due to the fact that other products are produced from milk processing, an extension of this study could consider the impact of other products in the current production. Secondly, a potential improvement considering the collaboration between every company in Ireland would enhance the dairy network and sharing costs such as transportation and storage would create a win-win environment for all the stakeholders. Finally, exploring economic influences such as Brexit and its impact on dairy production could also lead to changes in the current strategy such as exportation to other countries.

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APPENDIX A

A.1 Simulation Model from the Current Process

The simulation model was developed in Extend Sim® Package. The average and standard deviation from 24 runs were conducted where downtimes were not incorporated into the model. The dataset used to present the dispersion in the Chapter 4 is given in Table A1.

Table A.1
Samples from the model - No Downtimes

RUNS	*Sum of Qt Caseinate Hour*	*Sum of Qt Casein Hour*
1	*65*	*95*
2	*69*	*95*
3	*68*	*95*
4	*65*	*95*
5	*69*	*96*
6	*69*	*95*
7	*68*	*95*
8	*63*	*94*
9	*68*	*95*
10	*67*	*95*
11	*69*	*95*
12	*66*	*95*
13	*66*	*92*
14	*68*	*96*
15	*68*	*96*
16	*66*	*95*
17	*69*	*95*
18	*67*	*95*
19	*67*	*95*
20	*67*	*94*
21	*68*	*96*
22	*68*	*96*
23	*67*	*95*
24	*68*	*95*
Average	*67.29166667*	*95*
SD	*1.485461956*	*0.816496581*

The average and standard deviation from 24 runs were conducted in the dataset given by Table A.2 and downtimes were incorporated into the model. The dataset used to present the dispersion in the Chapter 4.

Table A.2
Samples from the model – Downtimes Incorporated

Row Labels	*Sum of Qt Caseinate Hour*	*Sum of Qt Casein Hour*
1	*66*	*92*
2	*66*	*93*
3	*68*	*95*
4	*68*	*95*
5	*67*	*95*
6	*66*	*95*
7	*67*	*95*
8	*65*	*92*
9	*69*	*95*
10	*63*	*90*
11	*66*	*91*
12	*65*	*93*
13	*63*	*87*
14	*64*	*92*
15	*63*	*90*
16	*66*	*93*
17	*65*	*93*
18	*68*	*93*
19	*68*	*94*
20	*67*	*94*
21	*66*	*93*
22	*65*	*94*
23	*67*	*94*
24	*65*	*91*
Grand Total	*65.95833333*	*92.875*
Standard Deviation	*1.680558051*	*2.006781979*

A.2 Simulation Model for the proposed model

The comparison between the current production and the proposed were conducted comparing the results of different scenarios presented in Table A.3 and A.4.

Table A.3

Table of Scenario from the current process

Sceanrios	BN Casein	BN Caseinate	Milk Flow	Total Casein	Total Caseinate	Process 1 Casein	Process 2 Casein	Process 1 Caseinate	Process 2 Caseinate
Scenario 24	0	1.224744871	1.341640786	1.300827782	0.31820627	0.68215959	0.61513137	0.039350774	0.23583684
Scenario 20	0	0	1.341640786	1.300827782	1.012474495	0.6961731	0.62395308	0.039492494	0.31144348
Scenario 32	1.224744871	0	1.341640786	1.300827782	1.359608607	0.70893187	0.48831221	0.03952381	0.31713019
Scenario 13	0	-1.224744871	-1.341640786	1.300827782	1.359608607	0.68943484	0.62752563	0.039352435	0.45504259
Scenario 14	0	-1.224744871	-0.447213595	1.300827782	1.012474495	0.70750098	0.64458301	0.03952381	0.44695864
Scenario 27	1.224744871	-1.224744871	0.447213595	1.300827782	1.012474495	0.69529594	0.48420855	0.03952381	0.4457094
Scenario 36	1.224744871	1.224744871	1.341640786	1.031690999	1.359608607	0.69856378	0.4781568	0.039249652	0.24525386
Scenario 30	1.224744871	0	-0.447213595	1.031690999	0.665340382	0.67907017	0.47171386	0.038913253	0.31007312
Scenario 35	1.224744871	1.224744871	0.447213595	0.762554217	1.012474495	0.68163641	0.47159209	0.038547282	0.23985132
Scenario 23	0	1.224744871	0.447213595	0.493417434	1.359608607	0.66770461	0.60500443	0.038364962	0.24513084
Scenario 01	-1.224744871	-1.224744871	-1.341640786	0.493417434	0.31820627	0.67892295	0.87507153	0.03815137	0.43168479
Scenario 11	-1.224744871	1.224744871	0.447213595	0.224280652	0.31820627	0.6710125	0.87304702	0.03800282	0.23417233
Scenario 22	0	1.224744871	-0.447213595	0.224280652	-0.376061955	0.65744773	0.59479134	0.037857732	0.22582523
Scenario 06	-1.224744871	0	-0.447213595	0.224280652	0.665340382	0.65907291	0.86594607	0.037725132	0.30795214
Scenario 07	-1.224744871	0	0.447213595	0.224280652	-0.028927843	0.65962776	0.86809372	0.037812279	0.29810214
Scenario 29	1.224744871	0	-1.341640786	0.224280652	0.31820627	0.66401728	0.45812028	0.037763088	0.30541268
Scenario 26	1.224744871	-1.224744871	-0.447213595	0.224280652	0.665340382	0.66045749	0.45526528	0.038041656	0.43835219
Scenario 10	-1.224744871	1.224744871	-0.447213595	-0.04485613	-0.028927843	0.66045519	0.86327072	0.037597477	0.23122613
Scenario 12	-1.224744871	1.224744871	1.341640786	-0.04485613	-0.028927843	0.64751442	0.85359559	0.037390695	0.23236853
Scenario 34	1.224744871	1.224744871	-0.447213595	-0.04485613	0.31820627	0.65431353	0.45728511	0.037410373	0.23559658
Scenario 17	0	0	-1.341640786	-0.04485613	-0.028927843	0.6690688	0.60258624	0.037677147	0.3012287
Scenario 18	0	0	-0.447213595	-0.04485613	-0.376061955	0.65690945	0.60168234	0.037624094	0.295058
Scenario 04	-1.224744871	-1.224744871	1.341640786	-0.04485613	-0.376061955	0.66481512	0.85641089	0.037336199	0.41854096
Scenario 21	0	1.224744871	-1.341640786	-0.313992913	-0.376061955	0.64941607	0.59256277	0.03710656	0.22894751
Scenario 08	-1.224744871	0	1.341640786	-0.313992913	-0.028927843	0.65396498	0.84619126	0.037089348	0.29899151
Scenario 15	0	-1.224744871	0.447213595	-0.313992913	-0.028927843	0.66033022	0.5895842	0.036994226	0.42444517
Scenario 25	1.224744871	-1.224744871	-1.341640786	-0.313992913	-0.376061955	0.66254998	0.45456102	0.036972374	0.42025186
Scenario 09	-1.224744871	1.224744871	-1.341640786	-0.583129695	-0.723196068	0.66415646	0.84199443	0.036690108	0.22331864
Scenario 33	1.224744871	1.224744871	-1.341640786	-0.583129695	-0.723196068	0.63674036	0.44014024	0.036719282	0.22326791
Scenario 31	1.224744871	0	0.447213595	-0.583129695	0.31820627	0.64990339	0.44827487	0.036725807	0.30558861
Scenario 03	-1.224744871	-1.224744871	0.447213595	-0.583129695	-0.723196068	0.65413502	0.84433401	0.036810144	0.41386098
Scenario 05	-1.224744871	0	-1.341640786	-1.12140326	-1.07033018	0.62175324	0.81192389	0.035724651	0.28740937
Scenario 19	0	0	0.447213595	-1.12140326	-1.417464293	0.62939458	0.5752363	0.03579279	0.28167244
Scenario 28	1.224744871	-1.224744871	1.341640786	-1.12140326	-1.07033018	0.63349881	0.43621047	0.03587313	0.41102979
Scenario 02	-1.224744871	-1.224744871	-0.447213595	-2.467087172	-2.45886663	0.59229807	0.77505865	0.033766712	0.38349354
Scenario 16	0	-1.224744871	1.341640786	-3.274497519	-3.153134855	0.58322748	0.52255411	0.032743402	0.36892692

Table A.2

Table of Scenarios from the proposed model

Sceanrios	Milk Flow	Total Casein	Total Caseinate	Process 1 Casein	Process 2 Casein	Process 1 Caseinate	Process 2 Caseinate
Scenario 1	-1.463850109	0.961523948	0	0.4437287	0.59077014	0.29581914	0.45182062
Scenario 2	-0.878310066	-0.68680282	0	0.44163483	0.58427583	0.29442322	0.45171923
Scenario 3	-0.292770022	1.785687331	0	0.43822216	0.59642739	0.2921481	0.45096019
Scenario 4	0.292770022	-0.68680282	0	0.44319893	0.58262854	0.29546595	0.45154167
Scenario 5	0.878310066	-0.68680282	-1.732050808	0.44195483	0.58206416	0.29463655	0.44871175
Scenario 6	1.463850109	-0.68680282	1.732050808	0.44166704	0.57905759	0.29444469	0.4576165

APPENDIX B

B.1 Data from Market Price

Costs and profitability were combined and given in Chapter 4 according to the proportion in the total end product value. Considering the fact that Casein Powered is a commodity, companies in general uses the market price to guide them in the negotiation. Picture B.1 presents the price of Casein during 2017.

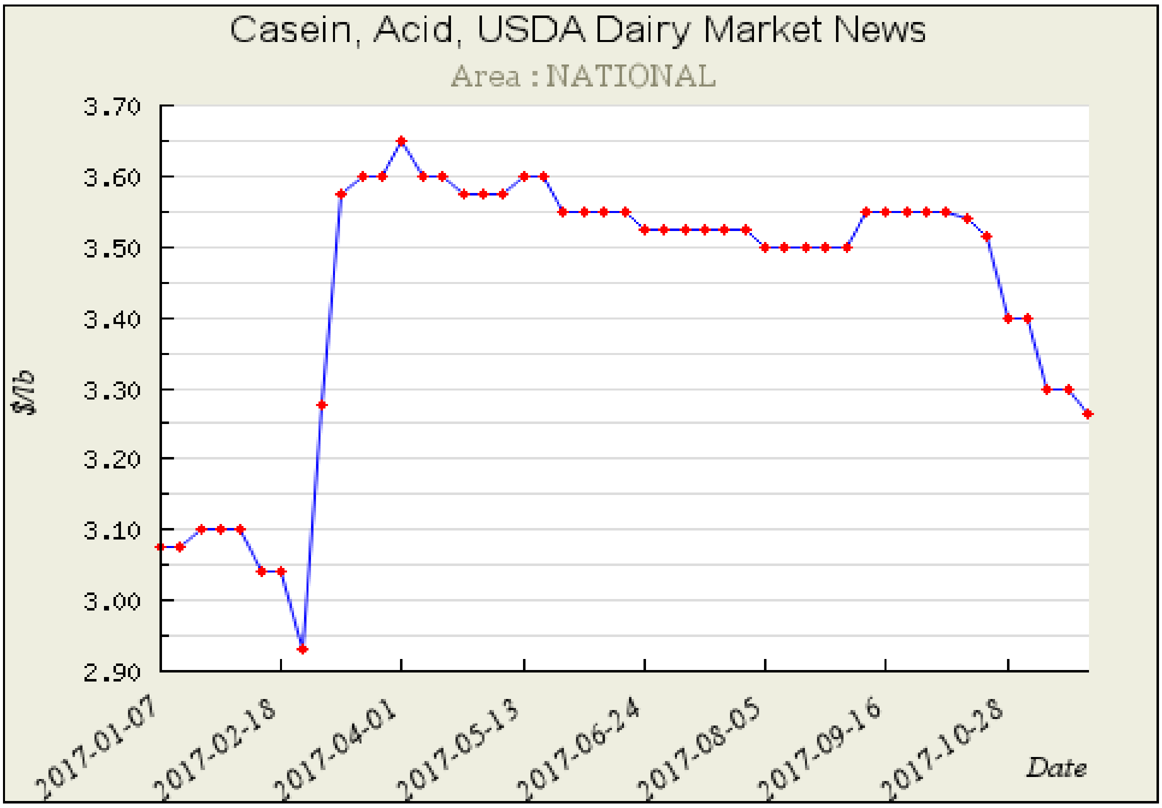

Figure B1 – Market Price for Casein in 2017

APPENDIX C

C.1 First version model developed using ExtenSim®