Development of planning rules and an optimised Master Production Schedule for a new water and ice tea bottling plant

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Executive Summary

The Clover group, a well-established branded consumer goods company in South Africa, has recently acquired a brand new water and ice tea bottling facility. In order to align the operations of this facility with the efficiency and effectiveness objectives of the Group as a whole, this facility requires a specially tailored optimised master production schedule (MPS). Infor Advanced Scheduler software, which is the software that the Group uses in all of their other manufacturing facilities for production scheduling, is used to develop this optimal production schedule. Some general production planning rules need to be developed as guidelines for the development of the optimal MPS. Accompanying the MPS, a job schedule that organises labour to ensure that the labour resources required are aligned with the production plan, is also required for this facility.

Extensive literature studies focused at specifically sales and operations planning, capacity planning and operations research tools and techniques, specifically Mixed Integer Linear Programming (MILP) gives direction to the development of this MPS. In the first stages, sales and operations functions and rough cut capacity planning is used to identify production planning rules fitting the specifications of the facility in terms of equipment capabilities, available capacity, sales and demand forecasts and company-wide general rules and assumptions. After establishing the basic rules and parameters, all of the important factors that influence the MPS are systematically optimised, and a MILP to determine the optimal lot sizes for different scheduling alternatives is developed. All the optimised factors are then combined to develop two alternative production schedules, one that is a continuous production schedule of which the monthly schedule remains constant throughout the year. The second alternative, which resulted in the optimal schedule alternative, is a production schedule with one off-peak schedule followed for six months, combined with a peak schedule for the other six months. The peak and off-peak periods are identified through analysis of sales and demand forecasts for the coming year. Job schedules with different shift configuration alternatives are created for both of the schedule alternatives, and this is how the optimal schedule is selected, by evaluating the cost of labour associated with the selected MPS.

All the alternative schedules are confirmed as feasible solutions, and the selected MPS alternative is optimal in terms of the determined lot sizes, average inventory holding cost and labour cost related to the accompanying job schedule. A sensitivity analysis is done to evaluate the rigidity of the MPS, should safety stock levels be adjusted, and the MPS proved to be rigid enough as the schedule would barely change based on production time required. The sensitivity analysis does prove that major cost savings can occur if safety stock levels are reduced, but future work on improving forecasting accuracy is recommended first. Other future work possibilities have emerged such as warehouse utilisation optimisation, distribution and procurement planning and optimisation and forecasting improvement. This project, along with future work recommendations are all ultimately aimed at developing and optimising the operations of the Clover Waters Facility, in order to manage resource constraints as efficiently and cost effectively as possible and satisfy customer demand.

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BOM	Bill Of Materials
ERP	Enterprise Resource Planning
FMCG	Fast Moving Consumer Goods
JIT	Just In Time
MILP	Mixed Integer Linear Program
MPS	Master Production Schedule
MRP	Manufacturing Resources Planning
MRP	Material Requirements Planning
OR	Operations Research
PSE	Process Systems Engineering
R&D	Research And Development
RCCP	Rough Cut Capacity Planning
ROA	Reduce And Optimise Approach
SKU	Stock Keeping Unit

Chapter 1: Introduction

Since the early 1900's, beverage companies across the world have evolved; from regional companies with manual labour intensive bottling facilities which mainly produced for local markets, into the corporate giants of today, that produce for national and even international markets. The great shift began when the advancement in bottling technology allowed the beverage manufacturing sector to adopt mass production techniques that allowed for expansion. Mass production created the need for production scheduling in order to coordinate and organise the production of these increasing volumes of goods.

In the industry of manufacturing and bottling liquid products, specifically in this case beverages, the efficient and economical scheduling of lot production is becoming increasingly more important. This is due to the specialisation of numerous products to satisfy customer demands, which causes higher numbers of lots of smaller volumes that should be produced. However, specialisation and differentiation in products leads to production planning becoming increasingly complex. It is worth it in the end, since satisfaction of customers leads to increased demand; greater demand means more sales, and more sales results in increased profitability. The key to maximising profitability lies in the ability to quickly and effectively schedule an entire multi-product facility, based on a number of recipes.

Clover Industries Limited is a branded foods and beverages Group that is continuously striving to improve customer service, demand satisfaction and especially increase their profitability. Clover has enjoyed much success during the development of South Africa's dairy and fast moving consumer goods (FMCG) industry over the past 100 years. The core competencies of the Group is the production of dairy and non-dairy beverage consumer products, the distribution of chilled and ambient consumer products, and in the sales and merchandising of consumer goods. The Group produces and distributes (for itself and other FMCG companies) a diverse range of dairy and consumer products through one of the largest chilled, and most extensive distribution networks in Southern Africa (Clover, 2016).

One of the newest facilities owned by Clover is an ice tea and water manufacturing and bottling plant, which was planned to open for production during June 2016. The facility is equipped with four filling lines and is directly connected to a natural spring as water source. This facility will produce ice tea in various flavours and bottle sizes, as well as still, sparkling and flavoured water for different brands in varying bottle sizes. A total of 46 various products classified according to stock keeping unit (SKU) descriptions, will initially be produced at this facility, and this number could change as product development introduces new SKU's or as some SKU's are removed from the market. As with all of their facilities, Clover will strive to operate this bottling facility as optimally as possible in production of this large variety of products, to assure alignment with the supply chain and corporate strategies.

Basset (1996) stated that numerous aspects of the production process are optimised through scheduling, which ultimately leads to increased profits. First, and foremost, production scheduling addresses the issue of efficiently allocating scarce resources such as raw materials, work force, time, storage, etc. From this statement, it is evident that an efficient and effective master production schedule (MPS) automatically serves as a starting point to an accompanying worker-schedule and storage plan for a bottling facility. Thus, an optimised MPS would ease the process of developing these two plans as optimally as possible.

Production planning and scheduling lies at the core of the aim to integrate the new facility into the operations of the expansive supply chain network operated by Clover. If optimisation is achieved through major time, cost and capacity considerations, and with the consideration of the most accurate demand forecasts, the operation of this new facility will help the company in their mission to expand their distribution network. They aim to expand this network efficiently and effectively over a wider region including neighbouring Southern African countries, where the demand for purified bottled water is quickly increasing.

An optimised MPS will also enable the expansion and improvement of their supply chain in line with the objectives of the Supply Chain Development Department of the Clover Group, and build on their legacy of quality products, on time delivery and guaranteed customer satisfaction.

The ultimate aim of this project is developing a MPS based on an optimised production sequence developed specifically for this facility, along with a tailored job schedule. A multitude of studies and literature on this type of problem, and problems related to production planning and scheduling have been published. It is evident that there are many ways to approach the specific problem, depending on the specifications, and requirements for the solution. The key was to review as many relevant studies as possible and identify similarities of the problems in those cases, whether there are similar processes, constraints, industries, demand patterns, or any other similarities in the problems. The similarities can be used to find approaches that are applicable to this specific problem. Many of those approaches were combined to develop a unique solution approach specifically aimed at solving the production scheduling problem for Clover's water and ice tea bottling facility.

1.1. Background

Production planning and scheduling has a major impact on many aspects of the business, including utilisation, lead time to customer, sales order availability, availability of finished product, quality, forecast accuracy, raw materials supply, sequencing of orders, variability, dead stock, inventory of finished goods, etc. All of these factors need to be incorporated into the operations of the facility from the start to implement the process of Kaizen, the practice of continuous improvement throughout the life of this new facility. To enable the incorporation of all the above-mentioned factors, a comprehensive understanding of the industry sphere, the company, the facility and its operations was obtained.

1.1.1. The beverage packaging industry

Henninger (2009) has done research on the issues that industries and facilities in the liquid packaging industry face, from paint, to chemicals, to beverages. His research has proven that there is one big issue encountered by all the facilities: changeover and setup costs incurred between producing different products. The Clover Waters Facility will be producing 45 unique SKU's, which motivates the desire to have an optimised MPS that reduces unnecessary costs.

A clear trend is that changeover and setup costs get higher as the degree of incompatibility between successive products increases. Clover has some varying degrees of compatibility between their successive products due to product characteristics. These characteristics include a) the type of products produced and bottled such as ice tea, water or flavoured water; b) whether it is a carbonated drink or not might affect the filling rate and c) bottle and cap sizes vary according to volume and the brand of product. This type of research originated in the packaging industry, but it is known that sequencing issues are encountered by various other industries, and it is applicable to any type of manufacturer that produces a multitude of varying products on a limited number of packaging, or in the case of this study, filling lines.

Henninger (2009) found that even though some of the issues encountered by facilities and industries are quite similar, the strategies to address these issues are vastly different, due to the varying current state of the bottling industry. The state varies due to factors such as machinery, techniques, company strategies and facility capacity and capabilities, which are different in each industry or company. The states can even vary between facilities in the same company. One theme that he identified throughout the entire industry is the need to increase market share, increase profits, improve the efficiency and effectiveness of operations and reducing operations costs. The implementation of lean manufacturing, just-in-time (JIT) manufacturing principles, and effective and thoroughly conducted operations research activities can help a company to meet these objectives, starting with production planning and scheduling.

Currently, the norm for companies that produce a wide variety of products is to use a manufacturing resources planning (MRP) system to schedule production. Although very effective, the cumulative errors or inaccuracies within an MRP system will lead to very high levels of safety stock. Combining MRP systems and methods with JIT principles to determine optimal lot sizes for each product will assist in reducing inventory and lead-time. Incorporating JIT into MRP, along with the mathematical modelling technique used to determine the optimal lot sizes, will provide a guide to sequence products that are to be bottled based on the changeover times and production time duration of each lot. This will balance the trade-off between smooth production flows; order fulfilment, mixture of products produced and lost time and capacity due to changeovers between products.

1.1.2. Production planning and scheduling

At its core, production planning can be seen as the heartbeat of any manufacturing process. The main purpose of production planning and scheduling is to minimise production time and costs, organise and effectively allocate resources, and maximise the efficiency of operations. This is done by determining the time sequence of orders, jobs, tasks and other operations, and relating these with their required resources as effectively as possible

Scheduling involves the process of defining of starting and finishing times and the assignment of resources to each task that needs to be completed, while being restricted by several constraints, which may involve those tasks and/or the resources. Scheduling is a decision making process that plays a very important role in most manufacturing and service industries. At the Clover Waters Facility, all the different SKU's need to be assigned to different filling lines which have the capability to produce that specific SKU. This facility particularly only has one filler line with mixing tanks, consequently, all products which requires carbonation or mixing with syrup or flavouring is automatically assigned to this particular line.

In a recently published article, Sauer (2016), the author refers to the MPS as the "cornerstone for synchronisation". This is a very accurate description of the importance of a well-defined MPS. Essentially the MPS serves as the driver of resource requirements, it aims to align demand planning (sales forecasts) with production operations and it orchestrates the sequence of procurement dates that should ensure raw materials are consistently available and ready for use. This has an influence on the planning schedules of the procurement department, thus the best approach would be to derive the material requirements plan (MRP) directly from the MPS. Sauer also mentions that one of the biggest obstacles to synchronise an MRP with the MPS, occurs when you have multiple products with unique bills of materials (BOM's). Fortunately for Clover, the main ingredient, common in all of the SKU's that are produced and bottled at the Clover Waters Facility, is water. This water is sourced from a borehole right on location. The electronically controlled pump is directly linked to the computer system, which uses information signals from their operation planning software, Infor AS. The other added ingredients; ice tea syrup, water flavouring and CO_2 for sparkling drinks, along with all the bottles and labels still needs some diligent planning effort. Procurement of these components has to be initiated and completed on time to have the required material on hand at the correct time. It would be a great concern if procurement is the cause of a bottleneck, since it is a problem that can easily be avoided through effective and diligent planning.

Morten and Pentico (1993) identified that the production environment is a dynamic mode where unforeseen events can happen at any time. These disturbances will have an impact on the production statement. A good schedule system is the one that has the capability of dynamic decision making for the aforementioned scheduling function in a timely and high quality fashion while simultaneously maximising throughput, satisfying customer wants and needs, and minimising direct operating costs. Sequencing, timing, routing, reconfiguration, forecasting, labelling, grouping, aggregation, and disaggregation are the main issues of the scheduling function.

Clover's Planning Department currently makes use of the production planning software Infor AS (Advanced Scheduler). Infor Advanced Production Scheduling is a unique constraint-based scheduling solution that is uniquely designed with process manufacturing differences in mind. This software program delivers realistic, achievable production schedules that are optimised under the influence of several constraints. These constraints include capacity, materials and labour resources, optimum production sequencing that minimises unproductive time, management of volume-constrained resources such as tanks and vessels. The functionalities of Infor AS make it especially useful for the beverage production and packaging industry. It enables command of both continuous and lot flow environments, makes use of easy to use graphical and interactive scheduling solutions, and is a system that seamlessly integrates and operates alongside any ERP (Enterprise Resource Planning) system, in order to provide advanced shop floor scheduling.

Upon completion of this project, the expected outcome is an optimised MPS, with an accompanying best-suited job schedule, tailored specifically to suit the capacities, constraints and performance capabilities of the new ice tea and water bottling facility. The schedule will be handed over to the Operations Department of this facility. This will enable optimised warehouse utilisation, scheduling and maximised order fulfilment. The parameter values table which is also developed, along with standardised stock keeping unit (SKU) lot sizes can then be used to develop scheduling, production and warehouse management rules.

A flexible, well-defined MPS is of critical importance to the development of warehousing rules, inventory management, distribution planning and several other operations within the facility. The Supply Chain Development Department can use the MPS to integrate the new facility into the whole supply- and distribution plan seamlessly. The planning becomes a challenging task because it involves many products and deals with many aspects such as multiple resources, partial equipment connectivity, sequence-dependent changeovers, storage time, transfer time and lot splitting.

In order to develop an optimal MPS which can be used by the Supply Chain Development Department, a well-defined methodology will be followed which will ensure that all aspects, constraints, capabilities and requirements will be taken into account. This is to make sure that the outcome of the project thoroughly addresses the problem and satisfies all expectations.

1.2. Research design and methodology

The solution to the problem is a MPS with optimal lot sizes and production sequence, a job schedule, and production rules, which will be used in order to plan and operate the facility.

1.2.1. Problem statement

This brand new bottling facility of Clover will need an efficient and effective production plan and work schedule from the moment of start-up. Currently there is not such a schedule yet, and in order to ensure optimal performance of the facility, it is a priority for Clover to have a detailed production and work schedule. Clover aims to implement the MPS as soon as possible, aiming for September 2016.

1.2.2. Research design

To ensure that the operations are aligned with the strategic objectives of the company, the development of this optimised MPS will incorporate: strategic allocation of resources, fast problem resolution action plans, flexibility and agility. The MPS that is developed makes provision for satisfactory safety stock levels, ensures that the lot sizes which are produced will satisfy market demand, be of feasible volumes to fully utilise the facility equipment and the production frequencies will reduce changeover times in order to maximise the productivity of the facility. Job scheduling, which accompanies production scheduling, will ensure the efficient allocation of labour resources and minimising the cost, while adhering to constraints set by fair labour practise. The MPS, or plan, will make enough provision for downtime in order to perform maintenance. Should any unforeseen event such as a sudden stoppage, power failure for an extended period or machine failure occur, production can continue after the problem was resolved, without running into the time of the next week's production. The MPS will ensure that production and distribution of the products produced at Clover's new facility is executed as effectively and efficiently as possible.

The key to ensuring that production and distribution of the products, which will be produced at Clover's new facility, is executed effectively and efficiently lies in the quality of production planning and scheduling. The optimisation parameters that are of critical importance are:

- Minimum cost for production and distribution.
- Minimum working capital invested in inventory.
- Maximum market supply.
- Satisfactory levels of agility to react to demand fluctuations.

These optimisation parameters will be integrated into the development of the lot-sizing mathematical models and the scheduling process. The MPS will be designed to run over a period of four weeks during every month, starting on the Monday of every week. When the weekly production goals are met, production will stop for that week. This will provide a time allowance for maintenance to be done on equipment over weekends if necessary, and flexibility in case of emergencies or unplanned breakdowns or stoppages. The unexpected error, breakdown or problem can be adhered to and production can continue as scheduled without running into the danger of overrunning into the next weeks' scheduled production time.

1.2.3. Methodology

In order to address the problem and finding a good quality solution, which would be a flexible, adaptable and optimised production schedule, a process of chronological steps were followed. The results obtained in each stage were used as input for the proceeding stage. In this way, the solution was developed systematically over the course of six main stages:

Stage 1: Analysis of the facility and business strategies
The major functions of the facility were drawn up in a process flow chart. At each stage of the process the critical functions and parameters that link the production process with business strategies were identified. Meeting with Supply Chain Management team members assisted in the establishment of desired target levels, or values of these parameters. A table with each parameter and acceptable range of values per parameter was compiled and used as a parameter control table. This table was used during the alternative testing period in order to select the schedule that satisfies the most targets.

Stage 2: Forecast analysis and optimal lot-sizing
A Mixed Integer Linear Program (MILP) along with established confidence intervals of determining demand satisfaction, were used to determine the optimal lot sizes for each SKU. These lot sizes were set as a production rule. Determination of these lot sizes was reliant on the demand forecast of one year, divided into twelve monthly demand periods, in order to

ensure that aggregate demand over the long run is met. Demand is met by continuously producing a fixed lot size, which is the same for all the periods (months) and the shortages or excess will be minimal at certain times.

Stage 3: Production sequencing
A set of production parameters and rules to use as input for the Infor AS software were developed in this stage. All the production requirements and changeover determinants, i.e. syrup mixing for ice tea, required sterilisation processes, bottle size and bottle-cap type etc. of each SKU was listed, and a changeover time matrix between SKU_i and SKU_j was formulated.

The changeover time matrix was used to determine the optimal production sequence that ensures the minimum total changeover time. The lot sizes and optimal production sequence were then used accordingly as guidelines in stage 4, in order to create alternative MPSs exploring different MPS's for different seasons or a continuous schedule, or altering the sequence to fit into a predetermined shift configuration.

Stage 4a and 4b: Developing alternative MPSs
Infor AS, the production scheduling software currently used by Clover, was used in stage 4a. Results and outputs from stages 1, 2 and 3 were inputs for the design and development of alternative production schedules in the software program. Two alternative approaches were followed and production schedules were be drawn up.

Alternative 1 considered a production schedule with a constant production lot size that is the same size every month, produced monthly. Alternative 2 divided the demand into a peak period and an off-peak period. The production lot size that was determined for the peak period for each SKU was scheduled to be the same size for the six peak months, and the off-peak production lot size for each SKU determined the constant production lot size that was scheduled for the 6 off-peak months.

The software enabled simulation of the process using a certain schedule, giving starting and ending times and feasibility status as results. In stage 4b, the alternative schedules were evaluated and compared in terms of target values and parameters estimated in stage 2. According to this, the best alternative production schedule was selected as the MPS.

Stage 5: Job scheduling
The resulting MPS from stage 4 was used as guide to develop a job schedule for workers. Scheduling alternatives as two full shifts of either 8 or 12 hours, vs. single shifts plus sporadic overtime were evaluated in terms of cost, worker satisfaction, feasibility and labour legislation. The job schedule will ensure that the workforce required to attend to the production process is always available.

Stage 6: Finalising and presentation
The final MPS, job schedule and production rules that were developed during the course of this project, was compiled into tables, which summarises the production and job schedule. This document can then be presented as proposed rules for the operations planning, scheduling and management of the new bottling facility for Clover.

1.3. Document structure

The document is structured as follows: Chapter 2 documents the literature review, where several journal articles and research papers about operations research, production scheduling, lot sizing and production sequencing have are reviewed in order to find similarities and best approaches for solving the problem for this particular project. Chapter 3 documents all the critical information, data analysis and parameters which is obtained from the company, through data gathering, interviews, and a facility overview for optimisation parameters and general rules, or constraints. The information in Chapter 3 is used in Chapter 4, where the operations research model is developed with mathematical formulations. In Chapter 4 the output of the operations research model, which are optimal lot sizes and a production sequence, are analysed and documented for use in Chapter 5. Chapter 5 documents how all results obtained through optimisation and operations research modelling, and information gathered in the preceding chapters, are utilised to develop a MPS using Infor Advanced Scheduling software, and finally an accompanying job schedule is developed. Chapter 6 discusses the sensitivity analysis, which is done to determine the sensitivity of the MPS and job schedule along with cost implications of reduced stock levels. Chapter 7 concludes the project, reiterating the problem and solution that is developed, makes recommendations, and finally gives ideas for future work opportunities.

Chapter 2: Literature Review

Operations research is the technique that has been selected to address the problem posed in Chapter 1. It has been chosen since it is the technique best suited to address any constraints and requirements and incorporates optimisation in the search for a solution. A literature study was done to gain exposure to all the techniques available and aid in the selection of techniques and strategies. This was done to understand production planning and scheduling, and how operations research and the various ways in which it can, and have already been applied in the industry is relevant to this project.

2.1. Sales and operations planning

Within the field of industrial engineering, and specifically production scheduling, there is a multitude of techniques available to plan a certain aspect of the organisation or process as accurately or optimally as possible. If some, or all, of these techniques are used, it will help in improving the quality of the final developed MPS. This will only occur if the techniques are applied correctly, and all assumptions that were made were carefully considered, verified and validated.

Sales and operations planning is a process aimed at developing a single production plan that ensures the alignment of the objectives of (most commonly) sales, marketing, operations, R&D (Research and development), and finance. It allows the business to operate off a single set of numbers. The process has several stages, prior to the official sales and operations planning meeting, in which representatives from the various functions identify and attempt to resolve any inconsistencies between the customers demand and the organizations' ability to supply. The final meeting is to confirm the production plan and address any longer-term issues (Moore, 2007). In order to address the development of the production and job schedule for the Clover Waters Facility, the same approach is required. The aim is to align marketing strategies to achieve what the Sales Department has set as goals or forecasts. Manufacturing and distribution operations then need to be aligned accordingly in order to ensure a high-level coordinated process of translating demand forecasts and actual customer demand into enough products to distribute to customers to satisfy the realised demand.

Most companies have a department that is devoted to perform all the activities required for the planning of operations, as do Clover, referring to this department simply as the Sales and Operations Planning Department. This department does have some separated functions, which fall under either Sales or Operations Planning, but regular meetings ensure constant alignment. Main activities performed by this department, are forecasting, rough-cut capacity planning, master production scheduling and lot-sizing.

To comprehend the type of schedules that need to be developed, and all the demands that the production needs to satisfy, it was important to note the aggregate planning strategy of Clover. Clover follows a level capacity strategy for their aggregate planning. This strategy involves maintaining a steady rate of output on a regular basis while meeting the variations occurring in demand levels by relying on overtime production and inventories as buffers to absorb the fluctuations. The advantage of following this strategy, is that it ensures consistent output rates, which assures stability of the process and the workforce is sure of their working hours. Even though a level capacity has the advantage of consistency, some disadvantages of this strategy include increased inventory costs, more overtime or idle time occurrence which effectively means underutilisation of equipment. This strategy is also very reliant on information acquired through forecasts.

Scheduling and sequencing could also be considered as an output of operations research being interpreted and translated into management principles, which is why it falls under the planning category. A number of priority rules or heuristics can be used to select the order of jobs waiting for processing. Visual aids are often used during sequencing, and some examples of these are product wheels (a pie chart with products and changeovers), sequencing boards, and Gantt-charts. In order to make the developed MPS's understandable, colour coding and simple tables can be used to convey the most important information and thus helping the Sales and Operations Planning Department to communicate their plans to the workers in the facility, to ensure that information is communicated clearly and understandably across the board.

Sales and Operations planning is directly linked to the capabilities of the facility of interest. To perform sales and operations planning effectively, the capabilities of the manufacturing equipment and warehousing capacity available at the facility need to be taken into account. For this purpose, capacity planning is another planning process essential to the effective operations planning of any facility.

2.2. Capacity planning

The purpose of capacity planning is to determine if a plant has the capacity to meet current and future production demands. It requires knowledge of the degree of capacity utilisation (i.e., the degree to which plant and equipment are currently being used), the peak capacity (i.e., the maximum capacity under ideal condition), the effective capacity (i.e., the maximum sustainable output), and the capacity requirements of products. Production plans are assessed using this information determined through the process of rough cut capacity planning (RCCP) to identify bottlenecks and determine whether requirements can be met with available equipment (Moore, 2007). The Clover Waters Facility has a warehouse capacity of 5000 pallets, and equipment efficiency is always assumed or estimated at 80%. These factors are important further on in the report where more detailed capacity planning and capabilities of the facility are researched, and used in computations of lot sizes and development of the schedules.

The warehouse capacity is specifically important for understanding and estimating inventory holding costs and determining at what levels of safety stock the operations can be run. If capacity planning and sales and operations planning is done as an overview of what should be produced and what can be produced at a facility, the next step would be to zoom in and focus on exactly what the operations within this framework should be. Key performance indicators of the effectiveness of capacity planning include the measurement of warehouse utilisation and equipment utilisation. Operations research was used to provide a more focused perspective for all the various operations required to meet the sales planning requirements within the capabilities of the Clover Waters Facility.

2.3. Operations research

Operations research modelling is a very useful, comprehensive tool which has a very wide range of possibilities in terms of the types of problems for which can provide solutions, including the lot-sizing or lot-sizing problem. Many operations research models have been developed, specifically in the bottling industry, in order to determine optimal lot sizes. There are several different approaches and methods that can be considered, thus a literature review on some of the previous applications of these methods was done to consider the type of formulation that would best suit this project's problem.

The current approach to lot sizing at Clover, is based on equipment capacity. Instead of determining production lot sizes based on demand forecasts or sales requirements. As an example, if the mixing capacity of a tank is 10 000 litres, then the lot size of any SKU produced would amount to 10 000 litres, and based on demand signals, the production frequency per month would vary according to incoming orders and consolidated with inventory. This approach maximises the utilisation of equipment, however there is a big cost implication in terms of inventory holding costs, and demand fluctuations leading to possible demand surges causing stock-outs, or inventory build-up when the demand level suddenly drops.

When performing production lot-sizing and production scheduling activities for a beverage producing facility, there are various pieces of information that need to be considered in the planning time horizon simultaneously. Some of these information pieces include several machines with different specifications and capacities, multiple products to be produced with different levels of demand, and differing productions stages for every product. The production of some of the products involves mixing water and syrup, some mixes water and flavouring, others require carbonation, and others are just bottled water products only requiring water.

Even with all the information variables available, the development of good production plans remains a difficult and complex process. Moreover, sometimes it is necessary to reschedule or change production plans due to unforeseen events occurring such as unexpected raw material shortages or machine shutdowns. To align production lot-sizing with demand planning and forecasting, approaches which aims at determining production lot sizes through mathematical models that could save time and reduce the amount of tedious work required, were researched.

Academic researchers from two different communities have been developing several different mathematical formulations for the problem of lot sizing and scheduling of single stage continuous processes with complex setup structures. The two communities involved in this research field, are Operations Research (OR community), and Process System Engineering (PSE community). Not much communication on this common topic has been observed between the communities.

Amorim et al. (2013) drew a comparison between four different formulations where a sophisticated Mixed Integer Program solver was used to solve each formulation. The results were then compared and analysed in terms of performance. These four formulations are already well defined and published by both communities that deal with the operational production planning problem involving lot-sizing and scheduling decisions where a complex setup structure is present. The complex setup structures refer to sequence dependent changeovers, setup families, and setup carry-over. The OR community formulations studied were the well-known general lot-sizing and scheduling problem (small bucket) and capacitated lot-sizing and scheduling problem (big bucket). Formulations developed most recently by the PSE community are related to time slot, and precedence-based formulations. These formulations are very complex and would be of use for larger projects with more varying changeover times between certain SKU's. Sequencing is still relatively important for the Clover Waters Facility, however the problem is simple enough to solve through basic analysis, as the changeover times between products at this facility are either 100 minutes or 45 minutes. For addressing the production lot-sizing and scheduling problem of Clover's water and ice tea bottling facility, thus, the decision was made to focus on the operations research methods.

Operations research modelling is a critical component, or technique to use if the desired output, as in this case, should be as close as possible to optimal. From studies based on operations research it is evident that some decisions need to be made before conducting the formulation of the model. Firstly, deciding on desired model outputs, "What answers do we want to obtain from the model?" and secondly, determining the objective function "What do we want to minimise?" or "What factor causes the highest cost and needs to be minimised?" These decisions are directly linked to the aim of the project and business strategies. After these decisions, factors such as lot size restrictions (unconstrained vs. constrained lot sizes), family scheduling (grouping similar products), setup cost per lot (linked to changeover times), no overlapping of processing times, warehouse capacity, warehousing strategy and due dates (distinct vs. common), should all be evaluated and decided upon.

Hall and Potts (2003, 2005) looked at an integrated scheduling and lot-sizing problem where jobs are delivered to the customer in a single shipment. They considered various delivery time based objective functions. In another study, Selvarajah and Steiner (2006) addressed a lot scheduling problem that aims at finding the number and sizes of the lots in an optimal schedule that minimises the total inventory holding and delivery cost. Robert (2007) studied an integrated lot-streaming and pegging problem, which was aimed at minimising the sum of the lot creation costs, along with the associated weighted tardiness penalties, and in his work he proposed a dynamic programming algorithm. The minimisation of lot creation costs was not clearly defined, and since the equipment of the new facility is already installed, no change in processing other than scheduling would minimise the lot creation cost. This opened the arena for exploring other optimisation parameters to be considered for using in the objective function, such as: inventory holding cost, working capital invested in inventory and labour costs.

Chrétienne, Hazır and Kedad-Sidhoum (2011) also performed a study of integrated lot-sizing and scheduling like Hall and Potts, however they split their approach into two successive sections. First, they started by addressing the single order integrated lot-sizing and scheduling problem, and derived new structures of an optimal solution. After the properties were derived, they used them to address a multiple order problem with both common, and distinct due dates.

A new mixed integer linear program (MILP) formulation was proposed by Sundaramoorthy and Maravelias (2008) for the simultaneous lot selection, assignment, and sequencing in multistage multiproduct processes. The sequential structure of multistage processes is exploited by the model. Their model is based on a continuous time representation that includes precedence based sequencing variables, which makes accounting for sequence dependent changeovers much easier.

Wongthatsanekorn and Phruksaphanrat (2015) shows that a genetic algorithm is an effective way to develop a short term for make-and-pack lot production processes. In order to enable a comparison, ant colony optimisation and tabu (or taboo) search is also part of the research. They used data of processing resources, demand of final products, changeover time, and processing time, to develop a genetic algorithm with the objective to make a production plan that satisfies all constraints, while meeting demand requirements of packed products from various product families. The relevance of their research problem concerning the ice tea and water bottling facility project, is highlighted by their description of a typical make-and-pack production problem. They define this type of problem as follows: “A typical make-and-pack production problem occurs in processing plants that produces many products such as food and beverages, chemicals, and other products. A typical process starts from mixing process in a mixing tank. The mixture is transferred into multipurpose storage tanks of different capacities for a fixed period. Then this stored mixture is moved to packing lines. The final products in various formats are shipped to customers.”

Clark (2003) explored different heuristic solution approaches for a mixed integer linear program model, which is used to help a beverage manufacturer plan the packaging (canning and bottling) of a range of liquid products. He concluded in his work that the two best formulations make hybrid use of local search and integer programming; however, they use it in rather different ways.

A mixed integer optimisation model has been presented by Ferreira, Morabito and Rangel (2009), which considers synchronisation between production stages and integrates lot-sizing and scheduling decisions. This model integrates production lot-sizing and scheduling decisions of beverage plants, with sequence dependent setup times and costs. After the model was developed, it was found that the software used to solve the model was not satisfactory; thus, they explored the development of two specific solution strategies, namely the relaxation approach and the relax-and-fix strategies.

Comparison yielded that the mixed integer linear program, in combination with a relaxed approach algorithm provides a better solution than only direct solution of the model. It is also shown that solution strategies that are used to explore the problem structure can be useful in improving the performance of general purpose optimisation software. This model was developed to solve the production scheduling problem which occurs due to the nature of the process. Production of beverages occurs for different flavours of beverages, in different bottle sizes, and can be split into two stages, A- the liquid preparation stage, and B- the bottling stage. Between these stages, synchronisation is of critical importance, as the bottleneck may alter between the two stages. Synchronisation refers to the consideration of the fact that the liquid flavour in a given tank cannot be sent to the filling lines, unless they are ready to initiate the bottling process. If synchronisation is not present, the MPS may become infeasible in practice.

The work of Liu, Pinto and Papageorgiou (2009) focuses on the development of a mixed integer linear programming model (MILP) while using a hybrid discrete/continuous time representation, to address the problem of medium term planning of a multi-stage multi-product continuous plant. Their formulation was based on the travelling salesman problem approach, but in order to solve larger model instances, they had to develop a rolling horizon algorithm. The rolling horizon algorithm is useful in cases where inventory is carried over from each preceding period to the next, such as with this particular problem where production lots need to produce to satisfy demand for the current period and carry over inventory as safety stock for the succeeding demand periods.

In an article about finding a new approach to multi-product, multi-period inventory lot-sizing (Cárdenas-Barrón, González-Velarde and Treviño-Garza, 2015) there is an extensive literature review on how operations research applications have been applied in trying to solve similar problems, and many alternative types of algorithms are discussed. All of the algorithms eventually provided optimal solutions to their specific problems for which they have been tailored. In the article, there were also mentions of several lot-sizing problems solved by making use of MILP. This article points out that operations research as a whole is not only dedicated to single mathematical algorithms and optimising all factors at once, but by building a model with essential variables, obtaining those results, and then creating another model or using the results in optimising a second set of important factors dependent on the initial results. This is known as the reduce-and-optimise approach (ROA), which reduces the feasible optimal region based on the original approach and then optimising it. By obtaining optimal lot sizes, it does not mean that a MPS would be optimal, as the facility constraints, time constraints, labour scheduling, upstream processes and procurement of raw materials need to be considered. The optimisation of lot sizes does however provide a starting point, the reduced feasible region, which can be used to base the next round of research on.

Operations research was applied to a general planning problem: lot-sizing with backlogging for stepwise transportation cost (Hwang and Kang, 2016). Setup costs and transportation cost incentives or advantages due to larger truckloads being transported was brought into the model. This was done to achieve an optimised minimum cost and maximised transportation utilisation, where inventory is considered as an advantage to some extent since it enables the exploitation of reduced per-unit transportation cost. In the course of this project however, transportation costs are not considered, however cost of stock-out vs. advantage of product availability will be considered in the same light.

An article on efficient approximation schemes for Economic Lot-sizing in continuous time (Telha and Van Vyve, 2016) discusses the classic problems of economic ordering quantity and economic lot-size. They highlight that in practice, considering decisions in continuous time is becoming more and more realistic as production processes become fully automated. Discretisation of time is made during establishing economic lot-sizes, and the granularity of the discretisation depends on the planning horizon, which in the case of this project is a one year, twelve demand period problem, with forecasting accuracy estimated at 80%. This article promoted the development of the continuous MPS for the facility in order to have an alternative that considers the possibility of automation of the facility, which relies on a constant repetitive MPS. The establishment of a peak and off-peak schedule with long duration periods also caters to this continuous automated process, as these schedules could stretch over periods of several months. The article however, also gave an indication that having a MPS that is tailored to specifically produce to satisfy only the demand of a single period is not a practical option, due to all the fluctuations in job schedules, procurement, warehouse organisation and layout and distribution it would lead to. The conclusion drawn from this article was that longer fixed MPSs would ease the planning process and overall process and product flow of the facility.

Learning from literature that has been made available, one can conclude that each industry's production system has its own characteristics. These characteristics include operational restrictions, production process implementation strategies, facility capabilities and constraints, and company policies. Constraints that accommodate these characteristics all need to be included in the planning and scheduling process to ensure that the results obtained from the mathematical models are feasible and can be integrated into the facility without any restrictions.

After a MPS is determined, it is always very important to verify and validate the schedule, to ensure that using the schedule as input, will result in desired outputs. The work of Kaylani and Atieh (2016) proposed the use of discrete event simulation to evaluate the credibility of a proposed MPS for a firm that needs to produce a large product mix. The evaluation includes measuring resources utilisation, identifying bottlenecks, measuring throughput, and evaluating the impact of each item in the product mix on these performance measures. Applying the model in order to evaluate the plan will highlight opportunities for improvement, such as changes to the product mix, or a different way of allocating resources. This verification and validation process, which is suggested, is an inherent part of developing a feasible and validated MPS for the Clover Waters Facility. Infor AS is not a discrete event simulation tool; however, the software evaluates all the factors that are evaluated by discrete event simulation. Thus, by using Infor AS, the validation of the feasibility of the MPS is ensured. This software program verifies and validates the feasibility of each lot as it is scheduled. If feasibility is an issue, or some other error due to the upstream processes is encountered, the program does not allow that SKU lot production to be scheduled. The schedule then has to be changed or the production lot should be scheduled differently in order to ensure that all upstream resources required will be ready to produce the lot at the desired time.

Production planning software is becoming increasingly more sophisticated. These software packages have the built in functionality of being able to simulate the production process over a specified period, to enable validation and verification of the proposed MPS. Infor AS, the software used by Clover, is also equipped with this capability, and will be used along with operations research modelling in the development of an optimised MPS.

2.4. Infor Advanced Scheduler

Infor Advanced Scheduler is a software program that is used at Clover for scheduling the production at all of their other dairy processing and packaging facilities. For each facility, a database is set up which contains the details for the manufacturing of each individual product. It contains all the ratios of ingredients, time duration and equipment availability for each preceding process step up to the final production of the product.

In order to develop the MPS, each production lot is created by selecting the SKU and lot size. A coloured bar representing the created production lot is represented in the working area on a timeline. All the production lots that are created can then be sequenced within the timeframe specified in the database for the facility. If any rules are broken or time is exceeded, the program will not allow the discrepancy, and forces the user to either move a different SKU into the time slot, or move the problematic SKU into a timeslot where execution would not be problematic. This infeasibility prevention mechanism eliminates the problem of running into scheduling problems with coordinating upstream processes and raw material procurement planning. To show the user interface, Figure 2.1 is a screenshot of a typical MPS for a single day, and Figure 2.2 shows how the error of a production lot placed in an infeasible slot can immediately be observed.

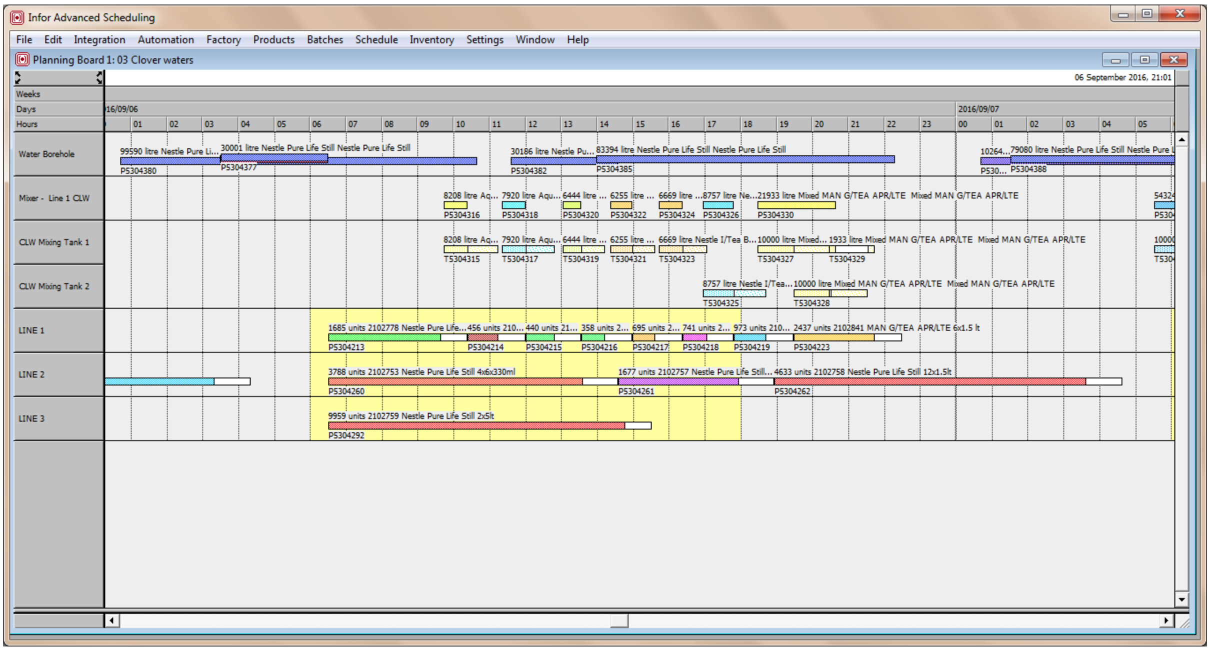

Figure 2.1: User interface for observing a typical MPS for a day.

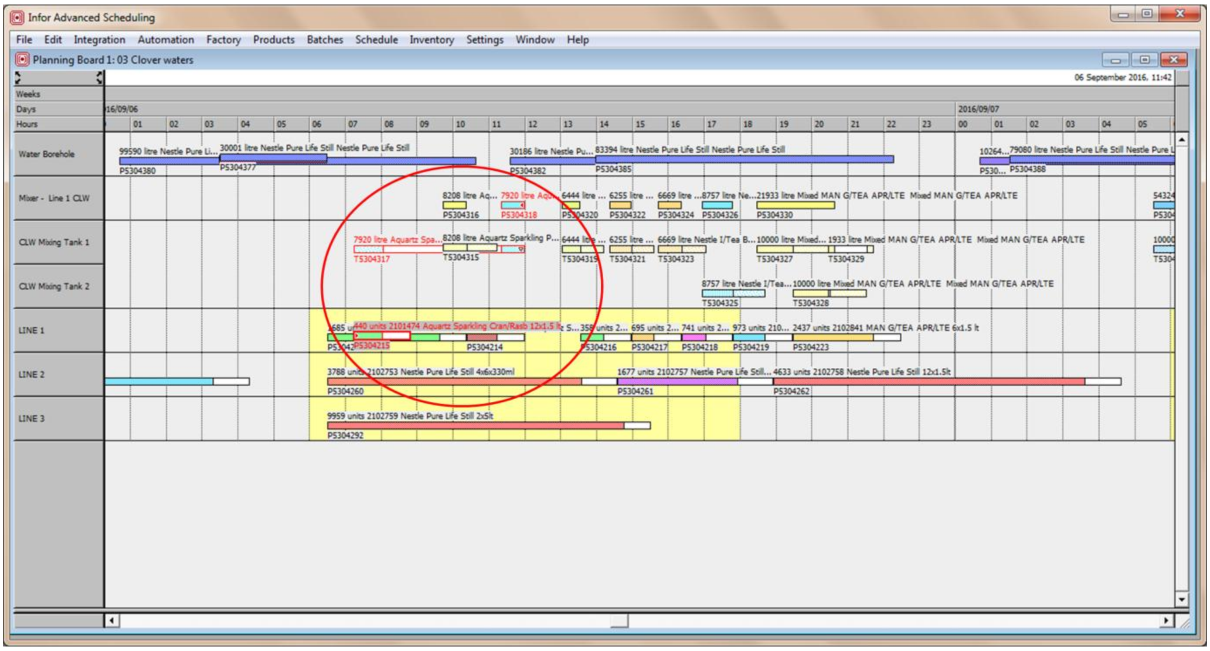

Figure 2.2: Red circle highlighting Infor AS's built in function to prevent infeasible scheduling by highlighting the problematic production lots in red.

After complete compilation of a production plan, a production run simulation is executed. This simulation of a production run draws data from all the databases including the facility information and created schedule, and ultimately the program delivers the output in an Excel spreadsheet format. The spreadsheet provides the execution details of the production plan, providing the starting and ending times of each lot, the total changeover times between lots. This output then enables analysis of total execution time and output of the schedule, which aids in the selection of a MPS that results in the highest production yield, within the smallest production time, with minimal overtime being required.

2.5. Conclusion

The literature review has confirmed that the application of operations research in order to address the lot-sizing and production sequence problem is a suitable approach and a good idea. Incorporating the results into the Infor AS software to test the execution and feasibility of proposed MPSs will provide all the necessary information to evaluate alternative schedules and make an informed decision on selecting the optimal schedule.

A mixed integer linear programming model with inventory constraints, making use of stepwise cost functions will be satisfactory in finding a solution for the problem. In order to construct these models, all the requirements, corporate rules, facility constraints and other critical factors need to be collected and translated into specific descriptive constraints. The next chapter will address this extensively.

Chapter 3: Process description, data analysis and parameter establishment

In this chapter the data about the bottling facility capabilities, the demand forecast of each SKU for the next year, facility capacity and capabilities and company policies are gathered and analysed. The data are used to formulate parameters and constraints which will be used as input parameters, firstly in an operations research model to determine optimal lot sizes per SKU, and secondly, at a later stage for a production scheduling model.

3.1. The facility

The ice tea and water bottling plant is situated in Centurion. This facility is equipped with four filling lines. Filling lines 1, 2 and 3 are the lines that are under investigation for the MPS. Filling line 4 is only used for bottling large 5l and 21l water bottles for corporate use and exports to neighbouring countries. This project will only focus on filling lines 1, 2 and 3. Filling line 1 produces the greatest variety of products, which includes Aquartz sparkling mineral and flavoured water in six different flavours, Nestlé Pure Life sparkling mineral water, Manhattan Ice Tea in ten different flavours and Nestea in three flavours. Filling line 2 only bottles still water, both Aquartz and Nestlé Pure Life, in a variety of sizes. Filling line 3 bottles Aquartz and Nestle Pure Life still mineral water in 5l bottles.

3.1.1. Process flow

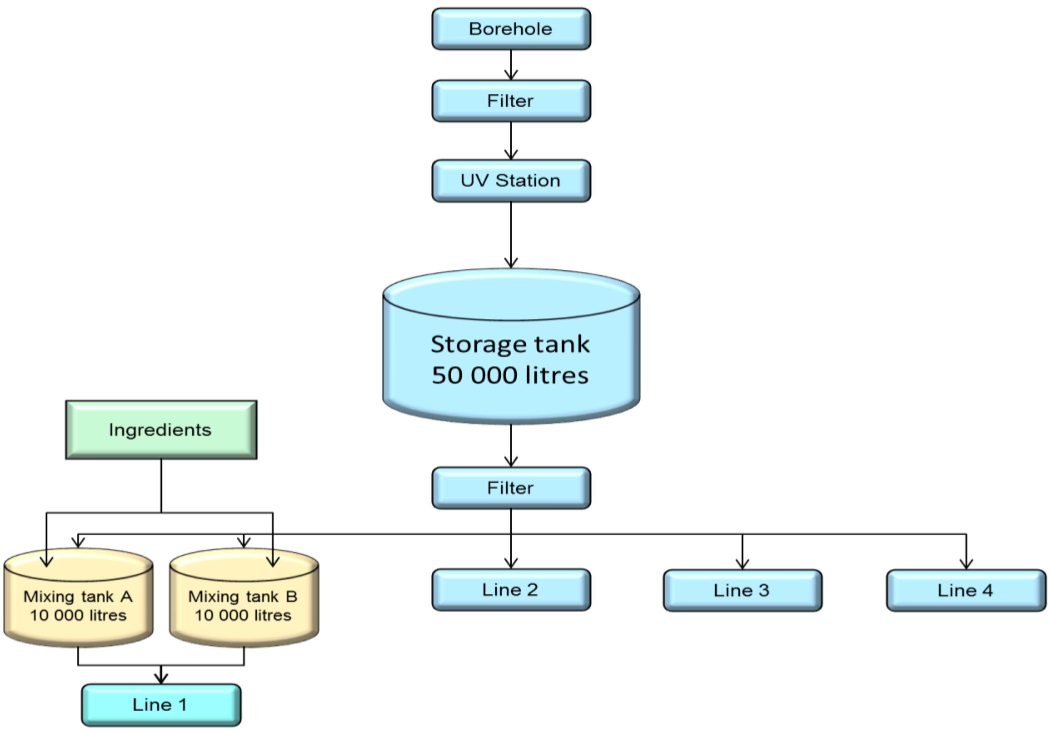

Figure 3.1: Clover water and ice tea bottling facility process flow.

The facility is equipped with three separate filling lines, which are all fed with water from a single borehole water source. The fresh water is pumped from the borehole to the first filtering stage, then through to a second filtering process, which uses ultra violet (UV) technology to ensure the water is as clean and pure as possible. The purified water is then pumped into a water storage tank with a capacity of 50 000 litres. When water is pumped out of the storage tank, it flows through another water filter, from which the line then splits into three different lines to feed each of the filling lines. Filling lines 2 and 3 only bottle pure still water, and are fed directly from the filter. Filling line 1, which produces ice tea, flavoured sparkling water and sparkling mineral water, has two on-line mixing tanks with a capacity of 10 000 litres each. In these mixing tanks, all the ingredients required, and water from the filtering process is mixed to produce the specific beverage. In the case of sparkling water, carbonation is also done in the mixing tanks. The mixing tanks then alternately feed the filling line, which ensures a continuous flow of product, while the one tank feeds, mixing is done in the other one. Figure 3.1 provides a visual representation of the process flow in the bottling facility.

3.1.2. Products

In Table 1 a description of all the products produced on each line is given, along with the different sizes in which they are produced. Filling line 1 is the only line that is used for flavoured and carbonated (sparkling) beverages; line 2 and 3 only bottles still mineral water. No mineral water is bottled on line 1, except for the Aquartz 750ml still water with a sports cap, as this is the only machine with the appropriate settings to accommodate for the bottling requirement of this particular stock keeping unit (SKU). The MPS that needs to be formulated considers 43 different SKU's.

Table 1: Products bottled at each filling line.

Filling line	Product	Size
1	Manhattan ice tea: Blackcurrant	500ml
1	Manhattan ice tea: Pineapple	500ml
1	Manhattan ice tea: Lemon	500ml / 1.5l
1	Manhattan ice tea: Peach	500ml / 1.5l
1	Manhattan ice tea: Lemon lite	500ml / 1.5l
1	Manhattan ice tea: Peach lite	500ml / 1.5l
1	Manhattan ice tea: Apple/mint with ginseng	500ml
1	Manhattan ice tea: Ruby grapefruit/strawberry	500ml /1.5l
1	Manhattan ice tea: Green tea kiwi/pear lite	500ml / 1.5l
1	Manhattan ice tea: White tea exotic fruit	500ml
1	Aquartz Sparkling flavoured water: Mango	500ml
1	Aquartz Sparkling flavoured water: Lemon/Lime	500ml
1	Aquartz Sparkling flavoured water: Litchi	500ml / 1.5l
1	Aquartz Sparkling flavoured water: Naartjie	500ml / 1.5l
1	Aquartz Sparkling flavoured water: Peach passion	500ml / 1.5l
1	Aquartz Sparkling flavoured water: Cran-/Raspberry	500ml
1	Nestea Peach	500ml / 1.5l

1	Nestea Berry	500ml / 1.5l
1	Nestea Lemon	500ml / 1.5l
1	Nestle Pure Life sparkling mineral water	500ml / 1.5l
1	Aquartz sparkling mineral water	500ml / 1.5l
1	Aquartz mineral water still	750ml sports cap
2	Nestle Pure Life still	330ml/500ml/750ml/1.5l
2	Aquartz mineral water still	500ml/1.5l
3	Nestle Pure Life still	5l / 18.9l
3	Aquartz mineral water still	5l

3.1.3. Production capacity

Each filling line has its own rate at which the different products are produced. This information is required to enable the scheduling of production to be performed accurately and in conjunction with product demand forecast, a detailed schedule with times and duration can be set up. These rates also affect the cost of manufacturing as it directly influences labour cost with regards to overtime. Manufacturing costs will be addressed in Section 3.2.2. Table 2 summarises the different rates at which each filling line produces the beverages.

Table 2: Processing times per bottle size of each filling line.

Filling line	Size	Units/hour	Litres/hour	80% efficiency (units)
1	1.5l	8 000	12 000	6 400
	750ml	9 000	6 750	7 200
	500ml	10 000	5 000	8 000
	330ml	10 000	3 300	8 000
2	1.5l	7 500	11 250	6 000
	750ml	15 000	11 250	12 000
	500ml	15 000	7 500	12 000
	330ml	15 000	4 950	12 000
3	5l	3 000	15 000	2 400

Setup times and changeover times are inherent to a process which requires different products to be manufactured on a single machine. Filling line 1 is subject to two factors which affect changeover time: a thorough rinse of the mixing tank is required between each flavour change, and bottle sizes need to be switched along with labels. Label and bottle size change is one combined factor that calls for adjustments on the equipment. The standardised changeover times used in planning for this facility are 45 minutes between flavours, and 100 minutes between bottle sizes. Another general rule is that when both flavour and size changeover happens simultaneously, the total duration is one hour, an assumption deducted from the fact that flavour changeover and size changeover are parallel processes. Filling line 2 is not subject to rinsing changeover time, since the water does not enter a mixing tank before filling because only still mineral water is produced. However, labels need to be switched and machine adjustments also have to be made during a size change or brand change, to suit the different cap sizes, bottle heights and neck sizes.

Considering the formulation of optimisation models, the most effective way to convey changeover information is in the form of a changeover time matrix. This matrix captures the changeover time in hours that is required between two different products. The changeover time matrix is available in Appendix B. Other scheduled production downtimes are for a weekly four-stage CIP (cleaning and inspection process) which has a duration time of two hours, and an hour long hot sterilisation process, which is mandated to be executed daily (except for days where CIP is performed) in order to ensure hygiene standards are adhered to and no compromise is made on quality.

Three important parameters that need to be taken into account concerning production capacity and planning are:

a. Scheduling must assume an 80% line efficiency.
b. The minimum lot size of any SKU is 5 000 litres.
c. The entire company works with the factor of 4.2 weeks per month.

The capabilities of the facility are now established and we know how the facility operates and what products can be produced. The next step is to determine what performance in terms of types of SKU's which are demanded, and the forecasting and capacity planning is the next phase.

3.2. Forecasting and capacity requirements planning

Each of the different departments make use different units of the products to communicate their forecasts or planning requirements or capacity. In order to understand and ease the conversion of data between the departments, Table 3 provides all the conversion factors for each product group. This table is very helpful to place the following section into context where there is referred to litres, units, cases and pallets in different parts, depending on the department where data originates from.

Table 3: Product conversion factors.

Product Group	litres / bottle	bottles / case	litres / case	cases / pallet
Aquartz sparkling/ still, flavoured/ mineral water 1.5l	1.50	12	18	50
Aquartz sparkling/ still, flavoured/ mineral water 500ml	0.50	24	12	72
Aquartz mineral still water w/ sports cap 750ml	0.75	12	9	90
Aquartz still mineral water 5l	5.00	4	20	48
Clover Manhattan Ice Tea all flavours 500ml	0.50	24	12	60
Clover Manhattan Ice Tea all flavours 1.5l	1.50	6	9	100
Nestea Ice Tea 500ml	0.50	24	12	60
Nestea Ice Tea 1.5l	1.50	6	9	100
Nestle Pure Life Still 4x6x330ml	0.33	24	7.92	108
Nestle Pure Life sparkling/still water 500 ml	0.50	24	12	84
Nestle Pure Life sparkling/still water 750ml	0.75	24	18	45
Nestle Pure Life sparkling/still water 1.5l	1.50	12	18	56

Nestle Pure Life sparkling/still water 5l	5.00	2	10	84

3.2.1. Sales forecast

The Sales Department has established a sales forecast for the year from July 2016 to June 2017, based on historical data and seasonal demand patterns. The forecast is done in litres required per SKU per month. Conversion factors were used to translate the forecasts into cases since planning and warehouse management is done in number of cases per SKU, and the forecasts were also converted into units per product required. The monthly forecast of each SKU for the entire forecasting period is available in Appendix C. These forecasts were used to establish how many direct hours of production will be required for each line per month.

The facility will run line 1 and 2 for two eight-hour shifts per day, and line 3 for only one eight-hour shift per day. In order to establish roughly how many days of production will be required at the very least, without incorporating specific changeover times, but an allowance factor for changeover times, the production rate data and forecasting data was used in conjunction with the planning rules to establish the production days per line required, which is given in Table 4. The allowance factor of changeover times is 2 times the number of SKU's on the line, divided by 14.5 (the effective production hours per day). This allowance factor is added to the total required days, to give an initial rough estimate of production time that will be required.

Table 4: Forecasted number of production days required.

Line	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	16	19	21	21	22	21	21	20	20	18	16	15
2	16	20	21	24	25	23	24	23	22	19	16	15
3	19	21	22	23	26	26	24	24	20	18	15	15

Through further analysis of the data, a peak and off-peak season was identified from looking at production hours required. Figure 3.2 illustrates the production hours, directly linked to demand required on each filling line and Figure 3.3 shows the total production time and a clear peak was observed between October and February.

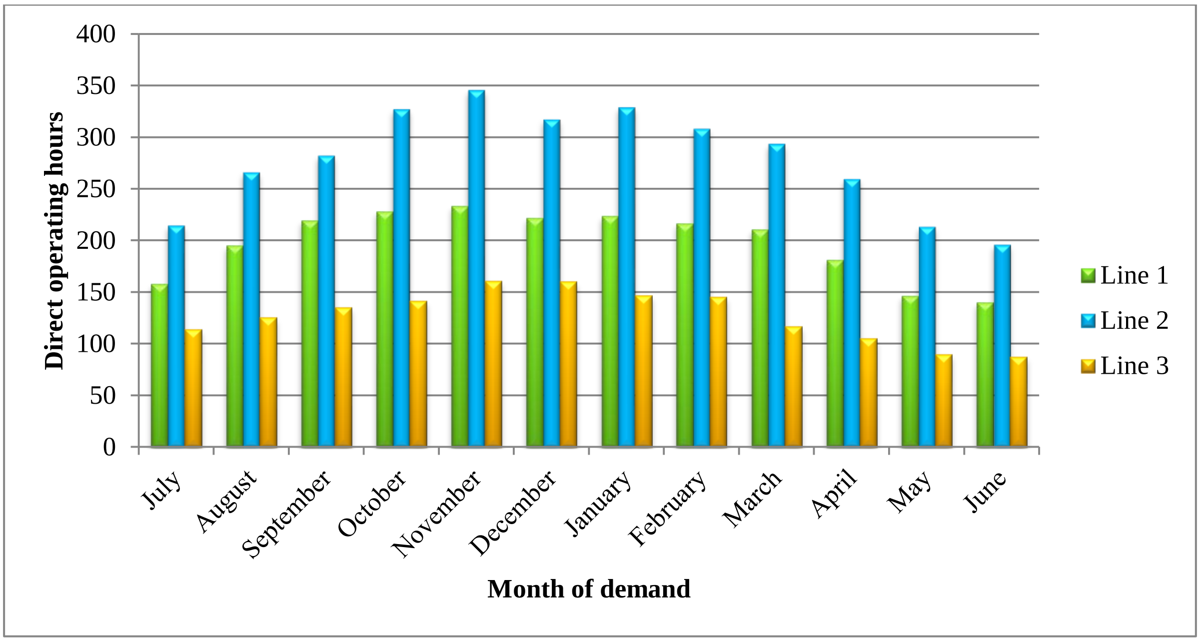

Figure 3.2: Forecasted required direct production hours per line per month from July 2016 to June 2017.

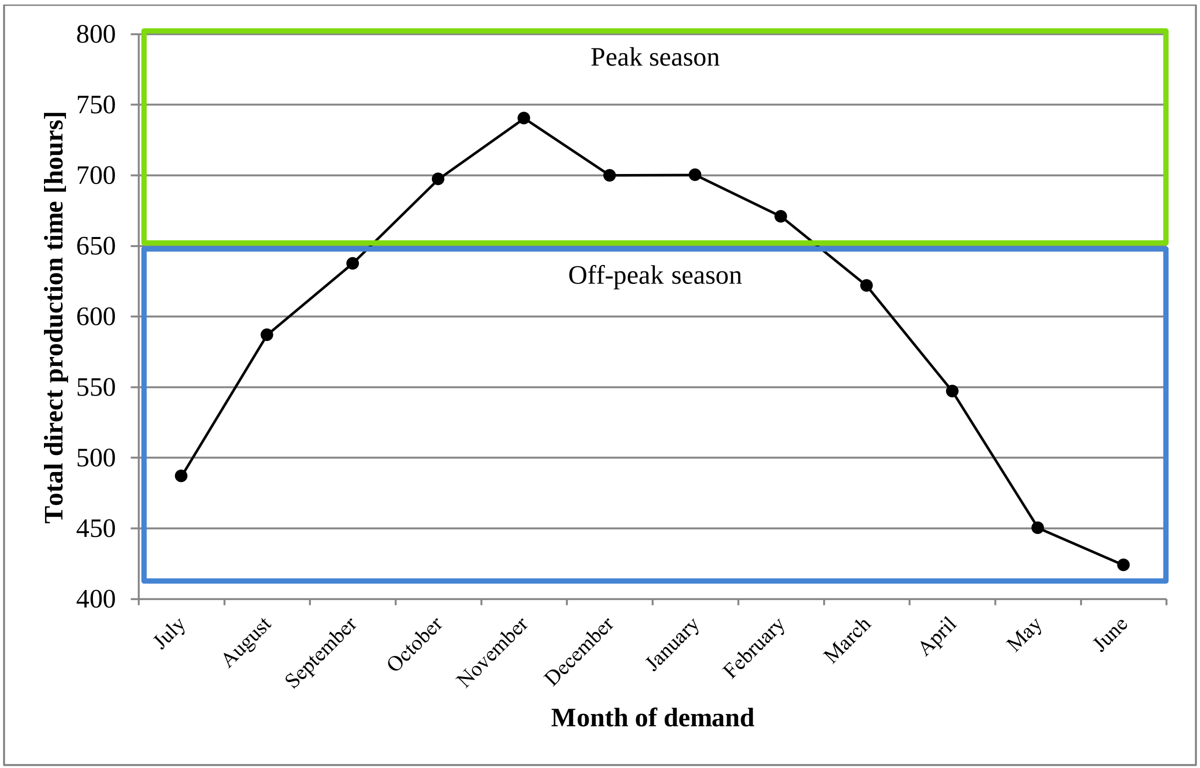

Figure 3.3: Total forecasted production hours identifying peak and off-peak season from July 2016 to June 2017.

From Figure 3.3 it can be concluded that the time period from October to February is peak-season; these are also the warmer months where consumers prefer cold beverages. March to September is off-peak season, the cooler months; the possibility of either building inventory at a steady rate during off-peak season, or developing a different MPS for the off-peak season, depending on labour costs, will be explored. Historical forecast versus sales data will be analysed during the optimisation phase of the project, in order to relate production frequency and agility of the facility to respond to actual market demand.

3.2.2. Costs

Two main cost components are considered in this facility as key factors in making decisions about the operation of the facility. These two cost components are labour costs, and inventory holding costs, and will be discussed in this section to give an overview of the factors creating these costs and the approximate amount of money involved.

3.2.2.1. Labour costs

The only cost directly related to the MPS is direct labour cost. If a shift is dropped, it could mean a major cost saving can be incurred. However, a shift can only be dropped if the required 180 normal working hours for which the workers are employed, are exceeded. Cost of labour is a major driver in the minimisation of production time, since the ultimate objective is to fulfil demand as effectively and efficiently as possible, at the lowest cost. Table 5 provides a summary of the costs of labour per production team. Each line has its own production team, which runs the entire line during the shift.

Table 5: Summary of labour cost per production team.

Role	Normal Time					Overtime		Sunday	
	Monthly cost to company	Basic	Normal hours	Normal rate/hour	Shift cost	Rate/hour	Shift cost	Rate/hour	Shift cost
Team leader	R13 000	R 11 100	180	R 72.22	R 577.78	R 92.50	R 740	R 123.33	R 986.67
Attendant 1	R 7 700	R 6 850	180	R 42.78	R 342.22	R 57.08	R 456.67	R76.11	R 608.89
Attendant 2	R 7 700	R 6 850	180	R 42.78	R 342.22	R 57.08	R 456.67	R76.11	R 608.89
Attendant 3	R 7 700	R 6 850	180	R 42.78	R 342.22	R 57.08	R 456.67	R76.11	R 608.89
General Worker 1	R 7 500	R 6 850	180	R41.67	R 333.33	R 57.08	R 456.67	R76.11	R 608.89
General Worker 2	R 7 500	R 6 850	180	R41.67	R 333.33	R 57.08	R 456.67	R76.11	R 608.89
Shift leader	R 23 000	R 20 000	180	R127.78	R 1022.22	R166.67	R 1 333.33	R 222.22	R 1777.78
Forklift driver	R 8 900	R 7 900	180	R49.44	R 395.56	R 65.83	R 526.67	R 87.78	R 702.22
TOTAL				R 461.11	R 3688.89	R 610.42	R 4883.33	R 813.89	R 6511.11

3.2.2.2. Inventory holding costs

The mandatory quarantine period for all ambient beverages is seven days. During this period samples undergo quality tests, and need to be approved before the products are allowed to be dispatched. The implication of the quarantine period is that all SKU's will incur a minimum inventory holding cost for the seven days it is held in quarantine. The Planning Department requires a minimum stockholding of two weeks in total. Any inventory holding costs above the two week mandatory stockholding can be considered as excess inventory expense incurred due to the MPS. Furthermore, storage capacity at the facility is limited to 5 000 pallets. Should the MPS incur a stockholding above the capacity, offsite storage should be organised, and an additional cost will be incurred per pallet above the 5 000 limit. The additional cost will be R135.00 per pallet per month or fraction of a month, and transportation costs to the alternative facility per pallet will be incurred at a rate of R101.75 per pallet.

3.3. Parameter establishment

After the completed data analysis, capacity establishment and requirements planning, a final set of governing parameters was identified, which will be used in the following sections regarding the operations research modelling, actual creation of alternative schedules, and evaluation of the alternatives to find the optimal schedule. The initial parameters, which are guidelines for the operations research modelling process, are:

1. Monthly demand for period (month) *t* per SKU must be met by the end of period (month) *t*.
2. Minimum lot size is 5 000 litres.
3. Preferred production frequency is weekly, thus, 4.2 times per demand period (month).
4. If the production frequency causes the lot size of a certain SKU to be less than 10 000 litres, the production frequency can be reduced for the specific SKU.
5. Changeover times should be linked to direct labour cost.
6. Inventory cost of R135 (storage) plus R101.75 (transportation) is incurred per pallet exceeding the warehouse capacity of 5 000 pallets.
7. Two weeks' worth of stock needs to be kept on hand at all times, for agility purposes, acting as a buffer between forecasted and actual market demand.
8. The total production time (including cleaning and changeovers), available per month for line 1 and 2 is calculated as: 7 days x 4.2 weeks per period (month) *t* x 16 hours per day = 470.4 hours, and line 3 is available for 235.2 hours.
9. Labour cost is a stepwise linear function. Cost of direct labour for the first 180 hours is R461.11 per hour, for every hour between 180 and 406 hours it is R610.42, and for every hour above that, R813.89.
10. Time for hot sterilisation is one hour per every 2 shifts of twelve hours of production, and 2 hours at the start of every week for the CIP is mandatory and needs to be incorporated into the models.

The parameters which have now been established, along with all the other important information and data which have been documented in Chapter 3 will be used in Chapter 4 in order to mathematically formulate the operations research models for optimising lot sizes and production sequencing.

Chapter 4: Operations research models and parameter optimisation

In this chapter, operations research takes action. Prior to the development of mathematical models for determining optimal lot sizes, other optimisation parameters which influence production time and inventory costs are also determined. This is to put the most realistic data into the models, and to use in the succeeding chapter to develop MPSs. The formulation of MILP optimisation models to determine optimal lot sizes are discussed. The lot-sizing models are programmed into Lingo and the results are analysed and adjusted with relaxation of some rules in order to enable tailoring the schedule to be feasible and optimal in context of the facility and the industry. All of the results obtained through the operations research applied are used to develop feasible MPS alternatives using Infor AS software.

4.1. Optimisation parameters

The following parameters which will be discussed contributes greatly toward the trade-offs and analytic decisions which went into sequencing and creating the alternative schedules. A lot of these involve initial judgement decisions to be made that can be verified afterwards when a schedule has been completed and the effect of the parameter can be determined. These factors needed to be determined, in order to be used as data inputs for the lot-sizing optimisation models, since they all are factors that have an influence on the objective of determining a schedule that minimises labour cost and inventory holding costs.

4.1.1. Changeover times

Minimising the changeover time (in minutes) between production lots is a big contributing factor that plays a role in setting up the MPS. To determine an optimal production sequence, a changeover time matrix was created, which enabled the identification of optimal production sequence paths that ensure the total changeover time during production is minimised.

For line 1, the different SKU's were grouped together according to the product type i.e. ice tea, flavoured sparkling water, still water or unflavoured sparkling water, and within the group, the changeover time is the minimum of 45 minutes regardless of the sequence. In order to sequence the different groups, changeover times needed to be selected, which was the smallest time to changeover from one group of SKU's to the next, thus minimising the occurrence of 100 minute changeovers. Three alternative sequence paths were identified, and all three of them resulted in exactly the same total changeover time, thus any path could be a viable optimal selection. Sequence path A as pictured in Figure 4.1 was selected as the optimal sequence due to its most logical chronological sequence.

It will be seen further on in the report where actual scheduling was done, that the sequence was used, however, alterations needed to be made to accommodate SKU's which need to be produced on a weekly frequency instead of the assumed once-monthly frequency. Neither line 2 nor line 3 have the possibility of optimising the production sequence, since the changeover time on both of these lines are set at 100 minutes between each SKU.

	PATH A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1	Aquartz Sparkling Peach/Passion 12x1.5lt	0	45	45	100	100	45	45	45	1	1	1	1	1	1	1	45	45	45	45	45	45	45	1	1	1	1	1	1	1	1	1	1	1	1	1	45	
2	Aquartz Sparkling Cran/Rasb 12x1.5lt	45	0	45	100	100	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
3	Aquartz Sparkling Lem/Lime 12x1.5lt	45	45	0	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
4	Aquartz Sparkling Mango 4x6x500ml	100	100	100	0	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
5	Aquartz Mineral Still 2x6x750ml	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
6	Nestea Ice Tea Berry 6x1.5LT	45	45	45	100	100	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
7	Nestea Ice Tea Peach 6x1.5LT	45	45	45	100	100	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
8	Nestea Ice Tea Lemon 6x1.5LT	45	45	45	100	100	45	45	0	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
9	Clover Manhattan Ice Tea Blackcurrent (6X4)X500ml	100	100	100	45	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
10	Clover Manhattan Ice Tea Pineapple (6X4)X500ml	100	100	100	45	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
11	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
12	Clover Manhattan Ice Tea Peach (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
13	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
14	Clover Manhattan Ice Tea Lemon (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
15	Nestle Pure Life Sparkling 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
16	Nestle Pure Life Sparkling 12x1.5lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
17	MAN G/TEA APR/LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
18	MAN I/TEA PEACH LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
19	MAN I/TEA PEACH 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
20	MAN I/TEA LEMON 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
21	MAN G/TEA RB/GF/ST 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
22	MAN G/TEA KI/PEA LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
23	Nestea Ice Tea Peach 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	45	100	
24	Nestea Ice Tea Berry 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	100	
25	Nestea Ice Tea Lemon 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	0	45	45	45	45	45	45	45	45	45	45	100	
26	Aquartz Sparkling Lemon/Lime 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	0	45	45	45	45	45	45	45	45	45	100	
27	Aquartz Sparkling Litchi 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	0	45	45	45	45	45	45	45	45	100	
28	Aquartz Sparkling Naartjie 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	0	45	45	45	45	45	45	45	100	
29	Aquartz Sparkling Peach Passion 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	0	45	45	45	45	45	45	100	
30	Aquartz Sparkling Cran/Raspberry 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	0	45	45	45	45	45	100	
31	Aquartz Mineral Water Sparkling 4X6X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	0	45	45	45	45	100	
32	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	0	45	45	45	100	
33	Manhattan White I/Tea Exotic Fruit 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	0	45	45	100	
34	Clover Manhattan Ice Tea Crisp Apple/Mint (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	0	45	100	
35	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry 6X4X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	0	100	
36	Aquartz Mineral Water Sparkling 12X1.5 lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	0	
	Sequence PATH A	1	2	3	6	7	8	16	17	18	19	20	21	22	36	23	24	25	26	27	28	29	30	31	32	33	34	35	9	10	11	12	13	14	15	4	5	
	Assigned changeover time	0	45	45	45	45	45	45	45	45	45	45	45	45	45	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	1685

Figure 4.1: Changeover time matrix with sequence path A.

	PATH B	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1	Aquartz Sparkling Peach/Passion 12x1.5lt	0	45	45	100	100	45	45	45	1	1	1	1	1	1	1	45	45	45	45	45	45	45	1	1	1	1	1	1	1	1	1	1	1	1	1	45	
2	Aquartz Sparkling Cran/Rasb 12x1.5lt	45	0	45	100	100	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
3	Aquartz Sparkling Lem/Lime 12x1.5lt	45	45	0	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
4	Aquartz Sparkling Mango 4x6x500ml	100	100	100	0	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
5	Aquartz Mineral Still 2x6x750ml	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
6	Nestea Ice Tea Berry 6x1.5LT	45	45	45	100	100	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
7	Nestea Ice Tea Peach 6x1.5LT	45	45	45	100	100	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
8	Nestea Ice Tea Lemon 6x1.5LT	45	45	45	100	100	45	45	0	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
9	Clover Manhattan Ice Tea Blackcurrent (6X4)X500ml	100	100	100	45	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
10	Clover Manhattan Ice Tea Pineapple (6X4)X500ml	100	100	100	45	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
11	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
12	Clover Manhattan Ice Tea Peach (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
13	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
14	Clover Manhattan Ice Tea Lemon (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
15	Nestle Pure Life Sparkling 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
16	Nestle Pure Life Sparkling 12x1.5lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
17	MAN G/TEA APR/LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
18	MAN I/TEA PEACH LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
19	MAN I/TEA PEACH 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
20	MAN I/TEA LEMON 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
21	MAN G/TEA RB/GF/ST 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
22	MAN G/TEA KI/PEA LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
23	Nestea Ice Tea Peach 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	45	100	
24	Nestea Ice Tea Berry 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	100	
25	Nestea Ice Tea Lemon 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	0	45	45	45	45	45	45	45	45	45	45	100	
26	Aquartz Sparkling Lemon/Lime 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	0	45	45	45	45	45	45	45	45	45	100	
27	Aquartz Sparkling Litchi 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	0	45	45	45	45	45	45	45	45	100	
28	Aquartz Sparkling Naartjie 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	0	45	45	45	45	45	45	45	100	
29	Aquartz Sparkling Peach Passion 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	0	45	45	45	45	45	45	100	
30	Aquartz Sparkling Cran/Raspberry 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	0	45	45	45	45	45	100	
31	Aquartz Mineral Water Sparkling 4X6X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	0	45	45	45	45	100	
32	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	0	45	45	45	100	
33	Manhattan White I/Tea Exotic Fruit 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	0	45	45	100	
34	Clover Manhattan Ice Tea Crisp Apple/Mint (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	0	45	100	
35	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry 6X4X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	0	100	
36	Aquartz Mineral Water Sparkling 12X1.5 lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	0	
	Sequence PATH B	9	10	11	12	13	14	15	4	23	24	25	26	27	28	29	30	31	32	33	34	35	36	22	21	20	19	18	17	16	8	7	6	3	2	1	5	
	Assigned changeover time	0	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	45	45	45	45	45	45	45	45	45	45	45	45	45	100	1685

Figure 4.2: Changeover time matrix with sequence path B.

	PATH C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
1	Aquartz Sparkling Peach/Passion 12x1.5lt	0	45	45	100	100	45	45	45	1	1	1	1	1	1	1	45	45	45	45	45	45	45	1	1	1	1	1	1	1	1	1	1	1	1	1	45	
2	Aquartz Sparkling Cran/Rasb 12x1.5lt	45	0	45	100	100	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
3	Aquartz Sparkling Lem/Lime 12x1.5lt	45	45	0	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
4	Aquartz Sparkling Mango 4x6x500ml	100	100	100	0	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
5	Aquartz Mineral Still 2x6x750ml	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
6	Nestea Ice Tea Berry 6x1.5LT	45	45	45	100	100	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
7	Nestea Ice Tea Peach 6x1.5LT	45	45	45	100	100	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
8	Nestea Ice Tea Lemon 6x1.5LT	45	45	45	100	100	45	45	0	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
9	Clover Manhattan Ice Tea Blackcurrent (6X4)X500ml	100	100	100	45	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
10	Clover Manhattan Ice Tea Pineapple (6X4)X500ml	100	100	100	45	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
11	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
12	Clover Manhattan Ice Tea Peach (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
13	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
14	Clover Manhattan Ice Tea Lemon (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	100	
15	Nestle Pure Life Sparkling 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
16	Nestle Pure Life Sparkling 12x1.5lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
17	MAN G/TEA APR/LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	0	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
18	MAN I/TEA PEACH LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	0	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
19	MAN I/TEA PEACH 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	0	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
20	MAN I/TEA LEMON 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	0	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
21	MAN G/TEA RB/GF/ST 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
22	MAN G/TEA KI/PEA LTE 6x1.5Lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100	45	
23	Nestea Ice Tea Peach 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	45	100	
24	Nestea Ice Tea Berry 4x6x500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	0	45	45	45	45	45	45	45	45	45	45	45	100	
25	Nestea Ice Tea Lemon 4x6x500ml	101	102	103	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	0	45	45	45	45	45	45	45	45	45	45	100	
26	Aquartz Sparkling Lemon/Lime 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	0	45	45	45	45	45	45	45	45	45	100	
27	Aquartz Sparkling Litchi 24X500 ml	102	103	104	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	0	45	45	45	45	45	45	45	45	100	
28	Aquartz Sparkling Naartjie 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	0	45	45	45	45	45	45	45	100	
29	Aquartz Sparkling Peach Passion 24X500 ml	103	104	105	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	0	45	45	45	45	45	45	100	
30	Aquartz Sparkling Cran/Raspberry 24X500 ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	0	45	45	45	45	45	100	
31	Aquartz Mineral Water Sparkling 4X6X500 ml	104	105	106	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	0	45	45	45	45	100	
32	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	0	45	45	45	100	
33	Manhattan White I/Tea Exotic Fruit 4x6x500ml	105	106	107	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	0	45	45	100	
34	Clover Manhattan Ice Tea Crisp Apple/Mint (6X4)X500ml	100	100	100	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	0	45	100	
35	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry 6X4X500ml	106	107	108	45	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45	45	45	45	45	45	45	0	100	
36	Aquartz Mineral Water Sparkling 12X1.5 lt	45	45	45	100	100	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	100	100	100	100	100	0	
	Sequence PATH C	5	36	8	7	6	16	17	18	19	20	21	22	3	2	1	15	14	13	12	11	10	9	23	24	25	26	27	28	29	30	31	32	33	34	35	4	
	Assigned changeover time	0	100	45	45	45	45	45	45	45	45	45	45	45	45	45	100	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	1685

Figure 4.3: Changeover time matrix with sequence path C.

4.1.2. Inventory holding cost

Minimised inventory is desired by all manufacturing facilities, as there are inherent holding costs, however, safety stock levels are important for the managing of demand satisfaction, inventory control and customer service levels that need to be maintained. Since this planning is being done for a new facility with no historical data that can be used to analyse forecast accuracy of these specific SKU's, the general forecasting accuracy of the company of 80% will be used, and customer service level has been set at 98%. The above-mentioned levels resulted in the decision to keep safety stock at a level of two weeks' stock. The general inventory constraints will be used to ensure the safety stock level, and a factor of 4.2 weeks per month will contribute in determining the amount of forecasted demand that will be the safety stock level for the following month.

Inventory management with limited capacity poses the challenge of an if-then constraint which is incorporated into the model. The constraint implies that if the total number of pallets in inventory exceeds the warehouse capacity, only then additional warehousing costs per pallet will be incurred. Clover's Supply Chain Manager confirmed that they purposefully designed the facility with a very large warehouse; however, certainty of satisfactory capacity was not obtained until the results of this research confirmed that the warehouse has been built large enough to accommodate the warehousing capacity required by all the MPSs. This implies that additional warehousing cost, however always an important factor, will not be an influencer on the evaluation and trade-offs between MPS alternatives for the Clover Waters Facility at the current demand levels, since it is zero.

The safety stock level decision by Clover will be challenged and evaluated during the sensitivity analysis in Chapter 6, where the cost of inventory and the effect of reduced inventory levels are explored. "If the safety stock level were to be reduced, what would the cost implication be on the MPS?", "Is it possible to operate on reduced inventories?" These questions can give an indication of how the operations and inventory management could possibly add to the efficiency and cost effectiveness of the MPS. Costs involved in calculating the inventory holding cost, which needed to be converted into holding cost per case per month that can be seen in Table 6 are:

- Cost of capital – 14% of production cost per year
- Handling cost per pallet
- Holding cost per litre

Table 6: Calculated holding cost per case of SKU per month.

SKU	Production cost (R)	Capital cost (R)	Holding cost (R)	Handling cost (R)	Total cost (R)
Aquartz Sparkling Peach/Passion 12x1.5l	78.89	0.92	0.83	2.04	R 3.79
Aquartz Sparkling Cran/Rasb 12x1.5l	84.56	0.99	0.83	2.04	R 3.85
Aquartz Sparkling Lem/Lime 12x1.5l	83.84	0.98	0.83	2.04	R 3.85
Aquartz Sparkling Mango 4x6x500ml	58.54	0.68	0.55	1.42	R 2.65
Aquartz Mineral Still 2x6x750ml	33.90	0.40	0.41	1.13	R 1.94
Nestea Ice Tea Berry 6x1.5l	38.52	0.45	0.41	1.02	R 1.88
Nestea Ice Tea Peach 6x1.5l	39.69	0.46	0.41	1.02	R 1.90
Nestea Ice Tea Lemon 6x1.5l	39.33	0.46	0.41	1.02	R 1.89
Clover Manhattan Ice Tea Blackcurrant (6X4)X500ml	78.68	0.92	0.55	1.70	R 3.17
Clover Manhattan Ice Tea Pineapple (6X4)X500ml	75.33	0.88	0.55	1.70	R 3.13
Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	74.47	0.87	0.55	1.70	R 3.12
Clover Manhattan Ice Tea Peach (6X4)X500ml	78.41	0.91	0.55	1.70	R 3.17
Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	77.98	0.91	0.55	1.70	R 3.16
Clover Manhattan Ice Tea Lemon (6X4)X500ml	77.81	0.91	0.55	1.70	R 3.16
Nestle Pure Life Sparkling 4x6x500ml	35.75	0.42	0.55	1.21	R 2.18
Nestle Pure Life Sparkling 12x1.5l	35.32	0.41	0.83	2.13	R 3.37
MAN G/TEA APR/LTE 6x1.5l	40.70	0.47	0.41	1.02	R 1.91
MAN I/TEA PEACH LTE 6x1.5l	41.23	0.48	0.41	1.02	R 1.92
MAN I/TEA PEACH 6x1.5Lt	40.95	0.48	0.41	1.02	R 1.91
MAN I/TEA LEMON 6x1.5l	40.74	0.48	0.41	1.02	R 1.91
MAN G/TEA RB/GF/ST 6x1.5l	41.07	0.48	0.41	1.02	R 1.91
MAN G/TEA KI/PEA LTE 6x1.5l	40.46	0.47	0.41	1.02	R 1.91
Nestea Ice Tea Peach 4x6x500ml	79.43	0.93	0.55	1.70	R 3.18
Nestea Ice Tea Berry 4x6x500ml	78.84	0.92	0.55	1.70	R 3.17
Nestea Ice Tea Lemon 4x6x500ml	74.52	0.87	0.55	1.70	R 3.12
Aquartz Sparkling Lemon/Lime 24X500 ml	31.64	0.37	0.55	1.42	R 2.34
Aquartz Sparkling Litchi 24X500 ml	55.84	0.65	0.55	1.42	R 2.62
Aquartz Sparkling Naartjie 24X500 ml	55.78	0.65	0.55	1.42	R 2.62
Aquartz Sparkling Peach Passion 24X500 ml	31.37	0.37	0.55	1.42	R 2.33

Aquartz Sparkling Cran/Raspberry 24X500 ml	31.86	0.37	0.55	1.42	R 2.34
Aquartz Mineral Water Sparkling 4X6X500 ml	40.45	0.47	0.55	1.42	R 2.44
Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	75.71	0.88	0.55	1.70	R 3.14
Manhattan White I/Tea Exotic Fruit 4x6x500ml	76.46	0.89	0.55	1.70	R 3.14
Clover Manhattan Ice Tea Crisp Apple/Mint with Ginseng (6X4)X500ml	74.09	0.86	0.55	1.70	R 3.12
Clover Manhattan Ice Tea Ruby Grapefruit/Sberry with Gingko Biloba 6X4X500ml	75.98	0.89	0.55	1.70	R 3.14
Aquartz Mineral Water Sparkling 12X1.5l	38.88	0.45	0.83	2.04	R 3.32
Nestle Pure Life Still 4x6x330ml	33.11	0.39	0.36	0.94	R 1.70
Nestle Pure life Still 4x6x500ml	35.75	0.42	0.55	1.21	R 2.18
Nestle Pure Life Still 4x6x750ml	60.59	0.71	0.83	2.27	R 3.80
Nestle Pure life Still 12x1.5l	34.02	0.40	0.83	1.82	R 3.05
Nestle Pure Life Still 2x12x500ml	30.83	0.36	0.55	1.21	R 2.13
Aquartz Mineral Water Still 12X1.5l	37.10	0.43	0.83	2.04	R 3.30
Aquartz Mineral Water Still 4X6X500 ml	38.72	0.45	0.55	1.42	R 2.42
Aquartz Mineral Water 4 x 5l	27.18	0.32	0.92	2.13	R 3.36
Nestle Pure Life Still 2x5l	13.55	0.16	0.46	1.21	R 1.83

4.1.3. Production frequency

The production frequency of any SKU refers to the number of times a lot of that specific SKU is produced during a month. With each production lot run, there is associated changeover time. Clover wants to produce as many SKU's as possible on a weekly basis, which implies much more time spent on changeovers. The capacity of the production equipment limits production lot sizes, which cannot be less than 5000 litres. The majority of the SKU's demand is not large enough to justify even a minimum production run on a weekly basis in order to always have available stock while the rest is in quarantine. The Sales Department have agreed that if safety stock levels are satisfactory, a single monthly production run would be acceptable. This enables the minimisation of frequent changeovers and limits repeating changeovers to only SKU's which are produced at a weekly or twice weekly frequency. Table 7 provides the production frequency per month, and specifies which SKU's will be produced at that frequency.

Table 7: Production frequencies of SKU's.

Monthly production frequency	SKU's
1	Line 1: 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36
4	Line 1: 5, 15, 16 Line 2: 1, 3, 4, 5, 6, 7
8	Line 2: 2
16	Line 3: 1, 2

4.1.4. Labour cost

Labour cost is a direct function of the total production time *t* spent during the month. With labour cost hourly rate increasing from R461.11 for the first 180 hours of production, to R610.43 per hour of overtime worked. Thereafter, if additional time needs to be worked on Sundays, the hourly rate increases to R813.83 per hour on a Sunday. Thus this cost aspect is handled as a piecewise linear function.

$$L(p) = \begin{cases} 461.11t & 0 < p \leq 180 \\ 610.42t - 26\,875.80 & 180 < p \leq 406 \\ 813.83t - 109\,460.29 & 406 < p \end{cases}$$

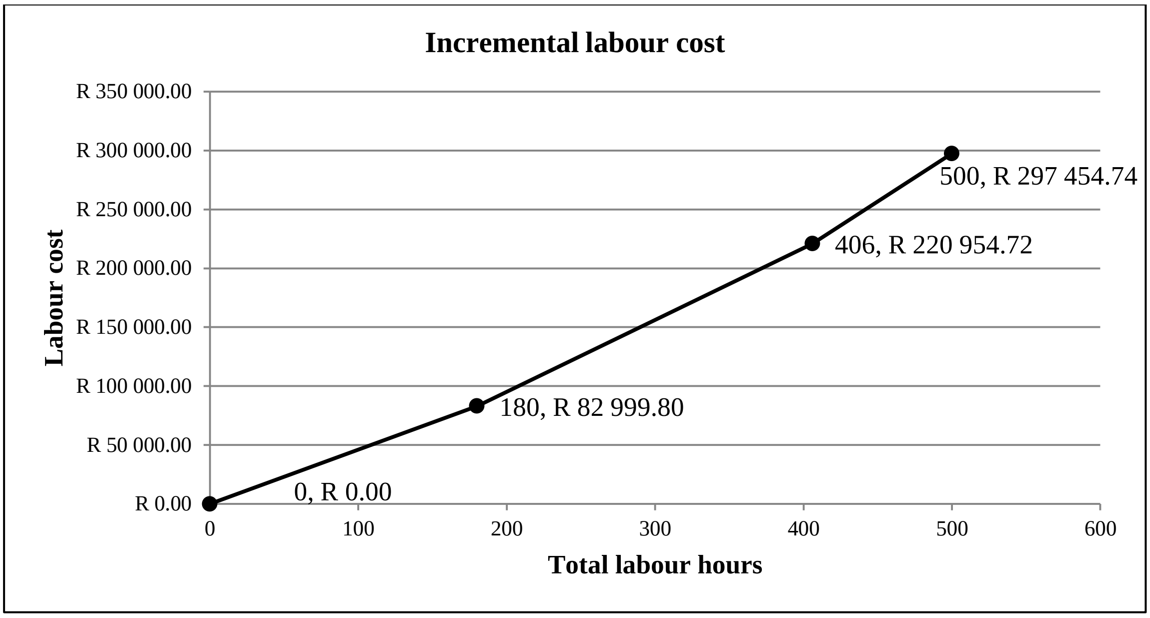

Figure 4.4: Graphical illustration of the incremental rise in labour cost.

Labour cost is used to determine which job scheduling option out of four varying alternative job schedules would best fit the MPS at the lowest cost.

4.2. Production lot-sizing optimisation model

Mixed Integer Linear Programming models have been constructed in order to determine the optimal lot size of each SKU to be produced on a monthly basis. This production lot-size should satisfy the demand of each period and produce enough items to ensure that the safety stock levels are kept at the required level of two weeks' worth of stock during each period. The objective of the determined lot-sizes is to minimise inventory at the end of the period and the total production time of the period.

Three different model groups were built. For scheduling alternative 1, Model group A looks at a continuous MPS. For scheduling alternative 2, group B determines the lot sizes for production during the peak demand period (September to February), and group C determines the lot sizes for the off-peak demand period (March to August). Within these three model groups, each one has three separate models that determine lot sizes for either line one, two or three.

The production lot size that is determined for the SKU is a fixed production lot size that will be produced every month during the specified production period. Figure 4.5 summarises this allocation of production lot sizes according to the scheduling approaches that are evaluated.

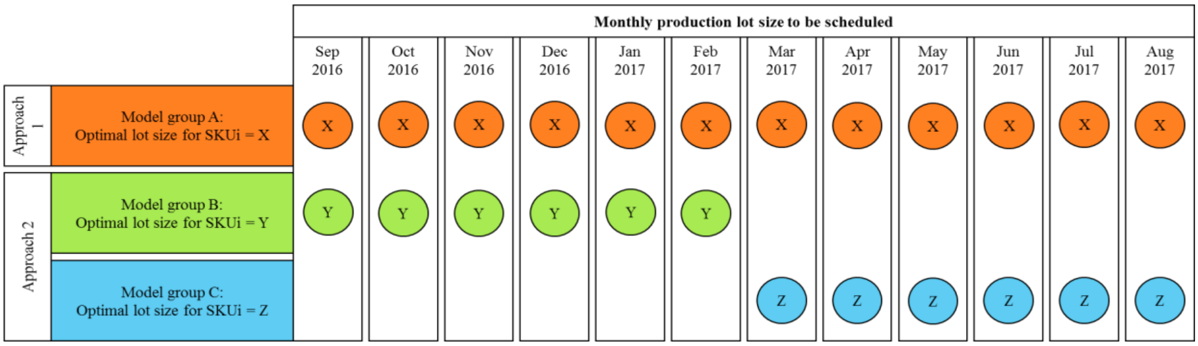

Figure 4.5: The allocation of production lot size results to each month according to the scheduling approach followed, for each SKU.

4.2.1. Mathematical model notation

The notation of the models will be the same for all three of the model groups. Each model group contains a model for each of the three different filling lines, thus within each model group, three different models will each have set $\mathbf{I_1}$, $\mathbf{I_2}$ or $\mathbf{I_3}$. Set **J** will be altered slightly to fit each unique model group. Table 8 explains the arrangement of the models.

Table 8: Arrangement of mathematical models.

	Mathematical model group	Set **J**	Set **I**
Scheduling alternative 1	**A (Continuous)**	$\mathbf{J_1}$	$\mathbf{I_1}$
			$\mathbf{I_2}$
			$\mathbf{I_3}$
Scheduling alternative 2	**B (Peak)**	$\mathbf{J_2}$	$\mathbf{I_1}$
			$\mathbf{I_2}$
			$\mathbf{I_3}$
	C (Off-peak)	$\mathbf{J_3}$	$\mathbf{I_1}$
			$\mathbf{I_2}$
			$\mathbf{I_3}$

The general notation will be as follows:

Sets:

$\mathbf{I_1}$ = the set of SKU's produced on line 1 where:

i	SKU description
1	Aquartz Sparkling Peach/Passion 12x1.5lt
2	Aquartz Sparkling Cran/Rasb 12x1.5lt
3	Aquartz Sparkling Lem/Lime 12x1.5lt
4	Aquartz Sparkling Mango 4x6x500ml
5	Aquartz Mineral Still 2x6x750ml
6	Nestea Ice Tea Berry 6x1.5LT
7	Nestea Ice Tea Peach 6x1.5LT
8	Nestea Ice Tea Lemon 6x1.5LT
9	Clover Manhattan Ice Tea Blackcurrant (6X4)X500ml

10	Clover Manhattan Ice Tea Pineapple (6X4)X500ml
11	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml
12	Clover Manhattan Ice Tea Peach (6X4)X500ml
13	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml
14	Clover Manhattan Ice Tea Lemon (6X4)X500ml
15	Nestle Pure Life Sparkling 4x6x500ml
16	Nestle Pure Life Sparkling 12x1.5lt
17	Man g/tea apr/lite 6x1.5lt
18	Man i/tea peach lite 6x1.5lt
19	Man i/tea peach 6x1.5lt
20	Man i/tea lemon 6x1.5lt
21	Man g/tea rb/gf/st 6x1.5lt
22	Man g/tea kiwi/pear lite 6x1.5lt
23	Nestea Ice Tea Peach 4x6x500ml
24	Nestea Ice Tea Berry 4x6x500ml
25	Nestea Ice Tea Lemon 4x6x500ml
26	Aquartz Sparkling Lemon/Lime 24X500 ml
27	Aquartz Sparkling Litchi 24X500 ml
28	Aquartz Sparkling Naartjie 24X500 ml
29	Aquartz Sparkling Peach Passion 24X500 ml
30	Aquartz Sparkling Cran/Raspberry 24X500 ml
31	Aquartz Mineral Water Sparkling 4X6X500 ml
32	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml
33	Manhattan White I/Tea Exotic Fruit 4x6x500ml
34	Clover Manhattan Ice Tea Crisp Apple/Mint with Ginseng (6X4)X500ml
35	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry with Gingko Biloba 6X4X500ml
36	Aquartz Mineral Water Sparkling 12X1.5 lt

I_2 = the set of SKU's produced on line 2 where:

i	**SKU description**
1	Nestle Pure Life Still 4x6x330ml
2	Nestle Pure life Still 4x6x500ml
3	Nestle Pure Life Still 4x6x750ml
4	Nestle Pure life Still 12x1.5lt
5	Nestle Pure Life Still 2x12x500ml
6	Aquartz Mineral Water Still 12X1.5 lt
7	Aquartz Mineral Water Still 4X6X500 ml

I_3 = The set of SKU's produced on line 3 where:

i	**SKU description**
1	Aquartz Mineral Water 4 x 5l

2	Nestle Pure Life Still 2x5l

$\mathbf{J_A}$ = The set of demand periods for which demand has been forecasted where:

j	**Month**
1	July 2016
2	August 2016
3	September 2016
4	October 2016
5	November 2016
6	December 2016
7	January 2017
8	February 2017
9	March 2017
10	April 2017
11	May 2017
12	June 2017

Denote:

D_{ij} ≜ The given forecasted demand [cases] (Appendix C) of SKU $i \in \mathbf{I}$ during demand period $j \in \mathbf{J}$.

O_{ij} ≜ The predetermined opening inventory balance of SKU $i \in \mathbf{I}$ during off-peak demand period $j \in \mathbf{J}$. (Only applicable to model group C.)

F_i ≜ The given production frequency (Table 7) per month of SKU $i \in \mathbf{I}$.

T_i ≜ The given production time (Table 2) per case [hours] of SKU $i \in \mathbf{I}$.

C_i ≜ The given conversion factor (Table 3) of cases of SKU $i \in \mathbf{I}$ per pallet.

G_i ≜ The given conversion factor (Table 3) of litres of SKU $i \in \mathbf{I}$ per case.

K_i ≜ The allocated changeover time in minutes allocated to setup of SKU $i \in \mathbf{I}$ based on selected production sequence (Figure 4.1).

$$v_j \triangleq \begin{cases} 1\text{: if additional warehousing is needed during period } j \in \mathbf{J} \\ 0\text{: if facility warehouse has enough capacity for all pallets during period } j \in \mathbf{J} \end{cases}$$

X_i ≜ Production lot size [cases] of SKU $i \in \mathbf{I}$.

B_j ≜ Total direct labour hours spent on production and setup during period $j \in \mathbf{J}$.

P_j ≜ Total operational time [hours] of the line during demand period $j \in \mathbf{J}$.

I_{ij} ≜ Inventory of SKU$i \in \mathbf{I}$ at the end of period $j \in \mathbf{J}$.

Z_i ≜ The total number of cases of SKU $i \in \mathbf{I}$ produced consistently during every demand period.

H_i ≜ Given (Table 6) inventory holding cost [R] per case of SKU $i \in \mathbf{I}$.

Q_{ij} ≜ The number of pallets of SKU $i \in \mathbf{I}$ at the end of period $j \in \mathbf{J}$.

L_j ≜ The total number of pallets at the end of period $j \in \mathbf{J}$.

E_j ≜ The total number of excess pallets at end of period $j \in \mathbf{J}$ in need of alternative warehousing.

M ≜ a Very large number

4.2.2. Mathematical model group A: Continuous

This model is used to determine the optimal lot sizes for a continuous MPS, which builds inventory during off-peak months for peak months, keeping production at one constant level.

Objective function: (1)

$$\text{Min } Z = \sum_{i \in I} I_{(i,12)} * H_i + \sum_{j \in J_1} P_j * 461.11$$

Subject to:

$F_i * X_i = Z_i$	$\forall\, j \in \mathbf{J_1}, \forall\, i \in \mathbf{I}$	(2)
$X_i * G_i \geq 5000$	$\forall\, i \in \mathbf{I}$	(3)
$\left(\frac{2}{4.2}\right) D_{i1} + Z_i - D_{i1} = I_{i1}$	$\forall\, i \in \mathbf{I}$	(4)
$I_{i1} + Z_1 \geq D_{i1}$	$\forall\, i \in \mathbf{I}$	(5)
$I_{ij-1} + Z_i \geq D_{ij}$	$\forall\, j \in \{2,..,12\}, i \in \mathbf{I}$	(6)
$I_{ij-1} + Z_i - D_{ij} = I_{ij}$	$\forall\, j \in \{2,..,12\}, i \in \mathbf{I}$	(7)
$I_{ij} \geq (\frac{2}{4.2}) * D_{ij+1}$	$\forall\, j \in (1,..,11), i \in \mathbf{I}$	(8)
$I_{ij} * \frac{1}{Ci} = Q_{ij}$	$\forall\, j \in \mathbf{J_1}, i \in \mathbf{I}$	(9)
$I_{ij} \geq (\frac{2}{4.2}) * D_{ij+1}$	$\forall\, j \in (1,..,11), i \in \mathbf{I}$	(8)
$I_{ij} * \frac{1}{Ci} = Q_{ij}$	$\forall\, j \in \mathbf{J_1}, i \in \mathbf{I}$	(9)
$\sum_{i \in I} Q_{ij} = L_j$	$\forall j \in \mathbf{J_1}$	(10)
$L_j - 5000 \geq Mv_j$	$\forall\, j \in \mathbf{J_1}$	(11)
$E_j + L_j - 5000 \leq M(1-v_j)$	$\forall\, j \in \mathbf{J_1}$	(12)

$$\sum_{i\in I} T_i * Z_{ij} + \sum_{i\in I} F_i * K_i = B_j \qquad \forall\, j \in \mathbf{J_1} \tag{13}$$

$$B_j + \left(\frac{1}{15}\right)B_j + 8 = P_j \qquad \forall\, j \in \mathbf{J_1} \tag{14}$$

$$P_j, X_i, Z_i, I_{ij}, B_j \geq 0 \qquad \forall\, j \in \mathbf{J_1}, i \in \mathbf{I} \tag{15}$$

$$v_j \in \{0,1\} \qquad \forall\, j \in \mathbf{J_1} \tag{16}$$

Explanation:

The objective function (1) strives to minimise the inventory cost at the end of the year and the total production cost, which is determined by multiplying the total operational time of the line [hours] by the hourly labour rate. (2) Determines the total number of cases produced of each SKU during the month by multiplying the optimal lot size with the given frequency. Constraint (3) ensures that the minimum lot size of 5000 litres is adhered to. (4) There is an adequate amount of stock (2 weeks' worth of demand) at the beginning of the MPS implementation period, which has been produced by other facilities for the forecasted demand of month one. (5) And (6) ensures that the combined inventory and production of each SKU always meets the forecasted demand. (7) Determines the inventory level of every SKU at the end of each month. (8) Ensures that rolling inventory provides 2 weeks' worth of buffer (safety) stock at the end of each month for the coming period. (9) Converts the number of cases of each SKU in inventory to pallets. (10) Determines the total amount of pallets that need to be stored at month end. (11) Determines whether there is excess storage needed and (12) determines exactly how many pallets are indeed going to be stored at an alternative facility. Constraint (13) determines the direct line operation time, including changeover times. (14) Determines the total direct labour required which includes mandatory cleaning processes and direct operation of the filler line. Constraint (15) ensures that the variables are non-negative values, and (16) defines v_j as a binary variable. The Lingo formulation can be seen in Appendix D.

4.2.3. Mathematical model group B: Peak

This model determines the optimal lot sizes during production months for the peak demand period. This model starts with September as the first month of peak demand production, since the production levels of September needs to satisfy the safety stock levels required in October which is the first month of the identified peak season. The rest of the model is identical to Model A, the only difference is Set $\mathbf{J_2}$.

Set $\mathbf{J_2}$:

j	**Month**
1	September 2016
2	October 2016
3	November 2016
4	December 2016
5	January 2017
6	February 2017

7	March 2017

Objective function:

$$\text{Min } Z = \sum_{i \in I} I_{(i,6)} * H_i + \sum_{j \in J_2} P_j * 461.11$$

The complete Lingo formulation can be seen in Appendix E.

4.2.4. Mathematical model group C: Off-peak

For the off-peak model, which determines the optimal lot sizes of the demand periods in the off-peak season, it was decided to start with March 2017 as the first month of production for the off-peak season. Additional forecasting data was required for the demand of July 2017 and August 2017. Clover's Forecasting Department suggested an assumption of a 2% sales increase. The Off-peak model also relies on month-end inventory results for February 2017 in order to continue with opening inventory data for the month of March 2017.

Set $\mathbf{J_3}$:

j	Month
1	March 2017
2	April 2017
3	May 2017
4	June2017
5	July 2017
6	August 2017
7	September 2017

Objective function:

$$\text{Min } Z = \sum_{i \in I} I_{(i,12)} * H_i + \sum_{j \in J_3} P_j * 461.11$$

$$O_{i1} + Z_i - D_{i1} = I_{i1} \qquad \forall\, i \in \mathbf{I} \qquad (2)$$

Equation (2) is an extra constraint added to the off-peak model, which replaces constraint (4) in model B. This is because the ending inventory of the peak season in February needs to be carried over into the off-peak season as the opening inventory for March.

4.3. Lot-sizing results

The global optimum optimal lot-size [in cases] results obtained from Lingo are summarised in Figures 4.6, 4.7 and 4.8.

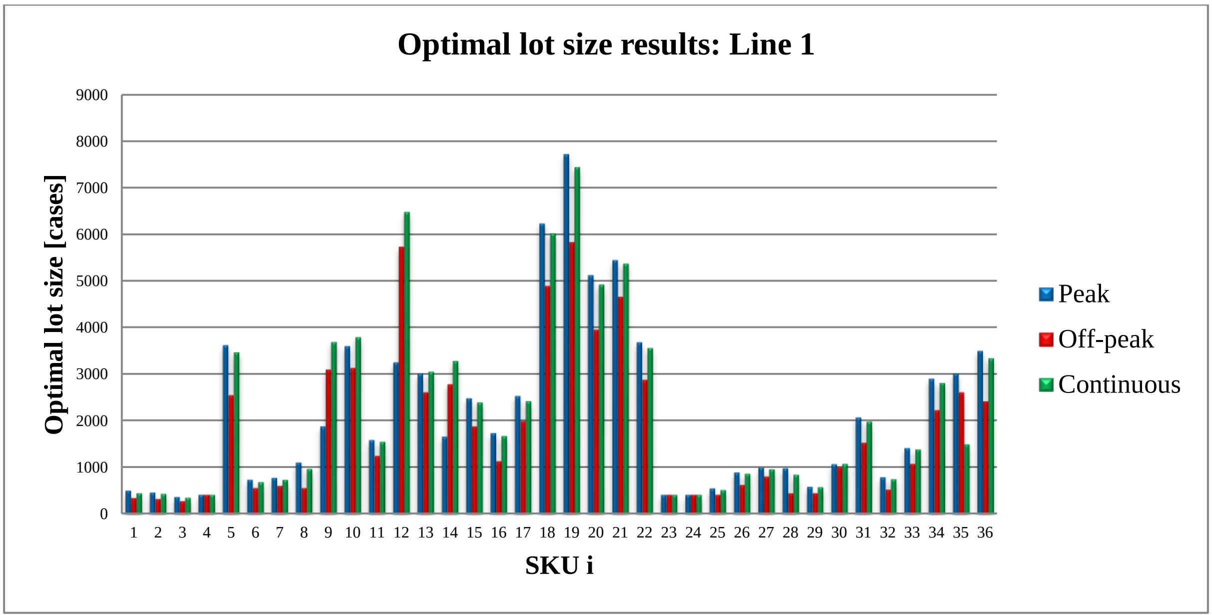

Figure 4.6: Graph showing the optimal lot size results for Line 1.

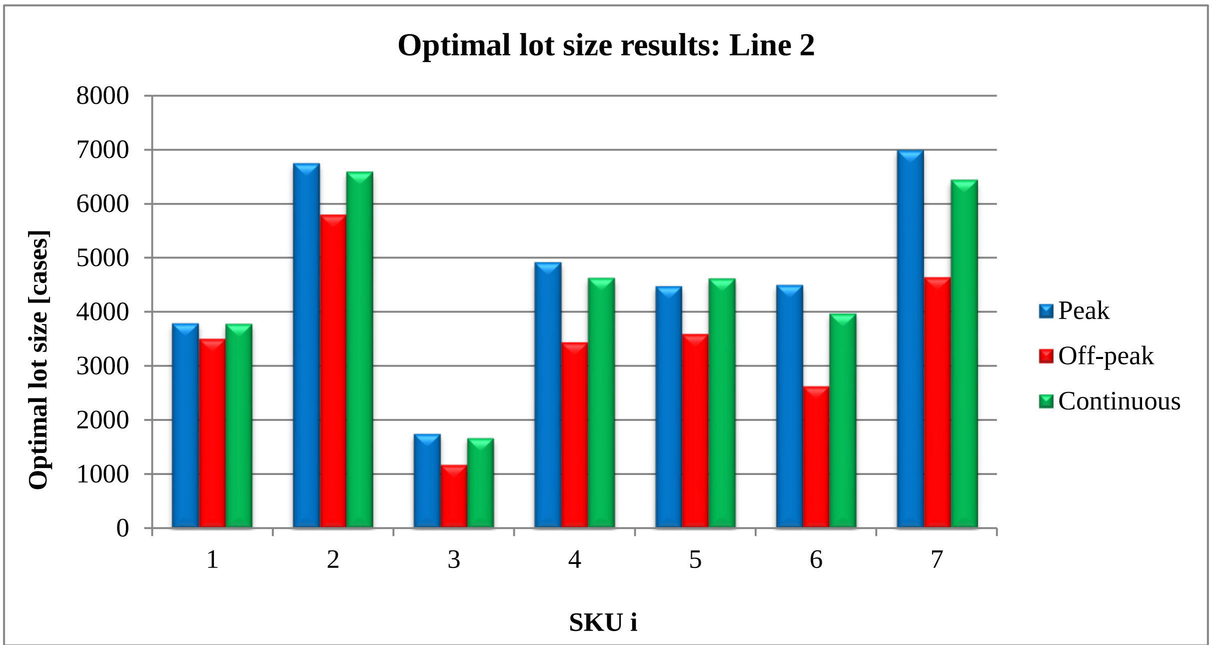

Figure 4.7: Graph showing the optimal lot size results for Line 2.

Results for both line 1 and line 2 are as expected, with the largest SKU lot sizes required during peak months, and the smallest lot sizes established for off-peak period production in general. SKU 9 and 12 on line 1 do not exhibit this due to the nature of their demands, but generally the peak and off-peak sizes conform to what is expected.

Figure 4.8: Graph showing the optimal lot size results for Line 3.

It can be seen from Figure 4.8 that the peak and off-peak demand periods differ for the products on line 3, where more products are scheduled for production during off-peak periods than in peak periods. This can be explained through the definition of the peak and off-peak periods. In order to keep consistency throughout the facility, management decided to define the periods for all three lines as the same times – peak from September to February, and off-peak from March to August. However, line 3 produces products mainly for exports, and those demand patterns are slightly different from the local demand patterns.

4.3. Conclusion

This chapter has explained how all of the important parameters which influence the MPS are addressed. The results that were obtained from the work done in this section will be used in Chapter 5, where the MPSs are conceptualised and then built in Infor AS, in order to test the feasibility of execution, and evaluate the two alternatives in order to make a decision on the optimal alternative MPS.

Chapter 5: Production scheduling and job scheduling

In this chapter, the information that has been gathered in Chapter 3 about the capacity and capabilities with the facility is used in conjunction with the operations research results obtained in Chapter 4 to devise alternative MPSs for the facility. The alternative schedules are used to develop accompanying job schedules with varying shift configurations, and a final cost analysis is then performed. The most cost effective schedule alternative and shift configuration is selected and identified as the optimised MPS for the Clover Waters Facility at the end of this chapter.

5.1. MPS conceptualisation

The two alternative MPSs will be built from all the information and parameters which have been obtained up to this point, which includes production lot sizes of each SKU, production frequency, shift times, production sequence and changeover times. Before building the schedules in Infor AS, the schedules were conceptualised in an Excel spread sheet, assigning certain SKU's to each of the four weeks of production per period. The aim is to ensure that the duration of production is relatively similar during each week to provide consistency in the schedule, and trying to make sure that every week has enough flexible time to recover from any potential breakdown which could delay production or surge in demand, or whatever other potential risk might occur which affects production timing.

Each SKU is assigned to a specific week of production. The coloured blocks are the SKU's, and right below each assigned each SKU is the total production time [minutes] of that particular lot, including the changeover time to the next production lot. The cumulative duration time was calculated as the scheduling progressed, in order to ensure that the workload in terms of production time is fairly evenly distributed over the 4 week production period. The concepts of the two alternative schedules, continuous and peak/off-peak, where the peak/off-peak schedule consists of two parts, one monthly schedule for peak demand production, and one for off-peak demand production, are shown below.

Colour legend
Week1
Week2
Week3
Week4
Weekly frequency
2 x Weekly frequency
4 x Weekly frequency

CONTINUOUS SCHEDULE: Line 1																
Week1	5	15	16	1	2	3	6	7	8	17	18	19	20	21	22
Duration [minutes]	100	100	234.56	96.30	94.50	85.28	84.09	86.68	99.73	182.08	384.53	463.95	322.65	348.02	246.09
Cummulative duration	100	200	434.56	530.86	625.36	710.64	794.73	881.41	981.14	1163.23	1547.75	2011.70	2334.35	2682.37	2928.46
Week2	5	15	16	36	23	24	25	26	27	28	29	30	31	32	33
Duration [minutes]	100	100	234.56	422.44	100.00	120.06	138.78	202.14	219.96	198.00	150.12	240.12	403.74	180.72	296.64
Cummulative duration	100	200	434.56	857.00	957.00	1077.06	1215.84	1417.98	1637.94	1835.94	1986.06	2226.18	2629.92	2810.64	3107.28
Week3	5	15	16	34	9	34	35	10							
Duration [minutes]	100	100	234.56	585.90	712.26	585.90	585.90	730.80							
Cummulative duration	100	200	434.56	1020.46	1732.72	2318.62	2904.52	3635.32							
Week4	5	15	16	4	11	12	13	14							
Duration [minutes]	100	100	234.56	120.06	325.98	1214.28	597.78	639.54							
Cummulative duration	100	200	434.56	554.62	880.60	2094.88	2692.66	3332.20							
CONTINUOUS SCHEDULE: Line 2															
Weekly	2	1	3	4	2	5	6	7							
Duration [minutes]	890.80	554.56	301.24	655.96	890.80	655.00	577.72	872.80							
Cummulative duration	890.80	1445.36	1746.61	2402.57	3293.37	3948.37	4526.09	5398.90							
CONTINUOUS SCHEDULE: Line 3															
Weekly	1	2	1	2	1	2	1	2							
Duration [minutes]	356.15	1095.9	356.15	1095.9	356.152	1095.9	356.152	1095.9							
Cummulative duration	356.15	1452.1	1808.2	2904.11	3260.26	4356.16	4712.31	5808.22							

Figure 5.1 Continuous MPS concept.

Schedule PEAK: Line 1															
Week1	5	15	16	1	2	3	6	7	8	17	18	19	20	21	22
Duration [minutes]	100	100	255.94	104.29	99.788	88.875	86.681	89.213	107.6	255.94	188.16	404.16	492.47	341.66	365.01
Total cummulative duration	100	200	455.94	560.23	660.01	748.89	835.57	924.78	1032	1288.3	1476.4	1880.6	2373.1	2714.7	3079.7
Week2	5	15	16	36	23	24	25	26	27	28	29	30	31	32	33
Duration [minutes]	100	100	255.94	254.25	100	120.06	157.5	219.96	232.6	229.32	159.3	159.3	159.3	244.98	432
Total cummulative duration	100	200	455.94	710.19	810.19	930.25	1087.7	1307.7	1540	1769.6	1928.9	2088.2	2247.5	2492.5	2924.5
Week3	5	15	16	4	34	35	9	*9	10	*note prod 9 (sku 2102193 is split over 2 days)					
Duration [minutes]	100	100	255.94	120.06	607.5	592.92	759.42	759.42	834.3						
Total cummulative duration	423.7	523.7	779.64	899.7	1507.2	2100.1	2859.5	3619	4453						
Week4	5	13	16	11	15	12	14	12	14						
Duration [minutes]	100	644.94	255.94	345.06	100	1248.7	684.36	1248.7	684.4						
Total cummulative duration	423.7	1068.6	1324.6	1669.6	3018.3	2918.3	3702.7	4167	4387						
Schedule PEAK: Line 2															
Weekly	2	1	3	4	2	5	6	7							
Duration [minutes]	937.2	554.56	324.4	700	937.24	692.08	643.72	993.64							
Total cummulative duration	937.2	1491.8	1816.2	2516.2	3453.5	4145.5	4789.3	5782.9							
Schedule PEAK: Line 3															
Weekly	1	2	1	2	1	2	1	2							
Duration [minutes]	401.5	1161.4	401.45	1161.4	401.45	1161.4	401.45	1161.4							
Total cummulative duration	401.5	1562.9	1964.3	3125.7	3527.2	4688.6	5090	6251.4							

Figure 5.2 Peak demand period MPS concept.

OFFPEAK Schedule: Line 1															
Week1	5	15	16	1	2	6	7	8	17	18	22	3	19	20	21
Duration [minutes]	100	100	158.63	86.063	79.2	76.556	92.363	76.5	202.4	329.12	227.03	76.275	360.9	281.48	294.98
Total cummulative duration	100	200	358.63	444.69	523.89	600.44	692.81	769.31	971.8	1300.9	1527.9	1604.2	1965.1	2246.5	2541.5
Week2	5	15	16	36	23	24	25	26	27	28	29	30	31	32	33
Duration [minutes]	100	100	158.63	287.66	100	120.78	120.06	146.16	194.4	124.2	120.06	221.58	310.5	133.38	232.38
Total cummulative duration	100	200	358.63	646.29	746.29	867.07	987.13	1133.3	1328	1451.9	1571.9	1793.5	2104	2237.4	2469.8
Week3	5	15	16	4	34	35	9	10							
Duration [minutes]	100	100	158.63	120.78	411.12	547.02	572.58	472.68							
Total cummulative duration	100	200	358.63	479.41	890.53	1437.5	2010.1	2482.8							
Week4	5	15	16	11	13	14	12								
Duration [minutes]	100	100	158.63	259.56	461.88	510.3	1050.5								
Total cummulative duration	100	200	358.63	618.19	1080.1	1590.4	2640.8								
OFFPEAK Schedule : Line 2															
Weekly	2	1	3	4	2	5	6	7							
Duration [minutes]	768.8	554.68	226.96	522.88	768.76	476.56	478.24	602.44							
Total cummulative duration	768.8	1323.4	1550.4	2842.1	2319.2	3318.6	3796.9	4399.3							
OFFPEAK Schedule : Line 3															
Weekly	1	2	1	2	1	2	1	2							
Duration [minutes]	322.8	783.1	322.75	783.1	322.75	783.1	322.75	783.1							
Total cummulative duration	322.8	1105.9	1428.6	2211.7	2534.5	3317.6	3640.3	4423.4							

Figure 5.3 Off-peak demand period MPS concept.

5.2. Infor AS: Production scheduling

The MPS concepts were used to build three MPSs in Infor AS, one for each concept, to test the feasibility of the MPS. Infor AS is quite interactive and restricts production lots which would cause problems with the schedule feasibility, so during the process of scheduling, mistake proofing is applied by the software itself.

Before scheduling was initiated, the starting time of daily shifts was agreed upon as 5:30 AM. This agreement was made in order to make sure that production only started after the weekly CIP sterilisation and cleaning process on Mondays which has a duration of two hours, and daily hot sterilisation on every other day of production which has a duration of one hour. Thus, production starts on a Monday at 07:30 AM, and all other days, production starts at 06:30 AM.

Figure 5.4 is a screenshot of the schedule for the first week of production for the peak demand period. All of the MPSs in Infor AS look relatively similar, therefor only that of week 1, peak is shown. The rest of the screenshots can be seen in Appendix G. All four weeks are integrated into a single monthly production run report generated by Infor AS. The Infor AS reports would highlight the differences rather that the visualised schedule seen in the screenshots. This report shows exact starting and ending times, changeover duration and quantities produced and total lot production duration.

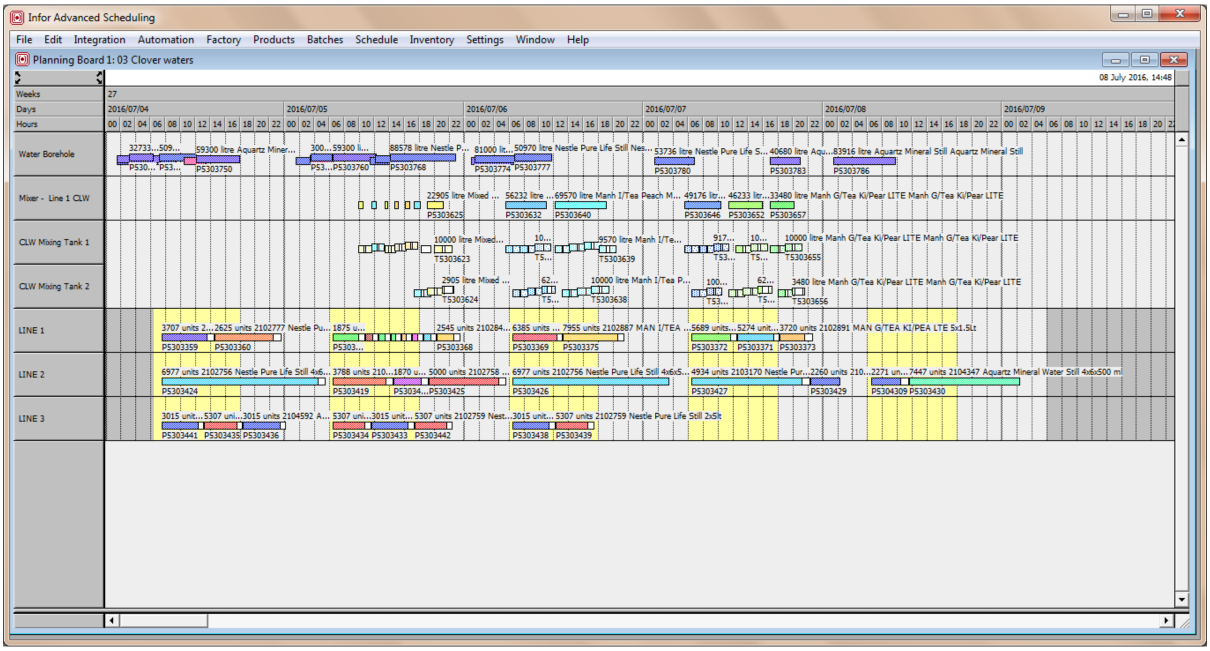

Figure 5.4 Infor screenshot of week 1 of peak demand period MPS.

The reports generated by the software are used to develop job schedules based on four different shift configurations, to evaluate the schedules in terms of total labour cost. The total number of pallets produced during the month is also calculated and added to the evaluation of the alternatives since inventory holding cost is another cost factor contributing to the selection of the best alternative MPS.

5.3. Job scheduling

Four different job shift configurations have been identified for job scheduling purposes:

A. Eight-hour shifts with overtime.
B. Eight-hour shifts with no overtime.
C. Twelve-hour shifts with overtime.
D. Twelve hour shifts with no overtime.

The start and ending times of production in the Infor AS reports were used to determine how much of each shift is required per day and whether overtime is required. This evaluation was then converted into monetary terms by applying labour costs and ultimately provided the total monthly labour cost of each MPS. Complete Infor AS reports can be viewed in Appendix G.

Labour cost was addressed in Chapter 4, and those rates are applied in this evaluation. Table 9 shows a summary of the cost analysis (what the monthly labour cost would be for each of the four different shift configurations and each schedule type). The detailed evaluation of each schedule alternative is included in Appendix H.

Table 9: Labour cost shift analysis summary

Schedule alternative	A	B	C	D	Best shift configuration
Peak	R433 803.98	R509 065.44	R482 422.45	R509 065.44	A
Off-peak	R324 968.87	R387 332.40	R422 855.69	R453 732.24	A
Continuous	R420 295.62	R461 110.00	R437 584.91	R481 398.84	A

It is clear that the best way of distributing labour over all of the MPSs, is by working 8-hour shifts with some overtime, as long as the legally mandated 15 hours overtime limit is not exceeded. After selection of the optimal MPS, a job schedule based on that schedule would be configured in the form of 8-hour shifts with overtime.

5.4. Optimal MPS selection

Before the selection of MPS, inventory holding costs incurred (if any) also needs to be considered, before finally determining the annual cost for the schedule alternatives. Every lot produced needs to be kept in quarantine for one week, and thereafter it is distributed out of the warehouse. The total number of pallets produced during each week was calculated and the results are summarised in Table 10.

Table 10: Total pallets produced during each week.

Schedule alternative	Week 1	Week 2	Week 3	Week 4
Peak	4848	4712	4724	4729
Off-peak	3420	3283	3297	3318
Continuous	4831	4698	4703	4722

As can be seen from the results of counting the total pallets, the amount of storage space required to accommodate the produced SKU's never exceeds the warehouse maximum capacity, thus no additional inventory holding cost will be incurred during the operation of any one of the MPSs.

Both of the MPSs that have been developed have been confirmed to be feasible schedules which allows for enough time for upstream processes. Since both are feasible solutions, the final decision-maker for selection of the optimal MPS is the total annual operating cost in terms of labour. Table 11 compares the annual operation cost of the two alternative schedules based on the job shift configurations as described in Section 5.3.

Table 11: Annual operating cost comparison of schedule alternatives.

Schedule alternative	A	B	C	D
A: Continuous	R 5 043 547.44	R 5 533 320.00	R 5 251 018.92	R 5 776 786.08
B: Peak –Off-peak	R 4 552 637.10	R 5 378 387.04	R 5 431 668.84	R 5 776 786.08

Alternative A, which is a monthly MPS that remains the same for the next twelve months, has a total estimated labour cost of R5 043 547.44 for the next year based on a job schedule comprised of 8-hour shifts with sporadic overtime (shift configuration A). Alternative B consists of two schedules, peak and off-peak, which would each be repeated for 6 months, and the total estimated labour cost for this alternative for the next year on shift configuration A is R4 552 637.10.

Alternative A is also the more costly option when shift configuration B, 8-hour shifts without any overtime, is used. When 12-hour shifts are considered, schedule alternative A, continuous production, would be the less expensive alternative. For the shift configuration of only 12-hour shifts however, the decision is an indifferent one, since the labour would be scheduled exactly the same for both MPS alternatives.

This brings us to the conclusion that MPS alternative B: Peak/Off-peak production with job shift configuration A: 8-hour shifts with sporadic overtime, is selected as the optimal MPS for the Clover Waters Facility due to it being the most cost effective schedule. In the Section 5.5 an accompanying job schedule is designed to accompany this MPS.

5.5. Optimal MPS accompanying job schedules

The peak production period job schedule was devised in a manner to ensure that overtime is distributed equally for all workers regardless of whether they work day or night shift. Table 12 is the job schedule during the peak period for each of the three lines. The job schedule is specified for each week. Overtime has been assigned to both work teams, ensuring equal assignment of working hours.

The company is aware of labour legislation, which stipulates that workers working between 23:00 PM and 06:00 AM need to be informed about the hazards of working those hours. The workers during these shifts will be provided with transportation to and from the facility as required by legislation. This job schedule starts on a Monday and end on a Friday. Weekends will always be open for maintenance purposes. In the case of unexpected breakdowns, the open weekends will be used to catch up on lost production time.

Table 12: Peak period job schedule for the months of September to February.

	Line 1			**Line 2**			**Line 3**		
	8-hour shifts	Overtime [hours]	Times	8-hour shifts	Overtime [hours]	Times	8-hour shifts	Overtime [hours]	Times
Week 1									
Mon	2	2	05:30-14:30 14:30-23:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	2	05:30-14:30 14:30-23:30
Tue	2	2	05:30-14:30 14:30-23:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	1	5:30-13:30 13:30-22:30
Wed	2		05:30-13:30 13:30-21:30	3		05:30-13:30 13:30-21:30 21:30-05:30	1	4	05:30-17:30
Thu	2	1	5:30-13:30 13:30-22:30	3		05:30-13:30 13:30-21:30 21:30-05:30			
Fri				3		05:30-13:30 13:30-21:30 21:30-05:30			
Week 2									
Mon	2	2	05:30-14:30 14:30-23:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	2	05:30-14:30 14:30-23:30
Tue	2	1	05:30-14:30 14:30-22:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	1	5:30-13:30 13:30-22:30
Wed	2	3	05:30-14:30 14:30-00:30	3		05:30-13:30 13:30-21:30 21:30-05:30	1	4	05:30-17:30

Thu	2		05:30-13:30 13:30-21:30	3		05:30-13:30 13:30-21:30 21:30-05:30			
Fri				3		05:30-13:30 13:30-21:30 21:30-05:30			
Week 3									
Mon	2	2	05:30-14:30 14:30-23:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	2	05:30-14:30 14:30-23:30
Tue	2	1	05:30-14:30 14:30-22:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	1	5:30-13:30 13:30-22:30
Wed	2	3	05:30-14:30 14:30-00:30	3		05:30-13:30 13:30-21:30 21:30-05:30	1	4	05:30-17:30
Thu	2	5	05:30-16:30 16:30-02:30	3		05:30-13:30 13:30-21:30 21:30-05:30			
Fri				3		05:30-13:30 13:30-21:30 21:30-05:30			
Week 4									
Mon	2	3	05:30-15:30 15:30-00:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	2	05:30-14:30 14:30-23:30
Tue	2	3	05:30-14:30 14:30-00:30	3		05:30-13:30 13:30-21:30 21:30-05:30	2	1	5:30-13:30 13:30-22:30
Wed	2	1	05:30-14:30 14:30-22:30	3		05:30-13:30 13:30-21:30 21:30-05:30	1	4	05:30-17:30
Thu	2	1	05:30-13:30 13:30-22:30	3		05:30-13:30 13:30-21:30 21:30-05:30			
Fri				3		05:30-13:30 13:30-21:30 21:30-05:30			

Table 13: The off-peak job schedule that will be implemented from March to August.

	Line 1			**Line 2**			**Line 3**		
	8-hour shifts	Overtime [hours]	Times	8-hour shifts	Overtime [hours]	Times	8-hour shifts	Overtime [hours]	Times
Week 1									
Mon	2		05:30-13:30 13:30-21:30	2	3	05:30-15:30 15:30-00:30	1	2	05:30-15:30
Tue	2	3	05:30-15:30 15:30-00:30	2	3	05:30-14:30 14:30-00:30	1		5:30-13:30
Wed	2	2	05:30-14:30 14:30-23:30	2	2	05:30-14:30 13:30-21:30	1	2	05:30-15:30
Thu				1		05:30-13:30	1		05:30-13:30
Fri				2	1	05:30-13:30 13:30-22:30			
Week 2									
Mon	2		05:30-13:30 13:30-21:30	2	3	05:30-15:30 15:30-00:30	1	2	05:30-15:30
Tue	2		05:30-13:30 13:30-21:30	2	3	05:30-14:30 14:30-00:30	1		5:30-13:30
Wed	2		05:30-13:30 13:30-21:30	2	2	05:30-14:30 13:30-21:30	1	2	05:30-15:30
Thu	1		05:30-13:30	1		05:30-13:30	1		05:30-13:30
Fri				2	1	05:30-13:30 13:30-22:30			
Week 3									
Mon	2	3	05:30-14:30 14:30-00:30	2	3	05:30-15:30 15:30-00:30	1	2	05:30-15:30
Tue	2	3	05:30-14:30 14:30-00:30	2	3	05:30-14:30 14:30-00:30	1		5:30-13:30

Wed	1	2	05:30-15:30	2	2	05:30-14:30 13:30-21:30	1	2	05:30-15:30
Thu	1	1	05:30-14:30	1		05:30-13:30	1		05:30-13:30
Fri				2	1	05:30-13:30 13:30-22:30			
Week 4									
Mon	2		05:30-13:30 13:30-21:30	2	3	05:30-15:30 15:30-00:30	1	2	05:30-15:30
Tue	2		05:30-13:30 13:30-21:30	2	3	05:30-14:30 14:30-00:30	1		5:30-13:30
Wed	2		05:30-13:30 13:30-21:30	2	2	05:30-14:30 13:30-21:30	1	2	05:30-15:30
Thu	1	4	05:30-17:30	1		05:30-13:30	1		05:30-13:30
Fri				2	1	05:30-13:30 13:30-22:30			

The optimal MPS has been selected, and the accompanying job schedules have been made, which was the main aim of the entire project. In Chapter 6 the decision of safety stock levels will be critically reviewed and the cost differences associated with adjusted safety stock levels will be determined and considered for possible alternatives.

Chapter 6: Sensitivity analysis

In order to perform an assessment of how rigid the MPS is, a sensitivity analysis was performed to assess how great a reduction in production time will be the result if safety stock levels are reduced with some percentage. Inventory holding costs are automatically incurred when inventory is kept in a warehouse, and it delays the turnover rate. The cost implication of inventory holding cost was also assessed to evaluate what the cost benefit would be if safety stock would be reduced. This is to motivate the improvement of forecasting accuracy in monetary terms.

6.1. Safety stock

Clover has a general principle which they have established throughout the company regarding long life products that is also applicable to this new facility concerning safety stock levels. The general rule is to have at least two weeks' safety stock on hand. This decision was made as that this is the level at which Clovers Planning department is comfortable with to compensate for forecasting accuracy of 80% and to sustain a customer service level of 98%.

Projected inventory levels based on the MPS that have been selected were used to evaluate the utilisation of the facility warehouse. The utilisation of equipment was measured through comparing the total hours scheduled for production with the total available time of the equipment. The scheduled time includes the mandatory CIP, since this sterilisation of equipment is necessary to ensure continued effective use. Figure 6.1 shows the weekly warehouse utilisation during the peak and off-peak production periods and figure 6.2 displays the utilisation of equipment.

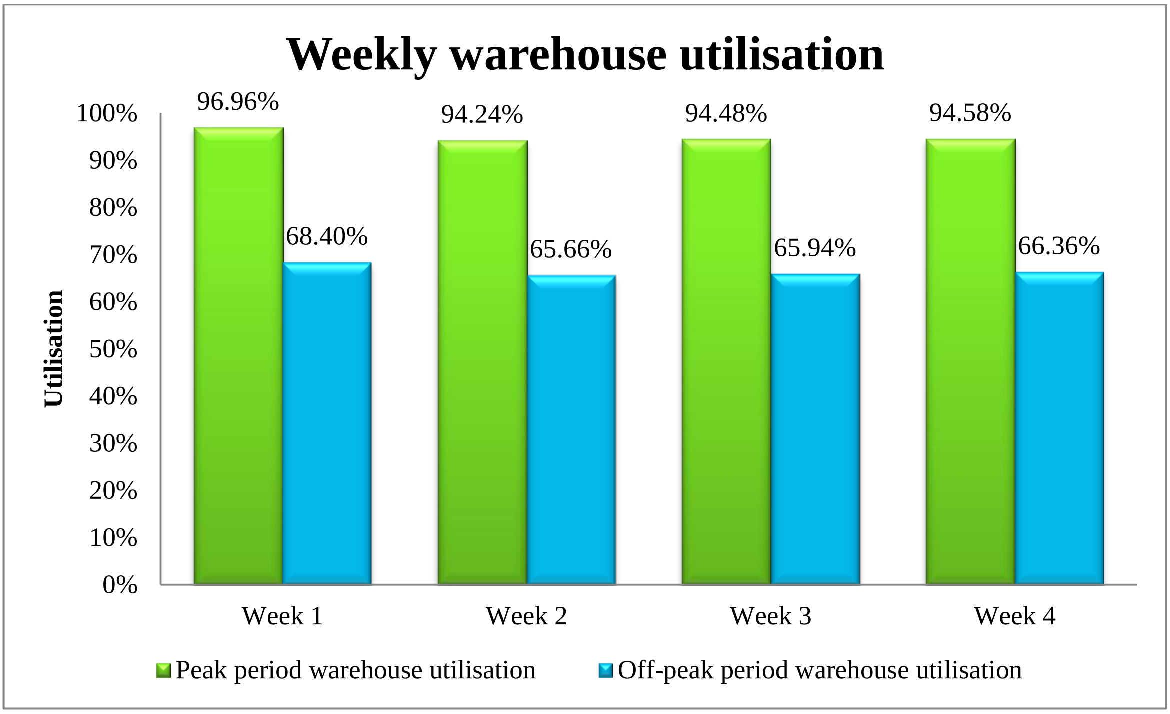

Figure 6.1: Projected peak and off-peak warehouse utilisation.

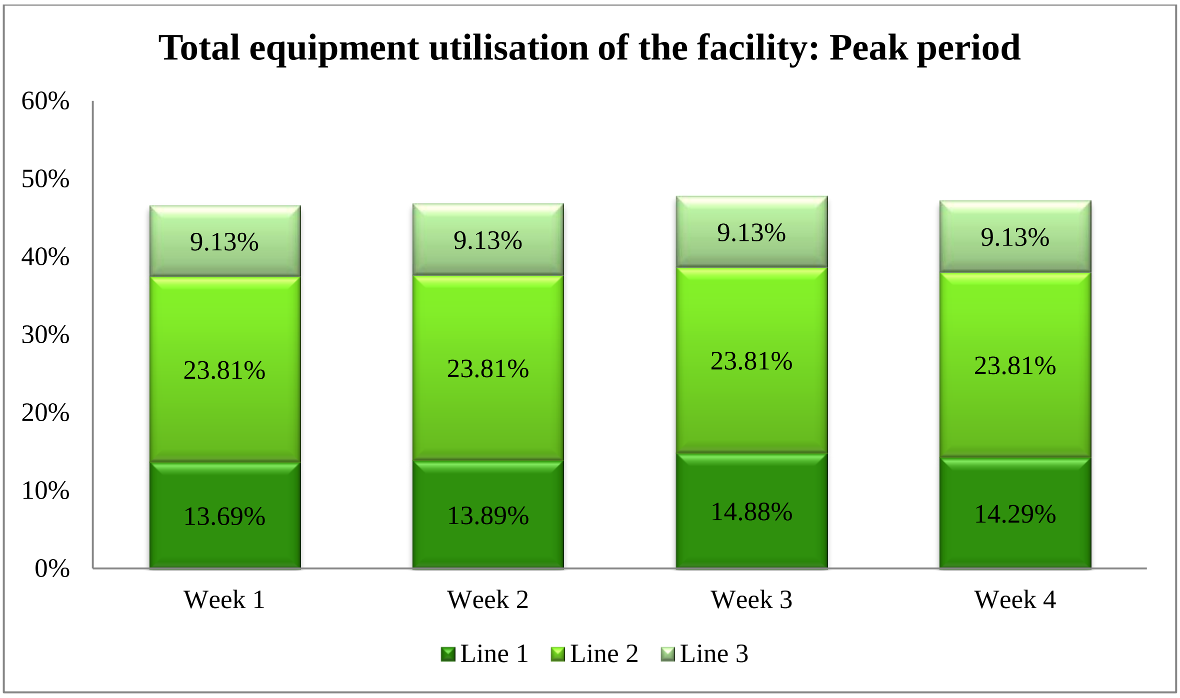

Figure 6.2 Graph showing the total equipment utilisation during peak production.

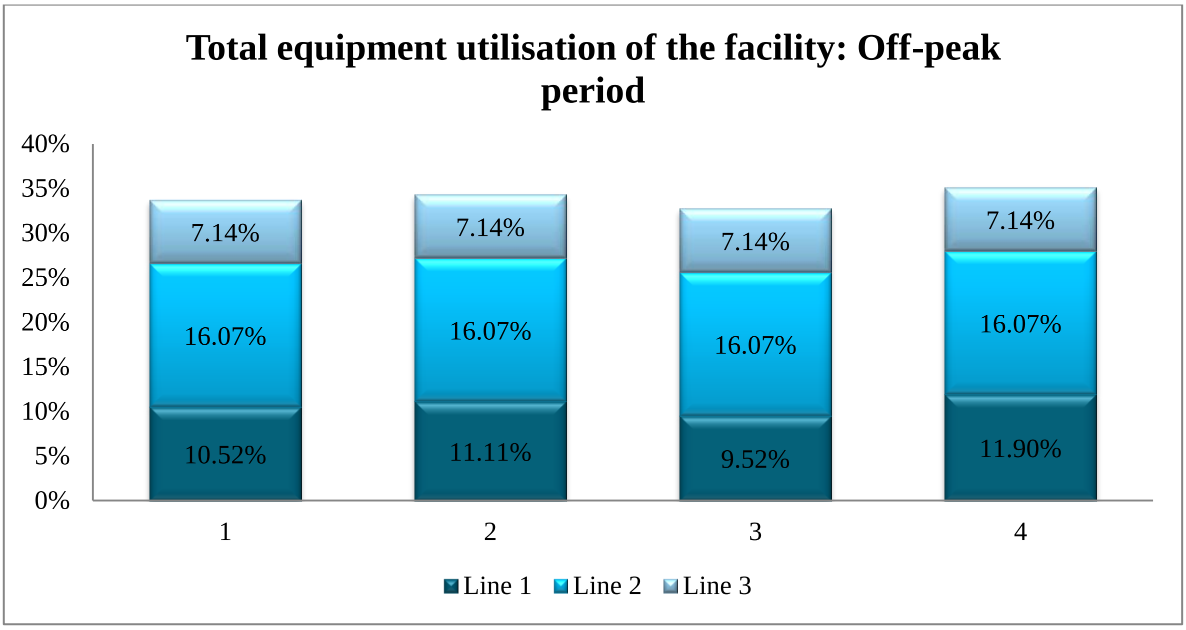

Figure 6.3 Graph showing total equipment utilisation during off-peak production.

Due to the low equipment utilisation levels, the opportunity exists for higher production levels; however, this would cause greater inventory levels unless safety stock levels are reduced.

Both ice tea and water are products with a long shelf life, thus it cannot spoil when kept in storage. The nature of demand for beverages is very dependent on weather patterns, which makes it even more difficult to forecast accurately, a simple example is during the first week of September 2015, there was snowfall and cold weather conditions, which stands in strong contrast with the first week of September 2016 where temperatures are reaching 30˚C. Due to the quarantine period of 7 days, safety stock levels can never be reduced with more than

50%. This implies that the minimum level of safety stock would be 1 weeks' worth of stock. Adhering to this rule, the sensitivity analysis looked at reducing safety stock levels with 50% in increments of 10%.

To perform the sensitivity analysis, firstly, new production lot sizes were determined at each level of reduction in safety stock (i.e. at 10%, 20%, 30%, 40% and 50% less safety stock). Interestingly, the results have shown that a majority of the SKU's lot sizes increased as the safety stock level decreased. This is explained by the fact that demand for a period should now be satisfied more through production lots produced during that specific period, rather than inventory which was carried over from a previous period. The effect on production lot sizes also depends on the successive demand patterns between the 6 demand periods grouped into peak and off-peak periods. Figures 6.4 and 6.5 show the different SKU's numbered 1 to 45 (the SKU's includes all products from line 1, 2 and 3), and how their optimal production lot sizes changed (percentage change from the originally calculated optimal lot sizes at 2week safety stock level).

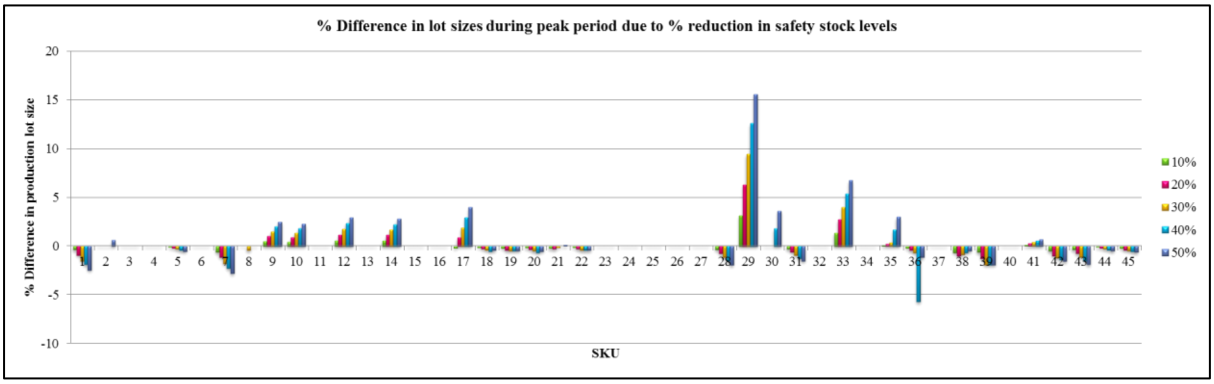

Figure 6.4 Peak production lot size changes due to reduction in safety stock levels.

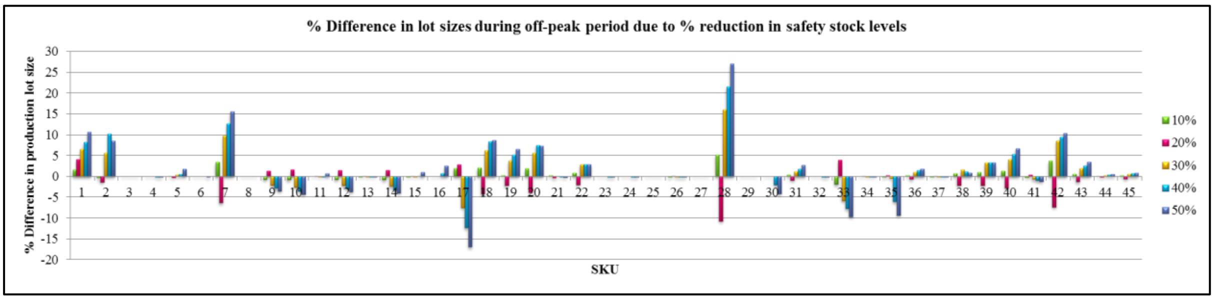

Figure 6.5 Off-peak production lot size changes due to reduction in safety stock levels.

After establishing the optimal lot sizes at different safety stock reduction levels, the average monthly inventory was determined. This enabled the evaluation of how reduced safety stock levels would affect operational costs, due to the reduction of inventory holding costs. In Figure 6.6, it can be seen that if the safety stock level is reduced with 10%, the resulting average monthly inventory holding cost during the peak period decreases with 6.7%. In the off-peak period, the average monthly inventory holding cost is decreased by 6%. All the safety stock reduction levels were evaluated in this way.

The reduction of inventory holding cost can be used as a motivation for Clover to invest in better, more accurate forecasting models and processes. Before pursuing this motivation, however, the effect of reduced safety stock levels on the MPS needs to be evaluated for two reasons: Firstly, to validate the rigidity of the developed production and job schedule. Secondly, the cost implication of producing the production lot sizes defined by the reduced safety stock levels need to be known. These effects are determined in Section 6.2.

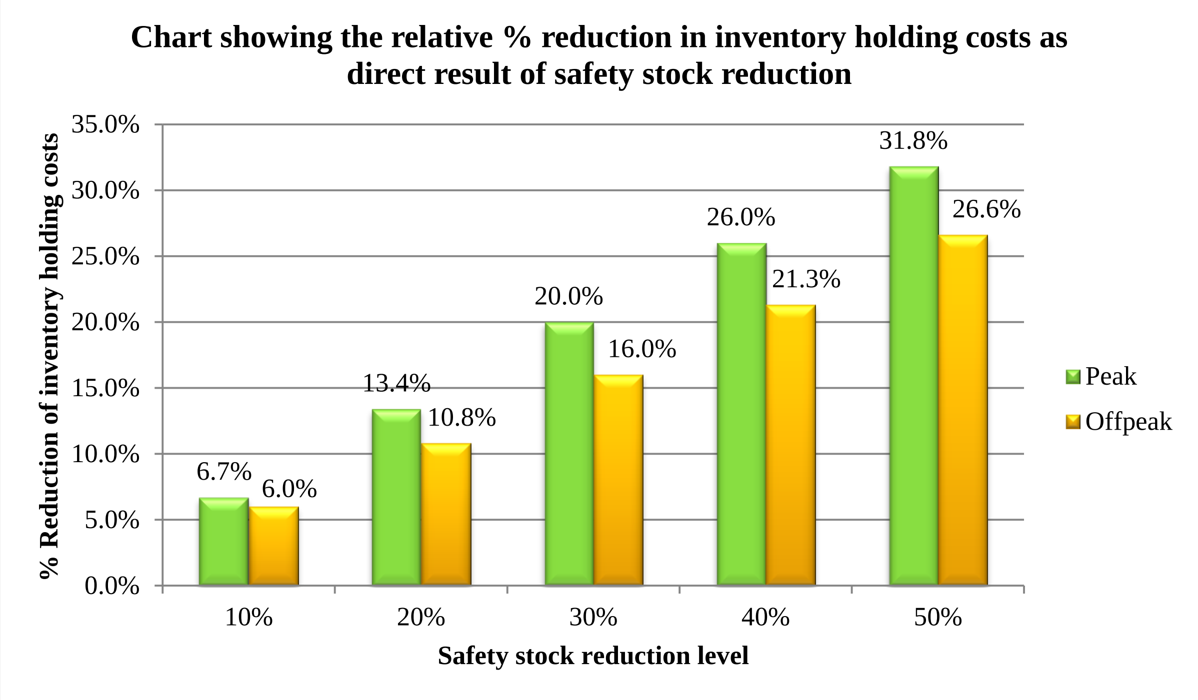

Figure 6.6 Chart depicting the % change in inventory holding costs as direct result of reduced safety stock levels.

6.2. Production time sensitivity analysis

Following the determination of lot sizes at every new safety stock level, the estimated required production time was determined. This test validates the rigidness of the established optimal MPS. It shows that the overall effect of changes in the production lot sizes only lead to a minimal increase in the production time required for the entire production period. The changes can be observed in Figure 6.4.

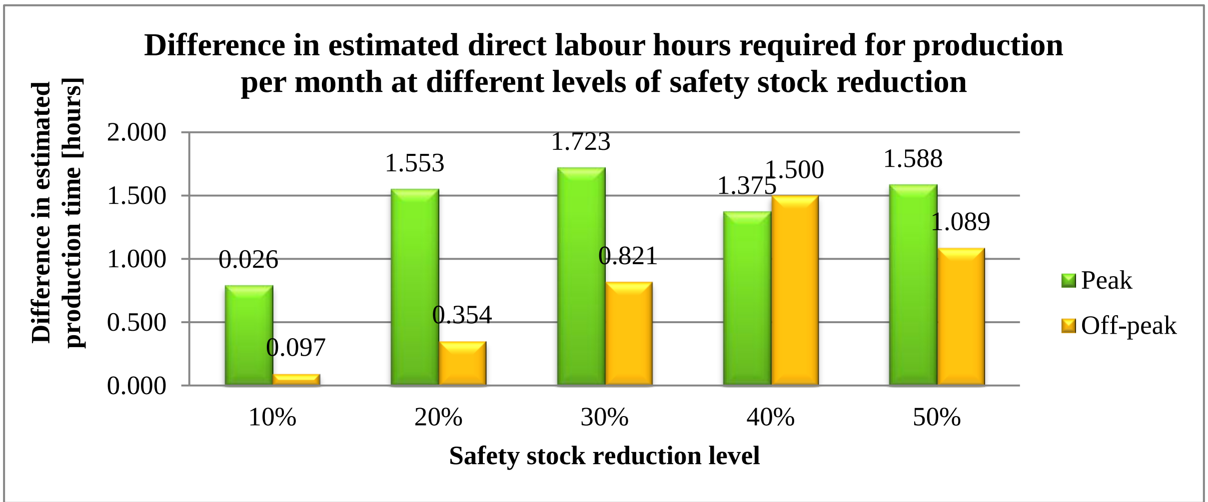

Figure 6.7: Graph of increased estimated production time required if safety stock levels are reduced.

This proves that the production time requirements barely changes with adaptions in the lot sizes. It emphasises how rigid the MPS is. Regardless of the production lot sizes, the MPS and job schedule would essentially stay the same. These results have been combined with the results of Section 6.1, to determine what the effect of reduced safety stock levels would have on overall operational costs of the facility.

Table 14: Effect of reduced safety stock levels on annual operational costs of the facility.

Cost category	% Reduction in safety stock level.				
	10%	20%	30%	40%	50%
Production cost	+ R 2460.48	+ R 5277.23	+ R 7036.54	+ R 7955.36	+ R 7405.43
Inventory holding cost	- R 738 675	- R1 228 716.69	- R1 722 489.97	- R2 212 735.58	- R2 684 530.92

Table 14 can be considered as a monetary motivation for Clover to consider investing in better forecasting methods. If forecasting accuracy can be improved, the safety stock levels can be reduced and save a substantial amount of money annually. Currently, the warehouse is able to accommodate the 2-week safety stock level without any problems, thus, the reduction of safety stock is not a critical necessity, but an operational improvement opportunity.

Chapter 7: Conclusion

For concluding the work of this project, this chapter will discuss what has been done through the course of this project. Recommendations, which are based on the results obtained, and opportunities that have come to light are made. Some future work possibilities have also become apparent throughout the course of this project and are discussed.

7.1. The problem and solution

Clover has made a strategic decision to move all of their national ice tea and water bottling operations into one brand new bottling facility situated in centurion. The facility produces ice tea and bottled water on three filling lines. Each filler line has a specific set of SKU's which it mixes and bottles. Moving all of the bottling operations into one facility makes planning and control from a single source simpler. The company strives to optimise its operations in all aspects, from planning, sourcing, scheduling through to nationwide distribution. The new facility posed an opportunity to optimise the planning and operations of this facility from start-up.

The aim was to operate this new facility as optimally as possible from start of production in July 2016. The development of an optimised MPS and an accompanying job schedule were the first steps to coordinating all the operating activities of the facility. There were many planning rules and facility capacity constraints, which needed to be considered to develop the MPS in alignment with the company's general planning rules and within the operating capacity of the facility. Forecasting analysis indicated two seasonal demand periods, a peak and off peak season, each of duration of six months. Production is planned on a monthly basis. For each period, fixed production lot sizes need to be established that will be produced monthly.

Firstly, production rules were established to be adhered to as the development of the MPS progresses. These planning rules are summarised at the end of Chapter 3. Secondly, the changeover times, labour cost, inventory holding cost and production frequencies were optimised according to planning rules. After these factors were optimised, mathematical models using MILP were developed to determine optimal production lot sizes. These models incorporate the four major optimisation objectives mentioned in Chapter 1. These objectives are; Minimum production and distribution costs, minimised working capital invested in inventory, maximised market supply and satisfactory levels of agility to react to demand fluctuations.

After the lot sizes were determined, Infor Advanced Scheduler planning software was used to develop the MPS. The MPS consists of two one-month schedules, one for the peak period, which is repeated each month from September to February, and the other one for the off-peak period is repeated monthly from March to August. The reports generated through Infor AS were then used to develop the job schedule. A summary of the production lot sizes is given below in cases, and litres. The lot size in litres and frequency of production is important information to communicate to the persons responsible for procurement. The Procurement function needs to determine the quantities of concentrate and flavouring required for the lot sizes. They have to ensure that enough concentrate and flavouring is available on hand before production of the lot commences.

Table 15: Optimal production lot sizes used in the final MPSs in cases and litres, and frequency of lot production per month.

SKU	Production frequency per month	Peak lot size [cases]	Peak lot size [litres]	Off-peak lot size [cases]	Off-peak lot size[litres]
Line 1					
1	1	527	9486	365	6570
2	1	487	8766	304	5472
3	1	390	7020	278	5004
4	1	417	5004	421	5052
5	4	3707	33363	2497	22473
6	1	741	6669	561	5049
7	1	786	7074	842	7578
8	1	1112	10008	560	5040
9	1	3969	47628	2931	35172
10	1	4385	52620	2376	28512
11	1	1667	20004	1192	14304
12	1	6687	80244	5586	67032
13	1	3333	39996	2316	27792
14	1	3552	42624	2585	31020
15	4	2625	31500	1767	21204
16	4	1875	33750	1010	18180
17	1	2545	22905	2799	25191
18	1	6385	57465	5051	45459
19	1	7955	71595	5616	50544
20	1	5274	47466	4204	37836
21	1	5689	51201	4444	39996
22	1	3720	33480	3236	29124
23	1	417	5004	421	5052
24	1	417	5004	421	5052
25	1	625	7500	417	5004
26	1	972	11664	562	6744
27	1	1042	12504	830	9960
28	1	1024	12288	440	5280
29	1	635	7620	417	5004
30	1	1111	13332	981	11772
31	1	2150	25800	1475	17700
32	1	834	10008	491	5892
33	1	1469	17628	1041	12492
34	1	3125	37500	2034	24408

35	1	3044	36528	2789	33468
36	1	3792	68256	2157	38826
Line 2					
1	4	3788	30000.96	3789	30008.88
2	8	6977	83724	5573	66876
3	4	1870	33660	1058	19044
4	4	5000	90000	3524	63432
5	4	4934	59208	3138	37656
6	4	4531	81558	3152	56736
7	4	7447	89364	4187	50244
Line 3					
1	16	3015	60300	4455	89100
2	16	5307	53070	6831	68310

Tables 16 and 17 are the final MPSs that were created in Infor, using the real SKU numbers, which are already programmed into the system. Screenshots of the MPS on Infor AS can be seen in appendix I. The accompanying job schedules for the peak and off-peak periods are in table 12 and table 13, in Chapter 5. The planning rules, production lot sizes, MPS, and job schedule were the results of this project. This solves the major problem and requirements Clover has identified for the new bottling facility. These resulting components can be integrated into the operations management of the facility from the 1st of September.

Table 16: Monthly MPS for peak production (September to February).

Peak monthly MPS for September – February						
	Line 1		**Line 2**		**Line 3**	
Day	SKU no.	Lot size [cases]	SKU no.	Lot size [cases]	SKU no.	Lot size [cases]
Week 1						
Monday	2101648	3707	2102756	6977	2104592	3015
	2102777	2625			2102759	5307
					2104592	3015
Tuesday	2102778	1875	2102753	3788	2102759	5307
	2101472	527	2102757	1870	2104592	3015
	2101474	487	2102758	5000	2102759	5307
	2101475	390				
	2101808	741				
	2101813	786				
	2101814	1112				
	2102841	2545				
Wednesday	2102862	6385	2102756	6977	2104592	3015
	2102887	7955			2102759	5307
Thursday	2102888	5274	2103170	4934		
	2102890	5689	2104345	2260		

	2102891	3720				
Friday			2104345	2271		
			2104347	7447		
Week 2						
Monday	2101648	3707	2102756	6977	2104592	3015
	2102777	2625			2102759	5307
					2104592	3015
Tuesday	2102778	1875	2102753	3788	2102759	5307
	2104591	3792	2102757	1870	2104592	3015
	2102933	417	2102758	5000	2102759	5307
	102934	417				
	2102935	625				
Wednesday	2104668	972	2102756	6977	2104592	3015
	2104673	1042			2102759	5307
	2104674	1024				
	2104676	635				
	2104691	1111				
Thursday	2105036	2150	2103170	4934		
	2105132	834	2104345	2260		
	2105375	1469				
Friday			2104345	2271		
			2104347	7447		
Week 3						
Monday	2101648	3707	2102756	6977	2104592	3015
	2102777	2625			2102759	5307
					2104592	3015
Tuesday	2102778	1875	2102753	3788	2102759	5307
	2101569	417	2102757	1870	2104592	3015
	2104481	3125	2102758	5000	2102759	5307
Wednesday	2104483	3044	2102756	6977	2104592	3015
	2102193	2500			2102759	5307
Thursday	2102194	4385	2103170	4934		
	2102193	1469	2104345	2260		
Friday			2104345	2271		
			2104347	7447		
Week 4						
Monday	2101648	3707	2102756	6977	2104592	3015
	2102249	3333			2102759	5307
					2104592	3015
Tuesday	2102777	2625	2102753	3788	2102759	5307
	2102778	1875	2102757	1870	2104592	3015

	2102195	1667	2102758	5000	2102759	5307
Wednesday	2102196 2102252	3344 1776	2102756	6977	2104592 2102759	3015 5307
Thursday	2102196 2102252	3344 1776				
Friday			2104345 2104347	2271 7447		

Table 17: Monthly MPS for peak production (March to August).

Off-peak monthly MPS for March – August						
	Line 1		**Line 2**		**Line 3**	
Day	SKU no.	Lot size [cases]	SKU no.	Lot size [cases]	SKU no.	Lot size [cases]
Week 1						
Monday	2101648 2102777 2102778 2101472	2497 1767 1010 365	2102756	5573	2104592	4455
Tuesday	2101474 2101808 2101813 2101814 2102841 2102862 2102891	304 561 842 560 2799 5051 3236	2102753 2102757 2102758	3789 1058 3524	2102759	6831
Wednesday	2101475 2102887 2102888 2102890	278 5616 4204 4444	2102756	5573	2104592	4455
Thursday			2103170	3138	2102759	6831
Friday			2104345 2104347	3152 4187		
Week 2						
Monday	2101648 2102777 2102778	2497 1767 1010	2102756	5573	2104592	4455
Tuesday	2104591 2102933 2102934 2102935 2104668 2104673	2157 421 421 417 562 830	2102753 2102757 2102758	3789 1058 3524	2102759	6831
Wednesday	2104674 2104676 2104691 2105036 2105132	440 417 981 1475 491	2102756	5573	2104592	4455
Thursday	2105375	1041	2103170	3138	2102759	6831

Friday			2104345 2104347	3152 4187		
Week 3						
Monday	2101648 2102777 2102778 2101569	2497 1767 1010 421	2102756	5573	2104592	4455
Tuesday	2104481 2104483	2034 2789	2102753 2102757 2102758	3789 1058 3524	2102759	6831
Wednesday	2102193	2931	2102756	5573	2104592	4455
Thursday	2102194	2376	2103170	3138	2102759	6831
Friday			2104345 2104347	3152 4187		
Week 4						
Monday	2101648 2102777 2102778	2497 1767 1010	2102756	5573	2104592	4455
Tuesday	2102195 2102249	1192 2316	2102753 2102757 2102758	3789 1058 3524	2102759	6831
Wednesday	2102252 2102196	2585 2000	2102756	5573	2104592	4455
Thursday	2102196	3586	2103170	3138	2102759	6831
Friday			2104345 2104347	3152 4187		

7.2. Recommendations

To effectively integrate the solutions obtained into the operations of the facility, all three components: Planning rules, MPS and job schedule, need to be communicated to all involved departments clearly. The MPS is flexible enough to allow for urgent maintenance of equipment, should it be necessary in the middle of the week, however, there is ample time after the completion of each week's production runs to do any other procedure maintenance over weekends.

It has been evident from the sensitivity analysis that the MPS can stay the same with only production lot sizes that might change due to improved forecasting methods. The production lot sizes should be used as a baseline optimal value. The production lot sizes can be changed to accommodate demand growth or sudden changes in consumption patterns or if forecasting accuracy improved and lot sizes changed due to reduced safety stock levels.

It is recommended that Clover looks into possible ways of improving forecasting accuracy from the current accuracy level of 80% to a more accurate forecast. Improving forecasting accuracy would lead to reduced levels of safety stock required, leading to big cost cutting opportunities for the operation of the facility. If their safety stock levels can be reduced by 50% to their minimum allowable safety stock level, Clover could save up to R2.68 million annually from inventory holding costs. This statement is proved through the inventory holding cost sensitivity analysis in Chapter 6.

7.3. Future work

There is a large amount of work that can be taken on, which is actually a necessity to building on the development of the optimal MPS, in order to ensure that operations of the facility are synchronised with the MPS.

The next step on the inbound logistics and operational side of the facility, will be to derive a material requirements plan from the MPS. The material requirements plan is developed by identifying each SKU's required raw materials from the bill of materials; which in this case is the recipe for the beverage and the packaging. This will indicate to the Procurement Department what materials are required and when they should be available for production. Raw material sourcing will then be done according to the schedule. Economic ordering lot sizes for raw material need to be established at an optimum level for inventory control on the raw material side of operations.

On the outbound logistics side, warehouse management and distribution methods and processes should be established. These processes need to ensure a smooth flow of products from the filling lines, through quarantine, into the warehouse and finally out of the warehouse to distribution vehicles. These processes could include classifying products into categories of fast-movers and slow movers. Allocating general storage areas within the warehouse for different class movers would aid in warehouse management, the flow of products through the warehouse and inventory control.

Utilisation of the equipment is low. This opens up the opportunity of possibly finding other companies who would be interested in contracting with clover to produce beverages on their behalf. These companies would then still have the responsibility of providing offsite-warehousing facilities to keep inventory. Another opportunity is looking at using filling line 3 for bottling some of the products currently on line 2, in order to balance the workload. This would possibly require some capital investment for adjusting the filler line, and the trade-offs between the investment and cost of labour should be made to determine whether it would be an economically viable and feasible project.

The optimisation of operations of any facility is a continuous process. The aim should not be to optimise every individual aspect and then try to integrate them, no. The main objective should be to be relentlessly invested into the optimisation of the operations of an entire facility and all other logistic operations related to the facility as a holistic integrated optimised system of operations.

"Everything should be made as simple as possible, but not simpler." –Albert Einstein

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Appendix A: Project sponsorship form.

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

Final Year Projects may be published by the University of Pretoria on *UPSpace* and may thus be freely available on the Internet. These publications portray the quality of education at the University, but they have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide guidance to the student throughout the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Clover SA
Project Description:	Development of planning rules and an optimised production schedule for a new water and ice-tea bottling plant
Student Name:	Marilize Coetzer
Student number:	13011473
Student Signature:	
Sponsor Name:	Johann Coetzer
Designation:	Group Manager, Supply Chain Development.
E-mail:	johann.coetzer@clover.co.za
Tel No:	011 471 1508
Cell No:	082 334 9649
Fax No:	
Sponsor Signature:	

Appendix B: Changeover time matrices.

Line 1: Changeover time matrix. (changeover time in minutes)

		1	2	3	4	5	6	7	8
1	Aquartz Sparkling Peach/Passion 12x1.5lt	0	45	45	100	100	45	45	45
2	Aquartz Sparkling Cran/Rasb 12x1.5lt	45	0	45	100	100	45	45	100
3	Aquartz Sparkling Lem/Lime 12x1.5lt	45	45	0	100	100	45	45	45
4	Aquartz Sparkling Mango 4x6x500ml	100	100	100	0	100	100	100	100
5	Aquartz Mineral Still 2x6x750ml	100	100	100	100	0	100	100	100
6	Nestea Ice Tea Berry 6x1.5LT	45	45	45	100	100	0	45	45
7	Nestea Ice Tea Peach 6x1.5LT	45	45	45	100	100	45	0	45
8	Nestea Ice Tea Lemon 6x1.5LT	45	45	45	100	100	45	45	0
9	Clover Manhattan Ice Tea Blackcurrant (6X4)X500ml	100	100	100	45	100	100	100	100
10	Clover Manhattan Ice Tea Pineapple (6X4)X500ml	100	100	100	45	100	100	100	100
11	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	100	100	100	45	100	100	100	100
12	Clover Manhattan Ice Tea Peach (6X4)X500ml	100	100	100	45	100	100	100	100
13	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	100	100	100	45	100	100	100	100
14	Clover Manhattan Ice Tea Lemon (6X4)X500ml	100	100	100	45	100	100	100	100
15	Nestle Pure Life Sparkling 4x6x500ml	100	100	100	45	100	100	100	100
16	Nestle Pure Life Sparkling 12x1.5lt	45	45	45	100	100	45	45	45
17	MAN G/TEA APR/LTE 6x1.5Lt	45	45	45	100	100	45	45	45
18	MAN I/TEA PEACH LTE 6x1.5Lt	45	45	45	100	100	45	45	45
19	MAN I/TEA PEACH 6x1.5Lt	45	45	45	100	100	45	45	45
20	MAN I/TEA LEMON 6x1.5Lt	45	45	45	100	100	45	45	45
21	MAN G/TEA RB/GF/ST 6x1.5Lt	45	45	45	100	100	45	45	45
22	MAN G/TEA KI/PEA LTE 6x1.5Lt	45	45	45	100	100	45	45	45
23	Nestea Ice Tea Peach 4x6x500ml	100	100	100	45	100	100	100	100
24	Nestea Ice Tea Berry 4x6x500ml	100	100	100	45	100	100	100	100
25	Nestea Ice Tea Lemon 4x6x500ml	100	100	100	45	100	100	100	100
26	Aquartz Sparkling Lemon/Lime 24X500 ml	100	100	100	45	100	100	100	100
27	Aquartz Sparkling Litchi 24X500 ml	100	100	100	45	100	100	100	100
28	Aquartz Sparkling Naartjie 24X500 ml	100	100	100	45	100	100	100	100
29	Aquartz Sparkling Peach Passion 24X500 ml	100	100	100	45	100	100	100	100
30	Aquartz Sparkling Cran/Raspberry 24X500 ml	100	100	100	45	100	100	100	100
31	Aquartz Mineral Water Sparkling 4X6X500 ml	100	100	100	45	100	100	100	100
32	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	100	100	100	45	100	100	100	100
33	Manhattan White I/Tea Exotic Fruit 4x6x500ml	100	100	100	45	100	100	100	100
34	Clover Manhattan Ice Tea Crisp Apple/Mint (6X4)X500ml	100	100	100	45	100	100	100	100
35	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry 6X4X500ml	100	100	100	45	100	100	100	100
36	Aquartz Mineral Water Sparkling 12X1.5 lt	45	45	45	100	100	45	45	45

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	1	1	1	1	1	1	45	45	45	45	45	45	45	1	1	1	1	1	1
100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100
45	45	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100
0	45	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45
45	0	45	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45
45	45	0	45	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45
45	45	45	0	45	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45
45	45	45	45	0	45	100	100	100	100	100	100	100	45	45	45	45	45	45	45
45	45	45	45	45	0	45	100	100	100	100	100	100	45	45	45	45	45	45	45
45	45	45	45	45	45	0	100	100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	0	45	45	45	45	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	0	45	45	45	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	0	45	45	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	0	45	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	0	45	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	0	45	100	100	100	100	100	100
100	100	100	100	100	100	100	45	45	45	45	45	45	0	100	100	100	100	100	100
45	45	45	45	45	45	45	100	100	100	100	100	100	100	0	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	0	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	0	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	0	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	0	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	0
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
45	45	45	45	45	45	45	100	100	100	100	100	100	100	100	45	45	45	45	45
100	100	100	100	100	100	100	45	45	45	45	45	45	45	100	100	100	100	100	100

29	30	31	32	33	34	35	36
1	1	1	1	1	1	1	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
45	45	45	45	45	45	45	100
100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
100	100	100	100	100	100	100	45
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
45	45	45	45	45	45	45	100
0	45	45	45	45	45	45	100
45	0	45	45	45	45	45	100
45	45	0	45	45	45	45	100
45	45	45	0	45	45	45	100
45	45	45	45	0	45	45	100
45	45	45	45	45	0	45	100
45	45	45	45	45	45	0	100
100	100	100	100	100	100	100	0

Line 2: Changeover time matrix. (changeover time in hours)

		1	2	3	4	5	6	7	8
1	Nestle Pure Life Still 4x6x330ml	0	1	1	1	1	1	1	1
2	Nestle Pure life Still 4x6x500ml	1	0	1	1	1	1	1	1
3	Nestle Pure Life Still 4x6x750ml	1	1	0	1	1	1	1	1
4	Nestle Pure life Still 12x1.5lt	1	1	1	0	1	1	1	1
5	Nestle Pure Life Still 2x5lt	1	1	1	1	0	1	1	1
6	Nestle Pure Life Still 2x12x500ml	1	1	1	1	1	0	1	1
7	Aquartz Mineral Water Still 12X1.5 lt	1	1	1	1	1	1	0	1
8	Aquartz Mineral Water Still 4X6X500 ml	1	1	1	1	1	1	1	0

Appendix C: Demand forecast for each SKU as forecasted for the period of June 2016 to July 2017

			Conversion factors			07/2016		
LINE	SKU no.	DESCRIPTION	litres/unit	litres/case	units/case	units	litres	cases
1	2101472	Aquartz Sparkling Peach/Passion 12x1.5l	1.5	18	12	3 333	5000	278
1	2101474	Aquartz Sparkling Cran/Rasb 12x1.5l	1.5	18	12	3 333	5000	278
1	2101475	Aquartz Sparkling Lem/Lime 12x1.5l	1.5	18	12	3 333	5000	278
1	2101569	Aquartz Sparkling Mango 4x6x500ml	0.5	12	24	10 000	5000	417
1	2101648	Aquartz Mineral Still 2x6x750ml	0.75	9	12	113 333	85000	9444
1	2101808	Nestea Ice Tea Berry 6x1.5l	1.5	9	6	3 333	5000	556
1	2101813	Nestea Ice Tea Peach 6x1.5l	1.5	9	6	3 333	5000	556
1	2101814	Nestea Ice Tea Lemon 6x1.5l	1.5	9	6	3 333	5000	556
1	2102193	Clover Manhattan Ice Tea Blackcurrent (6X4)X500ml	0.5	12	24	70 000	35000	2917
1	2102194	Clover Manhattan Ice Tea Pineapple (6X4)X500ml	0.5	12	24	70 000	35000	2917
1	2102195	Clover Manhattan Ice Tea Lemon Lite (6X4)X500ml	0.5	12	24	20 000	10000	833
1	2102196	Clover Manhattan Ice Tea Peach (6X4)X500ml	0.5	12	24	130 000	65000	5417
1	2102249	Clover Manhattan Ice Tea Peach Lite (6X4)X500ml	0.5	12	24	60 000	30000	2500
1	2102252	Clover Manhattan Ice Tea Lemon (6X4)X500ml	0.5	12	24	70 000	35000	2917
1	2102777	Nestle Pure Life Sparkling 4x6x500ml	0.5	12	24	144 000	72000	6000
1	2102778	Nestle Pure Life Sparkling 12x1.5l	1.5	18	12	36 000	54000	3000
1	2102841	MAN G/TEA APR/LTE 6x1.5l	1.5	9	6	10 000	15000	1667
1	2102862	MAN I/TEA PEACH LTE 6x1.5l	1.5	9	6	26 667	40000	4444
1	2102887	MAN I/TEA PEACH 6x1.5l	1.5	9	6	33 333	50000	5556
1	2102888	MAN I/TEA LEMON 6x1.5l	1.5	9	6	20 000	30000	3333
1	2102890	MAN G/TEA RB/GF/ST 6x1.5l	1.5	9	6	26 667	40000	4444
1	2102891	MAN G/TEA KI/PEA LTE 6x1.5l	1.5	9	6	16 667	25000	2778
1	2102933	Nestea Ice Tea Peach 4x6x500ml	0.5	12	24	10 000	5000	417
1	2102934	Nestea Ice Tea Berry 4x6x500ml	0.5	12	24	10 000	5000	417
1	2102935	Nestea Ice Tea Lemon 4x6x500ml	0.5	12	24	10 000	5000	417
1	2104668	Aquartz Sparkling Lemon/Lime 24X500 ml	0.5	12	24	10 000	5000	417
1	2104673	Aquartz Sparkling Litchi 24X500 ml	0.5	12	24	20 000	10000	833
1	2104674	Aquartz Sparkling Naartjie 24X500 ml	0.5	12	24	10 000	5000	417
1	2104676	Aquartz Sparkling Peach Passion 24X500 ml	0.5	12	24	10 000	5000	417
1	2104691	Aquartz Sparkling Cran/Raspberry 24X500 ml	0.5	12	24	30 000	15000	1250
1	2105036	Aquartz Mineral Water Sparkling 4X6X500 ml	0.5	12	24	40 000	20000	1667
1	2105132	Manhattan Ice Tea Green Tea Lite Kiwi Pear (6X4)X500ml	0.5	12	24	10 000	5000	417
1	2105375	Manhattan White I/Tea Exotic Fruit 4x6x500ml	0.5	12	24	20 000	10000	833
1	2104481	Clover Manhattan Ice Tea Crisp Apple/Mint with Ginseng (6X4)X500ml	0.5	12	24	50 000	25000	2083
1	2104483	Clover Manhattan Ice Tea Ruby Grapefruit/Sberry with Ginko Biloba 6X4X500ml	0.5	12	24	60 000	30000	2500
1	2104591	Aquartz Mineral Water Sparkling 12X1.5 l	1.5	18	12	30 000	45000	2500
2	2102753	Nestle Pure Life Still 4x6x330ml	0.33	7.92	24	363 636	120000	15152
2	2102756	Nestle Pure life Still 4x6x500ml	0.5	12	24	960 000	480000	40000
2	2102757	Nestle Pure Life Still 4x6x750ml	0.75	18	24	96 000	72000	4000
2	2102758	Nestle Pure life Still 12x1.5l	1.5	18	12	96 000	144000	8000
2	2103170	Nestle Pure Life Still 2x12x500ml	0.5	12	24	340 000	170000	14167
2	2104345	Aquartz Mineral Water Still 12X1.5 l	1.5	18	12	113 333	170000	9444
2	2104347	Aquartz Mineral Water Still 4X6X500 ml	0.5	12	24	400 000	200000	16667
3	2104592	Aquartz Mineral Water 4 x 5l	5	20	4	154 000	770000	38500
3	2102759	Nestle Pure Life Still 2x5l	5	10	2	120 000	600000	60000

08/2016			09/2016			10/2016			11/2016			12/2016		
units	litres	cases	units	litres	cases	units	litres	cases	units	litres	cases	units	litres	cases
3 333	5000	278	3333	5000	278	6667	10000	556	6667	10000	556	6667	10000	556
3 333	5000	278	6667	10000	556	3333	5000	278	6667	10000	556	6667	10000	556
3 333	5000	278	3333	5000	278	3333	5000	278	6667	10000	556	3333	5000	278
10 000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
146 667	110000	12222	160000	120000	13333	153333	115000	12778	186667	140000	15556	200000	150000	16667
3 333	5000	556	3333	5000	556	3333	5000	556	3333	5000	556	6667	10000	1111
3 333	5000	556	3333	5000	556	3333	5000	556	6667	10000	1111	3333	5000	556
3 333	5000	556	3333	5000	556	3333	5000	556	10000	15000	1667	3333	5000	556
80 000	40000	3333	100000	50000	4167	90000	45000	3750	100000	50000	4167	80000	40000	3333
80 000	40000	3333	110000	55000	4583	100000	50000	4167	80000	40000	3333	80000	40000	3333
40 000	20000	1667	40000	20000	1667	40000	20000	1667	40000	20000	1667	30000	15000	1250
150 000	75000	6250	170000	85000	7083	150000	75000	6250	170000	85000	7083	150000	75000	6250
70 000	35000	2917	80000	40000	3333	80000	40000	3333	70000	35000	2917	70000	35000	2917
70 000	35000	2917	90000	45000	3750	80000	40000	3333	80000	40000	3333	80000	40000	3333
216 000	108000	9000	216000	108000	9000	288000	144000	12000	216000	108000	9000	216000	108000	9000
72 000	108000	6000	72000	108000	6000	108000	162000	9000	72000	108000	6000	108000	162000	9000
10 000	15000	1667	16667	25000	2778	13333	20000	2222	16667	25000	2778	13333	20000	2222
33 333	50000	5556	36667	55000	6111	36667	55000	6111	40000	60000	6667	40000	60000	6667
40 000	60000	6667	43333	65000	7222	46667	70000	7778	50000	75000	8333	50000	75000	8333
26 667	40000	4444	30000	45000	5000	30000	45000	5000	33333	50000	5556	33333	50000	5556
30 000	45000	5000	33333	50000	5556	33333	50000	5556	36667	55000	6111	30000	45000	5000
20 000	30000	3333	20000	30000	3333	20000	30000	3333	23333	35000	3889	23333	35000	3889
10 000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
10 000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
10 000	5000	417	10000	5000	417	20000	10000	833	10000	5000	417	10000	5000	417
20 000	10000	833	20000	10000	833	20000	10000	833	30000	15000	1250	20000	10000	833
20 000	10000	833	20000	10000	833	20000	10000	833	30000	15000	1250	30000	15000	1250
10 000	5000	417	10000	5000	417	24000	12000	1000	24000	12000	1000	30000	15000	1250
10 000	5000	417	20000	10000	833	10000	5000	417	20000	10000	833	10000	5000	417
20 000	10000	833	30000	15000	1250	20000	10000	833	30000	15000	1250	30000	15000	1250
40 000	20000	1667	40000	20000	1667	50000	25000	2083	60000	30000	2500	50000	25000	2083
20 000	10000	833	10000	5000	417	20000	10000	833	30000	15000	1250	10000	5000	417
30 000	15000	1250	40000	20000	1667	30000	15000	1250	40000	20000	1667	30000	15000	1250
60 000	30000	2500	70000	35000	2917	80000	40000	3333	70000	35000	2917	60000	30000	2500
70 000	35000	2917	80000	40000	3333	60000	30000	2500	80000	40000	3333	70000	35000	2917
30 000	45000	2500	40000	60000	3333	43333	65000	3611	50000	75000	4167	46667	70000	3889
363 636	120000	15152	363636	120000	15152	363636	120000	15152	363636	120000	15152	363636	120000	15152
1 248 000	624000	52000	1248000	624000	52000	1440000	720000	60000	1152000	576000	48000	1248000	624000	52000
144 000	108000	6000	144000	108000	6000	192000	144000	8000	192000	144000	8000	144000	108000	6000
192 000	288000	16000	240000	360000	20000	192000	288000	16000	288000	432000	24000	240000	360000	20000
430 000	215000	17917	400000	200000	16667	460000	230000	19167	580000	290000	24167	360000	180000	15000
113 333	170000	9444	126667	190000	10556	170000	255000	14167	253333	380000	21111	246667	370000	20556
400 000	200000	16667	500000	250000	20833	750000	375000	31250	780000	390000	32500	720000	360000	30000
157 000	785000	39250	175000	875000	43750	166000	830000	41500	212000	1060000	53000	211000	1055000	52750
144 000	720000	72000	150000	750000	75000	174000	870000	87000	174000	870000	87000	174000	870000	87000

01/2017			02/2017			03/2017			04/2017			05/2017		
units	litres	cases	units	litres	cases	units	litres	cases	units	litres	cases	units	litres	cases
6667	10000	556	6667	10000	556	3333	5000	278	6667	10000	556	3333	5000	278
6667	10000	556	3333	5000	278	6667	10000	556	3333	5000	278	3333	5000	278
6667	10000	556	3333	5000	278	3333	5000	278	3333	5000	278	3333	5000	278
10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
180000	135000	15000	180000	135000	15000	133333	100000	11111	120000	90000	10000	106667	80000	8889
3333	5000	556	6667	10000	1111	3333	5000	556	3333	5000	556	3333	5000	556
3333	5000	556	6667	10000	1111	6667	10000	1111	3333	5000	556	3333	5000	556
6667	10000	1111	13333	20000	2222	3333	5000	556	3333	5000	556	3333	5000	556
90000	45000	3750	90000	45000	3750	90000	45000	3750	70000	35000	2917	60000	30000	2500
80000	40000	3333	80000	40000	3333	90000	45000	3750	80000	40000	3333	60000	30000	2500
40000	20000	1667	40000	20000	1667	40000	20000	1667	30000	15000	1250	30000	15000	1250
160000	80000	6667	140000	70000	5833	170000	85000	7083	140000	70000	5833	120000	60000	5000
60000	30000	2500	80000	40000	3333	70000	35000	2917	60000	30000	2500	60000	30000	2500
80000	40000	3333	80000	40000	3333	70000	35000	2917	70000	35000	2917	60000	30000	2500
288000	144000	12000	216000	108000	9000	216000	108000	9000	216000	108000	9000	144000	72000	6000
72000	108000	6000	72000	108000	6000	72000	108000	6000	72000	108000	6000	36000	54000	3000
13333	20000	2222	16667	25000	2778	20000	30000	3333	13333	20000	2222	10000	15000	1667
33333	50000	5556	36667	55000	6111	40000	60000	6667	30000	45000	5000	23333	35000	3889
43333	65000	7222	43333	65000	7222	46667	70000	7778	33333	50000	5556	26667	40000	4444
26667	40000	4444	30000	45000	5000	33333	50000	5556	26667	40000	4444	16667	25000	2778
30000	45000	5000	33333	50000	5556	33333	50000	5556	26667	40000	4444	26667	40000	4444
23333	35000	3889	23333	35000	3889	20000	30000	3333	20000	30000	3333	13333	20000	2222
10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417	10000	5000	417
10000	5000	417	20000	10000	833	10000	5000	417	10000	5000	417	10000	5000	417
20000	10000	833	20000	10000	833	20000	10000	833	10000	5000	417	20000	10000	833
20000	10000	833	20000	10000	833	30000	15000	1250	20000	10000	833	10000	5000	417
30000	15000	1250	20000	10000	833	20000	10000	833	10000	5000	417	10000	5000	417
10000	5000	417	20000	10000	833	10000	5000	417	10000	5000	417	10000	5000	417
20000	10000	833	30000	15000	1250	20000	10000	833	20000	10000	833	30000	15000	1250
50000	25000	2083	50000	25000	2083	40000	20000	1667	40000	20000	1667	30000	15000	1250
20000	10000	833	20000	10000	833	20000	10000	833	10000	5000	417	10000	5000	417
40000	20000	1667	30000	15000	1250	30000	15000	1250	30000	15000	1250	20000	10000	833
80000	40000	3333	60000	30000	2500	70000	35000	2917	50000	25000	2083	50000	25000	2083
80000	40000	3333	70000	35000	2917	70000	35000	2917	70000	35000	2917	50000	25000	2083
30000	45000	2500	40000	60000	3333	46667	70000	3889	30000	45000	2500	20000	30000	1667
363636	120000	15152	363636	120000	15152	363636	120000	15152	363636	120000	15152	272727	90000	11364
1344000	672000	56000	1344000	672000	56000	1248000	624000	52000	1152000	576000	48000	960000	480000	40000
192000	144000	8000	144000	108000	6000	144000	108000	6000	96000	72000	4000	96000	72000	4000
240000	360000	20000	240000	360000	20000	192000	288000	16000	192000	288000	16000	144000	216000	12000
370000	185000	15417	390000	195000	16250	440000	220000	18333	360000	180000	15000	290000	145000	12083
236667	355000	19722	240000	360000	20000	173333	260000	14444	146667	220000	12222	113333	170000	9444
730000	365000	30417	500000	250000	20833	600000	300000	25000	470000	235000	19583	430000	215000	17917
191000	955000	47750	193000	965000	48250	155000	775000	38750	139000	695000	34750	126000	630000	31500
162000	810000	81000	156000	780000	78000	126000	630000	63000	114000	570000	57000	90000	450000	45000

06/2017			07/2017			08/2017			09/2017		
units	litres	cases	units	litres	cases	units	litres	cases	units	litres	cases
3333	5000	278	3400	5100	283	3400	5100	283	3400	5100	283
3333	5000	278	3400	5100	283	3400	5100	283	6800	10200	567
3333	5000	278	3400	5100	283	3400	5100	283	3400	5100	283
10000	5000	417	10200	5100	425	10200	5100	425	10200	5100	425
100000	75000	8333	115600	86700	9633	149600	112200	12467	163200	122400	13600
3333	5000	556	3400	5100	567	3400	5100	567	3400	5100	567
3333	5000	556	3400	5100	567	3400	5100	567	3400	5100	567
3333	5000	556	3400	5100	567	3400	5100	567	3400	5100	567
70000	35000	2917	71400	35700	2975	81600	40800	3400	102000	51000	4250
60000	30000	2500	71400	35700	2975	81600	40800	3400	112200	56100	4675
20000	10000	833	20400	10200	850	40800	20400	1700	40800	20400	1700
110000	55000	4583	132600	66300	5525	153000	76500	6375	173400	86700	7225
50000	25000	2083	61200	30600	2550	71400	35700	2975	81600	40800	3400
50000	25000	2083	71400	35700	2975	71400	35700	2975	91800	45900	3825
144000	72000	6000	146880	73440	6120	220320	110160	9180	220320	110160	9180
36000	54000	3000	36720	55080	3060	73440	110160	6120	73440	110160	6120
10000	15000	1667	10200	15300	1700	10200	15300	1700	17000	25500	2833
23333	35000	3889	27200	40800	4533	34000	51000	5667	37400	56100	6233
30000	45000	5000	34000	51000	5667	40800	61200	6800	44200	66300	7367
20000	30000	3333	20400	30600	3400	27200	40800	4533	30600	45900	5100
23333	35000	3889	27200	40800	4533	30600	45900	5100	34000	51000	5667
13333	20000	2222	17000	25500	2833	20400	30600	3400	20400	30600	3400
10000	5000	417	10200	5100	425	10200	5100	425	10200	5100	425
10000	5000	417	10200	5100	425	10200	5100	425	10200	5100	425
10000	5000	417	10200	5100	425	10200	5100	425	10200	5100	425
10000	5000	417	10200	5100	425	20400	10200	850	20400	10200	850
20000	10000	833	20400	10200	850	20400	10200	850	20400	10200	850
10000	5000	417	10200	5100	425	10200	5100	425	10200	5100	425
10000	5000	417	10200	5100	425	10200	5100	425	20400	10200	850
20000	10000	833	30600	15300	1275	20400	10200	850	30600	15300	1275
30000	15000	1250	40800	20400	1700	40800	20400	1700	40800	20400	1700
10000	5000	417	10200	5100	425	20400	10200	850	10200	5100	425
20000	10000	833	20400	10200	850	30600	15300	1275	40800	20400	1700
40000	20000	1667	51000	25500	2125	61200	30600	2550	71400	35700	2975
50000	25000	2083	61200	30600	2550	71400	35700	2975	81600	40800	3400
20000	30000	1667	30600	45900	2550	30600	45900	2550	40800	61200	3400
272727	90000	11364	370909	122400	15455	370909	122400	15455	370909	122400	15455
864000	432000	36000	979200	489600	40800	1272960	636480	53040	1272960	636480	53040
96000	72000	4000	97920	73440	4080	146880	110160	6120	146880	110160	6120
144000	216000	12000	97920	146880	8160	195840	293760	16320	244800	367200	20400
210000	105000	8750	346800	173400	14450	438600	219300	18275	408000	204000	17000
113333	170000	9444	115600	173400	9633	115600	173400	9633	129200	193800	10767
400000	200000	16667	408000	204000	17000	408000	204000	17000	510000	255000	21250
126000	630000	31500	157080	785400	39270	160140	800700	40035	178500	892500	44625
84000	420000	42000	122400	612000	61200	146880	734400	73440	153000	765000	76500

Appendix D: Lingo formulation of model group A- Continuous production.

```
Model:
Title: SKU Production Lot-sizing continuous line 1;

SETS:
      PRODUCT/1..36/: F,H,T,C,X,Z,G,K;
      MONTH/1..12/: B,V,P,L,E;
      FORECAST(PRODUCT,MONTH):Demand,Inventory,Q;
ENDSETS
DATA:
Demand =      278   278   278   556   556   556   556   556   278   556   278
      278
              278   278   556   278   556   556   556   278   556   278   278
      278
              278   278   278   278   556   278   556   278   278   278   278
      278
              417   417   417   417   417   417   417   417   417   417   417
      417
              9444  12222 13333 12778 15556 16667 15000 15000 11111 10000
8889  8333
              556   556   556   556   556   1111  556   1111  556   556   556
      556
              556   556   556   556   1111  556   556   1111  1111  556   556
      556
              556   556   556   556   1667  556   1111  2222  556   556   556
      556
              2917  3333  4167  3750  4167  3333  3750  3750  3750  2917
      2500  2917
              2917  3333  4583  4167  3333  3333  3333  3333  3750  3333
      2500  2500
              833   1667  1667  1667  1667  1250  1667  1667  1667  1250
      1250  833
              5417  6250  7083  6250  7083  6250  6667  5833  7083  5833
      5000  4583
              2500  2917  3333  3333  2917  2917  2500  3333  2917  2500
      2500  2083
              2917  2917  3750  3333  3333  3333  3333  3333  2917  2917
      2500  2083
              6000  9000  9000  12000 9000  9000  12000 9000  9000  9000
      6000  6000
              3000  6000  6000  9000  6000  9000  6000  6000  6000  6000
      3000  3000
              1667  1667  2778  2222  2778  2222  2222  2778  3333  2222
      1667  1667
              4444  5556  6111  6111  6667  6667  5556  6111  6667  5000
      3889  3889
              5556  6667  7222  7778  8333  8333  7222  7222  7778  5556
      4444  5000
              3333  4444  5000  5000  5556  5556  4444  5000  5556  4444
      2778  3333
              4444  5000  5556  5556  6111  5000  5000  5556  5556  4444
      4444  3889
              2778  3333  3333  3333  3889  3889  3889  3889  3333  3333
      2222  2222
              417   417   417   417   417   417   417   417   417   417   417
      417
              417   417   417   417   417   417   417   417   417   417   417
      417
              417   417   417   833   417   417   417   833   417   417   417
      417
```

```
          417   833   833   833   1250  833   833   833   833   417   833
    417
          833   833   833   833   1250  1250  833   833   1250  833   417
    833
          417   417   417   1000  1000  1250  1250  833   833   417   417
    417
          417   417   833   417   833   417   417   833   417   417   417
    417
          1250  833   1250  833   1250  1250  833   1250  833   833
    1250  833
          1667  1667  1667  2083  2500  2083  2083  2083  1667  1667
    1250  1250
          417   833   417   833   1250  417   833   833   833   417   417
    417
          833   1250  1667  1250  1667  1250  1667  1250  1250  1250  833
    833
          2083  2500  2917  3333  2917  2500  3333  2500  2917  2083
    2083  1667
          2500  2917  3333  2500  3333  2917  3333  2917  2917  2917
    2083  2083
          2500  2500  3333  3611  4167  3889  2500  3333  3889  2500
    1667  1667;

F =  1 1 1 1 4 1 1 1 1 1 1 1 1 1 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1;
T =  0.001875    0.001875    0.001875    0.003 0.001666667 0.0009375
     0.0009375   0.0009375   0.003 0.003 0.003 0.003 0.003 0.003 0.003
     0.001875 0.0009375      0.0009375   0.0009375   0.0009375   0.000938
     0.000938    0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003
     0.003 0.003 0.003 0.003 0.001875;
C =  50    50    50    72    90    100   100   100   60    60    60    60
     60    60    84    48    100   100   100   100   100   100   60    60
     60    72    72    72    72    72    72    60    60    60    60    50;

G =  18    18    18    12    9     9     9     9     12    12    12    12
     12    12    12    18    9     9     9     9     9     9     12    12
     12    12    12    12    12    12    12    12    12    12    12    18;

K =  0     0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
     0.75  0.75  0.75  1.667 0.75  0.75  0.75  0.75  0.75  0.75  0.75
     0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
     0.75  0.75  1.667;
H =  3.79 3.85 3.85 2.65 1.94 1.88 1.90 1.89 3.17 3.13 3.12 3.17 3.16 3.16
     2.18 3.37 1.91 1.92 1.91 1.91 1.91 1.91 3.18 3.17 3.12 2.34 2.62 2.62
     2.33 2.34 2.44 3.14 3.14 3.12 3.14 3.32
ENDDATA

!OBJECTIVE FUNCTION;
[OBJECTIVE] min = @sum(PRODUCT(I): Inventory(i,12)*H(i))
+@sum(Month(j):P(j)*461.11);

!SUBJECT TO;

@FOR(FORECAST(i,j): F(i)*X(i)  = Z(i));
@FOR(FORECAST(i,j): X(i) *G(i)  >= 5000);

!Inventory constraint for month one where the assumption of satisfied
initial inventory is made;

@FOR(FORECAST(i,j)|j#LE#1: ((2/4.2)*Demand(i,j))+Z(i)-Demand(i,j)  =
Inventory(i,j));
@FOR(FORECAST(i,j)|j#GE#2: Inventory(i,j-1)+ Z(i) >= Demand(i,j));
```

```
@FOR(FORECAST(i,j)|j#GE#2: Inventory(i,j-1) + Z(i) - Demand(i,j) =
Inventory(i,j));
@FOR(FORECAST(i,j)|j#LE#11: Inventory(i,j)>= (2/4.2)*Demand(i,j+1) );
@FOR(FORECAST(i,j): Inventory(i,j)*(1/C(i)) = Q(i,j));
@FOR(MONTH(j):@sum(PRODUCT(i): Q(i,j)) = L(j));

!If-then model construct for excess inventory;

@FOR(MONTH(j):@BIN(V(j)));
@FOR(MONTH(j): L(j) - 5000 <= 5000*V(j));
@FOR(MONTH(j): E(j) + L(j) - 5000 <= 5000*(1-V(j)));

!Constraints determining production time;

@FOR(MONTH(j):@sum(PRODUCT(i):T(i)*Z(i))+@sum(PRODUCT(i):F(i)*K(i)) =B(j));
@FOR(MONTH(j):(B(j) + (1/15)*B(j) + 8 )= P(j));
@For(PRODUCT(i):@GIN(X(i)));

END
```

Appendix E: Lingo formulation of model group B – Peak production.

```
Model:
Title: SKU Production Lot-sizing Peak line 1;

SETS:
      PRODUCT/1..36/: F,H,T,C,G,K,Z,X;
      MONTH/1..7/: B,V,P,L,E;
      FORECAST(PRODUCT,MONTH):Demand,Inventory,Q;
ENDSETS
DATA:
      Demand = 278      556   556   556   556   556   278
               556      278   556   556   556   278   556
               278      278   556   278   556   278   278
               417      417   417   417   417   417   417
               13333    12778 15556 16667 15000 15000 11111
               556      556   556   1111  556   1111  556
               556      556   1111  556   556   1111  1111
               556      556   1667  556   1111  2222  556
               4167     3750  4167  3333  3750  3750  3750
               4583     4167  3333  3333  3333  3333  3750
               1667     1667  1667  1250  1667  1667  1667
               7083     6250  7083  6250  6667  5833  7083
               3333     3333  2917  2917  2500  3333  2917
               3750     3333  3333  3333  3333  3333  2917
               9000     12000 9000  9000  12000 9000  9000
               6000     9000  6000  9000  6000  6000  6000
               2778     2222  2778  2222  2222  2778  3333
               6111     6111  6667  6667  5556  6111  6667
               7222     7778  8333  8333  7222  7222  7778
               5000     5000  5556  5556  4444  5000  5556
               5556     5556  6111  5000  5000  5556  5556
               3333     3333  3889  3889  3889  3889  3333
               417      417   417   417   417   417   417
               417      417   417   417   417   417   417
               417      833   417   417   417   833   417
               833      833   1250  833   833   833   833
               833      833   1250  1250  833   833   1250
               417      1000  1000  1250  1250  833   833
               833      417   833   417   417   833   417
               1250     833   1250  1250  833   1250  833
               1667     2083  2500  2083  2083  2083  1667
               417      833   1250  417   833   833   833
               1667     1250  1667  1250  1667  1250  1250
               2917     3333  2917  2500  3333  2500  2917
               3333     2500  3333  2917  3333  2917  2917
               3333     3611  4167  3889  2500  3333  3889;


F =   1 1 1 1 4 1 1 1 1 1 1 1 1 1 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1;
T =   0.001875     0.001875     0.001875     0.003 0.001666667 0.0009375
      0.0009375    0.0009375    0.003 0.003 0.003 0.003 0.003 0.003 0.003
      0.001875 0.0009375        0.0009375    0.0009375    0.0009375    0.000938
      0.000938     0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003
      0.003 0.003 0.003 0.003 0.001875;
C =   50    50    50    72    90    100   100   100   60    60    60    60
      60    60    84    48    100   100   100   100   100   100   60    60
      60    72    72    72    72    72    72    60    60    60    60    50;

G =   18    18    18    12    9     9     9     9     12    12    12    12
      12    12    12    18    9     9     9     9     9     9     12    12
```

```
      12    12    12    12    12    12    12    12    12    12    12    18;

K =   0     0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  0.75  1.667 0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  1.667;
H =   3.79 3.85 3.85 2.65 1.94 1.88 1.90 1.89 3.17 3.13 3.12 3.17 3.16 3.16
      2.18 3.37 1.91 1.92 1.91 1.91 1.91 1.91 3.18 3.17 3.12 2.34 2.62 2.62
      2.33 2.34 2.44 3.14 3.14 3.12 3.14 3.32
ENDDATA

!OBJECTIVE FUNCTION;
[OBJECTIVE] min = @sum(PRODUCT(I): Inventory(i,6)*H(i)) +
@sum(Month(j):P(j)*461.11);

!SUBJECT TO;

@FOR(PRODUCT(i): F(i)*X(i) = Z(i));
@FOR(PRODUCT(i): X(i) *G(i) >= 5000);

!Inventory constraint for month one where the assumption of satisfied
initial inventory is made;

@FOR(FORECAST(i,j)|j#LE#1: (2/4.2)*Demand(i,j)+Z(i)-Demand(i,j) =
Inventory(i,j));
@FOR(FORECAST(i,j): Inventory(i,1)>= (2/4.2)*Demand(i,2) );

@FOR(FORECAST(i,j): Inventory(i,1)+ Z(i) >= Demand(i,2));
@FOR(FORECAST(i,j): Inventory(i,1) + Z(i) - Demand(i,2) = Inventory(i,2));
@FOR(FORECAST(i,j): Inventory(i,2)>= (2/4.2)*Demand(i,3) );

@FOR(FORECAST(i,j): Inventory(i,2)+ Z(i) >= Demand(i,3));
@FOR(FORECAST(i,j): Inventory(i,2) + Z(i) - Demand(i,3) = Inventory(i,3));
@FOR(FORECAST(i,j): Inventory(i,3)>= (2/4.2)*Demand(i,4) );

@FOR(FORECAST(i,j): Inventory(i,3)+ Z(i) >= Demand(i,4));
@FOR(FORECAST(i,j): Inventory(i,3) + Z(i) - Demand(i,4) = Inventory(i,4));
@FOR(FORECAST(i,j): Inventory(i,4)>= (2/4.2)*Demand(i,5) );

@FOR(FORECAST(i,j): Inventory(i,4)+ Z(i) >= Demand(i,5));
@FOR(FORECAST(i,j): Inventory(i,4) + Z(i) - Demand(i,5) = Inventory(i,5));
@FOR(FORECAST(i,j): Inventory(i,5)>= (2/4.2)*Demand(i,6) );

@FOR(FORECAST(i,j): Inventory(i,5)+ Z(i) >= Demand(i,6));
@FOR(FORECAST(i,j): Inventory(i,5) + Z(i) - Demand(i,6) = Inventory(i,6));
@FOR(FORECAST(i,j): Inventory(i,6)>= (2/4.2)*Demand(i,7) );

@FOR(FORECAST(i,j): Inventory(i,j)*(1/C(i)) = Q(i,j));
@FOR(MONTH(j):@sum(PRODUCT(i): Q(i,j)) = L(j));

!If-then model construct for excess inventory;


@FOR(MONTH(j): L(j) - 5000 <= 5000*V(j));
@FOR(MONTH(j): (-1)*E(j) + L(j) - 5000 <= 5000*(1-V(j)));

!Constraints determining production time;

@FOR(MONTH(j):@sum(PRODUCT(i):T(i)*Z(i))+@sum(PRODUCT(i):F(i)*K(i)) =B(j));
@FOR(MONTH(j):(B(j) + (1/15)*B(j) + 8 )= P(j));
@For(product(i):@GIN(X(i)));
END
```

Appendix F: Lingo formulation of model group C, Off-peak production.

```
Model:
Title: SKU Production Lot-sizing Offpeak line 1;

SETS:
      PRODUCT/1..36/: F,H,T,C,G,K,Z,X;
      MONTH/1..7/: B,V,P,L,E;
      FORECAST(PRODUCT,MONTH):Demand,Inventory,Q,O;
ENDSETS
DATA:
      Demand = 278      556   278   278   283   283   283
               556      278   278   278   283   283   567
               278      278   278   278   283   283   283
               417      417   417   417   425   425   425
               11111 10000 8889     8333  9633  12467 13600
               556      556   556   556   567   567   567
               1111     556   556   556   567   567   567
               556      556   556   556   567   567   567
               3750     2917  2500  2917  2957  3400  4250
               3750     3333  2500  2500  2957  3400  4675
               1667     1250  1250  833   850   1700  1700
               7083     5833  5000  4583  5525  6375  7225
               2917     2500  2500  2083  2550  2975  3400
               2917     2917  2500  2083  2975  2975  3825
               9000     9000  6000  6000  6120  9180  9180
               6000     6000  3000  3000  3060  6120  6120
               3333     2222  1667  1667  1700  1700  2833
               6667     5000  3889  3889  4533  5667  6233
               7778     5556  4444  5000  5667  6800  7367
               5556     4444  2778  3333  3400  4533  5100
               5556     4444  4444  3889  4533  5100  5667
               3333     3333  2222  2222  2833  3400  3400
               417      417   417   417   425   425   425
               417      417   417   417   425   425   425
               417      417   417   417   425   425   425
               833      417   833   417   425   850   850
               1250     833   417   833   850   850   850
               833      417   417   417   425   425   425
               417      417   417   417   425   425   850
               833      833   1250  833   1275  850   1275
               1667     1667  1250  1250  1700  1700  1700
               833      417   417   417   425   850   425
               1250     1250  833   833   850   1275  1700
               2917     2083  2083  1667  2125  2550  2975
               2917     2917  2083  2083  2550  2975  3400
               3889     2500  1667  1667  2550  2550  3400;
!Beginning inventory;
      O =   236.381 0 0 0 0 0 0
            406.76 0 0 0 0 0 0
            248.3 0 0 0 0 0 0
            198.57 0 0 0 0 0 0
            6983 0 0 0 0 0 0
            264.76 0 0 0 0 0 0
            534.76 0 0 0 0 0 0
            268.76 0 0 0 0 0 0
            2881.286 0 0 0 0 0 0
            6410.381 0 0 0 0 0 0
            1210.81 0 0 0 0 0 0
            4328.857 0 0 0 0 0 0
            3252.143 0 0 0 0 0 0
            2682.714 0 0 0 0 0 0
            7285.71 0 0 0 0 0 0
```

```
            5857.143 0 0 0 0 0 0
            1592.857 0 0 0 0 0 0
            3997 0 0 0 0 0 0
            5059.048 0 0 0 0 0 0
            3468.95 0 0 0 0 0 0
            4000.714 0 0 0 0 0 0
            1685.14 0 0 0 0 0 0
            198.5714 0 0 0 0 0 0
            198.5714 0 0 0 0 0 0
            614.57 0 0 0 0 0 0
            813.67 0 0 0 0 0 0
            816.67 0 0 0 0 0 0
            592.57 0 0 0 0 0 0
            456.67 0 0 0 0 0 0
            595.238 0 0 0 0 0 0
            1194.81 0 0 0 0 0 0
            619.57 0 0 0 0 0 0
            856.8 0 0 0 0 0 0
            2639 0 0 0 0 0 0
            1518 0 0 0 0 0 0
            3506 0 0 0 0 0 0;

F =   1 1 1 1 4 1 1 1 1 1 1 1 1 1 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1;
T =   0.001875    0.001875    0.001875    0.003 0.001666667 0.0009375
      0.0009375   0.0009375   0.003 0.003 0.003 0.003 0.003 0.003 0.003
      0.001875 0.0009375      0.0009375   0.0009375   0.0009375   0.000938
      0.000938    0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003 0.003
      0.003 0.003 0.003 0.003 0.001875;
C =   50    50    50    72    90    100   100   100   60    60    60    60
      60    60    84    48    100   100   100   100   100   100   60    60
      60    72    72    72    72    72    72    60    60    60    60    50;

G =   18    18    18    12    9     9     9     9     12    12    12    12
      12    12    12    18    9     9     9     9     9     9     12    12
      12    12    12    12    12    12    12    12    12    12    12    18;
K =   0     0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  0.75  1.667 0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75  0.75
      0.75  0.75  1.667;
H =   3.79 3.85 3.85 2.65 1.94 1.88 1.90 1.89 3.17 3.13 3.12 3.17 3.16 3.16
      2.18 3.37 1.91 1.92 1.91 1.91 1.91 1.91 3.18 3.17 3.12 2.34 2.62 2.62
      2.33 2.34 2.44 3.14 3.14 3.12 3.14 3.32
ENDDATA

!OBJECTIVE FUNCTION;
[OBJECTIVE] min = @sum(PRODUCT(I): Inventory(i,6)*H(i)) +
@sum(Month(j):P(j)*461.11) ;

!SUBJECT TO;

@FOR(PRODUCT(i): F(i)*X(i) = Z(i));
@FOR(PRODUCT(i): X(i) *G(i) >= 5000);

!Inventory constraint for month one where the assumption of satisfied
initial inventory is made;

@FOR(FORECAST(i,j)|j#LE#1: O(i,j)+Z(i)-Demand(i,j) = Inventory(i,j));
@FOR(FORECAST(i,j): Inventory(i,1)+ Z(i) >= Demand(i,2));
@FOR(FORECAST(i,j): Inventory(i,1) + Z(i) - Demand(i,2) = Inventory(i,2));
@FOR(FORECAST(i,j): Inventory(i,1)>= (2/4.2)*Demand(i,2) );
```

```
@FOR(FORECAST(i,j): Inventory(i,2)+ Z(i)  >= Demand(i,3));
@FOR(FORECAST(i,j): Inventory(i,2)  + Z(i)  - Demand(i,3)  = Inventory(i,3));
@FOR(FORECAST(i,j): Inventory(i,2)>=  (2/4.2)*Demand(i,3) );

@FOR(FORECAST(i,j): Inventory(i,3)+ Z(i)  >= Demand(i,4));
@FOR(FORECAST(i,j): Inventory(i,3)  + Z(i)  - Demand(i,4)  = Inventory(i,4));
@FOR(FORECAST(i,j): Inventory(i,3)>=  (2/4.2)*Demand(i,4) );

@FOR(FORECAST(i,j): Inventory(i,4)+ Z(i)  >= Demand(i,5));
@FOR(FORECAST(i,j): Inventory(i,4)  + Z(i)  - Demand(i,5)  = Inventory(i,5));
@FOR(FORECAST(i,j): Inventory(i,4)>=  (2/4.2)*Demand(i,5) );

@FOR(FORECAST(i,j): Inventory(i,5)+ Z(i)  >= Demand(i,6));
@FOR(FORECAST(i,j): Inventory(i,5)  + Z(i)  - Demand(i,6)  = Inventory(i,6));
@FOR(FORECAST(i,j): Inventory(i,5)>=  (2/4.2)*Demand(i,6) );

@FOR(FORECAST(i,j): Inventory(i,6)>=  (2/4.2)*Demand(i,7) );
@FOR(FORECAST(i,j): Inventory(i,j)*(1/C(i))  = Q(i,j));
@FOR(MONTH(j):@sum(PRODUCT(i): Q(i,j))  = L(j));

!If-then model construct for excess inventory;


@FOR(MONTH(j): L(j)  - 5000  <= 5000*V(j));
@FOR(MONTH(j):  (-1)*E(j)  + L(j)  - 5000  <= 5000*(1-V(j)));

!Constraints determining production time;

@FOR(MONTH(j):@sum(PRODUCT(i):T(i)*Z(i))+@sum(PRODUCT(i):F(i)*K(i))  =B(j));
@FOR(MONTH(j):(B(j)  + (1/15)*B(j)  + 8  )= P(j));

@For(product(i):@GIN(X(i)));
END
```

Appendix G: Infor AS MPS reports

PEAK INFOR PRODUCTION REPORT

Start date & time	End date & time	Duration [hh:mm]	Lot size [cases]	C/o [min]	Product description	Daily duration	Weekly duration
Week1							
Line 1							
04/07/2016 07:30:00	04/07/2016 13:40:00	06:10	3707	100	Aquartz Mineral Still 2x6x750 ml		
04/07/2016 14:40:00	04/07/2016 22:34:00	07:54	2625	100	Nestle Pure Life Sparkling 4x6x500ml	14:04	
05/07/2016 06:30:00	05/07/2016 10:01:00	03:31	1875	45	Nestle Pure Life Sparkling 12x1.5lt		
05/07/2016 10:50:00	05/07/2016 11:49:00	00:59	527	45	Aquartz Sparkling Peach Passion 12x1.5 lt		
05/07/2016 12:34:00	05/07/2016 13:28:00	00:54	487	45	Aquartz Sparkling Cran/Rasb 12x1.5 lt		
05/07/2016 14:13:00	05/07/2016 14:56:00	00:43	390	45	Aquartz Sparkling Lem/Lime 12x1.5 lt		
05/07/2016 15:41:00	05/07/2016 16:22:00	00:41	741	45	Nestle Ice Tea Berry 6x1.5Lt		
05/07/2016 17:07:00	05/07/2016 17:51:00	00:44	786	45	Nestle Ice Tea Peach 6x1.5Lt		
05/07/2016 18:36:00	05/07/2016 19:38:00	01:02	1112	45	Nestle Ice Tea Lemon 6x1.5Lt		
05/07/2016 20:23:00	05/07/2016 22:46:00	02:23	2545	45	MAN G/TEA APR/LTE 6x1.5 lt	10:57	
06/07/2016 06:31:00	06/07/2016 12:30:00	05:59	6385	45	MAN I/TEA PEACH LTE 6x1.5Lt		
06/07/2016 13:15:00	06/07/2016 20:42:00	07:27	7955	45	MAN I/TEA PEACH 6x1.5Lt	13:26	
07/07/2016 06:30:00	07/07/2016 11:50:00	05:20	5689	45	MAN G/TEA RB/GF/ST 6x1.5Lt		
07/07/2016 12:35:00	07/07/2016 17:31:00	04:56	5274	45	MAN I/TEA LEMON 6x1.5Lt		
07/07/2016 18:16:00	07/07/2016 21:45:00	03:29	3720	100	MAN G/TEA KI/PEA LTE 5x1.5Lt	13:45	52:12
Line 2							
04/07/2016 07:30:00	05/07/2016 04:30:00	21:00	6977	100	Nestle Pure Life Still 4x6x500ml	21:00	
05/07/2016 06:30:00	05/07/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
05/07/2016 14:36:00	05/07/2016 18:20:00	03:44	1870	100	Nestle Pure Life Still 4x6x750ml		
05/07/2016 19:20:00	06/07/2016 04:42:00	09:22	5000	100	Nestle Pure Life Still 12x1.5lt	20:12	
06/07/2016 06:30:00	07/07/2016 03:30:00	21:00	6977	0	Nestle Pure Life Still 4x6x500ml	21:00	
07/07/2016 06:30:00	07/07/2016 21:21:00	14:51	4934	100	Nestle Pure Life Still 2x12x500ml		
07/07/2016 22:21:00	08/07/2016 02:26:00	04:05	2260	0	Aquartz Minerals Water Still 12x1.5 lt	18:56	
08/07/2016 06:30:00	08/07/2016 10:36:00	04:06	2271	100	Aquartz Minerals Water Still 12x1.5 lt		
08/07/2016 11:36:00	09/07/2016 02:29:00	14:53	7447	0	Aquartz Mineral Water Still 4x6x500 ml	18:59	100:07
Line 3							
04/07/2016 07:30:00	04/07/2016 12:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
04/07/2016 13:16:00	04/07/2016 17:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
04/07/2016 18:26:00	04/07/2016 23:27:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L	14:27	
05/07/2016 06:26:00	05/07/2016 10:51:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
05/07/2016 11:36:00	05/07/2016 16:37:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
05/07/2016 17:22:00	05/07/2016 21:47:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	13:51	
06/07/2016 06:30:00	06/07/2016 11:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
06/07/2016 12:16:00	06/07/2016 16:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	09:26	37:44
WEEK 2							
Line 1							
11/07/2016 07:30:00	11/07/2016 13:40:00	06:10	3707	100	Aquartz Mineral Still 2x6x750 ml		
11/07/2016 14:40:00	11/07/2016 22:34:00	07:54	2625	100	Nestle Pure Life Sparkling 4x6x500ml	14:04	
12/07/2016 06:30:00	12/07/2016 10:01:00	03:31	1875	45	Nestle Pure Life Sparkling 12x1.5lt		
12/07/2016 10:46:00	12/07/2016 15:19:00	04:33	3792	100	Aquartz Mineral Water Sparkling 12x1.5 lt		
12/07/2016 16:19:00	12/07/2016 17:34:00	01:15	417	45	Nestle Ice Tea Peach 4x6x500ml		
12/07/2016 18:19:00	12/07/2016 19:34:00	01:15	417	45	Nestle Ice Tea Berry 4x6x500ml		
12/07/2016 20:19:00	12/07/2016 22:11:00	01:52	625	45	Nestle Ice Tea Lemon 4x6x500ml	12:26	
13/07/2016 06:30:00	13/07/2016 09:25:00	02:55	972	45	Aquartz Sparkling Lemon/Lime 24x500 ml		
13/07/2016 10:10:00	13/07/2016 13:18:00	03:08	1042	45	Aquartz Sparkling Litchi 24x500 ml		
13/07/2016 14:03:00	13/07/2016 17:08:00	03:05	1024	45	Aquartz Sparkling Naartjie 24x500 ml		
13/07/2016 17:53:00	13/07/2016 19:47:00	01:54	635	45	Aquartz Sparkling Peach Passion 24x500 ml		
13/07/2016 20:32:00	13/07/2016 23:52:00	03:20	1111	45	Aquartz Sparkling Cran/Raspberry 24x500 ml	14:22	
14/07/2016 06:30:00	14/07/2016 12:58:00	06:28	2150	45	Aquartz Mineral Water Sparkling 4x6x500 ml		
14/07/2016 13:43:00	14/07/2016 16:13:00	02:30	834	45	Manhattan Ice Tea Green Tea Lite Kiwi Pear 6x4x500ml		
14/07/2016 16:58:00	14/07/2016 21:23:00	04:25	1469	100	Manhattan White I/Tea Exotic Fruit 4x6x500m	13:23	51:54
Line 2							
11/07/2016 07:30:00	12/07/2016 04:30:00	21:00	6977	100	Nestle Pure Life Still 4x6x500ml	21:00	
12/07/2016 06:30:00	12/07/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
12/07/2016 14:36:00	12/07/2016 18:20:00	03:44	1870	100	Nestle Pure Life Still 4x6x750ml		
12/07/2016 19:20:00	13/07/2016 04:42:00	09:22	5000	100	Nestle Pure Life Still 12x1.5lt	20:12	
13/07/2016 06:30:00	14/07/2016 03:30:00	21:00	6977	0	Nestle Pure Life Still 4x6x500ml	21:00	
14/07/2016 06:30:00	14/07/2016 21:21:00	14:51	4934	100	Nestle Pure Life Still 2x12x500ml		
14/07/2016 22:21:00	15/07/2016 02:26:00	04:05	2260	0	Aquartz Minerals Water Still 12x1.5 lt	18:56	
15/07/2016 06:30:00	15/07/2016 10:36:00	04:06	2271	100	Aquartz Minerals Water Still 12x1.5 lt		
15/07/2016 11:36:00	16/07/2016 02:29:00	14:53	7447	0	Aquartz Mineral Water Still 4x6x500 ml	18:59	100:07
Line 3							
11/07/2016 07:30:00	11/07/2016 12:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
11/07/2016 13:16:00	11/07/2016 17:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
11/07/2016 18:26:00	11/07/2016 23:27:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L	14:27	
12/07/2016 17:26:00	12/07/2016 21:51:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
12/07/2016 11:40:00	12/07/2016 16:41:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
12/07/2016 06:30:00	12/07/2016 10:55:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	13:51	
13/07/2016 06:30:00	13/07/2016 11:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
13/07/2016 12:16:00	13/07/2016 16:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	09:26	37:44
Week 3							
Line 1							
18/07/2016 07:30:00	18/07/2016 13:40:00	06:10	3707	100	Aquartz Mineral Still 2x6x750 ml		
18/07/2016 14:40:00	18/07/2016 22:34:00	07:54	2625	100	Nestle Pure Life Sparkling 4x6x500ml	14:04	
19/07/2016 06:30:00	19/07/2016 10:01:00	03:31	1875	100	Nestle Pure Life Sparkling 12x1.5lt		
19/07/2016 11:01:00	19/07/2016 12:16:00	01:15	417	45	Aquartz Sparkling Mango 4x6x500 ml		
19/07/2016 13:01:00	19/07/2016 22:25:00	09:24	3125	45	Clover Manhattan Ice Tea Crisp Apple/Mint wi	14:10	
20/07/2016 06:30:00	20/07/2016 15:40:00	09:10	3044	45	Clover Mnahattan Ice Tea Ruby Grapefruit/Sberry with Ginko Biloba 6x4x500m		
20/07/2016 16:21:00	20/07/2016 23:52:00	07:31	2500	0	Clover Manhattan Ice Tea Blackcurrent 6x4x5	16:41	
21/07/2016 11:40:00	22/07/2016 00:52:00	13:12	4385	100	Clover Manhattan Ice Tea Pineapple 6x4x500ml		
21/07/2016 06:30:00	21/07/2016 10:55:00	04:25	1469	45	Clover Manhattan Ice Tea Blackcurrent 6x4x5	04:25	58:07
Line 2							
18/07/2016 07:30:00	19/07/2016 04:30:00	21:00	6977	100	Nestle Pure Life Still 4x6x500ml	21:00	
19/07/2016 06:30:00	19/07/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
19/07/2016 14:36:00	19/07/2016 18:20:00	03:44	1870	100	Nestle Pure Life Still 4x6x750ml		
19/07/2016 19:20:00	20/07/2016 04:42:00	09:22	5000	100	Nestle Pure Life Still 12x1.5lt	20:12	
20/07/2016 06:30:00	21/07/2016 03:30:00	21:00	6977	0	Nestle Pure Life Still 4x6x500ml	21:00	
21/07/2016 06:30:00	21/07/2016 21:21:00	14:51	4934	100	Nestle Pure Life Still 2x12x500ml		
21/07/2016 22:21:00	22/07/2016 02:26:00	04:05	2260	0	Aquartz Minerals Water Still 12x1.5 lt	18:56	
22/07/2016 06:30:00	22/07/2016 10:36:00	04:06	2271	100	Aquartz Minerals Water Still 12x1.5 lt		
22/07/2016 11:51:00	23/07/2016 02:44:00	14:53	7447	0	Aquartz Mineral Water Still 4x6x500 ml	18:59	100:07
Line 3							
18/07/2016 07:30:00	18/07/2016 12:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
18/07/2016 13:16:00	18/07/2016 17:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
18/07/2016 18:26:00	18/07/2016 23:27:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L	14:27	
19/07/2016 06:30:00	19/07/2016 10:55:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
19/07/2016 11:40:00	19/07/2016 16:41:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
19/07/2016 17:26:00	19/07/2016 21:51:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	13:51	
20/07/2016 06:30:00	20/07/2016 11:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
20/07/2016 12:16:00	20/07/2016 16:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	09:26	37:44
Week 4							
Line 1							
25/07/2016 07:30:00	25/07/2016 13:33:00	06:03	3637	100	Aquartz Mineral Still 2x6x750 ml		
26/07/2016 16:20:00	26/07/2016 23:51:00	07:31	2500	45	Nestle Pure Life Sparkling 4x6x500ml	13:34	
26/07/2016 06:30:00	26/07/2016 09:47:00	03:17	1750	100	Nestle Pure Life Sparkling 12x1.5lt		
26/07/2016 10:47:00	26/07/2016 15:35:00	04:48	1598	45	Clover Manhattan Ice Tea Lemon Lite 6x4x500ml		
25/07/2016 14:33:00	25/07/2016 23:39:00	09:06	3023	100	Clover Manhattan Ice Tea Peach Lite 6x4x50(	17:11	
27/07/2016 06:30:00	27/07/2016 16:19:00	09:49	3264	45	Clover Manhatta Ice Tea Peach 6x4x500ml		
27/07/2016 17:04:00	27/07/2016 22:05:00	05:01	1669	45	Clover Manhattan Ice Tea Lemon 6x4x500ml	14:50	
28/07/2016 06:30:00	28/07/2016 16:19:00	09:49	3264	45	Clover Manhatta Ice Tea Peach 6x4x500ml		
28/07/2016 17:04:00	28/07/2016 22:05:00	05:01	1669	100	Clover Manhattan Ice Tea Lemon 6x4x500ml	14:50	60:25
Line 2							
25/07/2016 07:30:00	26/07/2016 04:30:00	21:00	6977	100	Nestle Pure Life Still 4x6x500ml	21:00	
26/07/2016 06:30:00	26/07/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
26/07/2016 14:36:00	26/07/2016 18:20:00	03:44	1870	100	Nestle Pure Life Still 4x6x750ml		
26/07/2016 19:20:00	27/07/2016 04:42:00	09:22	5000	100	Nestle Pure Life Still 12x1.5lt	20:12	
27/07/2016 06:30:00	28/07/2016 03:30:00	21:00	6977	0	Nestle Pure Life Still 4x6x500ml	21:00	
28/07/2016 06:30:00	28/07/2016 21:21:00	14:51	4934	100	Nestle Pure Life Still 2x12x500ml		
28/07/2016 22:21:00	29/07/2016 02:26:00	04:05	2260	0	Aquartz Minerals Water Still 12x1.5 lt	18:56	
29/07/2016 06:30:00	29/07/2016 10:36:00	04:06	2271	100	Aquartz Minerals Water Still 12x1.5 lt		
29/07/2016 11:36:00	30/07/2016 02:29:00	14:53	7447	0	Aquartz Mineral Water Still 4x6x500 ml	18:59	100:07
Line 3							
25/07/2016 07:30:00	25/07/2016 12:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
25/07/2016 13:16:00	25/07/2016 17:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
25/07/2016 18:26:00	25/07/2016 23:27:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L	14:27	
26/07/2016 06:30:00	26/07/2016 10:55:00	04:25	5307	45	Nestle Pure Life Still 2x5lt		
26/07/2016 11:40:00	26/07/2016 16:41:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
26/07/2016 17:26:00	26/07/2016 21:51:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	13:51	
27/07/2016 06:30:00	27/07/2016 11:31:00	05:01	3015	45	Aquartz Minerals Water Still 4x5L		
27/07/2016 12:16:00	27/07/2016 16:41:00	04:25	5307	45	Nestle Pure Life Still 2x5lt	09:26	37:44

OFFPEAK INFOR PRODUCTION REPORT

Start date & time	End date & time	Duration [hh:mm]	Batch size [cases]	C/o [min]	Product description	Daily duration	Weekly duration
Week 1							
Line 1							
01/08/2016 07:30:00	01/08/2016 11:39:00	04:09	2497	100	Aquartz Mineral Still 2x6x750 ml		
01/08/2016 11:39:00	01/08/2016 16:58:00	05:19	1767	100	Nestle Pure Life Sparkling 4x6x500ml		
01/08/2016 17:58:00	01/08/2016 19:51:00	01:53	1010	45	Nestle Pure Life Sparkling 12x1.5lt		
01/08/2016 20:36:00	01/08/2016 21:17:00	00:41	365	45	Aquartz Sparkling Peach Passion 12x1.5 lt	12:02	
02/08/2016 06:30:00	02/08/2016 07:04:00	00:34	304	45	Aquartz Sparkling Cran/Rasb 12x1.5 lt		
02/08/2016 07:49:00	02/08/2016 08:20:00	00:31	561	45	Nestle Ice Tea Berry 6x1.5Lt		
02/08/2016 09:05:00	02/08/2016 09:52:00	00:47	842	45	Nestle Ice Tea Peach 6x1.5Lt		
02/08/2016 10:37:00	02/08/2016 11:08:00	00:31	560	45	Nestle Ice Tea Lemon 6x1.5Lt		
02/08/2016 11:53:00	02/08/2016 14:30:00	02:37	2799	45	MAN G/TEA APR/LTE 6x1.5 lt		
02/08/2016 15:15:00	02/08/2016 19:59:00	04:44	5051	45	MAN I/TEA PEACH LTE 6x1.5Lt		
02/08/2016 20:44:00	02/08/2016 23:46:00	03:02	3236	45	MAN G/TEA KI/PEA LTE 5x1.5Lt	12:46	
03/08/2016 06:36:00	03/08/2016 07:07:00	00:31	278	45	Aquartz Sparkling Lem/Lime 12x1.5 lt		
03/08/2016 07:52:00	03/08/2016 13:08:00	05:16	5616	45	MAN I/TEA PEACH 6x1.5Lt		
03/08/2016 13:53:00	03/08/2016 17:49:00	03:56	4204	45	MAN I/TEA LEMON 6x1.5Lt		
03/08/2016 18:34:00	03/08/2016 22:44:00	04:10	4444	100	MAN G/TEA RB/GF/ST 6x1.5Lt	13:53	38:41
Line 2							
01/08/2016 07:30:00	02/08/2016 00:17:00	16:47	5573	100	Nestle Pure Life Still 4x6x500ml	16:47	
02/08/2016 06:30:00	02/08/2016 13:36:00	07:06	3789	100	Nestle Pure Life Still 4x6x330ml		
02/08/2016 14:36:00	02/08/2016 16:42:00	02:06	1058	100	Nestle Pure Life Still 4x6x750ml		
02/08/2016 17:42:00	03/08/2016 00:18:00	06:36	3524	100	Nestle Pure Life Still 12x1.5lt	15:48	
03/08/2016 06:30:00	03/08/2016 23:17:00	16:47	5573	0	Nestle Pure Life Still 4x6x500ml	16:47	
04/08/2016 06:30:00	04/08/2016 15:57:00	09:27	3138	100	Nestle Pure Life Still 2x12x500ml		
05/08/2016 06:30:00	05/08/2016 12:11:00	05:41	3152	100	Aquartz Minerals Water Still 12x1.5 lt	15:08	
05/08/2016 13:11:00	05/08/2016 21:33:00	08:22	4187	0	Aquartz Mineral Water Still 4x6x500 ml	08:22	72:52
Line 3							
01/08/2016 07:30:00	01/08/2016 14:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
02/08/2016 06:30:00	02/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	
03/08/2016 06:30:00	03/08/2016 13:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
04/08/2016 06:30:00	04/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	26:12
Week 2							
Line 1							
08/08/2016 07:30:00	08/08/2016 11:39:00	04:09	2497	100	Aquartz Mineral Still 2x6x750 ml		
08/08/2016 12:39:00	08/08/2016 17:58:00	05:19	1767	100	Nestle Pure Life Sparkling 4x6x500ml		
08/08/2016 18:58:00	08/08/2016 20:51:00	01:53	1010	45	Nestle Pure Life Sparkling 12x1.5lt	11:21	
09/08/2016 06:30:00	09/08/2016 09:05:00	02:35	2157	100	Aquartz Mineral Water Sparkling 12x1.5 lt		
09/08/2016 10:05:00	09/08/2016 11:21:00	01:16	421	45	Nestle Ice Tea Peach 4x6x500ml		
09/08/2016 12:06:00	09/08/2016 13:22:00	01:16	421	45	Nestle Ice Tea Berry 4x6x500ml		
09/08/2016 14:07:00	09/08/2016 15:22:00	01:15	417	45	Nestle Ice Tea Lemon 4x6x500ml		
09/08/2016 16:07:00	09/08/2016 17:48:00	01:41	562	45	Aquartz Sparkling Lemon/Lime 24x500 ml		
09/08/2016 18:33:00	09/08/2016 21:03:00	02:30	830	45	Aquartz Sparkling Litchi 24x500 ml	10:33	
10/08/2016 06:30:00	10/08/2016 07:49:00	01:19	440	45	Aquartz Sparkling Naartjie 24x500 ml		
10/08/2016 08:34:00	10/08/2016 09:49:00	01:15	417	45	Aquartz Sparkling Peach Passion 24x500 ml		
10/08/2016 10:34:00	10/08/2016 13:31:00	02:57	981	45	Aquartz Sparkling Cran/Raspberry 24x500 ml		
10/08/2016 14:16:00	10/08/2016 18:42:00	04:26	1475	45	Aquartz Mineral Water Sparkling 4x6x500 ml		
10/08/2016 19:27:00	10/08/2016 20:55:00	01:28	491	45	Manhattan Ice Tea Green Tea Lite Kiwi Pear 6x4x500ml	11:25	
11/08/2016 06:30:00	11/08/2016 09:38:00	03:08	1041	100	Manhattan White I/Tea Exotic Fruit 4x6x500ml	03:08	36:27
Line 2							
08/08/2016 07:30:00	09/08/2016 00:17:00	16:47	5573	100	Nestle Pure Life Still 4x6x500ml	16:47	
09/08/2016 06:30:00	09/08/2016 13:36:00	07:06	3789	100	Nestle Pure Life Still 4x6x330ml		
09/08/2016 14:36:00	09/08/2016 16:42:00	02:06	1058	100	Nestle Pure Life Still 4x6x750ml		
09/08/2016 17:42:00	10/08/2016 00:18:00	06:36	3524	100	Nestle Pure Life Still 12x1.5lt	15:48	
10/08/2016 06:30:00	10/08/2016 23:17:00	16:47	5573	0	Nestle Pure Life Still 4x6x500ml	16:47	
11/08/2016 06:30:00	11/08/2016 15:57:00	09:27	3138	100	Nestle Pure Life Still 2x12x500ml		
12/08/2016 06:30:00	12/08/2016 12:11:00	05:41	3152	100	Aquartz Minerals Water Still 12x1.5 lt	15:08	
12/08/2016 13:11:00	12/08/2016 21:33:00	08:22	4187	0	Aquartz Mineral Water Still 4x6x500 ml	08:22	72:52
Line 3							
08/08/2016 07:30:00	08/08/2016 14:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
09/08/2016 06:30:00	09/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	
10/08/2016 06:30:00	10/08/2016 13:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
11/08/2016 06:30:00	11/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	26:12
Week 3							
Line 1							
15/08/2016 07:30:00	15/08/2016 11:39:00	04:09	2497	100	Aquartz Mineral Still 2x6x750 ml		
15/08/2016 12:39:00	15/08/2016 17:58:00	05:19	1767	100	Nestle Pure Life Sparkling 4x6x500ml		
15/08/2016 18:58:00	15/08/2016 20:51:00	01:53	1010	100	Nestle Pure Life Sparkling 12x1.5lt		
15/08/2016 21:51:00	15/08/2016 23:07:00	01:16	421	45	Aquartz Sparkling Mango 4x6x500 ml	12:37	
16/08/2016 06:30:00	16/08/2016 12:37:00	06:07	2034	45	Clover Manhattan Ice Tea Crisp Apple/Mint with Giseng 6x4x500ml		
16/08/2016 13:22:00	16/08/2016 21:46:00	08:24	2789	45	Clover Mnahattan Ice Tea Ruby Grapefruit/Sberry with Ginko	14:31	
17/08/2016 06:30:00	17/08/2016 15:19:00	08:49	2931	45	Clover Manhattan Ice Tea Blackcurrent 6x4x500ml	08:49	
18/08/2016 06:30:00	18/08/2016 13:39:00	07:09	2376	100	Clover Manhattan Ice Tea Pineapple 6x4x500ml	07:09	43:03
Line 2							
15/08/2016 07:30:00	16/08/2016 00:17:00	16:47	5573	100	Nestle Pure Life Still 4x6x500ml	16:47	
16/08/2016 06:30:00	16/08/2016 13:36:00	07:06	3789	100	Nestle Pure Life Still 4x6x330ml		
16/08/2016 14:36:00	16/08/2016 16:42:00	02:06	1058	100	Nestle Pure Life Still 4x6x750ml		
16/08/2016 17:42:00	17/08/2016 00:18:00	06:36	3524	100	Nestle Pure Life Still 12x1.5lt	15:48	
17/08/2016 06:30:00	17/08/2016 23:17:00	16:47	5573	0	Nestle Pure Life Still 4x6x500ml	16:47	
18/08/2016 06:30:00	18/08/2016 15:57:00	09:27	3138	100	Nestle Pure Life Still 2x12x500ml		
19/08/2016 06:30:00	19/08/2016 12:11:00	05:41	3152	100	Aquartz Minerals Water Still 12x1.5 lt	15:08	
19/08/2016 13:11:00	19/08/2016 21:33:00	08:22	4187	0	Aquartz Mineral Water Still 4x6x500 ml	08:22	72:52
Line 3							
15/08/2016 07:30:00	15/08/2016 14:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
16/08/2016 06:30:00	16/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	
17/08/2016 06:30:00	17/08/2016 13:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
18/08/2016 06:30:00	18/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	26:12
Week 4							
Line 1							
22/08/2016 07:30:00	22/08/2016 11:39:00	04:09	2497	100	Aquartz Mineral Still 2x6x750 ml		
22/08/2016 12:39:00	22/08/2016 17:58:00	05:19	1767	100	Nestle Pure Life Sparkling 4x6x500ml		
22/08/2016 18:58:00	22/08/2016 20:51:00	01:53	1010	100	Nestle Pure Life Sparkling 12x1.5lt	11:21	
23/08/2016 06:30:00	23/08/2016 10:05:00	03:35	1192	45	Clover Manhattan Ice Tea Lemon Lite 6x4x500ml		
23/08/2016 10:50:00	23/08/2016 17:48:00	06:58	2316	45	Clover Manhattan Ice Tea Peach Lite 6x4x500ml	10:33	
24/08/2016 06:30:00	24/08/2016 14:17:00	07:47	2585	45	Clover Manhattan Ice Tea Lemon 6x4x500ml		
24/08/2016 15:02:00	24/08/2016 21:03:00	06:01	2000	0	Clover Manhatta Ice Tea Peach 6x4x500ml	13:48	
25/08/2016 06:30:00	25/08/2016 17:18:00	10:48	3586	100	Clover Manhatta Ice Tea Peach 6x4x500ml	10:48	46:30
Line 2							
22/08/2016 07:30:00	23/08/2016 00:17:00	16:47	5573	100	Nestle Pure Life Still 4x6x500ml	16:47	
23/08/2016 06:30:00	23/08/2016 13:36:00	07:06	3789	100	Nestle Pure Life Still 4x6x330ml		
23/08/2016 14:36:00	23/08/2016 16:42:00	02:06	1058	100	Nestle Pure Life Still 4x6x750ml		
23/08/2016 17:42:00	24/08/2016 00:18:00	06:36	3524	100	Nestle Pure Life Still 12x1.5lt	15:48	
24/08/2016 06:30:00	24/08/2016 23:17:00	16:47	5573	0	Nestle Pure Life Still 4x6x500ml	16:47	
25/08/2016 06:30:00	25/08/2016 15:57:00	09:27	3138	100	Nestle Pure Life Still 2x12x500ml		
26/08/2016 06:30:00	26/08/2016 12:11:00	05:41	3152	100	Aquartz Minerals Water Still 12x1.5 lt	15:08	
26/08/2016 13:11:00	26/08/2016 21:33:00	08:22	4187	0	Aquartz Mineral Water Still 4x6x500 ml	08:22	72:52
Line 3							
22/08/2016 07:30:00	22/08/2016 14:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
23/08/2016 06:30:00	23/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	
24/08/2016 06:30:00	24/08/2016 13:55:00	07:25	4455	45	Aquartz Minerals Water Still 4x5L	07:25	
25/08/2016 06:30:00	25/08/2016 12:11:00	05:41	6831	45	Nestle Pure Life Still 2x5lt	05:41	26:12

CONTINUOUS INFOR PRODUCTION REPORT

Start date & time	End date & time	Duration [hh:mm]	Batch size [cases]	C/o [min]	Product description	Daily duration	Weekly duration
Week 1							
Line 1							
05/09/2016 07:30:00	05/09/2016 13:18:00	05:48	3488	100	Aquartz Mineral Still 2x6x750 ml		
05/09/2016 14:18:00	05/09/2016 21:33:00	07:15	2409	100	Nestle Pure Life Sparkling 4x6x500ml	13:03	
06/09/2016 06:30:00	06/09/2016 09:39:00	03:09	1685	45	Nestle Pure Life Sparkling 12x1.5lt		
06/09/2016 10:24:00	06/09/2016 11:15:00	00:51	456	45	Aquartz Sparkling Peach Passion 12x1.5 lt		
06/09/2016 12:00:00	06/09/2016 12:49:00	00:49	440	45	Aquartz Sparkling Cran/Rasb 12x1.5 lt		
06/09/2016 13:34:00	06/09/2016 14:14:00	00:40	358	45	Aquartz Sparkling Lem/Lime 12x1.5 lt		
06/09/2016 14:59:00	06/09/2016 15:38:00	00:39	695	45	Nestle Ice Tea Berry 6x1.5Lt		
06/09/2016 16:23:00	06/09/2016 17:04:00	00:41	741	45	Nestle Ice Tea Peach 6x1.5Lt		
06/09/2016 17:49:00	06/09/2016 18:43:00	00:54	973	45	Nestle Ice Tea Lemon 6x1.5Lt		
06/09/2016 19:28:00	06/09/2016 21:45:00	02:17	2437	45	MAN G/TEA APR/LTE 6x1.5 lt	10:00	
07/09/2016 06:30:00	07/09/2016 12:09:00	05:39	6036	45	MAN I/TEA PEACH LTE 6x1.5Lt		
07/09/2016 12:54:00	07/09/2016 19:53:00	06:59	7448	45	MAN I/TEA PEACH 6x1.5Lt	12:38	
08/09/2016 06:30:00	08/09/2016 11:07:00	04:37	4936	45	MAN I/TEA LEMON 6x1.5Lt		
08/09/2016 11:52:00	08/09/2016 16:55:00	05:03	5387	45	MAN G/TEA RB/GF/ST 6x1.5Lt		
08/09/2016 17:40:00	08/09/2016 21:01:00	03:21	3575	100	MAN G/TEA KI/PEA LTE 5x1.5Lt	13:01	48:42:00
Line 2							
05/09/2016 07:30:00	06/09/2016 03:20:00	19:50	6590	100	Nestle Pure Life Still 4x6x500ml	19:50	
06/09/2016 06:30:00	06/09/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
06/09/2016 14:36:00	06/09/2016 17:57:00	03:21	1677	100	Nestle Pure Life Still 4x6x750ml		
06/09/2016 18:57:00	07/09/2016 03:38:00	08:41	4633	100	Nestle Pure Life Still 12x1.5lt	19:08	
07/09/2016 06:30:00	08/09/2016 02:20:00	19:50	6590	0	Nestle Pure Life Still 4x6x500ml	19:50	
08/09/2016 06:30:00	08/09/2016 20:25:00	13:55	4625	100	Nestle Pure Life Still 2x12x500ml		
08/09/2016 21:25:00	09/09/2016 04:36:00	07:11	3981	100	Aquartz Minerals Water Still 12x1.5 lt	21:06	
09/09/2016 06:30:00	09/09/2016 19:22:00	12:52	6440	0	Aquartz Mineral Water Still 4x6x500 ml	12:52	92:46:00
Line 3							
05/09/2016 07:30:00	05/09/2016 16:03:00	08:33	5132	45	Aquartz Minerals Water Still 4x5L	08:33	
06/09/2016 06:30:00	06/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	
07/09/2016 06:30:00	07/09/2016 15:03:00	08:33	5132	45	Aquartz Minerals Water Still 4x5L	08:33	
08/09/2016 06:30:00	08/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	33:40:00
Week 2							
Line 1							
12/09/2016 07:30:00	12/09/2016 13:18:00	05:48	3488	100	Aquartz Mineral Still 2x6x750 ml		
12/09/2016 14:18:00	12/09/2016 21:33:00	07:15	2409	100	Nestle Pure Life Sparkling 4x6x500ml	13:03	
13/09/2016 06:30:00	13/09/2016 09:39:00	03:09	1685	45	Nestle Pure Life Sparkling 12x1.5lt		
13/09/2016 10:24:00	13/09/2016 14:25:00	04:01	3355	100	Aquartz Mineral Water Sparkling 12x1.5 lt		
13/09/2016 15:25:00	13/09/2016 16:40:00	01:15	417	45	Nestle Ice Tea Peach 4x6x500ml		
13/09/2016 17:25:00	13/09/2016 18:40:00	01:15	417	45	Nestle Ice Tea Berry 4x6x500ml		
13/09/2016 19:25:00	13/09/2016 20:59:00	01:34	521	45	Nestle Ice Tea Lemon 4x6x500ml	11:14	
14/09/2016 06:30:00	14/09/2016 09:07:00	02:37	873	45	Aquartz Sparkling Lemon/Lime 24x500 ml		
14/09/2016 09:52:00	14/09/2016 12:47:00	02:55	972	45	Aquartz Sparkling Litchi 24x500 ml		
14/09/2016 13:32:00	14/09/2016 16:05:00	02:33	850	45	Aquartz Sparkling Naartjie 24x500 ml		
14/09/2016 16:50:00	14/09/2016 18:35:00	01:45	584	45	Aquartz Sparkling Peach Passion 24x500 ml		
14/09/2016 19:20:00	14/09/2016 22:35:00	03:15	1084	45	Aquartz Sparkling Cran/Raspberry 24x500 ml	13:05	
15/09/2016 06:30:00	15/09/2016 12:30:00	06:00	1993	45	Aquartz Mineral Water Sparkling 4x6x500 ml		
15/09/2016 13:15:00	15/09/2016 15:31:00	02:16	754	45	Manhattan Ice Tea Green Tea Lite Kiwi Pear 6x4x500ml		
15/09/2016 16:16:00	15/09/2016 20:28:00	04:12	1398	100	Manhattan White I/Tea Exotic Fruit 4x6x500ml	12:28	49:50:00
Line 2							
12/09/2016 07:30:00	13/09/2016 03:20:00	19:50	6590	100	Nestle Pure Life Still 4x6x500ml	19:50	
13/09/2016 06:30:00	13/09/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
13/09/2016 14:36:00	13/09/2016 17:57:00	03:21	1677	100	Nestle Pure Life Still 4x6x750ml		
13/09/2016 18:57:00	14/09/2016 03:38:00	08:41	4633	100	Nestle Pure Life Still 12x1.5lt	19:08	
14/09/2016 06:30:00	15/09/2016 02:20:00	19:50	6590	0	Nestle Pure Life Still 4x6x500ml	19:50	
15/09/2016 06:30:00	15/09/2016 20:25:00	13:55	4625	100	Nestle Pure Life Still 2x12x500ml		
15/09/2016 21:25:00	16/09/2016 04:36:00	07:11	3981	100	Aquartz Minerals Water Still 12x1.5 lt	21:06	
16/09/2016 06:30:00	16/09/2016 19:22:00	12:52	6440	0	Aquartz Mineral Water Still 4x6x500 ml	12:52	92:46:00
Line 3							
12/09/2016 07:30:00	12/09/2016 16:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
13/09/2016 06:30:00	13/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	
14/09/2016 06:30:00	14/09/2016 15:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
15/09/2016 06:30:00	15/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	33:40:00
Week 3							
Line 1							
19/09/2016 07:30:00	19/09/2016 13:18:00	05:48	3488	100	Aquartz Mineral Still 2x6x750 ml		
19/09/2016 14:18:00	19/09/2016 21:33:00	07:15	2409	100	Nestle Pure Life Sparkling 4x6x500ml	13:03	
20/09/2016 06:30:00	20/09/2016 09:39:00	03:09	1685	100	Nestle Pure Life Sparkling 12x1.5lt		
20/09/2016 10:39:00	20/09/2016 19:09:00	08:30	2826	45	Clover Manhattan Ice Tea Crisp Apple/Mint with Gi	11:39	
21/09/2016 06:30:00	21/09/2016 17:40:00	11:10	3708	45	Clover Manhattan Ice Tea Blackcurrent 6x4x500ml		
21/09/2016 18:25:00	21/09/2016 22:56:00	04:31	1503	45	Clover Mnahattan Ice Tea Ruby Grapefruit/Sberry w	15:41	
22/09/2016 06:30:00	22/09/2016 17:58:00	11:28	3810	45	Clover Manhattan Ice Tea Pineapple 6x4x500ml		
22/09/2016 18:43:00	22/09/2016 23:14:00	04:31	1503	100	Clover Mnahattan Ice Tea Ruby Grapefruit/Sberry w	15:59	56:22:00
Line 2							
19/09/2016 07:30:00	20/09/2016 03:20:00	19:50	6590	100	Nestle Pure Life Still 4x6x500ml	19:50	
20/09/2016 06:30:00	20/09/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
20/09/2016 14:36:00	20/09/2016 17:57:00	03:21	1677	100	Nestle Pure Life Still 4x6x750ml		
20/09/2016 18:57:00	21/09/2016 03:38:00	08:41	4633	100	Nestle Pure Life Still 12x1.5lt	19:08	
21/09/2016 06:30:00	22/09/2016 02:20:00	19:50	6590	100	Nestle Pure Life Still 4x6x500ml	19:50	
22/09/2016 14:41:00	23/09/2016 04:36:00	13:55	4625	0	Nestle Pure Life Still 2x12x500ml		
22/09/2016 06:30:00	22/09/2016 13:41:00	07:11	3981	100	Aquartz Minerals Water Still 12x1.5 lt		
23/09/2016 06:30:00	23/09/2016 19:22:00	12:52	6440	0	Aquartz Mineral Water Still 4x6x500 ml	12:52	92:46:00
Line 3							
19/09/2016 07:30:00	19/09/2016 16:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
20/09/2016 06:30:00	20/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	
21/09/2016 06:30:00	21/09/2016 15:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
22/09/2016 06:30:00	22/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	33:40:00
Week 4							
Line 1							
26/09/2016 07:30:00	26/09/2016 13:14:00	05:44	3448	100	Aquartz Mineral Still 2x6x750 ml		
26/09/2016 14:14:00	26/09/2016 21:29:00	07:15	2409	100	Nestle Pure Life Sparkling 4x6x500ml	12:59	
27/09/2016 06:30:00	27/09/2016 09:39:00	03:09	1685	100	Nestle Pure Life Sparkling 12x1.5lt		
27/09/2016 10:39:00	27/09/2016 11:54:00	01:15	417	45	Aquartz Sparkling Mango 4x6x500 ml		
27/09/2016 12:39:00	27/09/2016 17:21:00	04:42	1561	45	Clover Manhattan Ice Tea Lemon Lite 6x4x500ml	09:06	
28/09/2016 06:30:00	29/09/2016 02:03:00	19:33	6496	45	Clover Manhatta Ice Tea Peach 6x4x500ml	19:33	
29/09/2016 06:30:00	29/09/2016 15:45:00	09:15	3071	45	Clover Manhattan Ice Tea Peach Lite 6x4x500ml		
29/09/2016 16:30:00	30/09/2016 02:26:00	09:56	3303	0	Clover Manhattan Ice Tea Lemon 6x4x500ml	09:56	51:34:00
Line 2							
26/09/2016 07:30:00	27/09/2016 03:20:00	19:50	6590	100	Nestle Pure Life Still 4x6x500ml	19:50	
27/09/2016 06:30:00	27/09/2016 13:36:00	07:06	3788	100	Nestle Pure Life Still 4x6x330ml		
27/09/2016 14:36:00	27/09/2016 17:57:00	03:21	1677	100	Nestle Pure Life Still 4x6x750ml		
27/09/2016 18:57:00	28/09/2016 03:38:00	08:41	4633	100	Nestle Pure Life Still 12x1.5lt	19:08	
28/09/2016 06:30:00	29/09/2016 02:20:00	19:50	6590	0	Nestle Pure Life Still 4x6x500ml	19:50	
29/09/2016 06:30:00	29/09/2016 20:25:00	13:55	4625	100	Nestle Pure Life Still 2x12x500ml		
29/09/2016 21:25:00	30/09/2016 04:36:00	07:11	3981	100	Aquartz Minerals Water Still 12x1.5 lt	21:06	
30/09/2016 06:30:00	30/09/2016 19:22:00	12:52	6440	0	Aquartz Mineral Water Still 4x6x500 ml	12:52	92:46:00
Line 3							
26/09/2016 07:30:00	26/09/2016 16:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
27/09/2016 06:30:00	27/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	
28/09/2016 06:30:00	28/09/2016 15:02:00	08:33	5123	45	Aquartz Minerals Water Still 4x5L	08:33	
29/09/2016 06:30:00	29/09/2016 14:47:00	08:17	9959	45	Nestle Pure Life Still 2x5lt	08:17	33:40:00

Appendix H: Schedule alternatives detailed labour cost analysis

Peak Production Labour cost evaluation

	8hr + Overtime			8hr		12hr + Overtime			12hr	
	Shift cost	Overtime cost	Total cost	Shift cost	Total cost	Shift cost	Overtime cost	Total cost	Shift cost	Total cost
Week 1	R 99 599.76	R 7 325.16	R 106 924.92	R 125 421.92	R 125 421.92	R 110 666.40	R 8 546.02	R 119 212.42	R 127 266.36	R 127 266.36
line1	R 29 511.04	R 3 052.15	R 32 563.19	R 40 577.68	R 40 577.68	R 33 199.92	R 5 493.87	R 38 693.79	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 55 333.20	R 55 333.20	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 18 444.40	R 4 273.01	R 22 717.41	R 29 511.04	R 29 511.04	R 22 133.28	R 3 052.15	R 25 185.43	R 27 666.60	R 27 666.60
Week 2	R 99 599.76	R 7 935.59	R 107 535.35	R 125 421.92	R 125 421.92	R 110 666.40	R 7 935.59	R 118 601.99	R 127 266.36	R 127 266.36
line1	R 29 511.04	R 3 662.58	R 33 173.62	R 40 577.68	R 40 577.68	R 33 199.92	R 4 883.44	R 38 083.36	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 55 333.20	R 55 333.20	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 18 444.40	R 4 273.01	R 22 717.41	R 29 511.04	R 29 511.04	R 22 133.28	R 3 052.15	R 25 185.43	R 27 666.60	R 27 666.60
Week 3	R 99 599.76	R 10 987.74	R 110 587.50	R 129 110.80	R 129 110.80	R 110 666.40	R 9 156.45	R 119 822.85	R 127 266.36	R 127 266.36
line1	R 29 511.04	R 6 714.73	R 36 225.77	R 44 266.56	R 44 266.56	R 33 199.92	R 6 104.30	R 39 304.22	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 55 333.20	R 55 333.20	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 18 444.40	R 4 273.01	R 22 717.41	R 29 511.04	R 29 511.04	R 22 133.28	R 3 052.15	R 25 185.43	R 27 666.60	R 27 666.60
Week 4	R 99 599.76	R 9 156.45	R 108 756.21	R 129 110.80	R 129 110.80	R 121 733.04	R 3 052.15	R 124 785.19	R 127 266.36	R 127 266.36
line1	R 29 511.04	R 4 883.44	R 34 394.48	R 44 266.56	R 44 266.56	R 44 266.56		R 44 266.56	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 55 333.20	R 55 333.20	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 18 444.40	R 4 273.01	R 22 717.41	R 29 511.04	R 29 511.04	R 22 133.28	R 3 052.15	R 25 185.43	R 27 666.60	R 27 666.60
Monthly Cost			R 433 803.98		R 509 065.44			R 482 422.45		R 509 065.44

Off-peak production labour cost evaluation

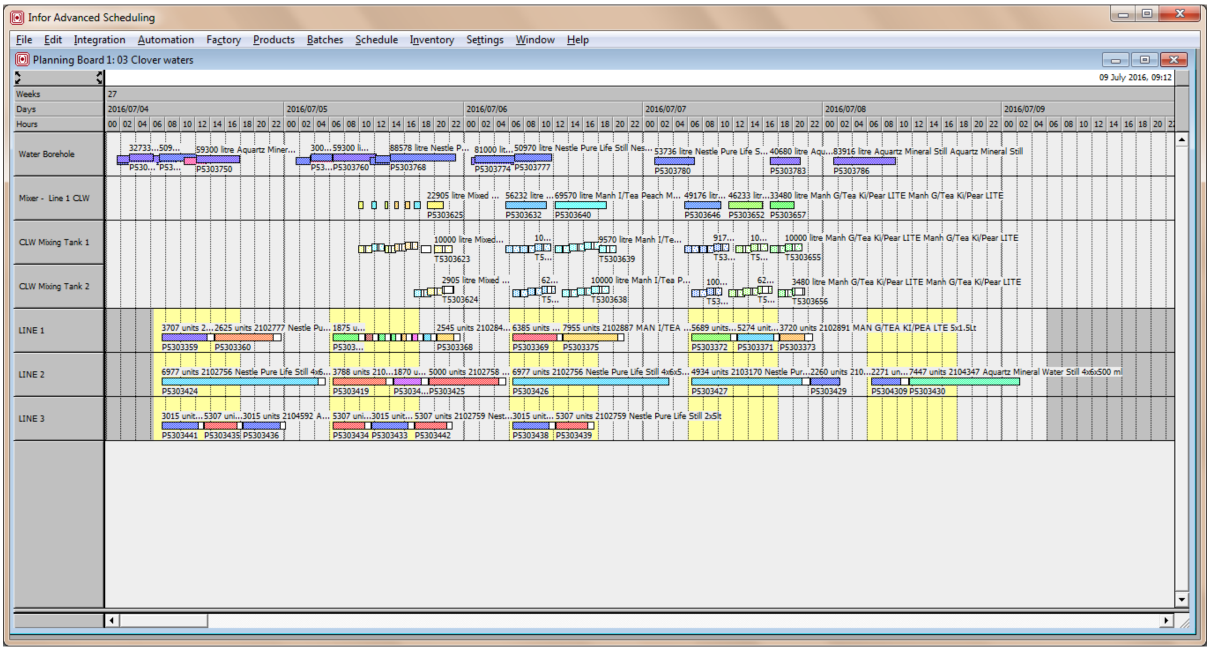
	8hr + Overtime			8hr		12hr + Overtime			8hr + Overtime	
	Shift cost	Overtime cost	Total cost	Shift cost	Total cost	Shift cost	Overtime cost	Total cost	Shift cost	Total cost
Week 1	R 70 088.72	R 10 987.74	R 81 076.46	R 95 910.88	R 95 910.88	R 105 133.08	R 2 441.72	R 107 574.80	R 110 666.40	R 110 666.40
line1	R 22 133.28	R 3 052.15	R 25 185.43	R 29 511.04	R 29 511.04	R 27 666.60	R 2 441.72	R 30 108.32	R 33 199.92	R 33 199.92
line2	R 33 199.92	R 5 493.87	R 38 693.79	R 51 644.32	R 51 644.32	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 2 441.72	R 17 197.24	R 14 755.52	R 14 755.52	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 2	R 73 777.60	R 7 935.59	R 81 713.19	R 92 222.00	R 92 222.00	R 99 599.76	R 5 493.87	R 105 093.63	R 116 199.72	R 116 199.72
line1	R 25 822.16		R 25 822.16	R 25 822.16	R 25 822.16	R 22 133.28	R 5 493.87	R 27 627.15	R 38 733.24	R 38 733.24
line2	R 33 199.92	R 5 493.87	R 38 693.79	R 51 644.32	R 51 644.32	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 2 441.72	R 17 197.24	R 14 755.52	R 14 755.52	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 3	R 70 088.72	R 7 935.59	R 78 024.31	R 99 599.76	R 99 599.76	R 99 599.76	R 5 493.87	R 105 093.63	R 110 666.40	R 110 666.40
line1	R 22 133.28		R 22 133.28	R 33 199.92	R 33 199.92	R 22 133.28	R 5 493.87	R 27 627.15	R 33 199.92	R 33 199.92
line2	R 33 199.92	R 5 493.87	R 38 693.79	R 51 644.32	R 51 644.32	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 2 441.72	R 17 197.24	R 14 755.52	R 14 755.52	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 4	R 73 777.60	R 10 377.31	R 84 154.91	R 99 599.76	R 99 599.76	R 99 599.76	R 5 493.87	R 105 093.63	R 116 199.72	R 116 199.72
line1	R 25 822.16	R 2 441.72	R 28 263.88	R 33 199.92	R 33 199.92	R 22 133.28	R 5 493.87	R 27 627.15	R 38 733.24	R 38 733.24
line2	R 33 199.92	R 5 493.87	R 38 693.79	R 51 644.32	R 51 644.32	R 55 333.20		R 55 333.20	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 2 441.72	R 17 197.24	R 14 755.52	R 14 755.52	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Monthly Cost			R 324 968.87		R 387 332.40			R 422 855.69		R 453 732.24

Continuous production labour cost evaluation

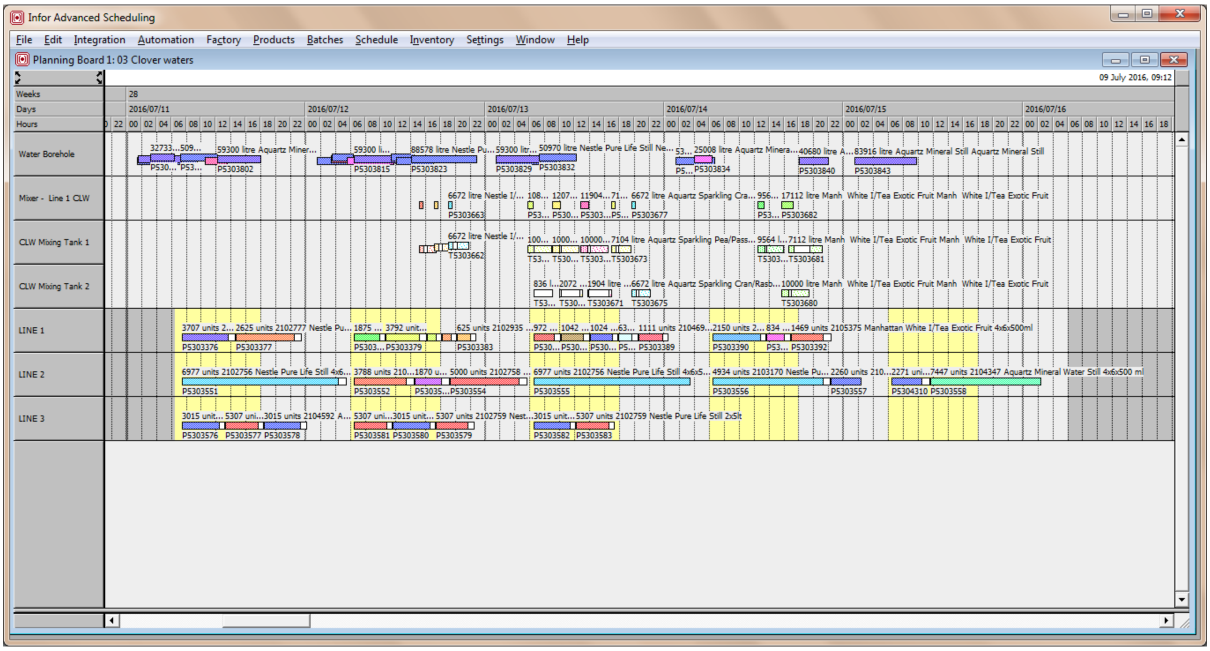
	8hr + Overtime			8hr		12hr + Overtime			8hr + Overtime	
	Shift cost	Overtime cost	Total cost	Shift cost	Total cost	Shift cost	Overtime cost	Total cost	Shift cost	Total cost
Week 1	R 95 910.88	R 7 325.16	R 103 236.04	R 114 355.28	R 114 355.28	R 105 133.08	R 5 493.87	R 110 626.95	R 121 733.04	R 121 733.04
line1	R 29 511.04	R 1 220.86	R 30 731.90	R 33 199.92	R 33 199.92	R 33 199.92	R 4 273.01	R 37 472.93	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 51 644.32	R 51 644.32	R 49 799.88	R 1 220.86	R 51 020.74	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 6 104.30	R 20 859.82	R 29 511.04	R 29 511.04	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 2	R 95 910.88	R 7 935.59	R 103 846.47	R 118 044.16	R 118 044.16	R 99 599.76	R 7 935.59	R 107 535.35	R 121 733.04	R 121 733.04
line1	R 29 511.04	R 1 831.29	R 31 342.33	R 36 888.80	R 36 888.80	R 27 666.60	R 6 714.73	R 34 381.33	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 51 644.32	R 51 644.32	R 49 799.88	R 1 220.86	R 51 020.74	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 6 104.30	R 20 859.82	R 29 511.04	R 29 511.04	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 3	R 95 910.88	R 9 156.45	R 105 067.33	R 110 666.40	R 110 666.40	R 105 133.08	R 5 493.87	R 110 626.95	R 121 733.04	R 121 733.04
line1	R 29 511.04	R 3 052.15	R 32 563.19	R 29 511.04	R 29 511.04	R 33 199.92	R 4 273.01	R 37 472.93	R 44 266.56	R 44 266.56
line2	R 51 644.32		R 51 644.32	R 51 644.32	R 51 644.32	R 49 799.88	R 1 220.86	R 51 020.74	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 6 104.30	R 20 859.82	R 29 511.04	R 29 511.04	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Week 4	R 99 599.76	R 8 546.02	R 108 145.78	R 118 044.16	R 118 044.16	R 105 133.08	R 3 662.58	R 108 795.66	R 116 199.72	R 116 199.72
line1	R 33 199.92	R 2 441.72	R 35 641.64	R 36 888.80	R 36 888.80	R 33 199.92	R 2 441.72	R 35 641.64	R 38 733.24	R 38 733.24
line2	R 51 644.32		R 51 644.32	R 51 644.32	R 51 644.32	R 49 799.88	R 1 220.86	R 51 020.74	R 55 333.20	R 55 333.20
line3	R 14 755.52	R 6 104.30	R 20 859.82	R 29 511.04	R 29 511.04	R 22 133.28		R 22 133.28	R 22 133.28	R 22 133.28
Monthly Cost			R 420 295.62		R 461 110.00			R 437 584.91		R 481 398.84

Appendix I: Infor screenshots for peak and off-peak MPSs.

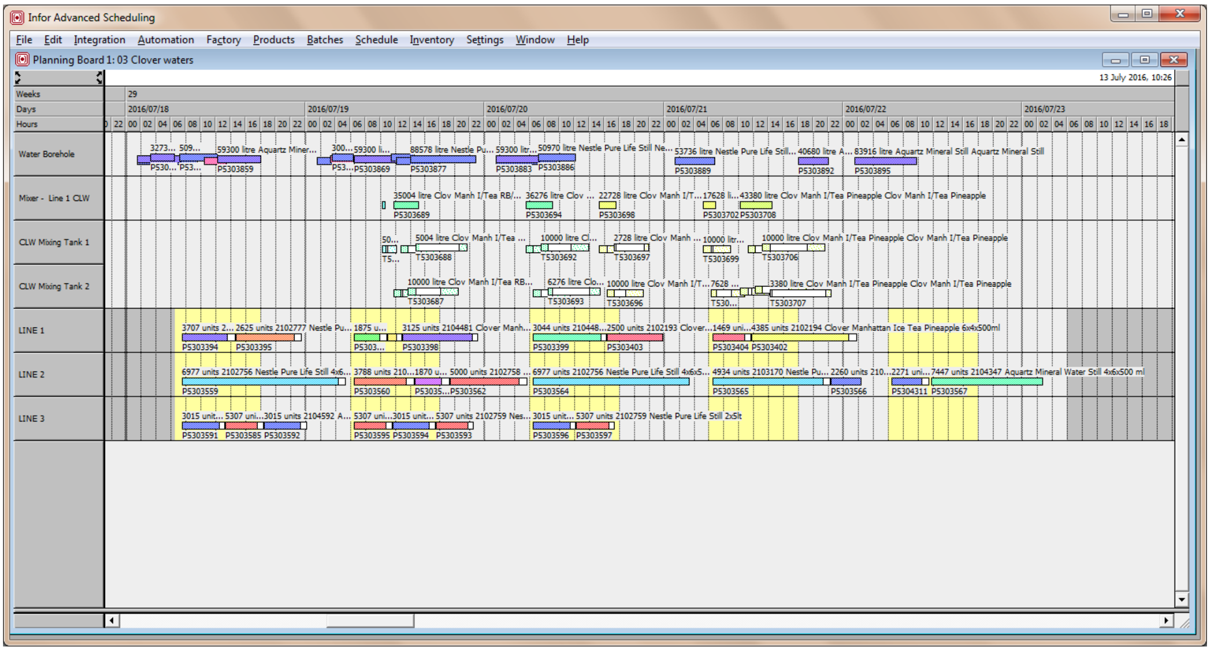
Peak Week 1:



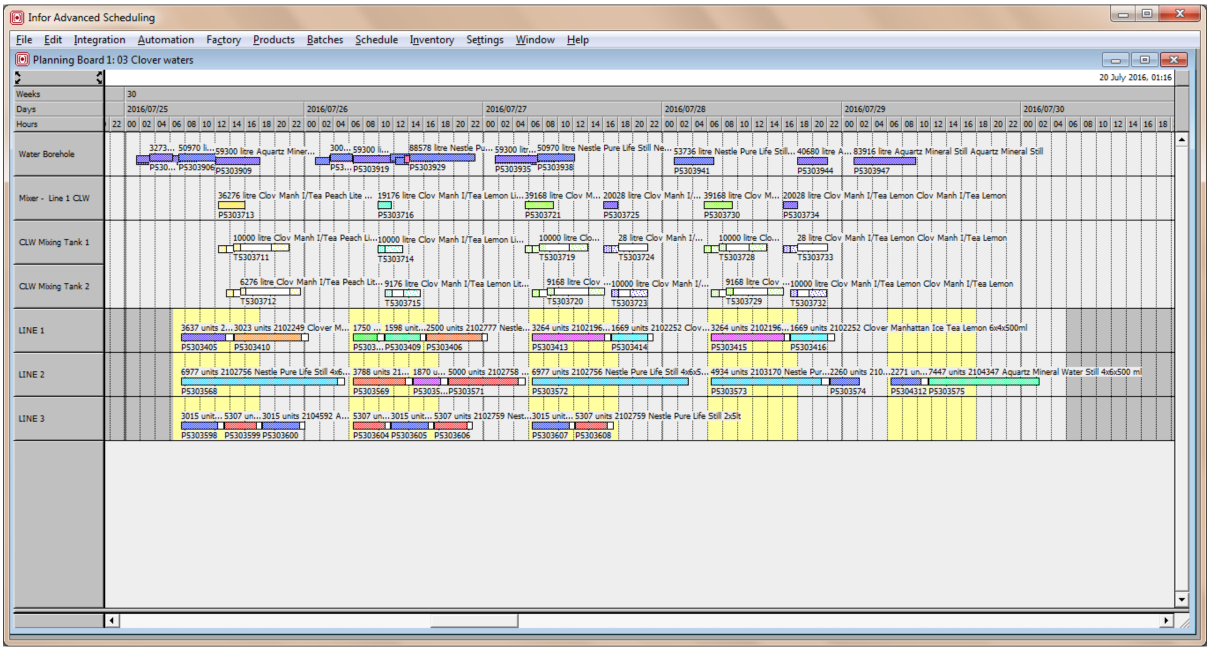
Peak Week 2:



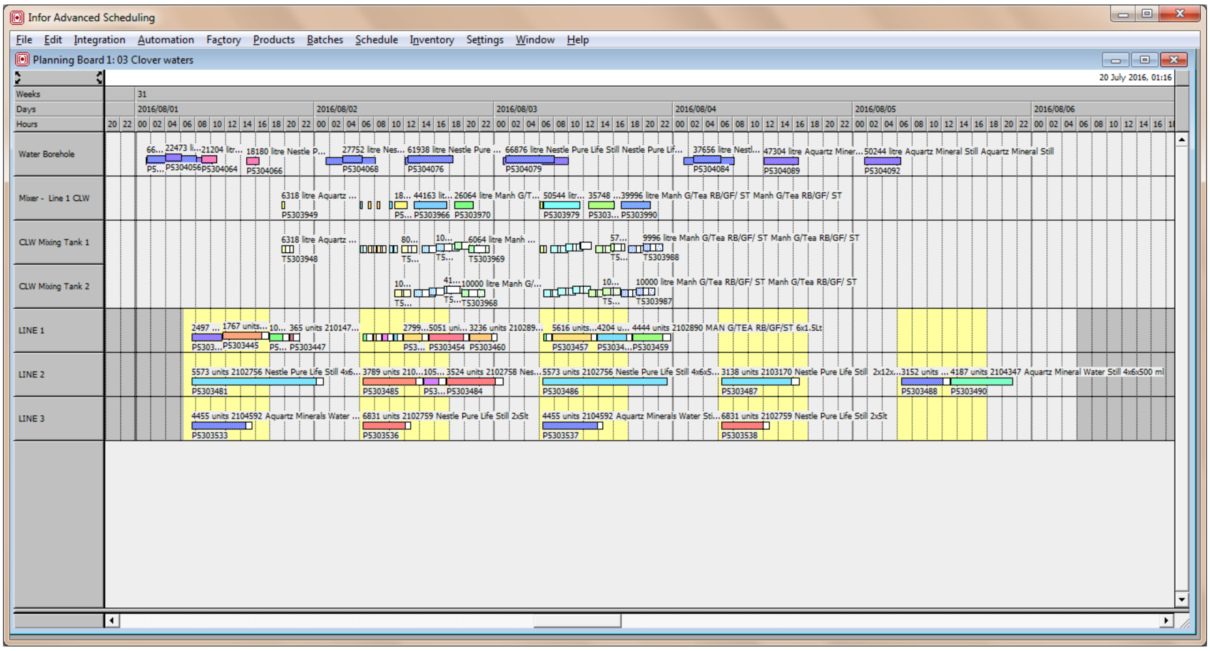
Peak Week 3:



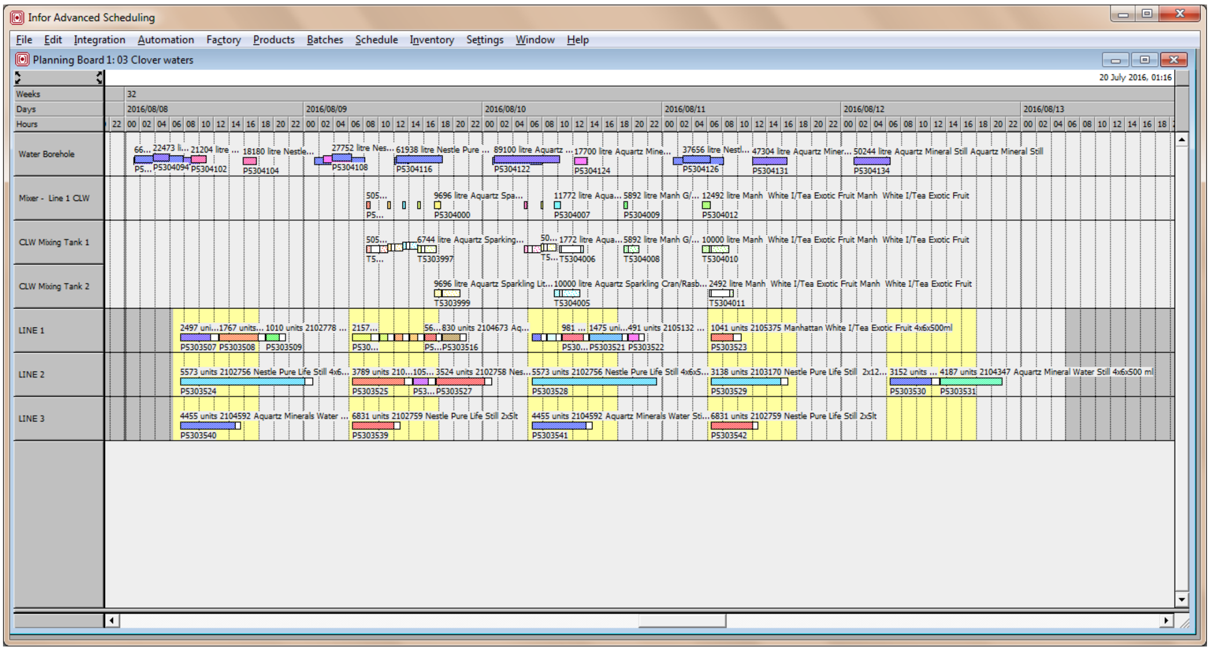
Peak Week 4:



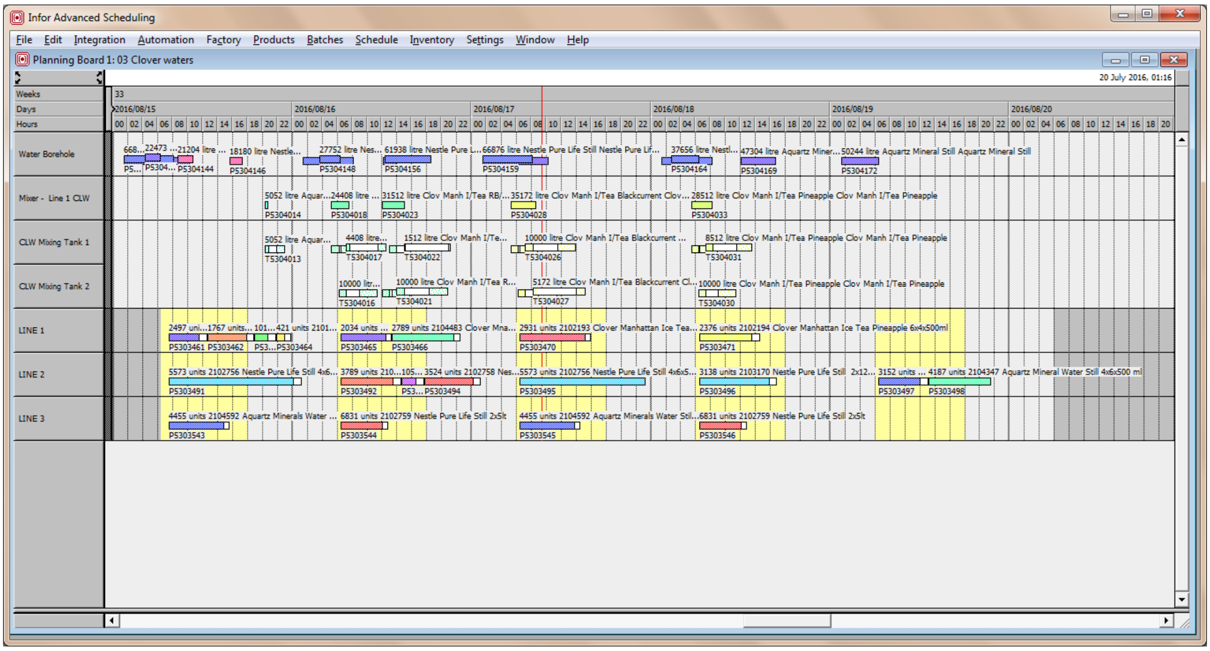
Off-peak Week 1:



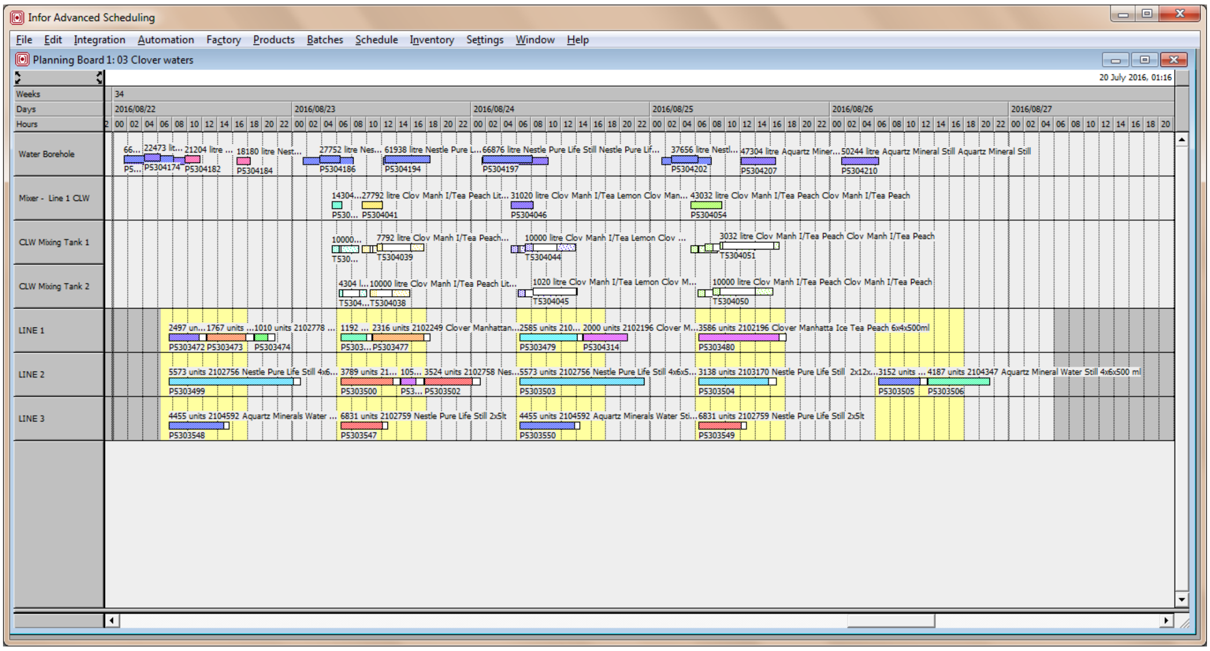
Off-peak Week 2:



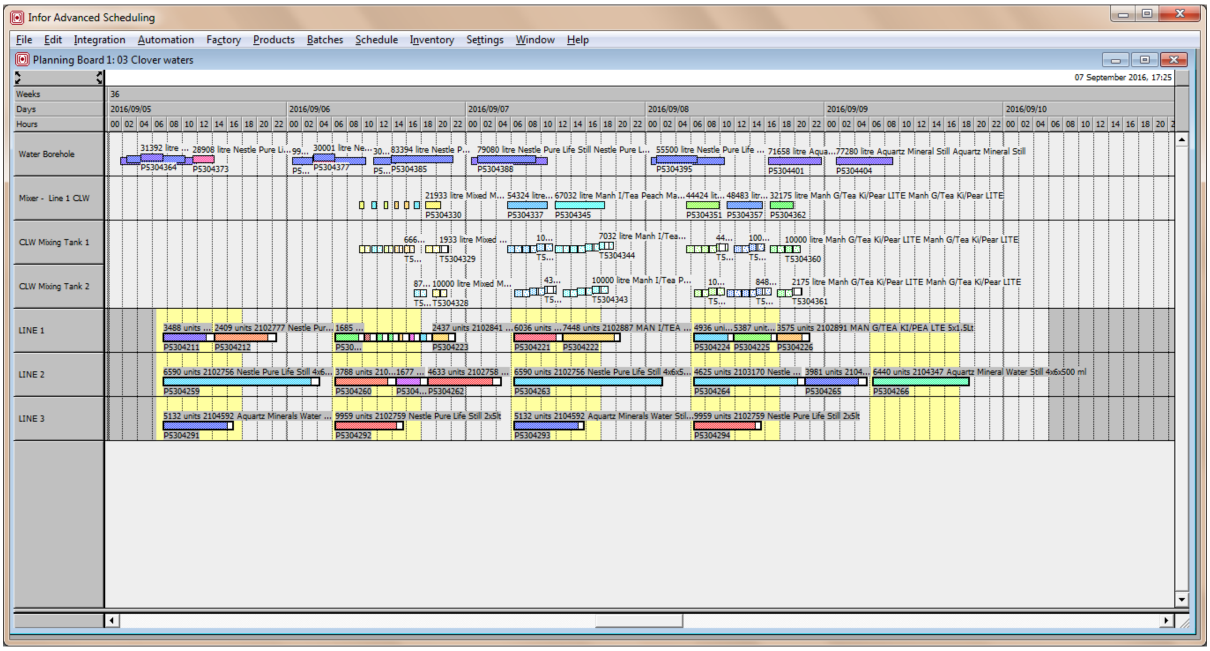
Off-peak Week 3:



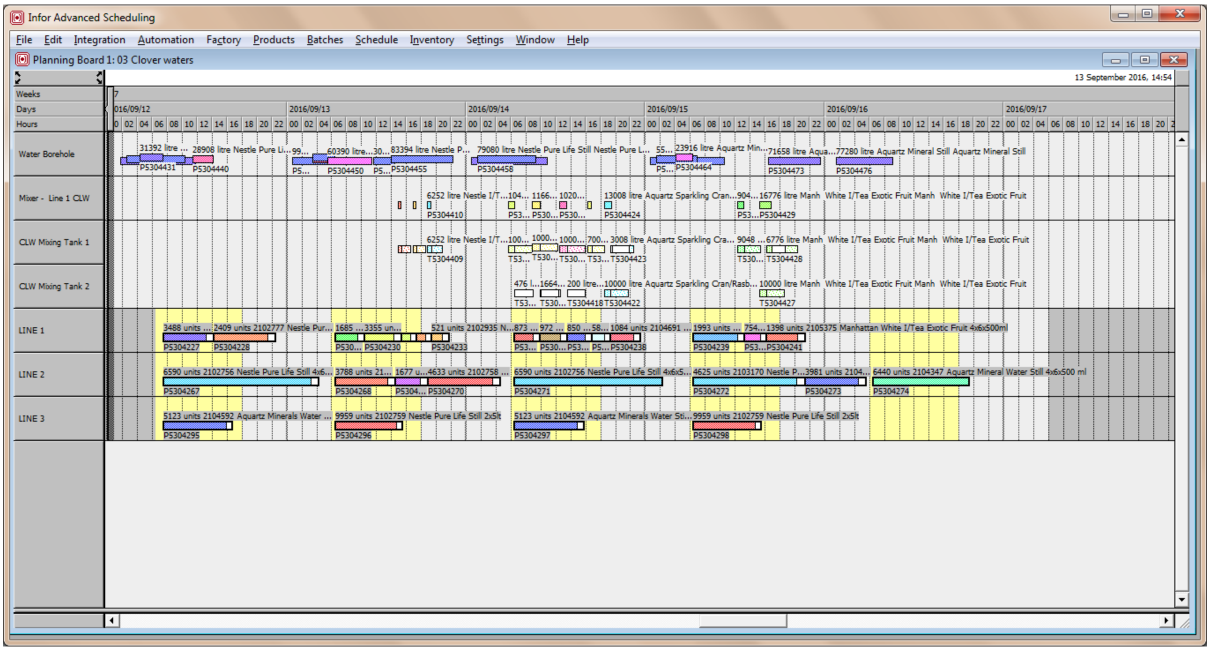
Off-peak Week 4:



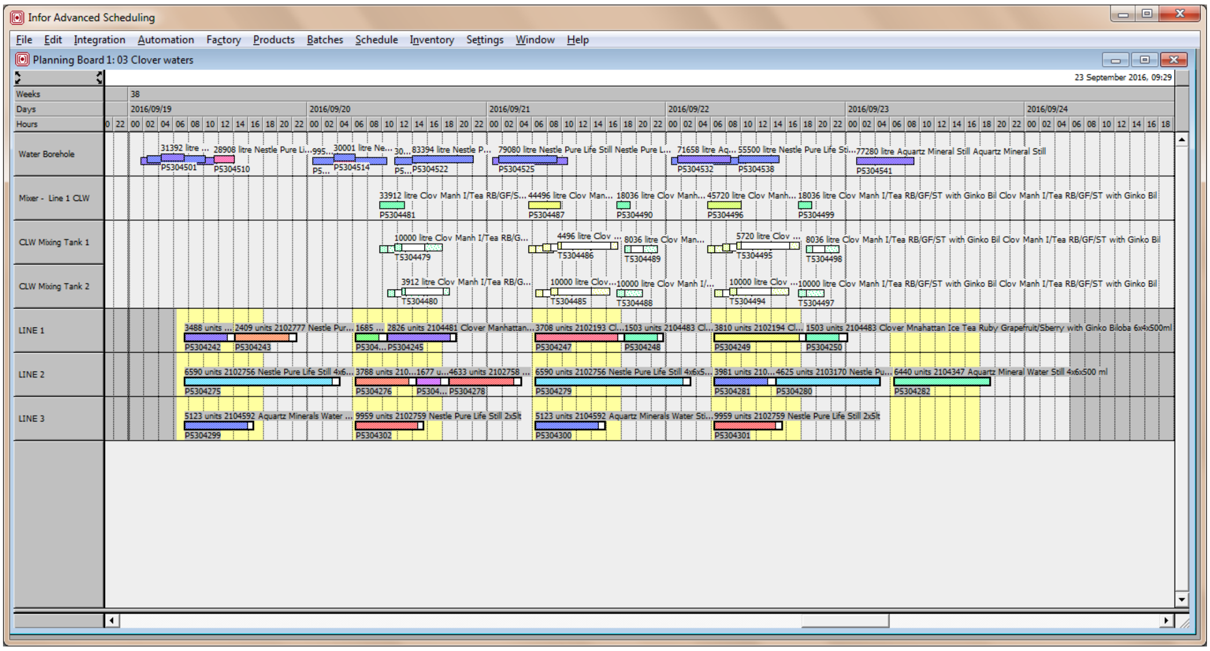
Continuous Week 1:



Continuous Week 2:



Continuous Week 3:



Continuous Week 4: