

Distribution centre planning

A systematic improvement of an existing distribution centre

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Executive Summary

Warehousing and especially distribution centres form an integral part of any mass production or procurement enterprise because it is a near impossible task to use JIT principles in a beverage company the size of SAB. In a society where the power struggle between consumer and producer has shifted enormously towards the consumer it is essential for a modern business to exploit the value added advantages that an optimized distribution centre can provide. Improvements in the distribution centre could provide improved customer service, increased volume output and better space utilization that will not only benefit the warehouse but the organization as a whole. Thus by using analytical engineering methods, skills, and tools this project aimed to identify opportunities for improving the distribution centre system and how to exploit these opportunities.

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1. Project Proposal

1.1 Introduction

SABMiller Ltd is a world-renowned brewer and distributor of beverages throughout the world. The company is currently on the JSE's top 40 and boasts to be the second largest listed company. In South Africa alone SAB is the largest contributor of alcoholic as well as non-alcoholic (ABI) beverages.

SAB is divided into two collective businesses, namely the beer and soft drink divisions. Each division uses a multiple team approach within their corporate structure. Thereby the brewery, distribution, marketing, sales and other relevant departments work separately from each other as if they were businesses on their own, however with a collective body that oversees the all departments of the company from the collective entity known as SAB.

Figure 1: Divisional structure of SAB



This project focussed on the sales and distribution division of SAB, specifically the Watloo distribution centre. The distribution centre of Watloo serves as a storage area for completed products from various breweries but mainly from the Rosslyn brewery in Pretoria. The centre is characterised as a preparation centre for ordered products, loading of products to the distribution trucks as well as a storage area for empty cases and bottles.

1.2 Project Aim

Even within a large corporate body as SAB there is still room for improvement as within the industry itself there is nothing that can be perfect or stay near perfect for long. In a peculiar twist, it is usually companies that are doing exceedingly well that are most at risk of outgrowing an existing warehouse thus putting the business in danger of losing its strong position, as stated by Meiring (2006).

Due to this, a company such as SAB must constantly assess the departments, especially the distribution department in regards to the ever-changing market.

This project aimed to optimize the existing Watloo distribution centre's operations to improve service to the supply chain.

The project focussed on improving existing systems as well as searching for new innovative systems and methods to improve the Watloo distribution centre, as well as other distribution centres in line with Watloo within the supply chain.

The improvement of such a warehouse could be of great value to multiple companies as in today's world, it is almost impossible to contemplate any efficient mass production or commercial distribution without a careful consideration of the role of warehousing (Henneberry, 1987; Power et al., 2007).

1.3 Project scope

The project started with an analysis of the distribution centre to determine its exact nature and if there are any problematic occurrences within the existing system.

With the distribution centre fully defined and understood, a literature study was undertaken to find similar centres as well as similar problems within the industry as well as looking for methodologies that are not within the industry. Goldratt (1984) confirms this in his book *The Goal* that answers to industries' questions are sometimes found in the strangest of places.

Following the literature study, this project will look at developing new systems within the distribution centre that is in line the findings.

The project scope does not initially include a practical implementation but the prospect of practical implementation relies on the approval of senior management within the Watloo distribution centre

1.4 Deliverables

The end state mission for this project will include the following deliverables:

An in depth analysis of the distribution centre that includes;

- Space utilization: Does Watloo utilize their allotted space efficiently?
- Flow utilization: Is the flow of products in the warehouse done according to a controlled thought out process?

The identification of problematic processes and opportunities for improvement;

The development of solutions towards problematic processes – the project examined different solutions for the problems and assessed these options;

An improved system methodology for the distribution of SAB products within the Watloo warehouse - this included an optimization program to determine if there are any shifts in an optimal layout for the warehouse.

In summary, the aim of this project was to improve the operations and lower the costs involved in this service within the supply chain.

1.5 Project Plan

In spite of the importance of warehouse design, a review of the literature concluded that relatively little has been written in academic journals on the systematic approach that should be taken by warehouse designers (Baker & Canessa, 2007). The project plan fell in line with the accepted industry norm. This included the following steps that were utilised by this project:

1. Defining system requirements;
2. Obtaining data (operational, and capacity information);
3. Determining existing operating procedures and methods;
4. Calculating equipment and product capacities and quantities;
5. Defining service and auxiliary operations as well as limitations;
6. Discussing findings with management and awaiting approval of findings;
7. Preparing possible improvements to existing system;
8. Evaluating all relevant solutions with SAB management;
9. Identifying preferred design.

Within the distribution centre, there are multiple opportunities for improvement. In the following section, the project will show what has already been done regarding the improvement of warehouses. The problem statement will be more refined as more information is shown concerning distribution centres.

2. Literature Study

2.1 Introduction

SAB has grown into not only a South African, but also International leading company within the beverage industry. In a short time span, it has acquired numerous products, the biggest acquisition being the partnership with Miller making the newly formed company SABMiller, the 2nd largest beer company in the world. South Africa, holding 21% of SABMiller's mark-up, was introduced to new products developed locally as well as established international products being brewed and sold here.

This new product range of SAB gave rise to a new challenge; the total restructuring of SAB's supply chain, this meant that the warehouses also needed restructuring. This operation went well and with minor changes throughout the years substantial; but as Bauhoff, (2003) states "Warehouses that once seemed spacious, well organized and easy to operate are now congested, unorganized, labour intensive and riddled with product damage." This is why, like other departments of SAB, the Watloo Distribution Centre has to redesign and develop a new facility plan that will not only increase its overall volume utility but also its value added services that will become increasingly more important over the next few years.

With the introduction of the new Brandhouse Brewery in Sedibeng, competition for SAB, especially in the premium brand sector, will become fiercer. The service aspect of SAB therefore may be lacking and has to improve dramatically as SAB was the sole supplier in South Africa for a number of years. This is one of the reasons why SAB increased marketing on their Castle LITE product.

The nature of the beverage industry, especially the beer/cider sector, has cyclic variations of its products whereby a product is implemented, popularized, matured and eventually becomes obsolete. This is accredited to the fact that a product can be popularized in one generation and mature with that generation. Lion Lager is an example of this as it was a very popular beer during the 1980's and early 1990's but was phased out with the aggressive marketing of Castle Lager. This same phenomenon is happening with Castle Lager slowly being replaced by Black Label as SAB's middle class flagship.

All of these factors contribute to Watloo's need to redesign its facility for future operations as a beverage operations expert stated, "Beverage warehouses, in spite of elimination efforts,

automation improvements, and computerized order processing, won't go away!" (Koss, 1996).

2.2 Formulating the design process

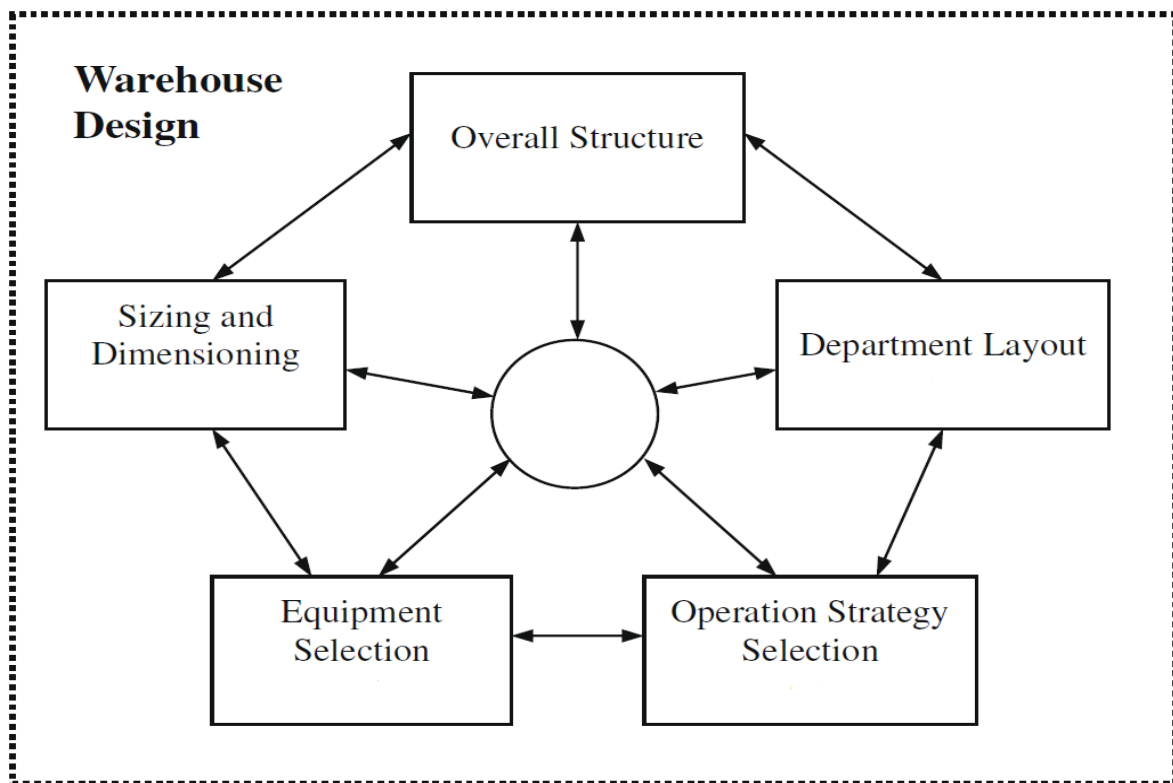
Despite the need for the systematic development of the warehouse layout there aren't many reviews published that address this issue and little has been written in academic journals on the systematic approach that should be taken by warehouse designers (Baker & Canessa, Warehouse design: A structured approach, 2009).

We are dealing with the redesigning of the Watloo Distribution centre thus our capacity will be the same as the original. Thus a higher emphasis must be put on other aspects of the warehouse efficiencies such as department layout, pallet stacking, automation, equipment selection, operation strategy and especially order picking.

Gu, Goetschalckx, & McGinnis, (2010) States that warehouse design involves five major decisions as illustrated in Fig 2.

Figure 2: Warehouse design problems

Source: (Gu, Goetschalckx, McGinnis 2010)



From figure 2 the five major problems are:

1. **Warehouse structure:** The location of departments that govern the warehouses' flow of material as well as interdepartmental flow.
2. **Sizing & Dimensioning:** The size of the warehouse and frequency of warehouses. (This department, as earlier stated has been omitted, as the facility's size has already been determined).
3. **Department Layout:** The warehouses physical policy regarding aisle and retrieval configuration, pallet bins, automation and order picking.
4. **Equipment selection:** The appropriate equipment for the desired facility.
5. **Operation Strategy:** Company's policy regarding storage, order-picking etc.

To accommodate these major decisions in the design of the warehouse the planning process used further in this project is formulated. The following steps were taken to develop the most suitable facility for the Watloo Warehouse:

Systematic improvement of an existing distribution centre

1. Define system objectives

A clear study was made to understand and identify the system vision and if any changes might have occurred since the last facility evaluation.

2. Define order-picking requirements

In an average warehouses order-picking accounts for up to 55% of operational and is the one department most prone to pile up and create a bottleneck within the facility expenses (de Koster, Le-Duc, & Roodbergen, 2007). Thus in this project we developed the facility around the order-picking department.

3. Define Storage requirements

4. Relationships between storage bins and order picking

5. Define other department requirements and its relationships

These include service and auxiliary operations.

6. Equipment selection

Choose equipment that will best suite the operational strategies of order-picking and storage.

7. Put all proposals under a performance evaluation

8. Reevaluate and determine best proposal

Even though the proposal is orthodox regarding the whole process revolving around the order picking it is understandable that warehouse design follows more in an iterative than a sequential process thus the process that causes the most change and delays within the system should be looked at first to minimize it's variability (Baker & Canessa, Warehouse design: A structured approach, 2009). By using the steps above, all five warehouse design decisions will be met, but as a facility has a life cycle re-evaluation of the process should be undertaken constantly to seek foreseeable problems (Tompkins et al 2003).

9. Prepare existing facility for implementation

This includes building extensions, new equipment acquisition, staff training and notification of changes. The last step will be excluded in this project.

2.3 Define system objectives

To determine the system objectives the question asked is: Why is Watloo distribution centre there in the first place? According to Koss (1996) it is known that it is an irreplaceable department in the beverage supply chain. But why? The Watloo Distribution Centre provides the following services to the supply chain; transportation consolidation, production economy, service policy, buffer against variability, time and space utility, product mixing. All of these and more are divided into three categories: capacity, selectivity and productivity (Bauhoff, 2003). The three major components that a warehouse gives to the supply chain are:

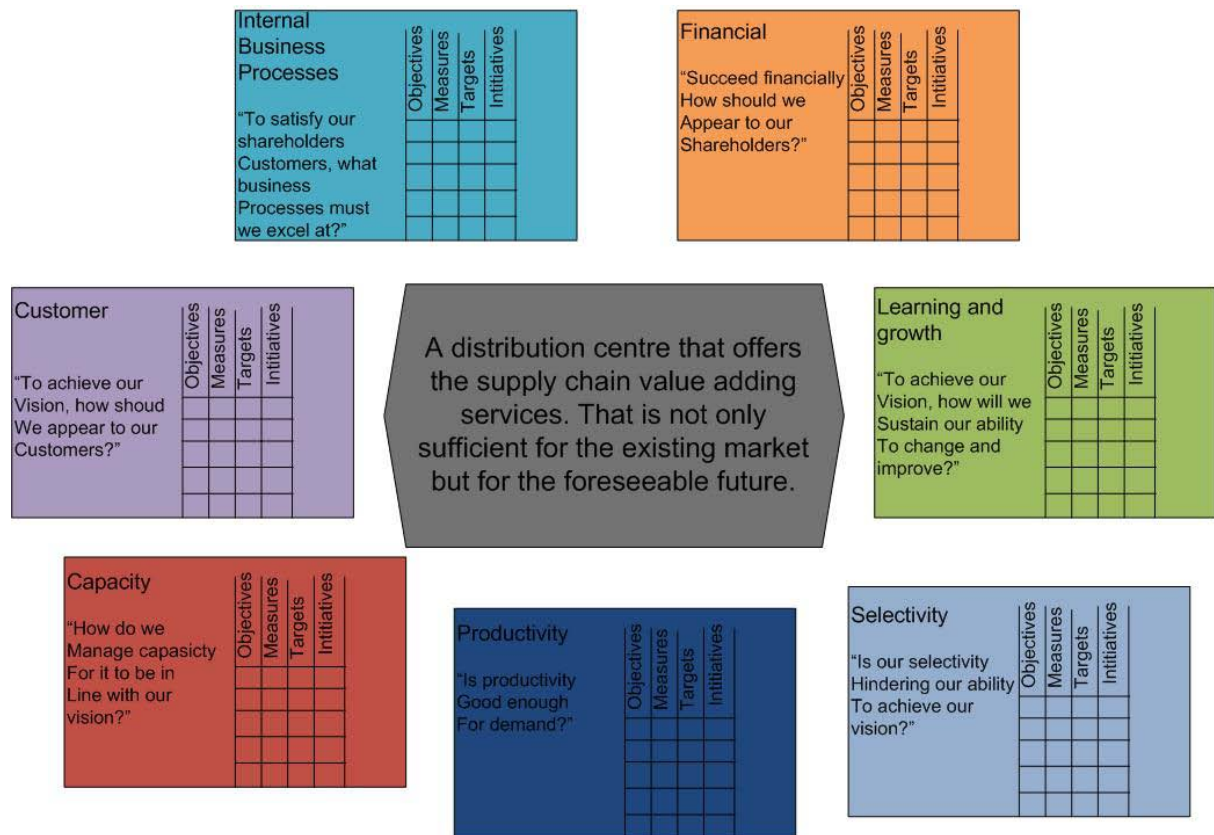
Capacity: Breweries would not be able to brew a substantial amount if the brewery had to work on a JIT basis.

Selectivity: The warehouse offers the supply chain an opportunity to pick orders in an orderly and controlled fashion.

Productivity: Reduces time between orders and the receiving of the products ordered.

So the question is where does Watloo fall short? To determine this a scorecard was used. Together with the three above-mentioned factors, we introduced four more. These four are four distinguishable perspectives of performance measures: Customer, Internal processes, Financial, Learning, and growth (Bigliardi & Bottani, 2010). On the following page figure 3 depicts the scoreboard.

Figure 3: The scorecard for evaluating current performance



Together with the market analysis that checked for any market changes this formed the data for developing the System Objectives.

2.4 Define order-picking requirements

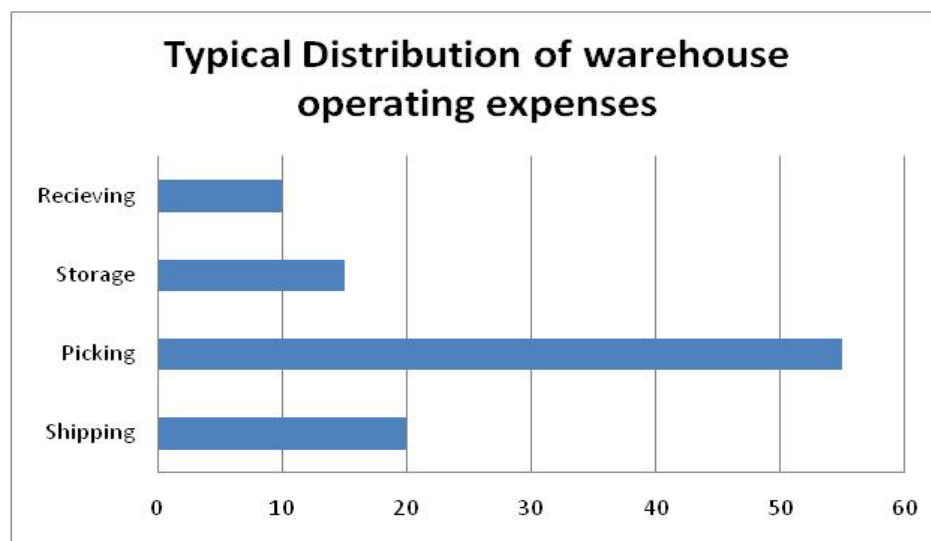
2.4.1 Introduction

The majority of time and effort were dedicated to the order picking department of Watloo Distribution Centre. The reasons for this will be identified later on this review.

Due to the complexity of order-picking it is a very intricate process and very little research has been developed in this area (Gu, Goetschalckx, & McGinnis, 2010). In many warehouses, especially beverage related, the pick pace is poor. According to Kibort (1999) this could be because of poor warehouse layout design or wrong operating strategies and other factors.

Figure 4: Typical distribution of warehouse operating expenses

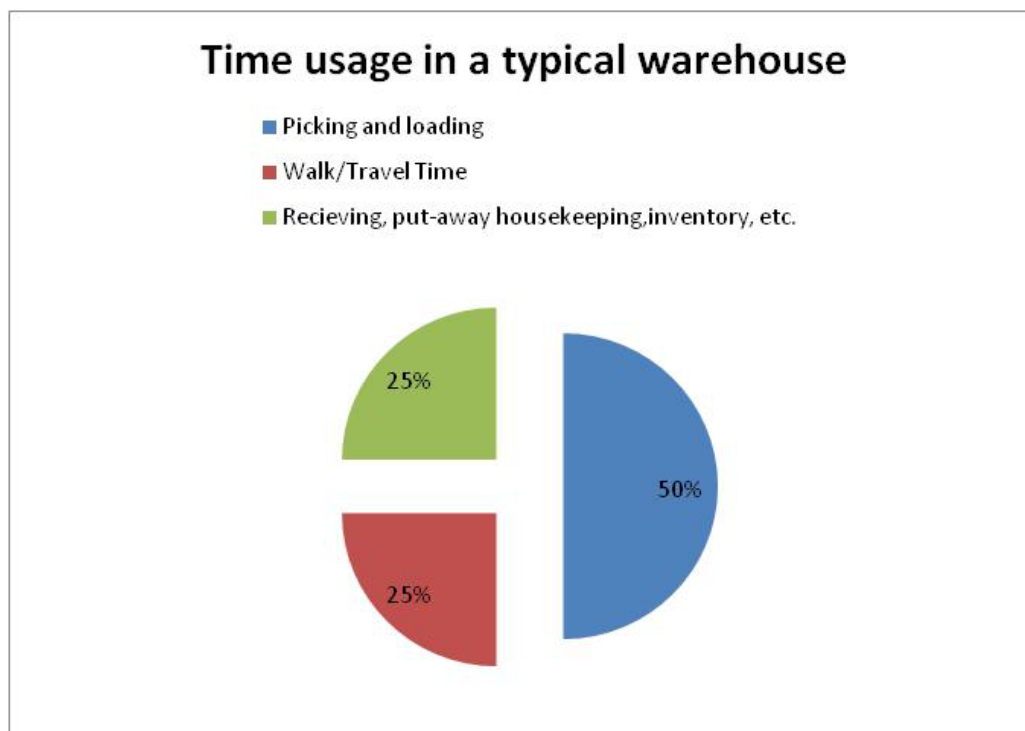
Source: (Tompkins, White, Bozer, & Tanchoco, 2003)



Order-picking contributes up to 55% of expenses and 25% of time in a warehouse. Thus, the importance of getting the optimal strategy in a warehouse is essential for the overall success of a warehouse. Figure 4 shows the graph for expenses and figure 5 (next page) shows the graph for time spent in a warehouse.

Many of the problems that occur in a warehouse are attributed to order picking. The completed scorecard will show that order picking is one of the major contributors to the system's limitations to achieve its vision. In Figure 5 it shown how much time order picking takes up in the warehouse.

Figure 5: Time usage in typical warehouse



Order-picking is the most labour intensive operation in manual warehouses and a very expensive operation in automated warehouses (de Koster, Le-Duc, & Roodbergen, 2007). This leaves order picking as a department with many opportunities in cost and time reduction.

2.4.2 Facility layout and storage layout

Most literature studies revolve around high-level automated material handling even though the majority of companies utilize low level manual strategies as seen in Europe where 80% of the latter is used (de Koster, Le-Duc, & Roodbergen, 2007). Currently the order picking method utilizes the following for their order picking at the Watloo Distribution:

As with other distribution centres, order picking systems that has a large amount of orders to fulfil in a short amount of time, SAB Watloo uses a Put order system. According to this system, a forklift uses a picker-to-parts method to replenish a forward-reserve allocation bay whereby labourers then complete orders onto pallets (parts-to-picker). Watloo also implements a wave-length policy whereby trucks orders are completed in conjunction with each other.

This current system is evaluated using performance measures prescribed by the industry namely mean daily labour and mean percentage of late orders (Gu, Goetschalckx, & McGinnis, 2010). This entails thorough data collection of various indicators including throughput time, space utilization, labour utilization and accessibility of items.

Other layouts should be examined for implementation. There may be a possibility that a new proposed system could be more effective than the already installed layout. The main criteria are to minimize time for an order before being completed thus maximizing throughput. In a labour driven system workers strain should also be minimized by looking at ergonomic principles.

Using the given market analysis and future forecasts a new forward reserve formulation is evolved by using Pareto analysis. Hereby if any the new top contributors should be allocated in the forward reserve bay.

Storage assignment policies should then be reworked. These include the most popular under warehouses using a forward reserve bay, and these are (de Koster, Le-Duc, & Roodbergen, 2007):

Random: Incoming products are assigned to any given open storage location.

Closest open location: Assigned to the first bay.

Dedicated: Each product has its own dedicated bin area.

Full turnover: Products assigned by their turn over; high turnover is the easiest accessible.

Class based: Classes based on Pareto's rule.

The choice of storage is simulated to reduced travel time and this is done using ARENA. Workers strain should also be a factor, ergonomic principles are used to search for limitations

The location for the order pick layout should also be optimized. This is discussed under the Relationships between storage bins and order picking.

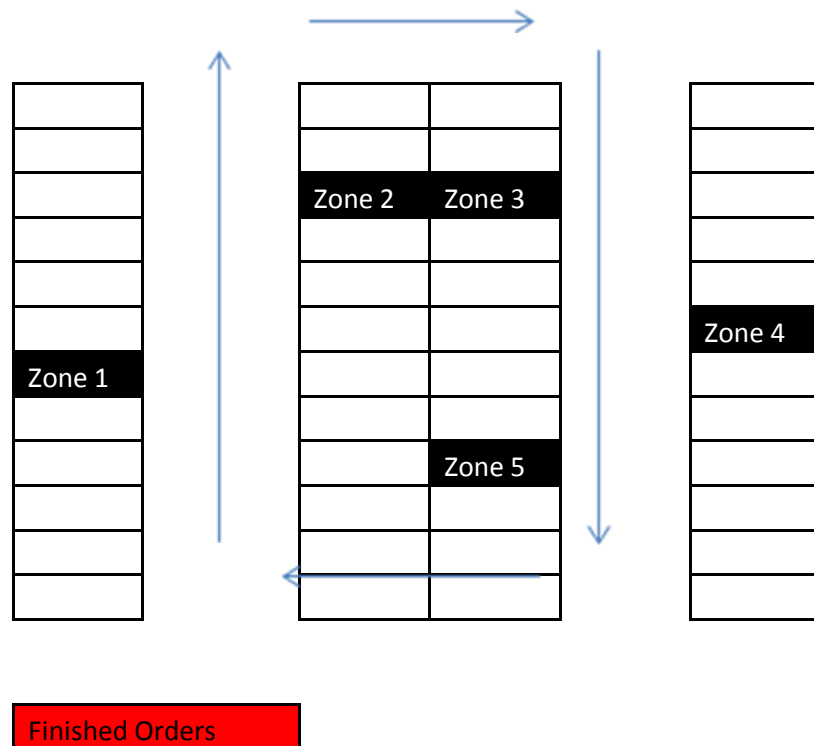
2.4.3 Zoning and Batching

Two very different policies from the method used currently is zoning and batching. Both employs multiple picking locations but are also very different from each other. The first part of the chapter will be a description of zoning and the second about batching.

Also known as the pick-and-pass policy, order pickers are assigned to certain zones where and when an order comes by (automated or manually driven) the picker will then complete the order only relevant within the assigned zone. Advantages are that an order picker would travel a smaller distance for an order, reduce congestion, pickers becomes familiar to the assigned zone. There are disadvantages and limitations regarding zoning. These include the fact that a forklift can only complete one order per tour. This can be solved by mixing zoning and batching.

In zoning the one order per tour problem becomes bigger when orders are small but multiple. Batching implies that orders be grouped together to go through one tour. Optimizing a Batch tour could be a tedious task especially when combining batching with wave principles.

Figure 6: Possible Zone-Batch policy

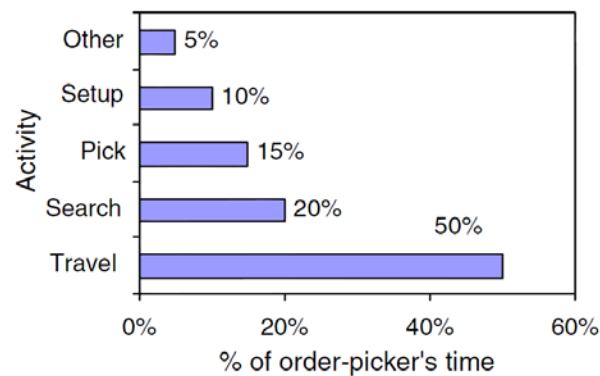


2.5 Define storage requirements

Storage design should be developed in close conjunction with order picking as the biggest factor contributing to order throughput is the time spent by order pickers travelling and searching for products. This is closely related to the distance between products in storage and the order picking zone/s. “Travel time is a waste. It costs labour hours but does not add value” (Bartholdi and Hackman2005). It is an objective that often, if not always, has to be improved in warehouse optimization (de Koster, Le-Duc, & Roodbergen, 2007). Figure 7 shows how much time is spent by order pickers travelling and searching for products.

Figure 7: Typical distribution of an order picker's time

Source: (Tompkins, White, Bozer, & Tanchoco, 2003)



Firstly, it is necessary to examine the market analysis to determine bin sizes (may vary) and number of bins required for each product that is housed in Watloo. Kibort (1999) states that the velocity of each stock keeping unit (SKU) and the relationship of SKUs towards each other must drive any beverage warehouse layout. Therefore, the results must not also be determined in conjunction with the receiving SKUs but satisfy all requirements of the receiving SKUs. Note that space utilization would be the limiting factor (Gu, Goetschalckx, & McGinnis, 2010).

The next question is what types of products need to be racked. These products are usually slow moving with low volume. If these products are not racked, they waste vertical space that could have been utilized by multiple SKUs. Racking also optimizes pick areas and reduces picker travel time (Kibort, 1999), but is for the exceptions. Most products that display typical beverage industry SKUs namely high pallet count with low SKU operations (Elicker, 1998) are usually floor stacked. This method is a cheap and effective way of storing beverages that is highly flexible and easy to change. The limitation for floor racking is the product strength for if a bin would be stacked to high it might become structurally instable and that could lead to product damage.

The norm for the storage policy is to accommodate the order picking as much as possible.

2.6 Relationship between storage bins and order-picking

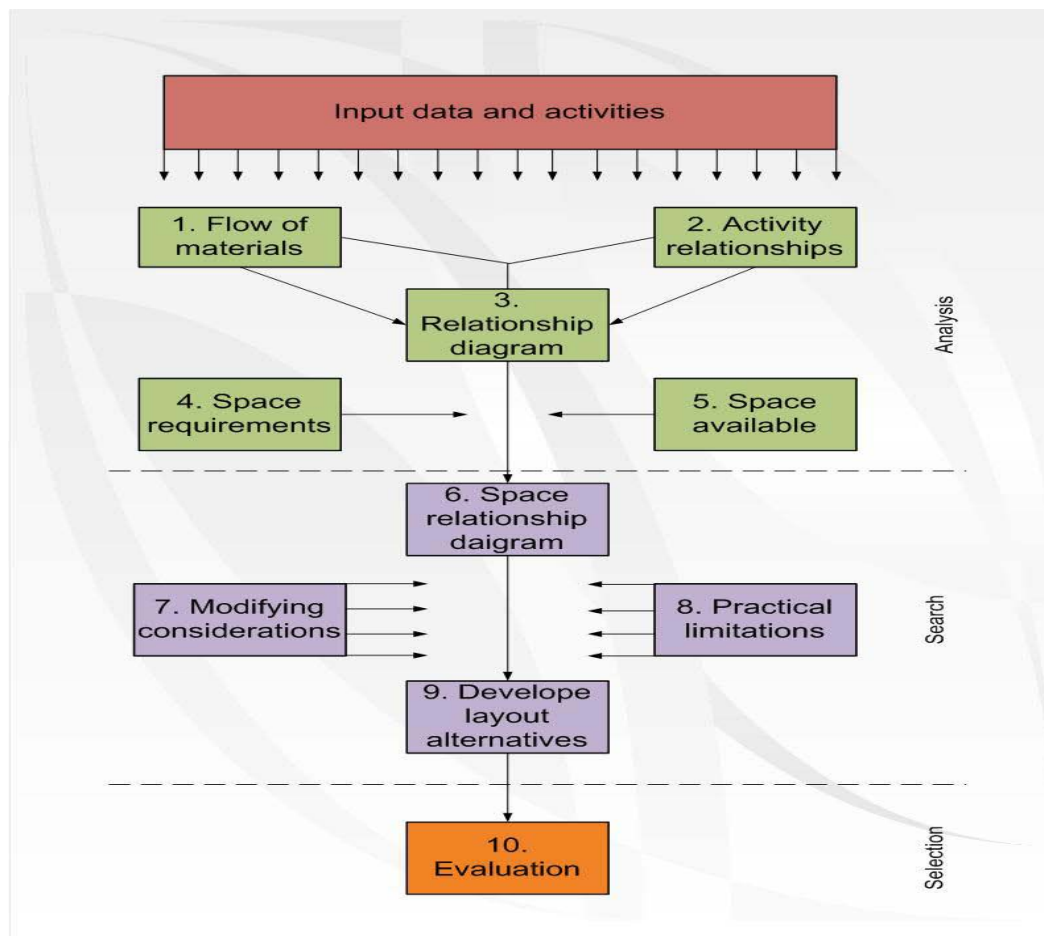
As with forward reserve bins the same types of storage policies apply to storage bins. These include random, closest open location, dedicated, full turnover and class based. For the latter three Pareto analysis was used for a long time, and, as this was a non-linear optimizing approach research was done to determine if storage could be solved using LP methods (Onut, Tuzkaya, & Dogac, 2008). There were various successes, including a paper reel IP, S-shape heuristic, a travel time model and various other models that were introduced throughout the years.

Onut, Tuzkaya and Dogac (2008) proposes that a particle swarm optimization model should be used that is a stochastic technique for multiple level storage (racking) while Hsu, Chen and Chen (2005) propose a genetic algorithm. Both of these were constructed in conjunction with the order picking department.

A fully developed model should be used to determine the policy of placing bins for products. This will be developed in conjunction with the chosen operating strategies for order picking. The systematic approach for layout planning is presented in Muther's procedure in Figure 8.

Figure 8: Systematic layout planning (SLP) procedure.

Source: (Tompkins, White, Bozer, & Tanchoco, 2003)



Muther's systematic approach was utilized to develop the optimum distribution centre for the purposes of this project.

The relationship and space relationship diagram was developed to identify a basic layout configuration and to check if the optimum storage requirements met the current space available. For the purposes of this project, we used an algorithm (to be identified later in this document). This solution was compared to the manual method to identify any practical limitations.

After the optimum storage layout was developed, we examined it for any limitations or modifications that might be present. Following this examination, alternatives were developed and assessed using the following performance criteria and constraints (Gu, Goetschalckx, & McGinnis, 2010):

- Storage capacity and efficiency
- Picker capacity and efficiency
- System response time
- Item retrieval policy (FIFO,LIFO etc)

All evaluations involve a simulation with ARENA and/or a separate SWOT analysis. Once the best alternatives were determined, they are compared to the old systems performance.

Upon identification of the preferred design, the other departments present in the facility are incorporated. The following section of this report discusses this inclusion.

2.7 Define other departments and its requirements

Service and auxiliary operations appears to be derived from the experience of the warehouse designer and sometimes formulised into checklists of requirements (Baker & Canessa, Warehouse design: A structured approach, 2009). There are various departments other than the order picking and storage departments within a distribution centre. All of these were identified and its requirements and limitations were thoroughly studied. Some of these departments are listed below:

- **Receiving and shipping lanes:** These are the dedicated lanes for trucks to enter and exit the distribution centre.
- **Receiving and shipping depot:** Both are currently at the same location. The depot is next to the completed orders storage area for the purposes of minimizing handling distance.
- **Completed orders bay:** After order picking, completed orders are moved here.
- **Communication office:** A fixed office that is in the warehouse itself that communicates with the marketing department to receive new orders.

Other departments at Watloo that are not in the warehouse but on the facility include:

- **Marketing department:** Including all SAB representatives and a call-centre for placing orders.
- **Managers' offices**
- **Reception**
- **Truck servicing centre:** Repairs to distribution trucks are done here.
- **Employee parking**
- **Restrooms**
- **Food services**

For the warehouse relationship phase only the departments located within the distribution centre were considered. Regarding the receiving and shipping lanes there must be space allocated for the trucks to manoeuvre in and out of the warehouse. There should also be space for a truck to pass another truck within the warehouse. The shipping and receiving depot should be allocated near the communication office to minimize travel time and improve visibility.

These departments must be implemented in the already optimized model to represent the warehouse as a whole using Muther's principles as stated earlier in the study. Note none of the bins or the order-picking department should be moved.

2.8 Equipment selection

Equipment selection is dependant upon the decisions made up to that point specifically the Operation strategy policies formulated.

Many new advances in facility equipment have been made over the years. Other advancements that is potentially beneficial but have not been realised in using the appropriate equipment in warehouses. Warehouses utilising the advantages of new technology has been slow, as it seems that managers are more inclined to take the conservative approach (Forcinio, 1998). Even though many articles in academic journals revolve around automation and its potential, South Africa in general is not ready for a fully automated storage and retrieval system (AS/RS) system.

Equipment used to date includes standard counter balanced forklifts for material handling, SABS standardized pallets and a warehouse management systems (WMS) that is based on a SAP interface. This equipment is relatively efficient but the process can be improved by implementing new technology. Possibly developing and utilizing in-house software that is custom made for the operations within the Watloo distribution centre.

First of the proposed new equipment is the Tygard claw. This is a counter balanced forklift modified to handle layers of products on a pallet instead of only a single pallet at a time. In Forcinio (1998) Tygard's general manager Jim Wilhide explains that with the Tygard Claw one person can do in an hour what would normally require six people during the same time frame.

Figure 9 and 10: Examples of the Tygard claw

Source: (Tygardclaw.com)



As pressure mounts on warehouses to meet value adding standards, WMS has become an integral part of warehousing operations (Min, 2006). As of yet SAB uses the SAP interface to track stock and to communicate up and down stream. This is of yet an advance system of WMS.

The wireless label reader can also be used to improve product visibility within the warehouse. This systems allows that selected bines are scanned and then the products are re-scanned once assigned to a order. There are readers available that can be mounted on the finger for ease of use for order pickers.

2.9 Putt all proposals under a performance evaluation

A predetermined performance evaluation system should be in place to evaluate each proposed performance method including benchmarking, analytic models and simulations. This step is concerned with validating the layout under evaluation for operational and technical feasibility (Oxley, 1994).

Gu, Goetschalckx, and McGinnis (2010) propose using Data Envelope Analysis (DEA) as an appropriate tool to identify and reveal the relative shortcomings of inefficient warehouses. An open source DEA system known as iDEAS is available on the internet at <http://www2.isye.gatech.edu/ideas/>. This is a model developed by Keck Labs at Georgia Tech, USA. The tool allows a warehouse to be compared to other anonymous warehouses and then generates a report. McGinnis, Johnson, & Villarreal (2006) stated that by April 2006 there were 390 warehouses that had complete input and output data.

Aisle based analytic models are the appropriate model for our proposal if the evaluation is analytically assessed.

Simulations are the most used method for assessing layouts, as it is relatively inexpensive compared to implementing a system blindly. If simulations are chosen will entail a comprehensive simulation that analyse factors such as throughput efficiencies, space usage efficiencies and flow congestion. In this project we utilized the simulation power of ARENA.

2.10 Reevaluate and determine best proposal

Once a layout passes, the criteria determined in the first point of the Systematic improvement of an existing distribution centre procedure namely, defining system objectives, it is classified as an appropriate and valid proposal for replacing the old system. The evaluation could identify factors where the new layout are or would become problematic. These areas are reassessed for improvements following the procedure that formulated it.

After the revaluation is completed the new proposed layout is ready for implementation preparation. The following steps are beyond the scope of this project.

2.11 Conclusion

To ensure the successful redesign of an existing distribution centre, related topics were researched thoroughly and extensively. The first objective was to formulate a systematic design process with the emphasis on order picking. It was concluded that this orthodox method could be viable and that order picking is problematic in the industry.

Further research is necessary to identify the best suitable alternative methods of operational strategy for the new design process. A number of strategies that could be beneficial in our design are identified later in this report.

In the following section, the problem statement within the distribution centre is identified and formulated. Methods and techniques used on the formulation of the solution are discussed.

In conjunction with this literature study and data acquired from the distribution centre, an appropriate layout proposal are developed and designed using the systematic improvement

of an existing distribution centre principles as mentioned in this literature review as a reference model.

3. Final Project

3.1 Introduction

The final stage of my project revolved around stating the necessities of maintaining an optimum distribution centre and formulating the solution for the problem. During the time spent in the warehouse the necessary information to develop the solution was collected. The implementation of this information are further discussed in this section.

3.2 Define system objectives

Observations at the Watloo distribution centre demonstrated three very distinct yet interlinked factors that if unaddressed and left without constant evaluation would most certainly cause problems within the system. These three are:

- **In-house transportation distance:** By reducing transportation distance, the costs involved with the forklifts cannot only be reduced but the maximum volume of orders picked would be increased, as order-picking time would decrease.
- **Space utilization:** By improving the space utilization, the warehouse space would be more effectively utilised. Thus over the long term fewer extensions or new warehouses would be necessary thus reducing capital layout for these ventures.
- **Order picking speed:** By optimizing the warehouse layout, the overall speed of order-picking in the warehouse can be improved.

By addressing these three factors the balanced scorecard proposed in the literature study will be improved:

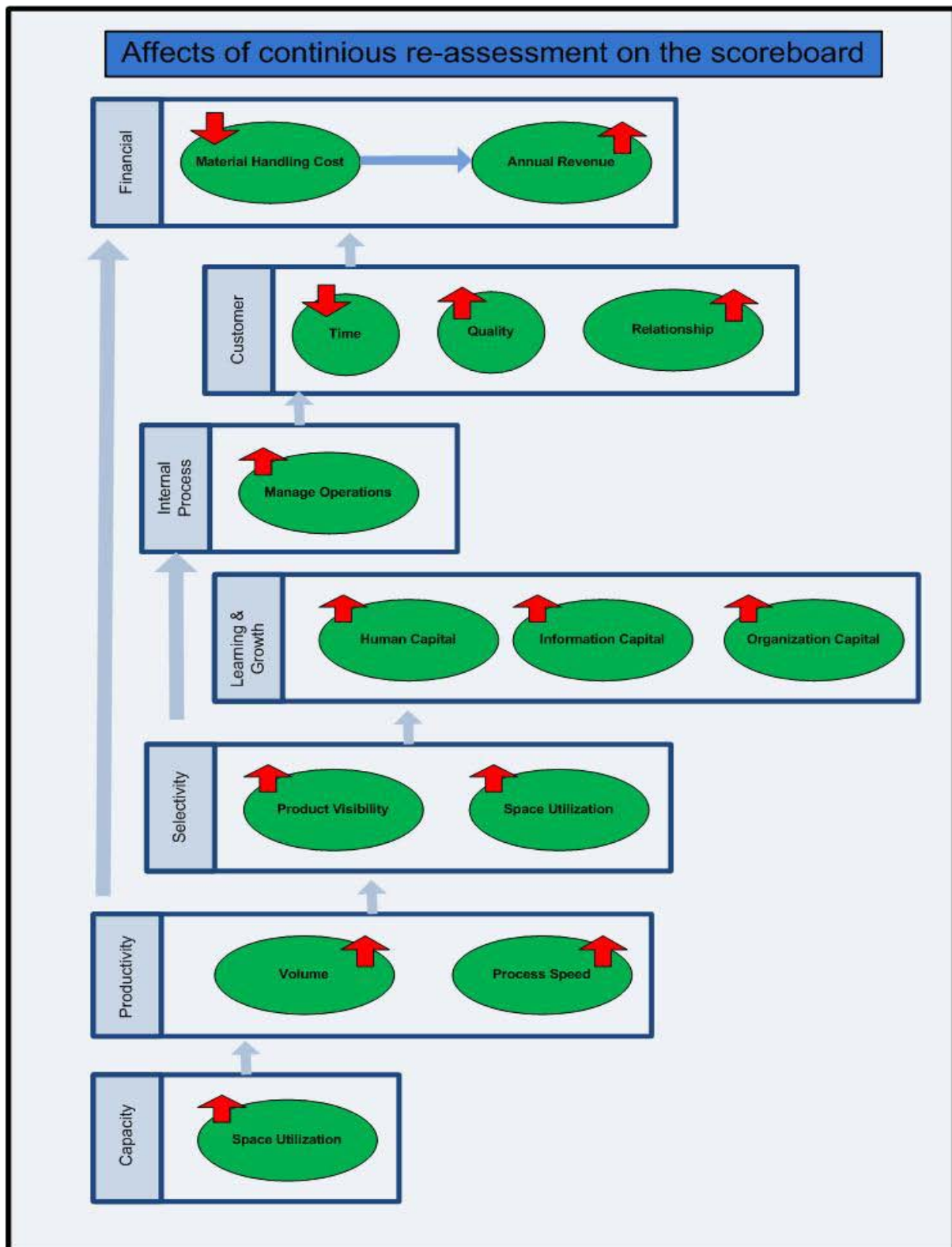
The development of the scorecard will not be dealt within this document. For the purposes of this project it will be demonstrated how a balanced scorecard could be affected through the optimization of the three factors mentioned above. Below is a brief description of the effect the above-mentioned factors could have on the scoreboard. Figure 11 on page 27 depicts these changes.

- The financial factor are improved by lower transportation costs and higher volumes.
- Continuous improvement and reassessment of the system improves the learning and growth factor.

- Selectivity of products increases due to better space utilization.
- Overall productivity increases as the volumes will go up.
- Better capacity management contribute to the improvement of the capacity factor.
- Quicker service and less faulty orders made will increase the customer factor and the customer relationship contributor.
- The internal business process is improved.

Thus, by improving the in-house transportation distance, space utilization, and Order picking speed an overall system improvement could be achieved. The primary objective is to find a way of improving these factors using engineering methods.

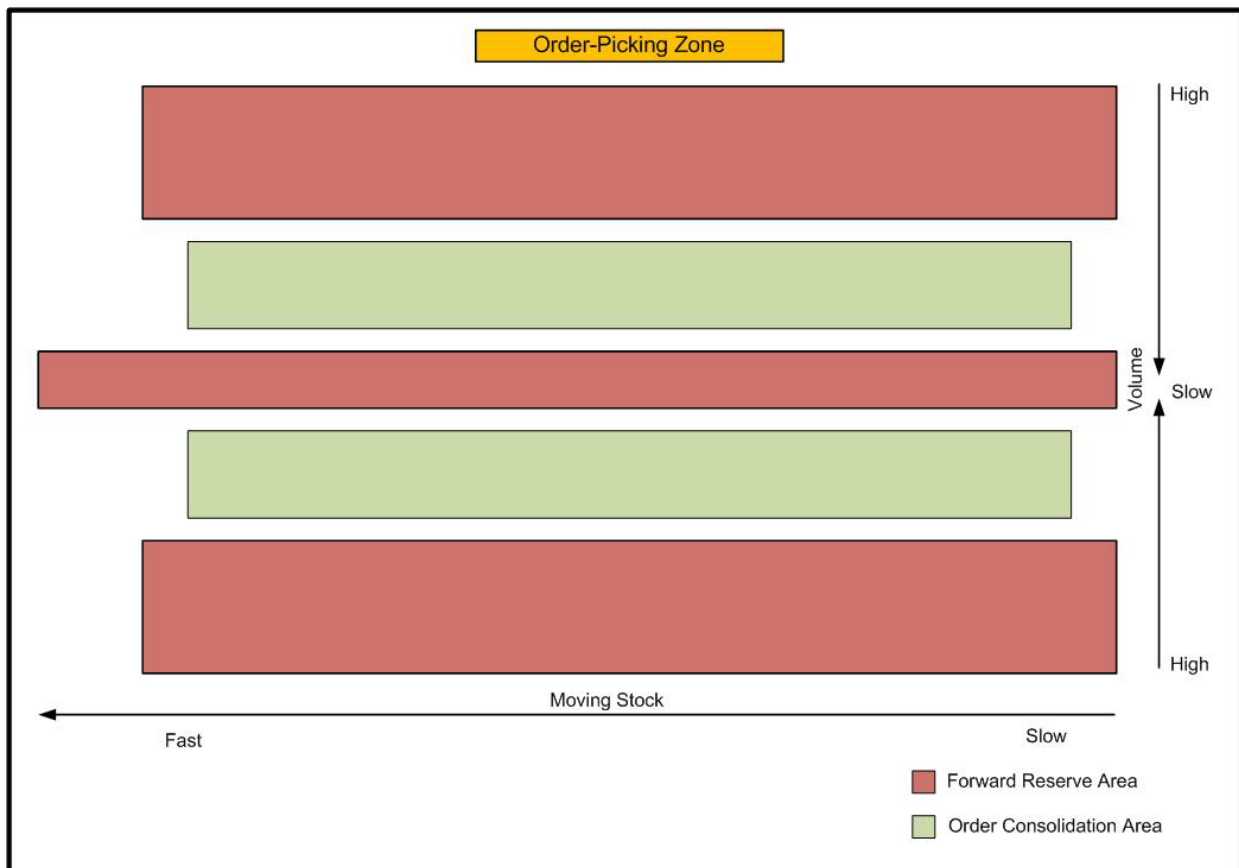
Figure 11: The Affects of continous re-assessment on the scoreboard



3.3 Defining Order picking requirements

The order-picking system at Watloo was specially developed for the nature of the distribution centre. Various order-picking principles are combined to form the order-picking zone. Figure 12 shows the order-picking layout.

Figure 12: Sketch of the Order-Picking zone



The order-picking zone (OPZ) has a forward reserve that has dedicated storage areas for all products. These areas are arranged from fast moving to slow moving stock and high volume stock on the outside to low volume stock in the inside of the OPZ. There are two alleyways where workers manually consolidate products for orders on pallets. The job orders are given in batches determined by truckloads. After an order is filled, a forklift is despatched to pick up the completed pallet and move it to the completed order zone. The forklifts also replenish the forward reserve as the bins are depleted.

The order-picking zone is an optimized zone for the order-fulfilment process. Other departments that have an effect on the OPZ will be examined. The most notable of these is the storage area around the OPZ where forklifts get pallets of products to replenish the OPZ.

3.4 Define storage requirements

Currently at SAB Watloo the full turnover based storage principles are used whereby high turnover products are the easiest accessible. This current system is however based on outdated information of demand and forecasts.

During the past season, SAB's product family structure has seen dramatic changes as mentioned earlier in the literature study. This raises the question; is the current storage system optimal for SAB's needs? The possibility that the current system might not be optimal for Watloo will be further investigated but firstly what are the requirements the storage are must meet?

Firstly, the storage area must meet the inventory needs of the volume of products that utilizes this facility. If not SAB either should expand the warehouse or look at other options such as outsourcing their warehousing or acquiring new storage facilities.

Extra space should be found for the sorting of returnable bottles once returned. This operation consists of sorting pallets with complete crates of empty bottles. These pallets are loaded onto arriving trucks bringing new stock from the breweries.

The layout should optimize in-house transportation distance, space utilization and order picking speed as these three factors are optimal for the following advantages to be reaped:

- Higher volume of orders can be processed as well as the speed at which an order is made,
- Lower material handling costs,
- Fewer accidents as a more structured layout would minimize the risk of human error,
- More storage volume as the utilization of space is optimized.

From this point forward engineering methods are used to develop a more optimal storage layout.

3.5 The problem solution

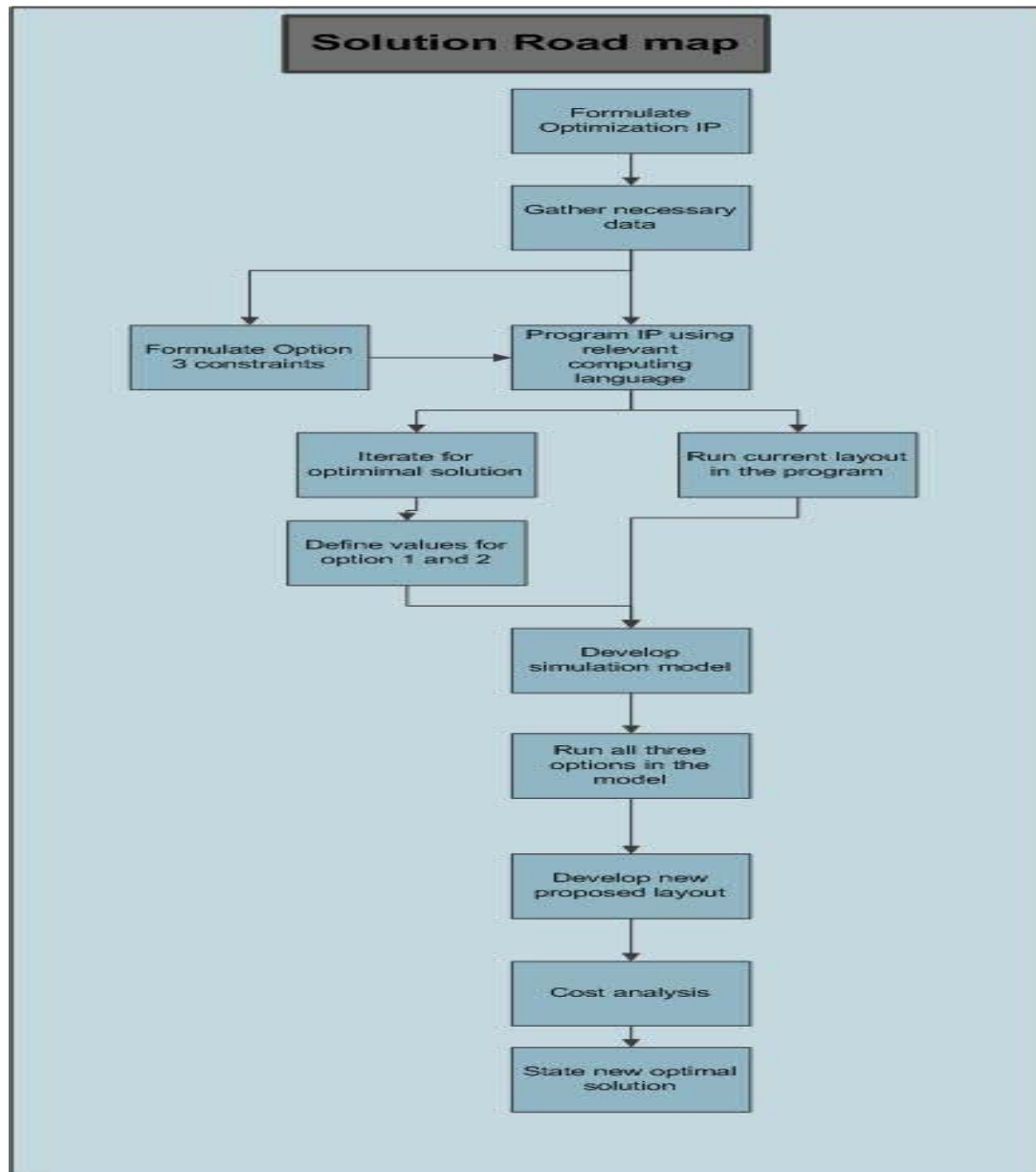
Solution statement

The current operations research techniques were used to develop a more optimal storage layout. From the solution formulation, three possible solutions were acquired.

The first was the current layout of the warehouse, followed by the second being an optimal solution given by the computer model and the last option was the optimization model subject to current restrictions given to products regarding their bin assignment. The reasoning for developing these two different models was that if option 2 ended up as the optimal solution it would confirm that the current bin layout and constraints must be revised.

The three options were then subjected to a performance measurement analysis where they were tested on their space utilization, order processing speed and transportation costs. This was done using simulation principles in ARENA. A new layout based upon the analysis of the three models was developed to ensure the best compromise between the three options was achieved and the needs and wants of the distribution centre were met. The final part was a cost-analysis aimed at determining the estimated cost reductions for the new solution. A road map of the proposed solution is supplied in figure 13.

Figure 13: Solution road map.

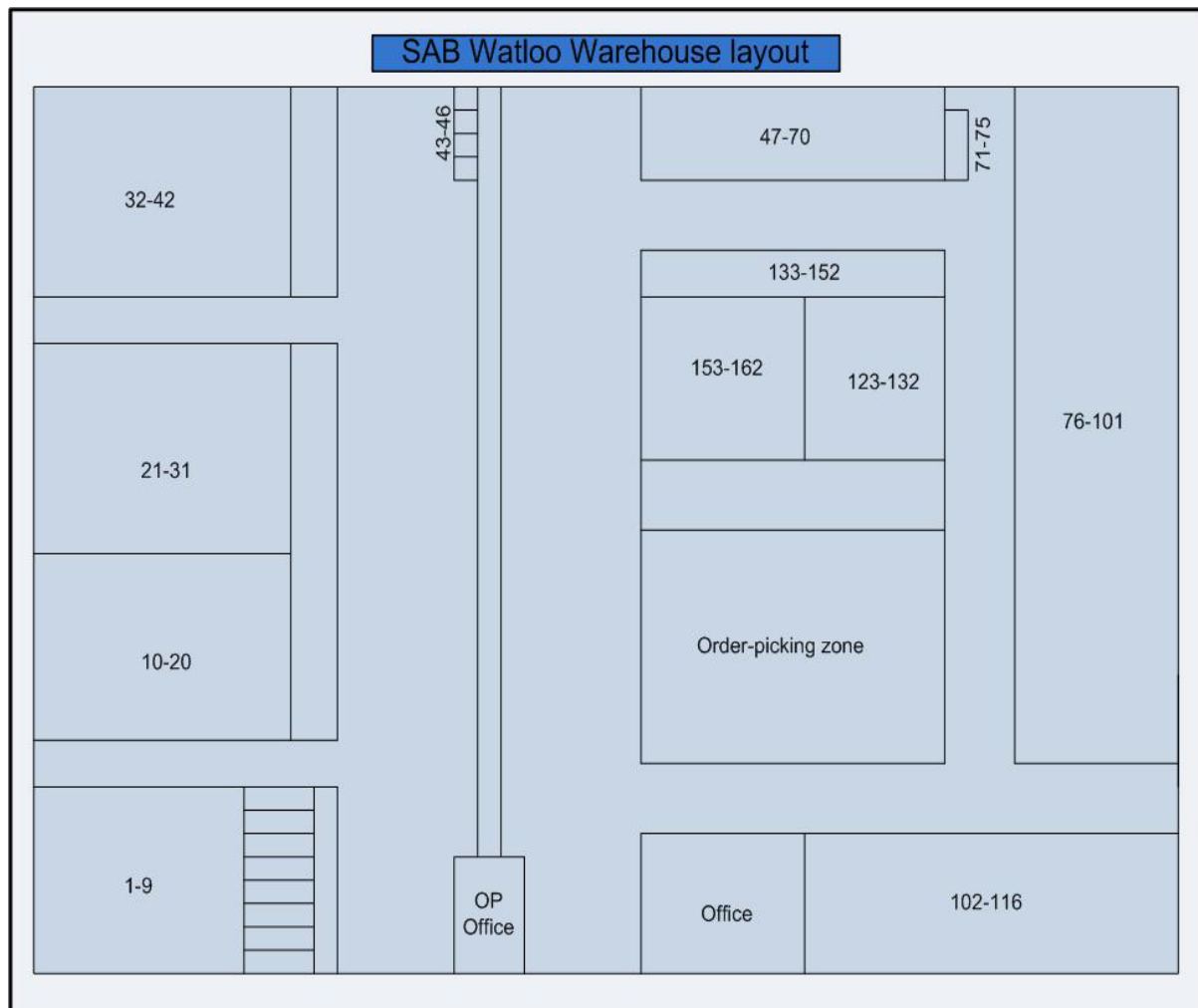


3.6 Operations Research on the storage layout

In this section, the minimization program used to optimize the warehouse is described. The objective of this optimization is to minimize the total length that a forklift travels during a set time. This will minimize the total material handling costs incurred during a set time as well as the time it takes for an order to be completed. Two options were developed for the solution with the first option only having the necessary constraints while the second option will have a few assignment constraints as to where some products may be assigned. Both are a bin-packing type 0-1 Linear Program.

Below is the layout wherein the linear program will optimize the assignment of products.

Figure 14: Current Warehouse layout



3.6.1 Option 1 Linear Program

The first option Linear Program (LP) includes only four constraints. These four are essential for the success of the LP. Note that not all four constraints restrict a variable to be assigned to a bin. This will be dealt with in the second constraint.

Underneath is the 0-1 Integer Program developed and used.

Formulation of the 0-1 IP:

$x_{ri} \triangleq 1$ If product r is assigned to bin i , 0 otherwise, where $r \in \{1, \dots, N\}, i \in \{1, \dots, S\}$

$P_r \triangleq$ Demand of product r (in pallets), where $r \in \{1, \dots, N\}$

$BP_i \triangleq$ The distance between bin i to the order picking zone, where $i \in \{1, \dots, S\}$

$I_r \triangleq$ Incoming Inventory of product r , where $r \in \{1, \dots, N\}$

$BI_i \triangleq$ The distance between bin i and the drop off zone, where $i \in \{1, \dots, S\}$

$IN_r \triangleq$ Required Inventory level for product r , where $r \in \{1, \dots, N\}$

$BC_i \triangleq$ The bin capacity of bin i , where $i \in \{1, \dots, S\}$

$k \triangleq$ The cost per meter of the fork lifts

The objective function:

$$\text{Min } z = k \sum_{r=1}^N [(x_{ri}P_rBP_i) + (x_{ri}I_rBI_i)]$$

Subject to:

$$1) \sum_{r=1}^N x_{ri} = 1 \quad i \in \{1, \dots, S\}$$

The first constraint defines that one product must be assigned to a bin.

$$2) \sum_{i=1}^S x_{ri} \geq 1 \quad r \in \{1, \dots, N\}$$

The second constraint states that a product must at least be assigned to one bin.

$$3) \sum_{i=1}^S x_{ri}BC_i \geq IN_r \quad r \in \{1, \dots, N\}$$

The third constraint states that the total capacity assigned to a product must be higher than the expected inventory level.

4) $x_{ri} = 0$ or 1

The fourth constraint only states that the x variable can only be assigned to a one if product r is assigned to bin i , and 0 if not.

3.6.2 Option 2 Linear Program

In the second option, assignment rules for products currently used by the depot were introduced. This is that all returnable bottle pallets should be stored in the left hand side bins.

Formulation of the 0-1 IP:

$x_{ri} \triangleq 1$ If product r is assigned to bin i , 0 otherwise, where $r \in \{1, \dots, N\}, i \in \{1, \dots, S\}$

$P_r \triangleq$ Demand of product r (in pallets), where $r \in \{1, \dots, N\}$

$BP_i \triangleq$ The distance between bin i to the order picking zone, where $i \in \{1, \dots, S\}$

$I_r \triangleq$ Incoming Inventory of product r , where $r \in \{1, \dots, N\}$

$BI_i \triangleq$ The distance between bin i and the drop off zone, where $i \in \{1, \dots, S\}$

$IN_r \triangleq$ Required Inventory level for product r , where $r \in \{1, \dots, N\}$

$BC_i \triangleq$ The bin capacity of bin i , where $i \in \{1, \dots, S\}$

$k \triangleq$ The cost per meter of the fork lifts

The objective function:

$$\text{Min } z = k \sum_{r=1}^N [(x_{ri}P_rBP_i) + (x_{ri}I_rBI_i)]$$

Subject to:

$$1) \sum_{r=1}^N x_{ri} = 1 \quad i \in \{1, \dots, S\}$$

The first constraint defines that one product must be assigned to a bin.

$$2) \sum_{i=1}^S x_{ri} \geq 1 \quad r \in \{1 \dots N\}$$

The second constraint states that a product must at least be assigned to one bin.

$$3) \sum_{i=1}^S x_{ri}BC_i \geq IN_r \quad r \in \{1, \dots, N\}$$

The third constraint states that the total capacity assigned to a product must be higher than the expected inventory level.

$$4) \sum_{i=47}^{162} x_{ri} = 0 \quad r \in \{1, \dots, 9\}$$

$$5) \sum_{i=47}^{162} x_{ri} = 0 \quad r \in \{41, \dots, 46\}$$

Constraints 4 and 5 states that products 1 to 9 and 41 to 46 can not be assigned to bins 47 to 162.

$$4) \quad x_{ri} = 0 \text{ or } 1$$

The fourth constraint only states that the x variable can only be assigned to a one if product r is assigned to bin i, and 0 if not.

3.6.3 Variable assignments

The products currently available in the warehouse will be assigned as follows:

RB – Returnable Bottle

NRB – Non Returnable Bottle

Product Name	Type
P1: Brutal Fruit Peach 660ml	RB
P2: Brutal Fruit Lemon 660ml	RB
P3: Brutal Fruit Litchi 660ml	RB
P4: Carling Black Label 750ml	RB
P5: Hansa Pilsner 750ml	RB
P6: Castle Milk Stout 750ml	RB
P7: Castle Lager 750ml	RB
P8: Castle Light 660ml	RB
P9: Hansa Marzen Gold 660ml	RB
P10: Carling Black Label 330ml	RB
P 11: Castle Lager 330ml	RB
P 12: Hansa Pilsner 330ml	RB
P 13: Castle Light 340ml	NRB
P 14: Hansa Pilsner 340ml	NRB
P 15: Castle Lager 340ml	NRB
P 16: Carling Black Label 340ml	NRB
P 17: Hansa Marzen Gold 340ml	NRB
P18: Peroni 330ml	NRB
P 19: Carling Black Label 340ml	Can
P20: Castle 340ml	Can
P21: Castle Milk Stout 340ml	Can
P22: Castle Light 340ml	Can
P23: Hansa Pilsner 340ml	Can
P24: Skelters 330ml	NRB
P25: Grolsch 330ml	NRB
P26: Castle Lager 450ml	Can
P27: Castle Milk Stout 440ml	Can
P28: Carling Black Label 440ml	Can
P29: Millers Genuine Draft 330ml	NRB
P30: Pilsner Urquell 330ml	NRB
P31: Sarita 330ml	NRB
P32: Brutal Fruit Lemon 275ml	NRB
P33: Brutal Fruit Mango 275ml	NRB
P34: Brutal Fruit Litchi 275ml	NRB
P35: Brutal Fruit Strawberry 275ml	NRB
P36: Brutal Fruit Peach 275ml	NRB
P37: Redds Dry 340ml	NRB
P38: Redds 340ml	NRB
P39: Castle Milk Stout 340ml	NRB
P40: Dreher 350ml	NRB
P41: Redds 660ml	RB
P42: Redds Dry 660ml	RB
P43: Brutal Fruit Mango 660ml	RB
P44: Millers Genuine Draft 660ml	RB
P45: Brutal Fruit Strawberry 660ml	RB
P46: Brutal Fruit Berry 660ml	RB

The bins will be assigned to the number assigned to a bin within the warehouse. Currently there are 162 bins in the warehouse each with its own allocated space and capacity. The stacking method used in all of the bins is floor stacking. This method, as discussed in the literature study, is a cheap method ideally suited for the beverage industry. The bins are grouped into families that share the same capacity values and are relatively close to each other, these families are outlined in table 1 below:

Table 1: Families of binsError! Bookmark not defined.

Name
1-9
10-20
21-31
32-42
43-46
47-70
71-75
76-101
102-116
117-122
123-132
133-152
153-162

3.6.4 Constant values

Below is a brief description of the calculation of the constant values for the integer program (IP). All values are tabulated in Appendix B.

P_r Demand: The demand of a product is the total amount of pallets distributed to clients in a set time. For this project the past two months of actual demands were used to formulate an average using a weighted average method. The weight factors are supplied in table 2.

Table 2: Weighted Averages

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
0.02	0.05	0.08	0.11	0.13	0.16	0.19	0.26

All values are tabulated in Appendix B1.

BP_i Bin Distance: This distance is the length in meters from the order-picking zone to the specified bin. The distance was measured using a meter wheel, measuring the longest distance and the shortest distance possible. This was done a few times after which an average was found and used for the Bin distance value.

All values are tabulated in Appendix B2.

I_r Incoming Inventory: This is the amount of pallets a product receives from the breweries in a set time.

BI_r Bin Distance: This distance is the length in meters from the off loading zone to the specified bin. The methods specified in the order-picking bin distance was also applied in the off loading zone bin distance constant.

All values are tabulated in Appendix B2.

IN_r Inventory level: This inventory level must be maintained within the warehouse. The standard is a level that may supply seven days based upon a three-month forecast from previous demands with a safety factor of 5%.

All Inventory levels are tabulated in Appendix B3.

BC_i Bin Capacity: The maximum amount of pallets allocated in a bin.

All values are tabulated in Appendix B2.

k Cost: The cost is an estimate of the cost per meter of the forklifts travelling within the warehouse.

3.7 Current layout

To compare and evaluate the new layouts the current layout at the depot must first be examined under the LP conditions to determine its objective value. This was done by evaluating the current layout using Matlab r2007a. The code used for this section is in Appendix C. Table 3 shows where the products are assigned:

Table 3: Current layout product assignment

Product Code	Bins	Product Code	Bins
P1	47,48	P24	102
P2	49,50	P25	103
P3	51,52	P26	101
P4	3,4,14,15,16,26	P27	100
P5	1,2,,9,37,38,17,18,19	P28	99
P6	10,11,12	P29	91,123
P7	5,13	P30	124
P8	6,7,8	P31	125
P9	41	P32	126
P10	21	P33	127
P11	22	P34	128
P12	42	P35	129
P13	161,162	P36	130
P14	159,160	P37	131
P15	158,153	P38	88
P16	156,157	P39	82,87
P17	114,115	P40	86
P18	111	P41	23
P19	92	P42	40
P20	93	P43	32
P21	94	P44	38
P22	95	P45	31
P23	96	P46	32

Below is a sketch depicting the current assignment of products to bins. Note that only primary bins for products are depicted and used in the model and that all reserve bins will be next or near to the primary bin.

Figure 15: Current layout



Note that all layout sketches were subjected to the following rules:

- Background colour:
- Black: Returnable quart pallets
 - White: Non-Returnable bottle pallets
 - Red: Can pallets
 - Green: 440ml can pallets
 - Blue: Returnable bottle pallets

After the current layout was iterated, the current objective value was found:

Objective Value: $1.0916 \times 10^6 \text{m}$

Please note that the objective value is in the form of length and not monetary. The cost per meter constant will be brought into the equation later in the cost analysis section. From this point, attempts will be made to improve the current objective value. Further analysis of the current layout will also be conducted in conjunction with the other solutions in subsequent sections.

3.8 The computer model and test run results

The model was formulated in LINGO 6.0 and Matlab 2007. Both models are shown in Appendix C.

Regarding the Matlab model: To get the optimum solution it was decided that an iteration number of 8000 valid functions would be used. This was determined to be sufficient due to every valid iteration consist of an average of 100 of non-valid iterations, thus a total amount of 80,000 iterations will be formulated in the model. The model would thus have a probability of 1.784×10^{-13} to skip an iteration. We can then say with statistical certainty that the model will iterate all of the possible solutions. After the model was run for the first draft, it was noted that the model was not feasible. The results for the Matlab model are shown in the Results section.

After the computer model were run. The following results were provided.

Figure 16 on the following page shows a plot of the 8000 iterations provided. Statistical values of the results are shown in table 4. All results are shown in Appendix D.

Table 4: Statistical values

Type	Value
Mean	1278197
Std Deviation	263502.1
Min	484020
Range	2323180
Max	2807200

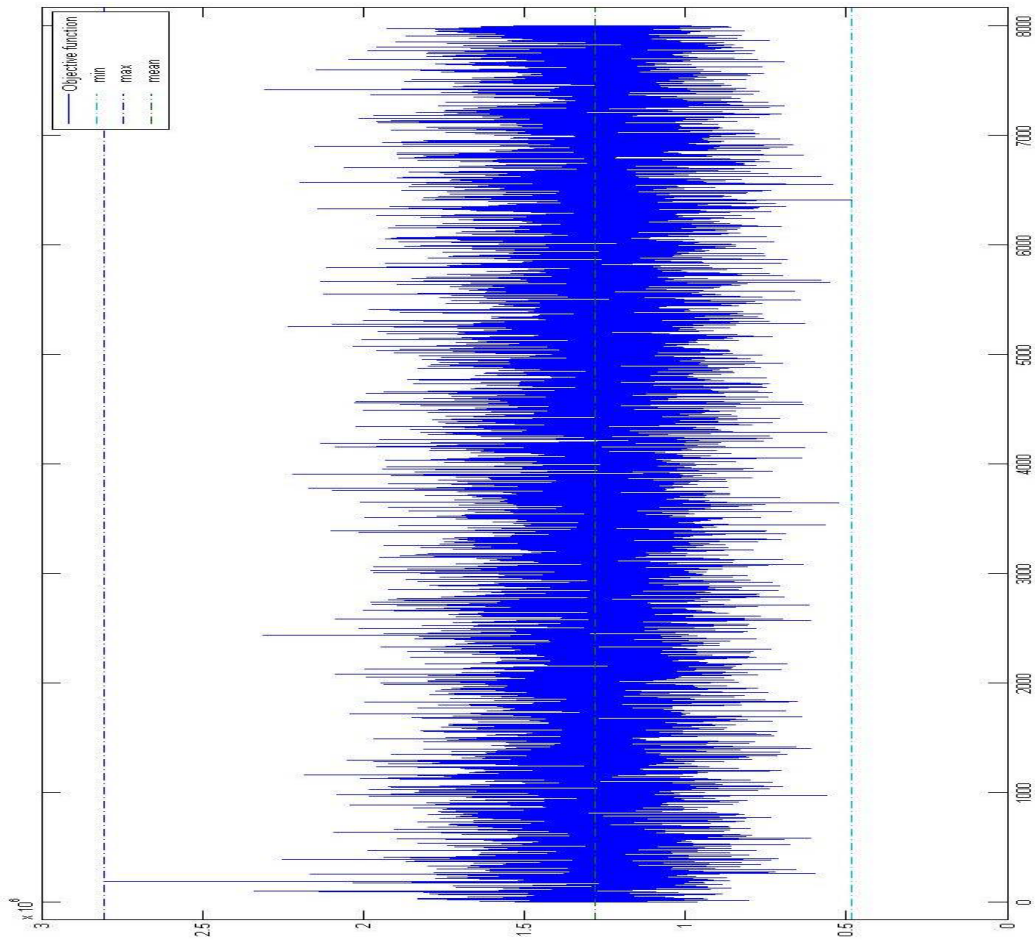
The percentage deviation is 20.61% and the range is 2323180m thus there are a lot of room for improvement but as well as error if the wrong layout would be chosen. From the program used it was found that the minimization problem result is 484020m. The solution matrix is shown in Appendix E. The following x_{ij} values were obtained:

$x_{1,22}, x_{1,66}, x_{1,74}, x_{1,116}, x_{1,150}, x_{1,154}, x_{2,72}, x_{3,21}, x_{3,69}, x_{3,115}, x_{4,143}, x_{6,34}, x_{6,112}, x_{7,57}, x_{7,111}, x_{8,10}, x_{9,79},$
 $x_{9,81}, x_{9,94}, x_{9,152}, x_{10,42}, x_{10,65}, x_{10,118}, x_{10,162}, x_{11,97}, x_{11,105}, x_{11,142}, x_{11,153}, x_{12,35}, x_{12,41}, x_{12,71}, x_{12,75},$
 $x_{12,98}, x_{12,147}, x_{13,132}, x_{14,9}, x_{14,10}, x_{14,155}, x_{16,63}, x_{16,107}, x_{17,38}, x_{17,39}, x_{17,110}, x_{17,136}, x_{18,5}, x_{18,68}, x_{18,84},$

$X_{19,54}, X_{19,64}, X_{19,131}, X_{19,132}, X_{19,144}, X_{20,123}, X_{21,56}, X_{22,4}, X_{22,28}, X_{22,31}, X_{22,86}, X_{22,95}, X_{22,130}, X_{23,7}, X_{23,30},$
 $X_{23,138}, X_{24,3}, X_{24,36}, X_{24,66}, X_{24,67}, X_{24,102}, X_{25,62}, X_{25,108}, X_{25,133}, X_{25,140}, X_{25,151}, X_{26,77}, X_{26,82}, X_{26,158}, X_{27,1}$
 $X_{27,13}, X_{27,15}, X_{27,24}, X_{27,44}, X_{27,76}, X_{27,99}, X_{27,120}, X_{28,2}, X_{28,23}, X_{28,52}, X_{28,53}, X_{28,134}, X_{28,141}, X_{28,149}, X_{29,113},$
 $X_{30,49}, X_{30,78}, X_{30,146}, X_{31,26}, X_{31,47}, X_{31,70}, X_{31,83}, X_{31,85}, X_{32,14}, X_{32,18}, X_{32,55}, X_{32,58}, X_{32,114}, X_{32,159}, X_{33,51},$
 $X_{33,51}, X_{33,128}, X_{34,16}, X_{34,43}, X_{34,96}, X_{34,101}, X_{34,104}, X_{34,121}, X_{35,124}, X_{36,106}, X_{36,117}, X_{36,145}, X_{37,92}, X_{37,100},$
 $X_{37,160}, X_{38,20}, X_{38,73}, X_{38,87}, X_{38,88}, X_{38,122}, X_{39,36}, X_{39,50}, X_{39,126}, X_{39,137}, X_{40,11}, X_{40,19}, X_{40,29}, X_{40,40}, X_{40,60},$
 $X_{40,103}, X_{41,12}, X_{42,6}, X_{42,17}, X_{42,24}, X_{42,45}, X_{43,119}, X_{43,124}, X_{43,127}, X_{44,59}, X_{44,93}, X_{44,156}, X_{44,161}, X_{45,8},$
 $X_{45,27}, X_{46,32}, X_{46,91}, X_{46,139}, X_{46,157} = 1$

From inspection, it is clear that the solution is not feasible as product 5 has no bin assigned to it and a number of products' bin capacities are not enough.

Figure 16: Matlab plot of all iterations performed.



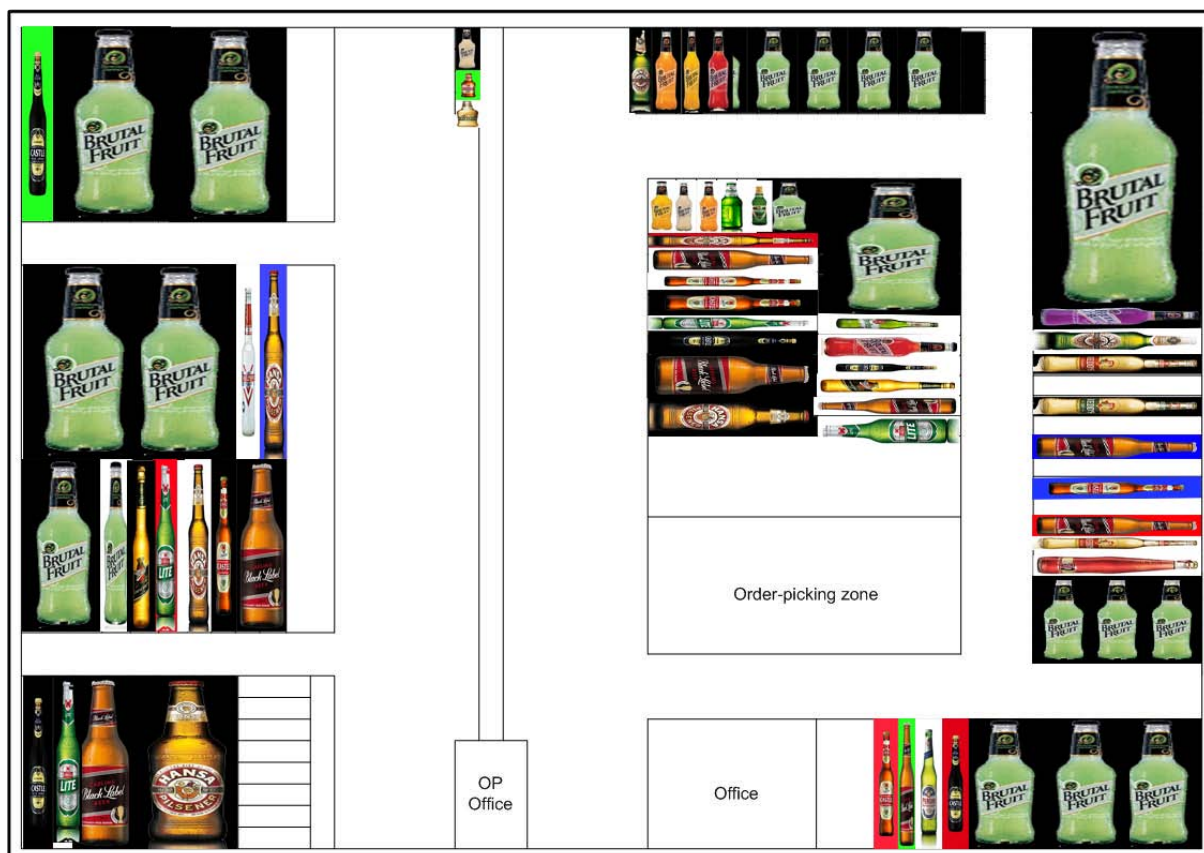
Programming the LP using LINGO was continued and both options were formulated and optimized using LINGO. After the first run with the first option, the following results were formulated.

Objective value: 1040024m

Assignment values are given in Appendix E.

The sketch below depicts the results given by the model.

Figure 17: Sketch of the test run results



Following further inspection it can clearly be observed that something was wrong with the model as product P2, namely the Brutal Fruit Lemon 660ml RB, are assigned to too many bins. This fault was due to constraint number 1 namely:

$$1) \sum_{r=1}^N x_{ri} = 1 \quad i \in \{1, \dots, S\}$$

The first constraint defines that one product must be assigned to a bin.

Because each bin had at least one product LINGO assigned unnecessary bins to products. This problem was rectified by changing constraint 1 to the following:

$$1) \sum_{r=1}^N x_{ri} \leq 1 \quad i \in \{1, \dots, S\}$$

The first constraint defines that at most one product is assigned to a bin.

The rectified LINGO program is shown in Appendix C

The second run gave the results needed to formulate the conclusion. The results are discussed in the following section.

3.9 Results produced by LINGO

The following solutions were formulated after the two models were run in LINGO. All results are tabulated in Appendix F.

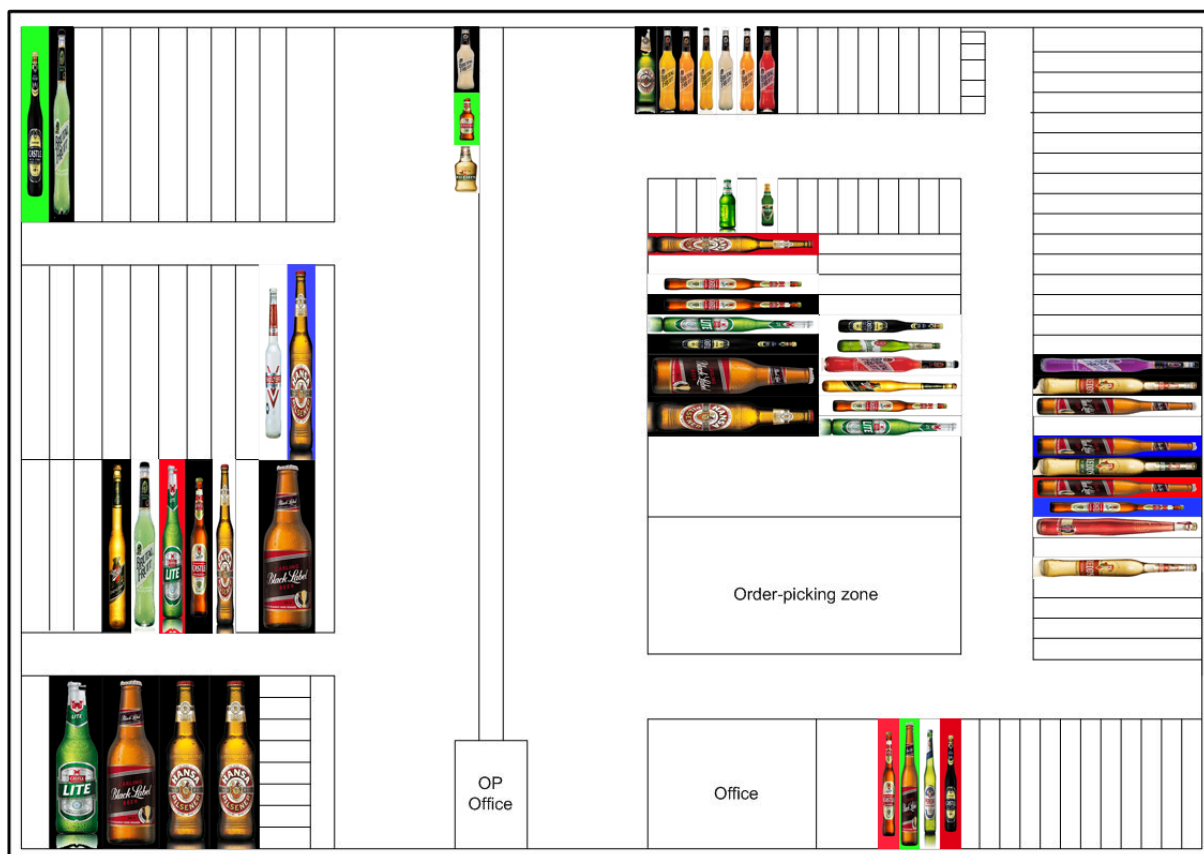
3.9.1 Option 1 results

The LINGO program stopped at iteration 2273. The Global optimal solution calculated was:

Objective Value: 1036147m

This is an improvement from the current layout. Figure 18 below is a sketch of the primary bins allocated in this LP for Option 1 given by LINGO.

Figure 18: Sketch of Option 1 product assignment



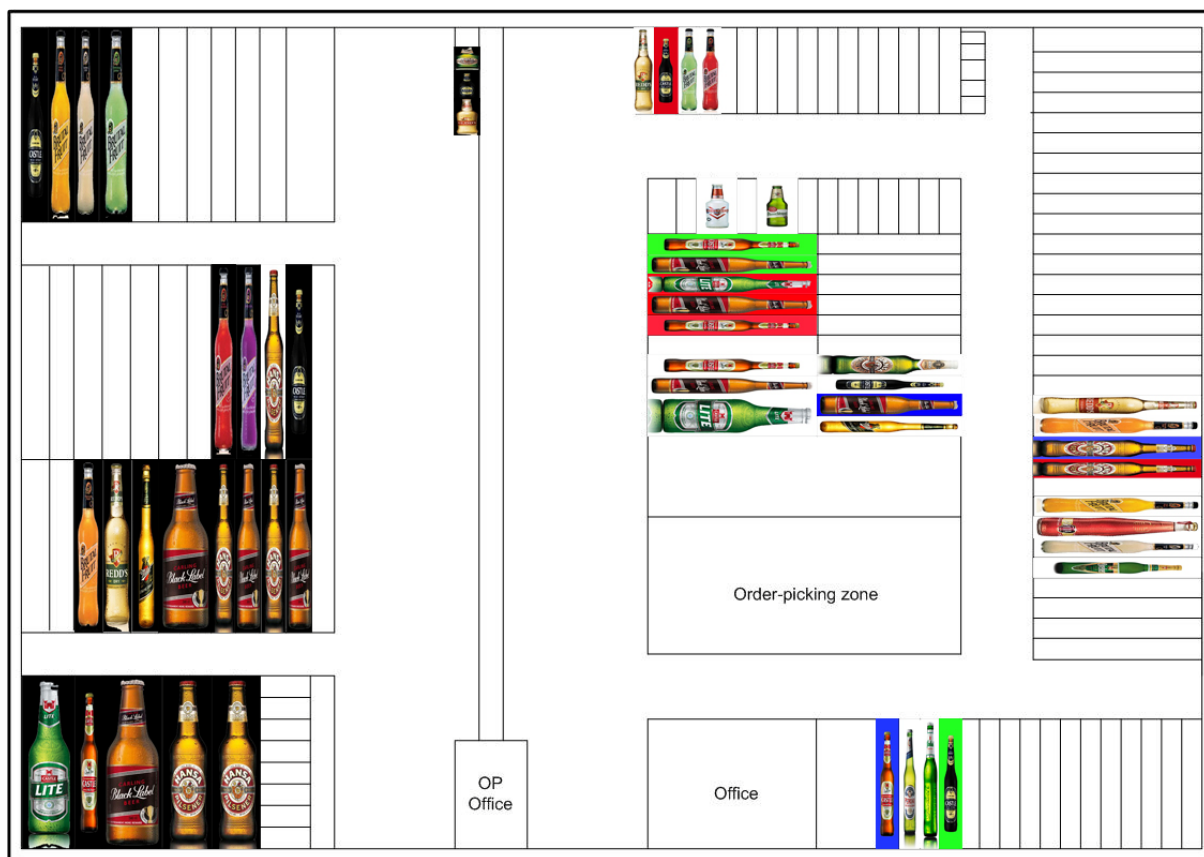
3.9.2 Option 2 results

The program did not stop to produce a global minimum. The local minimum found was:

Objective Value: 1142236m

The objective value is a lot more than option one's value. Even though option two's objective value is less, its product grouping is better than the one in option one. In the following sections, the current solution and the new two options are analyzed. After this a hybrid between the current solution and the two new solutions will be developed and the conclusion will be provided.

Figure 19: Sketch of Option 2 product assignment



3.10 Space Utilization

In this section, the space utilization of the layouts will be examined. A high percentage of unutilized space indicates poor assignment of bins to products. It will mean that bins will not be fully utilized, thus putting the depot at risk of running out of space quickly. The space utilization analysis will also indicate how close a product is from being full. Table 5 shows the utilization of the current three layouts. The values were derived from Appendix G.

Table 5: Weekly space utilization

Product	Current Unused	Option 1 Unused	Option 2 Unused
P1	0.974289352	0.948578704	0.98638848
P2	0.994597222	0.996960938	0.998263393
P3	0.979863426	0.954692708	0.99352753
P4	0.02253461	0.006510587	0.02253461
P5	0.088843618	0.00025897	0.013954053
P6	0.287142565	0.226473848	0.218156362
P7	0.440482407	0.237021465	0.100775298
P8	0.347654018	0.021481027	0.021481027
P9	0.970537946	0.816680556	0.816680556
P10	0.848610437	0.837571615	0.837571615
P11	0.861822816	0.851747396	0.762795833
P12	0.960459821	0.930804688	0.930804688
P13	0.181583333	0.127022222	0.181583333
P14	0.474670735	0.011144914	0.011144914
P15	0.632958008	0.265916016	0.265916016
P16	0.448493652	0.448493652	0.448493652
P17	0.962644792	0.95330599	0.95330599
P18	0.905144241	0.905144241	0.905144241
P19	0.720110286	0.552176458	0.720110286
P20	0.591539974	0.346463958	0.591539974
P21	0.98423724	0.974779583	0.94395463
P22	0.722870182	0.739171936	0.722870182
P23	0.845665495	0.845665495	0.845665495
P24	0.978893632	0.98758449	0.98680852
P25	0.967610228	0.78406819	0.979756393
P26	0.940130859	0.760523438	0.940130859
P27	0.958934245	0.958934245	0.934294792
P28	0.850848958	0.761358333	0.850848958
P29	0.683753581	0.683753581	0.683753581
P30	0.994577962	0.994577962	0.942164931
P31	0.950522624	0.950522624	0.950522624
P32	0.973922038	0.975456036	0.973922038
P33	0.92554069	0.92554069	0.92554069
P34	0.965259766	0.965259766	0.965259766
P35	0.956869792	0.956869792	0.956869792
P36	0.955297526	0.955297526	0.955297526
P37	0.95986849	0.839473958	0.857310185
P38	0.967620443	0.967620443	0.967620443
P39	0.872210807	0.872210807	0.872210807
P40	0.993982901	0.935817606	0.993982901
P41	0.919400735	0.914363281	0.695513889
P42	0.730286201	0.528000851	0.555765507
P43	0.979311567	0.871271973	0.965924934
P44	0.958997407	0.932466317	0.932466317
P45	0.998263315	0.989193957	0.997139577
P46	0.993527238	0.988672666	0.98933898
Average	0.798312765	0.728193598	0.742719699

From Table 5 it can clearly be seen that option 1 is the better candidate with unused space of 72.82% this may seem high as an average but upon closer inspection, this value can be justified:

The high volume products space utilization is 80%. These products contribute approximately 70% of all orders fulfilled. The remaining unutilized 20% is used as safety stock for unforeseen demand rises.

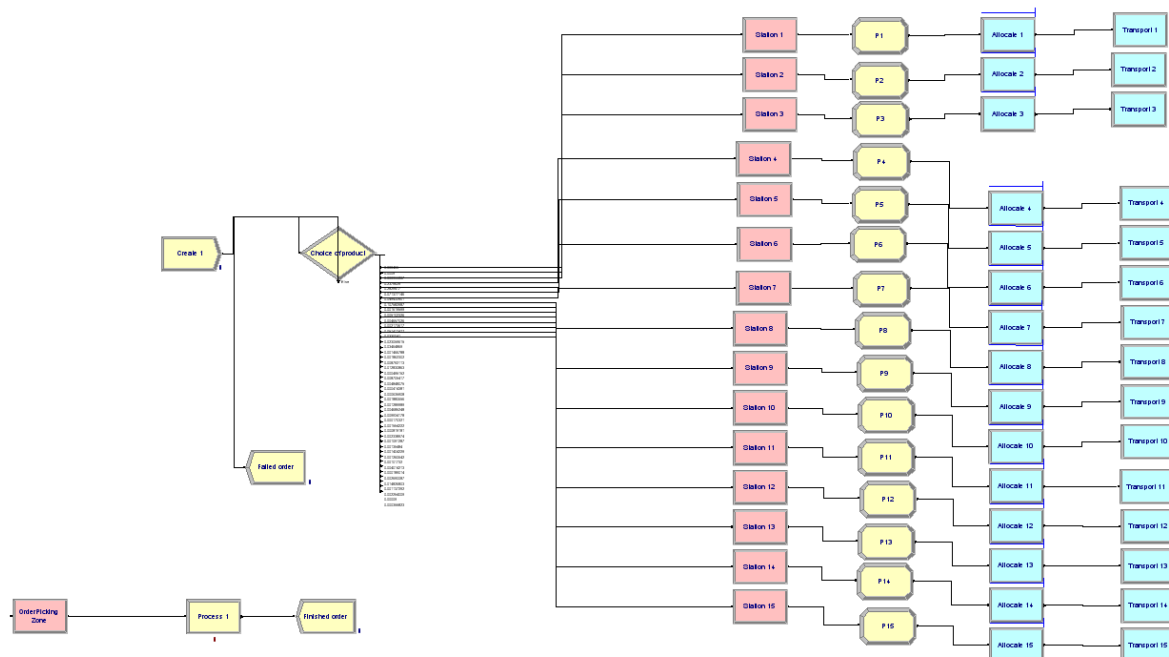
It is advantages for slow moving products to have more than a one-week cycle time as this means that these products will not have to be ordered every time an order is issued. A requisite for this is to keep enough space for a once off large order. It is the case in all three solutions. Thus, there is enough space to implement a four-week cycle for slow moving products.

However, some bins are above the 90% not utilized mark this may indicate that smaller bins should be issued for these products. Splitting certain bins in the warehouse could prove useful regarding this problem as the current smaller bins are too far for some products. An example of this is a medium pace product may fit into a bin from the 140 bin range but it will be too far from the order-picking zone and the off-loading zone. Therefore, it will have a negative effect on the total transportation length.

3.11 Maximum Output: ARENA Simulation

All simulations were done in ARENA 11.0. The objective of this simulation is to determine the order process capability of each option. In this simulation, orders were deliberately made more than the system can handle to determine the maximum capacity of the three options. Thus, a hypothetical simulation was developed between the three options and not a real life simulation depicting the actual flow of products. Figure 20 is a image of the simulation, due practicality only a portion of the system is illustrated (there are 46 product stations in total).

Figure 20: ARENA simulation model



The model was developed under the following conditions:

- Orders arrive in batches of 10 every second.
- The orders then go into a decision process that is determined by the probability that a product will be ordered. This is done by finding the percentage contribution each product has on the total of the demand. The results are tabulated in table 7.
- Following this each order will go to its assigned product station, with each station representing a product.
- The order is then allocated to a forklift. If all the forklifts are in use, the order has to wait until a forklift becomes available.

- The order will then be transported to the order-picking station. The distance between each station and the op station are determined by the distance between the op zone and the allocated bin of the product. In the case where there are multiple bins for a product the average between the bins are calculated with the belief that each bin has an equal probability that the forklift operator will select it. The speed at which the forklift moves is 0.5m per second. When the orders arrive at the op station it goes into a delay process of triangular distribution of 0.5,1 and 1.5 after this it is disposed from the system.

The simulation was run for 10 replications each of four hours length.

Table 6: Decision Probabilities

Product Code	Probaility	Product Code	Probability
P1	0.000454299	P24	0.000414381
P2	9.54654E-05	P25	0.000635908
P3	0.000355807	P26	0.001880656
P4	0.237962965	P27	0.001289989
P5	0.282641748	P28	0.004685249
P6	0.071377139	P29	0.009934178
P7	0.049432518	P30	0.000170321
P8	0.107582999	P31	0.001554222
P9	0.001619599	P32	0.000819181
P10	0.005102328	P33	0.002338973
P11	0.004657024	P34	0.001091287
P12	0.002173617	P35	0.001354839
P13	0.051417467	P36	0.001404229
P14	0.033004101	P37	0.001260642
P15	0.023059615	P38	0.001017132
P16	0.034648699	P39	0.004014212
P17	0.001466789	P40	0.000189014
P18	0.001862302	P41	0.002690087
P19	0.008792114	P42	0.014826804
P20	0.012830864	P43	0.001137292
P21	0.000495152	P44	0.002254009
P22	0.008705416	P45	9.54697E-05
P23	0.004848074	P46	0.000355823

The table below shows the results given after the simulations were completed.

Table 7: Results from the ARENA simulation

Solution	Number of finished orders
Current	2.8748E+05
Option One	2.8175E+05
Option Two	2.8507E+05

Option one proved to be the best option when examining the system capability. It had a 2% improvement from the current layout while option 2 had a 0.8% improvement. This means that if Option one was chosen the distribution centres maximum output could improve by 2%. This may seem minuscule but when looking at the volumes the warehouse does this will account to a substantial amount.

In the next section, a new layout and product assignment for the Watloo Depot is proposed. From the results of both analyses, it is evident that emphasis must be placed on Option one's solution. As it will not be economically viable as well as a logistically challenging to change the warehouse completely to Option one only some elements will be changed in the current solution as to utilize Option one's advantages without disturbing the warehouses' flow completely.

3.12 The development of a new layout.

During the operations research and results analysis, the following observations were made:

- Assigning some bins of the 150s range for high volume returnable bottles will bring the transportation length down.
- Splitting some bins will improve the space utilization.
- Any effort to minimize the distance between a bin's entrance and the order-picking zone will improve the maximum output of the depot.

During the time spent at the warehouse, another problem was observed. The warehouse is currently short of space for the sorting of empty returnable bottle pallets. This sorting process entails the organization of bottles into the correct crates and creating returnable pallets to send to the manufacturing plants.

After all these factors were examined, the new proposed layout as illustrated in figure 21 was developed. The following changes were made to the design of the layout:

Bins 1-7 were rotated so that their entrances face the truck avenue. By doing this the distance were lowered as follows:

B1:	42.05	- 36.2	B4	51.55	- 42
B2:	45.4	- 38	B5	55.15	- 45.5
B3	48.35	- 40.85	B6	58.4	- 46
B7	61.65	- 47			

The rotation also gives an extra three bins to be used later.

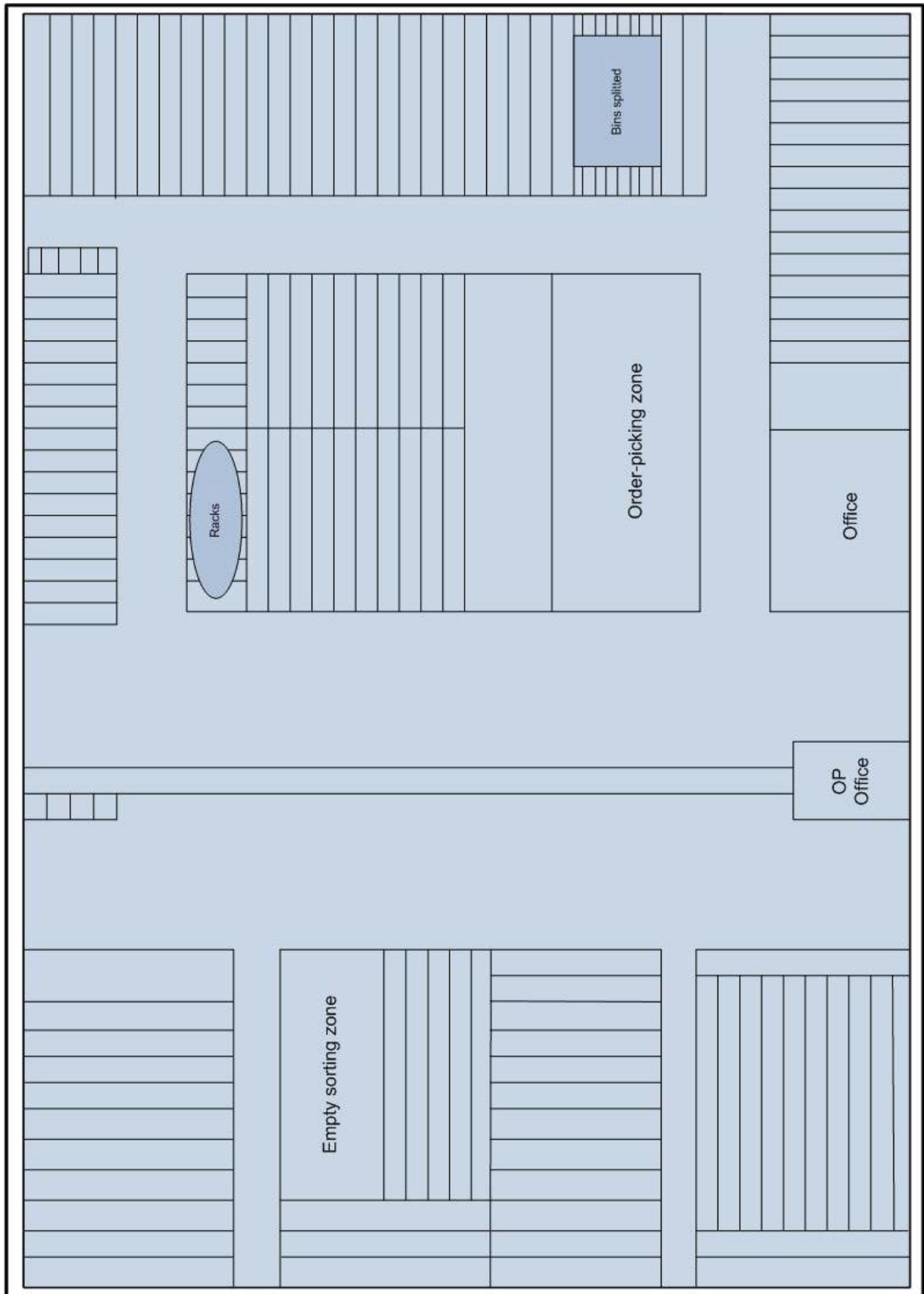
Bins 21 – 25 were also rotated and bins 26 – 28 were moved to the extra three bins created in the first move. The differences in distances are as follows:

B21: 65	- 60	B25: 78	- 64
B22: 68.25	- 61	B26: 81.25	- 49.5
B23: 71.5	- 62	B27: 84.5	- 52.5
B24: 74.75	- 63	B28: 87.75	- 55.45

By doing two moves an open space was created so that the depot can utilise this for sorting the empties (see figure 15 for reference).

Rack storage for bins 143 – 152 is also proposed for creating small bins for very slow moving products. Also splitting bins 95 – 99 to create smaller bins that are near the order-picking zone.

Figure 21: Proposed new layout



Products were then allocated to bins keeping product families relatively together. Table 8 shows the products and their allocated bins.

Table 8: Proposed layout product assignment

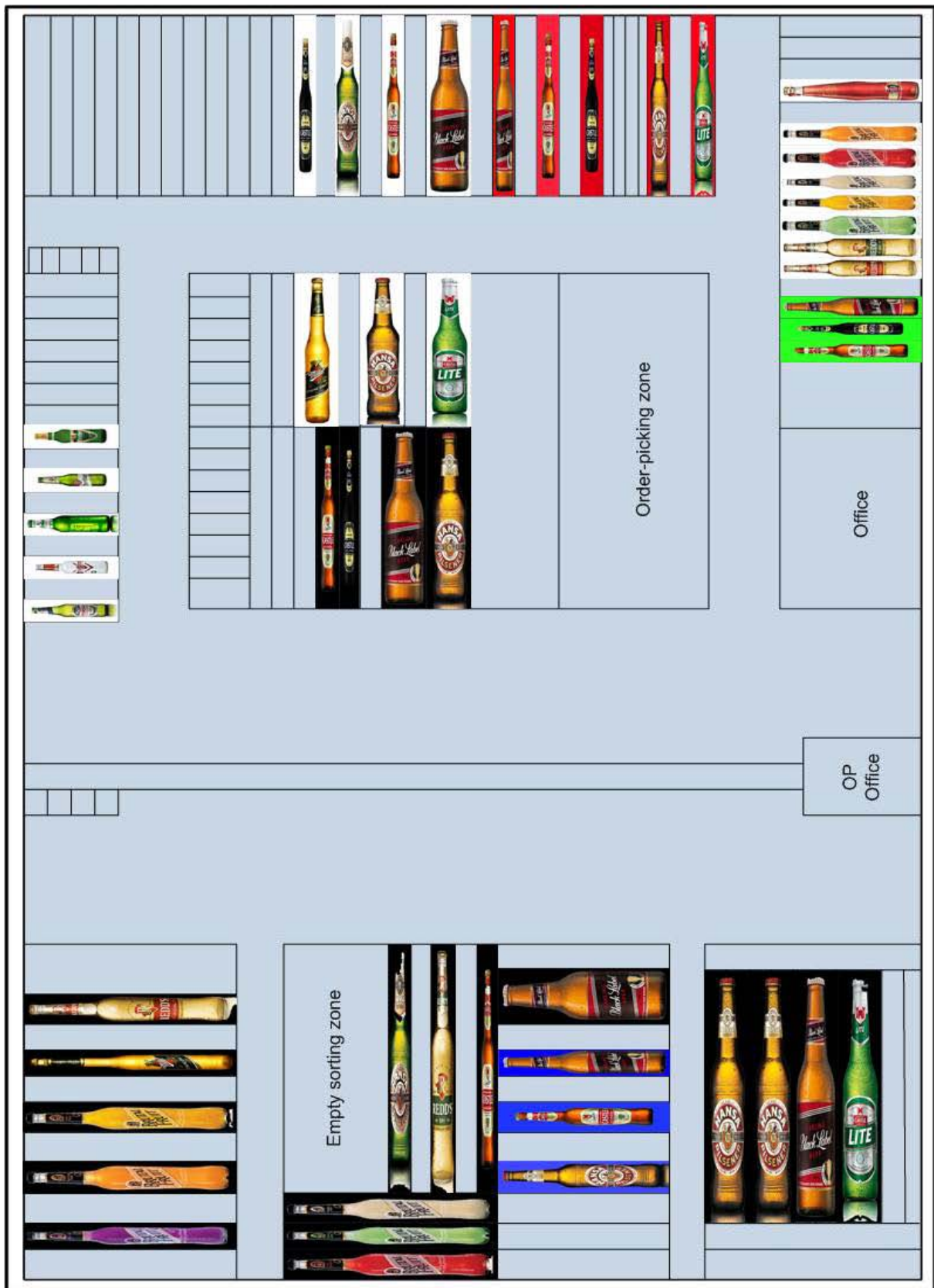
Product Code	Bins	Product Code	Bins
P1	39	P24	48
P2	38	P25	49
P3	35	P26	115
P4	5,6,19,20,159,160	P27	114
P5	1,2,3,4,161,162	P28	116
P6	157	P29	127
P7	21,156	P30	50
P8	7,8	P31	112
P9	25	P32	107
P10	18	P33	113
P11	17	P34	106
P12	16	P35	111
P13	123,124	P36	109
P14	125,126	P37	110
P15	89,90	P38	108
P16	91,92	P39	87
P17	88	P40	51
P18	47	P41	42
P19	100	P42	23
P20	101	P43	40
P21	94	P44	41
P22	95	P45	36
P23	96	P46	37

The objective value was calculated using Matlab and the results for the new proposed value is:

Objective Value = 9.4163E+005

This is an improvement of 149970m per week of transportation length. The total amount of saving per annum to be calculated in the following section namely the cost analysis study. Figure 22 is a sketch depicting the above table.

Figure 22: Schematic sketch of the proposed product assignments



3.13 Cost analysis study

To determine the cost per meter travelled by the forklifts calculations were done using current Key Performance Indicators (KPI) from the warehouse. During three months the following KPI's were observed

Table 9: KPI's for three months

KPI	Month 1	Month 2	Month 3
Fuel (Diesel) L	8084	9350	8235
Fuel (Gas) L	1283	1911	2519
Total	9367	11261	10754

During a one month cycle the current system has a total transportation length of:

$$(1.0916 \times 10^6) \times 4 = 4.3664810^6 \text{m}$$

Thus meters per litre are:

Month 1 = 466.15m

Month 2 = 387.75m

Month 3 = 406.03m

Average = 419.9m

Thus, the total amount of litres the warehouse will save is 357.15L per week. Fuel price will be taken at an average of 740c for the following year. The total savings in rands will be:

R2 642.91 per week

R11 496.66 per month

This will reduce actual costs by 2.3%

Other indirect costs such as improved delivery time of products to the order-picking zone will also have a positive effect on the overheads of the warehouse

By making these small changes within the warehouse to implement the new layout the warehouse can reduce overhead costs incurred in their operations.

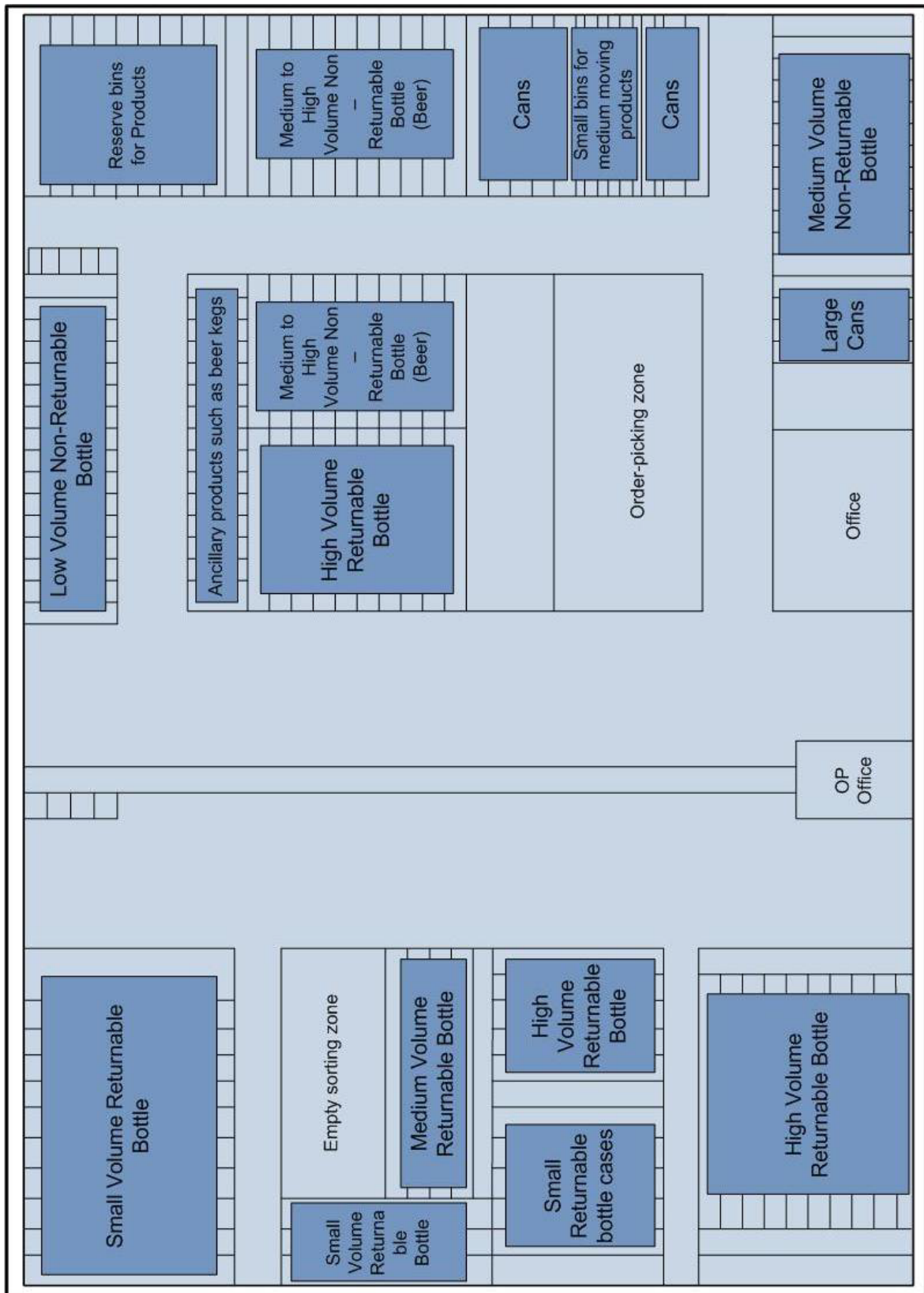
3.14 Final Layout methodology

Below is a set of rules that the warehouse should adhere to in order to keep the warehouse optimal. These rules will ensure that the warehouse, under accepting conditions, will always resemble the proposed layout with acceptable deviations. This methodology will act as a framework for future restructuring. These rules are:

- High Volume Returnable Bottles should be stored in Bins 1-9; 16-20; the new 26-28 and 153-162
- Medium Volume Returnable Bottles should be kept in Bins 21 – 25 and then from 42 down to 32 if there aren't any space left in the afore mentioned.
- Small Returnable Bottles such as the Castle 330ml returnable bottles are reserved in Bins 10-15.
- The remainder namely the Small Returnable Bottles to be kept in Bins 29 to 42.
- Low Volume Non-Returnable Bottles to be kept in Bins 47 to 70.
- Medium Volume Non-Returnable Bottles that are beer are reserved in Bins 82-92 and 123 to 132
- Cans to be stored in Bins 93-95 and 99-102
- Large Cans namely the 440ml cans to be kept in Bins 116-111
- Medium Volume Non-Returnable Bottles under which the Brutal Fruit range falls to be stored in bins 103-110
- There are bins available for other products and these are the new split bins 96 to 98 and the ancillary bins that are used for special products such as promotional packaging(cooler box packaging) or kegs

Figure 23 depicts these set of rules on the next page.

Figure 23: Warehouse methodology



4. Conclusion

During this project, the aim was to improve the Watloo Depot. The literature study examined different areas of opportunity to improve the warehouse. These ranged from the development or acquisition of new material handling systems to the restructuring of the whole warehouse. Following the literature study, it was decided to improve the warehouse by optimizing the position of the products.

A linear program that will optimize the layout was formulated. A derivation of the LP was also developed to test some rules within the current warehouse layout. This proved to be useful as it confirmed that the current rules within the warehouse should be amended. Analysis was done on the two solutions and the current layout and Option one proved the best candidate. A new layout plan was developed that utilized minor changes that will invoke minimal hassle to implement. A storage methodology was also developed for the warehouse. This set of rules could be used as a reference for future layout restructuring and planning.

In this project, the maximum order capacity of the warehouse was improved by 2% and this in turn lowered overhead costs by 2.3%. Although this change may seem minimal, when examining the amount of input the depot would have to do to achieve this advantage it is definitely viable to implement the new system.

The objectives for this project were met as the operations of the warehouse were improved while lowering the costs involved. The end deliverables are an improved Watloo depot layout and an optimization program that will notify users when products need to be shifted due to demand changes over time. A storage methodology for the current state of the warehouse was formulated. This may be used as reference as to where new products must be stored.

In conclusion it is stated that the study within facility design can be done utilizing Industrial Engineering tools and techniques and that this can in turn have a positive impact on warehouses throughout the world to better serve their respectable supply chains.

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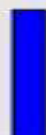
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Appendix A: Gant Chart

ID	Task Name	Start	Finish	Duration	May 2010			Jun 2010			Jul 2010			Aug 2010			Sep 2010			Oct 2010										
					25	95	165	235	305	66	136	206	276	47	117	187	257	18	88	158	228	298	59	129	199	269	339	1010	1710	
1	1. Define system objectives	2010/05/03	2010/05/28	4w																										
2	2. Define order-picking requirements	2010/05/28	2010/07/01	5w																										
3	3. Define Storage requirements	2010/06/15	2010/07/12	4w																										
4	4. Relationships between storage bins and order-picking	2010/07/05	2010/07/30	4w																										
5	5. Define other departmental requirements and it's relationships	2010/07/14	2010/07/20	1w																										
6	6. Develop new relationship policy	2010/06/21	2010/08/20	9w																										
7	7. Put all proposals under performance evaluation	2010/08/16	2010/08/27	2w																										
8	8. Reevaluate and determine best proposal	2010/08/30	2010/09/03	1w																										
9	9. Prepare existing facility for implementation	2010/11/01	2010/11/01	0w	Falls outside the scope of this project																									
10	10. Implement new facility layout	2010/11/01	2010/11/01	0w	Falls outside the scope of this project																									
11	11. Maintenance and continuous improvement of the facility	2010/11/01	2010/11/01	0w	Falls outside the scope of this project																									

Appendix B: Constant values

Table B1: P_r Demand Values

Code	Product Name	Demand
P1	Brutal Fruit Peach 660R BF	1.322262
P2	Brutal Fruit Lemon 660R BF	0.277857
P3	Brutal Fruit Litchi 660R BF	1.035595
P4	Carling Black Label 750 Ret	692.604
P5	Hansa Pilsener 750 Ret	822.644
P6	Castle Milk Stout 750 Ret	207.747
P7	Castle Lager 750 Ret	143.876
P8	Castle Lite 660R CasLite	313.1261
P9	Hansa Marzen Gold 750R Green	4.713929
P10	Carling Black Label 330 Ret	14.8506
P11	Castle Lager 330 Ret	13.55452
P12	Hansa Pilsener 330 Ret	6.326429
P13	Castle Lite 340 Nrb	149.6533
P14	Hansa Pilsener 340 Nrb	96.06021
P15	Castle Lager 340 Nrb	67.11625
P16	Carling Black Label 340 Nrb	100.8469
P17	Hansa Marzen Gold 340 Nrb	4.269167
P18	Peroni 330 Nrb	5.420329
P19	Carling Black Label 330 Can	25.58992
P20	Castle Lager 330 Can	37.34492
P21	Castle Milk Stout 330 Can	1.441167
P22	Castle Lite 330 Can	25.33758
P23	Hansa Pilsener 330 Can	14.11058
P24	Skelters 330 Nrb	1.206078
P25	Grolsch 330 Nrb	1.850844
P26	Castle Lager 440 Can	5.47375
P27	Castle Milk Stout 440 Can	3.754583
P28	Carling Black Label 440 Can	13.63667
P29	Miller Genuine Draft 330 Nrb	28.91396
P30	Pilsner Urquell 330 Nrb	0.495729
P31	Sarita Ruby Dry 330N SAR	4.523646
P32	Brutal Fruit Lemon 275 NRB	2.384271
P33	Brutal Fruit Mango 275 NRB	6.807708
P34	Brutal Fruit Litchi 275 NRB	3.17625
P35	Brutal Fruit Strawberry 275 NRB	3.943333
P36	Brutal Fruit Peach 275 NRB	4.087083
P37	Redds Dry 340 Nrb	3.669167
P38	Redds Premium 340 Nrb	2.960417
P39	Castle Milk Stout 340 Nrb	11.68358
P40	Dreher 340 NRB	0.550135
P41	Redds Premium 660 Ret	7.829643
P42	Redds Dry 660 Ret	43.15421
P43	Brutal Fruit Mango 660R BF	3.310149
P44	Miller Genuine Draft 660R MGD	6.560415
P45	Brutal Fruit Lemon 660R BF	0.27787
P46	Brutal Fruit Litchi 660R BF	1.035642

Table B2: BP_i , BI_i , BC_i Bin Distance Order-picking, Bin distance OLZ, Bin Capacity.

	Bin Distances OP			Bin Distances Off-Load			Bin Capacity
Name	Long	Middel	Short	Long	Middel	Short	
A1	64.7	55.45	46.2	67.7	58.45	49.2	30
A2	62.13	53.365	44.6	65.13	56.365	47.6	30
A3	59.56	51.28	43	62.56	54.28	46	30
A4	56.99	49.195	41.4	59.99	52.195	44.4	30
A5	54.42	47.11	39.8	57.42	50.11	42.8	30
A6	51.85	45.025	38.2	54.85	48.025	41.2	30
A7	49.28	42.94	36.6	52.28	45.94	39.6	30
A8	46.71	40.855	35	49.71	43.855	38	30
A9	44.14	39.07	34	47.14	42.07	37	30
A10	40	36.7	33.4	43	39.7	36.4	30
1	43.9	42.05	40.2	46.9	45.05	43.2	168
2	46.8	45.4	44	49.8	48.4	47	168
3	49.7	48.35	47	52.7	51.35	50	168
4	52.6	51.55	50.5	55.6	54.55	53.5	168
5	55.5	55.15	54.8	58.5	58.15	57.8	168
6	58.4	58.4	58.4	61.4	61.4	61.4	168
7	61.3	61.65	62	64.3	64.65	65	168
8	67.1	66.25	65.4	70.1	69.25	68.4	168
9	70	69.5	69	73	72.5	72	168
10	69	68	67	72	71	70	102
11	65.8	64.75	63.7	68.8	67.75	66.7	102
12	62.6	61.5	60.4	65.6	64.5	63.4	102
13	59.4	58.25	57.1	62.4	61.25	60.1	102
14	56.2	55	53.8	59.2	58	56.8	102
15	53	51.75	50.5	56	54.75	53.5	102
16	49.8	48.5	47.2	52.8	51.5	50.2	102
17	46.6	45.25	43.9	49.6	48.25	46.9	102
18	43.4	42	40.6	46.4	45	43.6	102
19	40.2	38.75	37.3	43.2	41.75	40.3	102
20	37	35.5	34	40	38.5	37	102
21	76	65	54	54	43	32	102
22	79.3	68.25	57.2	57.3	46.25	35.2	102
23	82.6	71.5	60.4	60.6	49.5	38.4	102
24	85.9	74.75	63.6	63.9	52.75	41.6	102
25	89.2	78	66.8	67.2	56	44.8	102
26	92.5	81.25	70	70.5	59.25	48	102
27	95.8	84.5	73.2	73.8	62.5	51.2	102
28	99.1	87.75	76.4	77.1	65.75	54.4	102
29	102.4	91	79.6	80.4	69	57.6	102
30	105.7	94.25	82.8	83.7	72.25	60.8	102
31	109	97.5	86	87	75.5	64	102
32	77	66.5	56	55	44.5	34	96
33	80.3	69.7	59.1	58.3	47.7	37.1	96
34	83.6	72.9	62.2	61.6	50.9	40.2	96
35	86.9	76.1	65.3	64.9	54.1	43.3	96

	Bin Distances OP			Bin Distances Off-Load			Bin Capacity
Name	Long	Middel	Short	Long	Middel	Short	
36	90.2	79.3	68.4	68.2	57.3	46.4	96
37	93.5	82.5	71.5	71.5	60.5	49.5	96
38	96.8	85.7	74.6	74.8	63.7	52.6	96
39	100.1	88.9	77.7	78.1	66.9	55.7	96
40	103.4	92.1	80.8	81.4	70.1	58.8	96
41	106.7	95.3	83.9	84.7	73.3	61.9	96
42	110	98.5	87	88	76.5	65	96
43	89	77.85	66.7	67	55.85	44.7	24
44	86.8	69	51.2	64.8	47	29.2	24
45	84.6	65.15	45.7	62.6	43.15	23.7	24
46	82.4	66.7	51	60.4	44.7	29	24
47	60.4	55.85	51.3	57.4	52.85	48.3	27
48	61.9	57.25	52.6	58.9	54.25	49.6	27
49	63.4	58.65	53.9	60.4	55.65	50.9	27
50	64.9	60.05	55.2	61.9	57.05	52.2	27
51	66.4	61.45	56.5	63.4	58.45	53.5	27
52	67.9	62.85	57.8	64.9	59.85	54.8	27
53	69.4	64.25	59.1	66.4	61.25	56.1	27
54	70.9	65.65	60.4	67.9	62.65	57.4	27
55	72.4	67.05	61.7	69.4	64.05	58.7	27
56	73.9	68.45	63	70.9	65.45	60	27
57	75.4	69.85	64.3	72.4	66.85	61.3	27
58	76.9	71.1	65.3	73.9	68.1	62.3	27
59	78.4	72.65	66.9	75.4	69.65	63.9	27
60	79.9	74.05	68.2	76.9	71.05	65.2	27
61	81.4	75.45	69.5	78.4	72.45	66.5	27
62	82.9	76.85	70.8	79.9	73.85	67.8	27
63	84.4	78.25	72.1	81.4	75.25	69.1	27
64	85.9	79.65	73.4	82.9	76.65	70.4	27
65	87.4	81.05	74.7	84.4	78.05	71.7	27
66	88.9	82.45	76	85.9	79.45	73	27
67	90.4	83.85	77.3	87.4	80.85	74.3	27
68	91.9	85.25	78.6	88.9	82.25	75.6	27
69	92.5	86.2	79.9	89.5	83.2	76.9	27
70	93.2	87.2	81.2	90.2	84.2	78.2	27
71	94	88.5	83	91	85.5	80	9
72	96	89.7	83.4	93	86.7	80.4	9
73	98	90.9	83.8	95	87.9	80.8	9
74	100	92.1	84.2	97	89.1	81.2	9
75	102.2	93.6	85	99.2	90.6	82	9
76	100	91.5	83	97	88.5	80	96
77	97.3	89	80.7	94.3	86	77.7	96
78	94.6	86.5	78.4	91.6	83.5	75.4	96
79	91.9	84	76.1	88.9	81	73.1	96
80	89.2	81.5	73.8	86.2	78.5	70.8	96
81	86.5	79	71.5	83.5	76	68.5	96

	Bin Distances OP			Bin Distances Off-Load			Bin Capacity
Name	Long	Middel	Short	Long	Middel	Short	
82	83.8	76.5	69.2	80.8	73.5	66.2	96
83	81.1	74	66.9	78.1	71	63.9	96
84	78.4	71.5	64.6	75.4	68.5	61.6	96
85	75.7	69	62.3	72.7	66	59.3	96
86	73	66.5	60	70	63.5	57	96
87	70.3	64	57.7	67.3	61	54.7	96
88	67.6	61.5	55.4	64.6	58.5	52.4	96
89	64.9	59	53.1	61.9	56	50.1	96
90	62.2	56.5	50.8	59.2	53.5	47.8	96
91	59.5	54	48.5	56.5	51	45.5	96
92	56.8	51.5	46.2	53.8	48.5	43.2	96
93	53.8	48.75	43.7	50.8	45.75	40.7	96
94	56.7	51.3	45.9	53.7	48.3	42.9	96
95	59.6	53.85	48.1	56.6	50.85	45.1	96
96	62.6	56.45	50.3	59.6	53.45	47.3	96
97	63.1	57.4	51.7	60.1	54.4	48.7	96
98	63.6	58.3	53	94.6	89.3	84	96
99	64.1	59.2	54.3	95.1	90.2	85.3	96
100	64.6	60.1	55.6	95.6	91.1	86.6	96
101	65.1	61.05	57	96.1	92.05	88	96
102	76.4	72.7	69	107.4	103.7	100	60
103	73.5	69.85	66.2	104.5	100.85	97.2	60
104	70.6	67	63.4	101.6	98	94.4	60
105	67.7	64.15	60.6	98.7	95.15	91.6	60
106	64.8	61.3	57.8	95.8	92.3	88.8	60
107	61.9	58.45	55	92.9	89.45	86	60
108	59	55.6	52.2	90	86.6	83.2	60
109	56.1	52.75	49.4	87.1	83.75	80.4	60
110	53.2	49.95	46.7	84.2	80.95	77.7	60
111	50.3	47.15	44	81.3	78.15	75	60
112	47.4	44.35	41.3	78.4	75.35	72.3	60
113	44.5	41.55	38.6	75.5	72.55	69.6	60
114	41.6	38.75	35.9	72.6	69.75	66.9	60
115	38.7	35.95	33.2	69.7	66.95	64.2	60
116	35.8	33.15	30.5	66.8	64.15	61.5	60
117	These are used for breakage storage						
118							
119							
120							
121							
122							
123	48	45	42	45	42	39	84
124	51	47.95	44.9	48	44.95	41.9	84
125	54	50.9	47.8	51	47.9	44.8	84
126	57	53.85	50.7	54	50.85	47.7	84
127	60	56.8	53.6	57	53.8	50.6	84

	Bin Distances OP			Bin Distances Off-Load			Bin Capacity
Name	Long	Middel	Short	Long	Middel	Short	
128	63	59.8	56.6	60	56.8	53.6	84
129	65.9	62.65	59.4	62.9	59.65	56.4	84
130	68.8	65.55	62.3	65.8	62.55	59.3	84
131	71.7	68.45	65.2	68.7	65.45	62.2	84
132	74.7	71.55	68.4	71.7	68.55	65.4	84
133	88.5	83.75	79	85.5	80.75	76	9
134	84	80.75	77.5	81	77.75	74.5	9
135	82.5	79.25	76	79.5	76.25	73	9
136	81	77.75	74.5	78	74.75	71.5	9
137	79.5	76.25	73	76.5	73.25	70	9
138	78	74.75	71.5	75	71.75	68.5	9
139	76.5	73.25	70	73.5	70.25	67	9
140	75	71.75	68.5	72	68.75	65.5	9
141	73.5	70.25	67	70.5	67.25	64	9
142	72	68.75	65.5	69	65.75	62.5	9
143	70.5	67.25	64	67.5	64.25	61	9
144	69	65.75	62.5	66	62.75	59.5	9
145	67.5	64.25	61	64.5	61.25	58	9
146	66	62.75	59.5	63	59.75	56.5	9
147	64.5	61.25	58	61.5	58.25	55	9
148	63	59.75	56.5	60	56.75	53.5	9
149	61.5	58.25	55	58.5	55.25	52	9
150	61	57.25	53.5	58	54.25	50.5	9
151	61	56.5	52	58	53.5	49	9
152	59.2	54.6	50	56.2	51.6	47	9
153	58	53	48	53	48	43	96
154	55.2	50.75	46.3	50.2	45.75	41.3	96
155	52.4	48.5	44.6	47.4	43.5	39.6	96
156	49.6	46.25	42.9	44.6	41.25	37.9	96
157	46.8	44	41.2	41.8	39	36.2	96
158	44	41.75	39.5	39	36.75	34.5	96
159	41.2	39.5	37.8	36.2	34.5	32.8	96
160	39.9	38	36.1	34.9	33	31.1	96
161	35.6	35	34.4	30.6	30	29.4	96
162	33.9	33.45	33	28.9	28.45	28	96

Table B3: Inventory levels

Code	Product Name	Inventory level
P1	Brutal Fruit Peach 660R BF	1.388375
P2	Brutal Fruit Lemon 660R BF	0.29175
P3	Brutal Fruit Litchi 660R BF	1.087375
P4	Carling Black Label 750 Ret	727.23425
P5	Hansa Pilsener 750 Ret	863.77625
P6	Castle Milk Stout 750 Ret	218.134375
P7	Castle Lager 750 Ret	151.06975
P8	Castle Lite 660R CasLite	328.782375
P9	Hansa Marzen Gold 750R Green	4.949625
P10	Carling Black Label 330 Ret	15.593125
P11	Castle Lager 330 Ret	14.23225
P12	Hansa Pilsener 330 Ret	6.64275
P13	Castle Lite 340 Nrb	157.136
P14	Hansa Pilsener 340 Nrb	100.8632188
P15	Castle Lager 340 Nrb	70.4720625
P16	Carling Black Label 340 Nrb	105.8892188
P17	Hansa Marzen Gold 340 Nrb	4.482625
P18	Peroni 330 Nrb	5.691345566
P19	Carling Black Label 330 Can	26.8694125
P20	Castle Lager 330 Can	39.2121625
P21	Castle Milk Stout 330 Can	1.513225
P22	Castle Lite 330 Can	26.6044625
P23	Hansa Pilsener 330 Can	14.8161125
P24	Skelters 330 Nrb	1.266382069
P25	Grolsch 330 Nrb	1.943386291
P26	Castle Lager 440 Can	5.7474375
P27	Castle Milk Stout 440 Can	3.9423125
P28	Carling Black Label 440 Can	14.3185
P29	Miller Genuine Draft 330 Nrb	30.35965625
P30	Pilsner Urquell 330 Nrb	0.520515625
P31	Sarita Ruby Dry 330N SAR	4.749828125
P32	Brutal Fruit Lemon 275 NRB	2.503484375
P33	Brutal Fruit Mango 275 NRB	7.14809375
P34	Brutal Fruit Litchi 275 NRB	3.3350625
P35	Brutal Fruit Strawberry 275 NRB	4.1405
P36	Brutal Fruit Peach 275 NRB	4.2914375
P37	Redds Dry 340 Nrb	3.852625
P38	Redds Premium 340 Nrb	3.1084375
P39	Castle Milk Stout 340 Nrb	12.2677625
P40	Dreher 340 NRB	0.577641544
P41	Redds Premium 660 Ret	8.221125
P42	Redds Dry 660 Ret	45.31191829
P43	Brutal Fruit Mango 660R BF	3.475656731
P44	Miller Genuine Draft 660R MGD	6.888435626
P45	Brutal Fruit Lemon 660R BF	0.291763157
P46	Brutal Fruit Litchi 660R BF	1.087424036

Appendix C: Octave and Lingo code.

C1: Lingo 8.0 Code

C1.1: Option 1

MODEL:

!Transportation cost optimization;

SETS:

PRODUCT/ P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P16 P17 P18 P19 P20 P21 P22 P23
P24 P25 P26 P27 P28 P29 P30 P31 P32 P33 P34 P35 P36 P37 P38 P39 P40 P41 P42 P43 P44 P45 P46 /
: DEMAND, INVENTORY, INCOMING;
BIN/ B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15 B16 B17 B18 B19 B20 B21 B22 B23 B24
B25 B26 B27 B28 B29 B30 B31 B32 B33 B34 B35 B36 B37 B38 B39 B40 B41 B42 B43 B44 B45 B46 B47
B48 B49 B50 B51 B52 B53 B54 B55 B56 B57 B58 B59 B60 B61 B62 B63 B64 B65 B66 B67 B68 B69 B70
B71 B72 B73 B74 B75 B76 B77 B78 B79 B80 B81 B82 B83 B84 B85 B86 B87 B88 B89 B90 B91 B92 B93
B94 B95 B96 B97 B98 B99 B100 B101 B102 B103 B104 B105 B106 B107 B108 B109 B110 B111 B112
B113 B114 B115 B116 B117 B118 B119 B120 B121 B122 B123 B124 B125 B126 B127 B128 B129 B130
B131 B132 B133 B134 B135 B136 B137 B138 B139 B140 B141 B142 B143 B144 B145 B146 B147 B148
B149 B150 B151 B152 B153 B154 B155 B156 B157 B158 B159 B160 B161 B162/ : CAPACITY,
OP_DISTANCE, OFFZONE_DISTANCE;
MATRIX(PRODUCT, BIN):ASSIGN;

ENDSETS

!Objective Function;

MIN = (@SUM(MATRIX(R,I): ASSIGN(R,I)*DEMAND(R)*OP_DISTANCE(I) +
ASSIGN(R,I)*INCOMING(R)*OFFZONE_DISTANCE(I)));

!Constraints;

!One product per bin constraint;

@FOR(BIN(I):@SUM(PRODUCT(R): ASSIGN(R,I)) = 1);

!A product should be assigned to at least one bin;

@FOR(PRODUCT(R): @SUM(BIN(I):ASSIGN(R,I)) >= 1);

!Total bin capacity of a product should be at least as much as the required inventory level;

@FOR(PRODUCT(R): @SUM(BIN(I): CAPACITY(I)*ASSIGN(R,I)) >= INVENTORY(R));

!Assignment given value one if assigned zero otherwise;

@FOR(MATRIX(R,I) : @BIN(ASSIGN(R,I)));

DATA:

!Product data;

DEMAND, INVENTORY, INCOMING = @OLE('C:\Users\Henk\Documents\Blng Bedryfs\BPJ
410\Program\Constant_Data.xls','Demand','Inventory','Incoming');

!Bin data;

CAPACITY, OP_DISTANCE, OFFZONE_DISTANCE = @OLE('C:\Users\Henk\Documents\Blng
Bedryfs\BPJ 410\Program\Constant_Data.xls','Capacity','OP_Distance','Off_Distance');

ENDDATA

C1.2: Option 2

MODEL:

!Transportation cost optimization;

SETS:

PRODUCT/ P1..P46 / : DEMAND, INVENTORY, INCOMING;

BIN/ B1..B162/ : CAPACITY, OP_DISTANCE, OFFZONE_DISTANCE;

MATRIX(PRODUCT, BIN):ASSIGN;

ENDSETS

!Objective Function;

MIN = (@SUM(MATRIX(R,I): ASSIGN(R,I)*DEMAND(R)*OP_DISTANCE(I) +
ASSIGN(R,I)*INCOMING(R)*OFFZONE_DISTANCE(I)));

!Constraints;

!One product per bin constraint;

@FOR(BIN(I):@SUM(PRODUCT(R): ASSIGN(R,I)) <= 1);

!A product should be assigned to at least one bin;

@FOR(PRODUCT(R): @SUM(BIN(I):ASSIGN(R,I)) >= 1);

!Total bin capacity of a product should be at least as much as the required inventory level;

@FOR(PRODUCT(R): @SUM(BIN(I): CAPACITY(I)*ASSIGN(R,I)) >= INVENTORY(R));

!RB Cases stored in the left hand side;

@FOR(PRODUCT(R) | R #LE# 9: @SUM(BIN(I) | I #GE# 47: ASSIGN(R,I)) = 0);

@FOR(PRODUCT(R) | R #GE# 41: @SUM(BIN(I) | I #GE# 47: ASSIGN(R,I)) = 0);

!Assignment given value one if assigned zero otherwise;

@FOR(MATRIX(R,I) : @BIN(ASSIGN(R,I)));

DATA:

!Product data;

DEMAND, INVENTORY, INCOMING = @OLE('C:\Users\Henk\Documents\BIng Bedryfs\BPJ
410\Program\Constant_Data.xls','Demand','Inventory','Incoming');

!Bin data;

CAPACITY, OP_DISTANCE, OFFZONE_DISTANCE = @OLE('C:\Users\Henk\Documents\BIng
Bedryfs\BPJ 410\Program\Constant_Data.xls','Capacity','OP_Distance','Off_Distance');

ENDDATA

END

C1.3: Option 1 rectified

MODEL:

!Transportation cost optimization;

SETS:

PRODUCT/ P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P16 P17 P18 P19 P20 P21 P22 P23
P24 P25 P26 P27 P28 P29 P30 P31 P32 P33 P34 P35 P36 P37 P38 P39 P40 P41 P42 P43 P44 P45 P46 /
: DEMAND, INVENTORY, INCOMING;
BIN/ B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15 B16 B17 B18 B19 B20 B21 B22 B23 B24
B25 B26 B27 B28 B29 B30 B31 B32 B33 B34 B35 B36 B37 B38 B39 B40 B41 B42 B43 B44 B45 B46 B47
B48 B49 B50 B51 B52 B53 B54 B55 B56 B57 B58 B59 B60 B61 B62 B63 B64 B65 B66 B67 B68 B69 B70
B71 B72 B73 B74 B75 B76 B77 B78 B79 B80 B81 B82 B83 B84 B85 B86 B87 B88 B89 B90 B91 B92 B93
B94 B95 B96 B97 B98 B99 B100 B101 B102 B103 B104 B105 B106 B107 B108 B109 B110 B111 B112
B113 B114 B115 B116 B117 B118 B119 B120 B121 B122 B123 B124 B125 B126 B127 B128 B129 B130
B131 B132 B133 B134 B135 B136 B137 B138 B139 B140 B141 B142 B143 B144 B145 B146 B147 B148
B149 B150 B151 B152 B153 B154 B155 B156 B157 B158 B159 B160 B161 B162/ : CAPACITY,
OP_DISTANCE, OFFZONE_DISTANCE;
MATRIX(PRODUCT, BIN):ASSIGN;

ENDSETS

!Objective Function;

MIN =(@SUM(MATRIX(R,I): ASSIGN(R,I)*DEMAND(R)*OP_DISTANCE(I) +
ASSIGN(R,I)*INCOMING(R)*OFFZONE_DISTANCE(I)));

!Constraints;

!One product per bin constraint;

@FOR(BIN(I):@SUM(PRODUCT(R): ASSIGN(R,I))<= 1);

!A product should be assigned to at least one bin;

@FOR(PRODUCT(R): @SUM(BIN(I):ASSIGN(R,I)) >= 1);

!Total bin capacity of a product should be at least as much as the required inventory level;

@FOR(PRODUCT(R): @SUM(BIN(I): CAPACITY(I)*ASSIGN(R,I)) >= INVENTORY(R));

!Assignment given value one if assigned zero otherwise;

@FOR(MATRIX(R,I) : @BIN(ASSIGN(R,I)););

DATA:

!Product data;

DEMAND, INVENTORY, INCOMING = @OLE('C:\Users\Henk\Documents\Blng Bedryfs\BPJ
410\Program\Constant_Data.xls','Demand','Inventory','Incoming');

!Bin data;

CAPACITY, OP_DISTANCE, OFFZONE_DISTANCE = @OLE('C:\Users\Henk\Documents\Blng
Bedryfs\BPJ 410\Program\Constant_Data.xls','Capacity','OP_Distance','Off_Distance');

ENDDATA

[illegible]

```

while (somsol(a) < 1) | (somcheck(a) < inventory(a))
    init_sol = zeros(46,162);

% Constraint 1 is met due to the nature of the generator
% C1 : Bin i can only have one product r assigned to it
for i = 1:162;
    init_sol(ceil(rand*46),i)= 1;
end
init_sol;

somsol = sum(init_sol,2);

for i = 1:162;
for r = 1:46;
    check(r,i) = init_sol(r,i)*bincapacity(i);
end
end
somcheck = sum(check,2);

somcheck;
somsol;
end
end
somcheck;

%Objective function
for r = 1:46;
    for i = 1:162;
        opvalue(r,i) = init_sol(r,i)*demand(r)*opbin_distance(i);
        offvalue(r,i) = init_sol(r,i)*incoming(r)*offbin_distance(i);
    end
end

newvalue = opvalue + offvalue;
finalvalue = k*newvalue;

somfinal = sum(finalvalue,2);

finalopt = sum(sum(finalvalue,2));
iterationmemory(s) = finalopt;

%optimum solution operator
If optval > finalopt;
opt_sol = init_sol;
optval = finalopt;

```

```
end  
end
```

```
dlmwrite('matrix.txt',init_sol,' ')  
dlmwrite('solution.txt',iterationmemory,' ')  
iterationmemory
```

C2.2: Matlab code for the current objective value.

```
mator = zeros(46,162);
mator(1,76) = 1;
mator(1,77) = 1;
mator(2,78) = 1;
mator(2,79) = 1;
mator(3,80) = 1;
mator(3,81) = 1;
mator(4,3) = 1;
mator(4,4) = 1;
mator(4,14) = 1;
mator(4,15) = 1;
mator(4,16) = 1;
mator(5,1) = 1;
mator(5,2) = 1;
mator(5,17) = 1;
mator(5,18) = 1;
mator(5,19) = 1;
mator(6,11) = 1;
mator(6,12) = 1;
mator(6,10) = 1;
mator(7,5) = 1;
mator(7,13) = 1;
mator(7,28) = 1;
mator(8,6) = 1;
mator(8,7) = 1;
mator(8,8) = 1;
mator(9,41) = 1;
mator(10,21) = 1;
mator(11,22) = 1;
mator(12,42) = 1;
mator(13,161) = 1;
mator(13,162) = 1;
mator(14,159) = 1;
mator(14,160) = 1;
mator(15,158) = 1;
mator(15,153) = 1;
mator(16,156) = 1;
mator(16,157) = 1;
mator(17,114) = 1;
mator(17,115) = 1;
mator(18,111) = 1;
mator(19,92) = 1;
mator(20,93) = 1;
mator(21,94) = 1;
mator(22,96) = 1;
mator(23,98) = 1;
mator(24,102) = 1;
mator(25,103) = 1;
mator(26,101) = 1;
mator(27,100) = 1;
```

```

mator(28,99) = 1;
mator(29,123) = 1;
mator(29,92) = 1;
mator(30,124) = 1;
mator(31,125) = 1;
mator(32,126) = 1;
mator(33,127) = 1;
mator(34,128) = 1;
mator(35,129) = 1;
mator(36,130) = 1;
mator(37,131) = 1;
mator(38,88) = 1;
mator(39,87) = 1;
mator(39,82) = 1;
mator(40,86) = 1;
mator(41,23) = 1;
mator(42,40) = 1;
mator(43,32) = 1;
mator(44,38) = 1;
mator(45,31) = 1;
mator(46,32) = 1;

```

```

%Objective Function;

```

```

%Order Picking value
opbin = reshape(opbin_distance,[],1);
offbin = reshape(offbin_distance,[],1);
demand = reshape(demand,1,[]);
incoming = reshape(incoming,1,[]);
opvalue = demand*mator*opbin;
offvalue = incoming*mator*offbin;
obvalue = opvalue + offvalue;

```

```

obvalue

```

```

dlmwrite('beginobvalue.txt',obvalue,')')

```

Appendix D: Table D1: Matlab results

1.22E+06	1.74E+06	9.40E+05	7.38E+05	1.58E+06	1.37E+06	1.33E+06	9.48E+05	1.51E+06
1.16E+06	9.10E+05	1.14E+06	1.04E+06	1.03E+06	1.07E+06	9.68E+05	1.75E+06	1.43E+06
1.27E+06	1.10E+06	1.18E+06	1.00E+06	1.10E+06	1.12E+06	7.32E+05	1.18E+06	1.27E+06
8.04E+05	1.16E+06	1.64E+06	9.40E+05	1.51E+06	1.19E+06	1.64E+06	1.25E+06	1.21E+06
1.03E+06	1.16E+06	1.07E+06	9.49E+05	1.34E+06	1.14E+06	1.04E+06	9.91E+05	9.07E+05
1.27E+06	1.49E+06	1.41E+06	1.43E+06	8.91E+05	1.12E+06	1.14E+06	1.38E+06	1.83E+06
1.29E+06	1.28E+06	1.09E+06	1.13E+06	1.75E+06	1.33E+06	1.59E+06	1.51E+06	2.09E+06
7.09E+05	1.59E+06	1.15E+06	1.38E+06	1.34E+06	1.52E+06	1.73E+06	1.64E+06	1.21E+06
1.22E+06	1.16E+06	1.41E+06	1.73E+06	1.32E+06	8.45E+05	8.60E+05	1.47E+06	8.61E+05
1.08E+06	7.84E+05	1.23E+06	1.10E+06	1.03E+06	1.53E+06	1.51E+06	1.12E+06	1.36E+06
1.99E+06	1.21E+06	1.26E+06	1.59E+06	1.15E+06	1.30E+06	1.55E+06	1.01E+06	1.07E+06
9.73E+05	1.37E+06	1.02E+06	1.22E+06	9.86E+05	1.73E+06	1.34E+06	1.29E+06	1.13E+06
1.64E+06	1.41E+06	1.27E+06	1.47E+06	1.13E+06	1.39E+06	1.74E+06	1.48E+06	9.64E+05
1.29E+06	1.62E+06	1.13E+06	1.27E+06	1.23E+06	1.36E+06	1.32E+06	1.30E+06	1.14E+06
1.22E+06	1.42E+06	2.00E+06	1.48E+06	1.48E+06	1.07E+06	9.64E+05	1.19E+06	8.84E+05
1.37E+06	1.62E+06	1.38E+06	1.28E+06	1.11E+06	9.52E+05	1.73E+06	1.21E+06	1.42E+06
1.17E+06	1.69E+06	1.75E+06	1.50E+06	1.71E+06	1.12E+06	9.43E+05	9.95E+05	1.18E+06
7.90E+05	1.09E+06	7.75E+05	8.27E+05	1.39E+06	1.86E+06	1.61E+06	1.02E+06	1.44E+06
1.51E+06	8.16E+05	9.21E+05	1.13E+06	9.10E+05	1.37E+06	9.46E+05	8.24E+05	8.98E+05
1.25E+06	1.33E+06	1.91E+06	1.51E+06	1.01E+06	1.22E+06	1.45E+06	9.31E+05	1.59E+06
7.97E+05	1.13E+06	1.19E+06	1.56E+06	1.43E+06	1.63E+06	1.35E+06	1.45E+06	1.20E+06
1.24E+06	1.45E+06	1.73E+06	1.35E+06	1.28E+06	1.61E+06	2.02E+06	1.24E+06	1.25E+06
1.17E+06	1.22E+06	1.20E+06	1.15E+06	1.28E+06	8.52E+05	8.22E+05	8.97E+05	1.77E+06
1.31E+06	1.38E+06	1.15E+06	1.39E+06	1.04E+06	1.07E+06	1.42E+06	1.43E+06	1.24E+06
1.17E+06	1.09E+06	1.49E+06	1.68E+06	1.16E+06	1.40E+06	1.22E+06	9.44E+05	1.64E+06
7.78E+05	1.40E+06	9.84E+05	1.25E+06	1.50E+06	1.17E+06	1.98E+06	1.45E+06	1.67E+06
1.06E+06	1.12E+06	1.54E+06	8.81E+05	1.01E+06	1.34E+06	1.31E+06	1.23E+06	1.42E+06
9.35E+05	1.28E+06	1.58E+06	1.49E+06	1.34E+06	1.44E+06	1.16E+06	1.10E+06	8.33E+05
1.70E+06	1.72E+06	9.87E+05	1.23E+06	1.26E+06	9.19E+05	1.29E+06	1.73E+06	1.48E+06
1.62E+06	1.27E+06	1.62E+06	1.03E+06	9.08E+05	1.40E+06	1.48E+06	1.44E+06	9.43E+05
1.56E+06	1.34E+06	1.80E+06	1.22E+06	1.59E+06	9.44E+05	8.59E+05	1.37E+06	1.40E+06
1.37E+06	1.47E+06	1.11E+06	1.24E+06	1.09E+06	1.43E+06	1.27E+06	1.57E+06	1.12E+06
1.57E+06	1.36E+06	1.08E+06	1.60E+06	1.05E+06	1.35E+06	1.28E+06	8.95E+05	1.14E+06
1.25E+06	1.68E+06	1.25E+06	1.17E+06	1.23E+06	1.43E+06	1.13E+06	1.70E+06	8.34E+05
1.66E+06	1.48E+06	1.46E+06	1.44E+06	1.44E+06	8.54E+05	1.48E+06	9.79E+05	1.82E+06
1.13E+06	8.91E+05	1.26E+06	1.03E+06	1.11E+06	1.40E+06	9.49E+05	1.31E+06	1.30E+06
1.24E+06	9.86E+05	1.26E+06	9.26E+05	1.59E+06	1.53E+06	1.27E+06	1.29E+06	1.50E+06
7.71E+05	1.36E+06	1.47E+06	1.69E+06	1.36E+06	1.51E+06	1.69E+06	6.90E+05	1.31E+06
1.32E+06	8.70E+05	8.18E+05	1.11E+06	1.30E+06	1.12E+06	1.09E+06	1.08E+06	1.31E+06
1.28E+06	1.44E+06	1.29E+06	1.06E+06	1.41E+06	9.14E+05	1.23E+06	1.27E+06	9.93E+05
1.27E+06	1.51E+06	1.23E+06	1.10E+06	1.44E+06	1.22E+06	1.19E+06	1.22E+06	1.44E+06
1.35E+06	1.22E+06	1.64E+06	1.08E+06	1.44E+06	7.96E+05	9.02E+05	1.44E+06	1.28E+06
1.53E+06	9.18E+05	1.59E+06	1.37E+06	1.43E+06	1.18E+06	1.03E+06	1.15E+06	1.94E+06
1.55E+06	1.63E+06	1.28E+06	8.62E+05	1.11E+06	1.41E+06	1.22E+06	1.05E+06	1.52E+06
9.47E+05	1.66E+06	1.25E+06	1.15E+06	1.12E+06	1.98E+06	1.21E+06	8.66E+05	1.45E+06
7.40E+05	1.71E+06	9.78E+05	1.06E+06	9.39E+05	9.70E+05	1.15E+06	1.12E+06	1.22E+06
1.29E+06	1.55E+06	1.46E+06	1.15E+06	1.15E+06	1.28E+06	1.07E+06	1.45E+06	1.26E+06

8.29E+05	1.22E+06	1.35E+06	1.43E+06	1.40E+06	1.33E+06	1.63E+06	1.53E+06	1.43E+06
1.03E+06	1.42E+06	1.37E+06	1.22E+06	1.39E+06	1.28E+06	1.06E+06	1.30E+06	1.19E+06
1.38E+06	1.29E+06	8.93E+05	1.03E+06	1.67E+06	1.64E+06	1.19E+06	1.30E+06	1.21E+06
1.71E+06	1.27E+06	1.55E+06	1.37E+06	7.76E+05	1.12E+06	1.48E+06	1.76E+06	1.18E+06
1.24E+06	8.49E+05	1.31E+06	1.27E+06	1.43E+06	1.28E+06	1.19E+06	1.63E+06	1.23E+06
1.23E+06	1.46E+06	1.17E+06	1.33E+06	1.06E+06	1.24E+06	1.64E+06	1.71E+06	1.39E+06
1.22E+06	1.43E+06	1.26E+06	1.53E+06	1.20E+06	1.56E+06	1.02E+06	1.83E+06	9.25E+05
1.06E+06	1.60E+06	1.16E+06	1.43E+06	1.49E+06	8.73E+05	1.39E+06	1.69E+06	1.09E+06
2.13E+06	9.10E+05	1.28E+06	1.50E+06	1.24E+06	1.83E+06	1.51E+06	1.16E+06	1.39E+06
1.08E+06	9.74E+05	9.72E+05	1.43E+06	1.04E+06	9.87E+05	1.53E+06	1.52E+06	1.20E+06
1.92E+06	1.27E+06	7.89E+05	1.09E+06	1.32E+06	8.59E+05	1.61E+06	1.06E+06	1.48E+06
1.58E+06	1.08E+06	8.47E+05	1.31E+06	1.21E+06	1.32E+06	7.41E+05	1.70E+06	1.61E+06
1.48E+06	1.04E+06	1.17E+06	1.48E+06	2.01E+06	1.39E+06	1.33E+06	9.99E+05	1.41E+06
1.30E+06	9.94E+05	1.18E+06	8.81E+05	1.32E+06	9.42E+05	1.07E+06	1.30E+06	1.39E+06
1.02E+06	1.02E+06	1.06E+06	1.30E+06	8.36E+05	1.25E+06	1.27E+06	8.97E+05	1.53E+06
7.88E+05	9.94E+05	1.50E+06	1.00E+06	1.04E+06	1.14E+06	1.19E+06	1.50E+06	1.33E+06
1.30E+06	1.11E+06	1.14E+06	1.17E+06	1.30E+06	1.25E+06	9.64E+05	1.40E+06	1.28E+06
1.24E+06	1.77E+06	1.24E+06	1.14E+06	1.33E+06	5.60E+05	1.46E+06	9.28E+05	1.06E+06
1.27E+06	9.01E+05	1.24E+06	1.31E+06	1.38E+06	1.23E+06	9.67E+05	1.91E+06	1.63E+06
1.45E+06	1.04E+06	1.10E+06	1.64E+06	8.65E+05	1.39E+06	1.37E+06	1.26E+06	1.90E+06
1.52E+06	1.81E+06	1.13E+06	1.36E+06	9.92E+05	1.55E+06	1.51E+06	1.02E+06	9.11E+05
1.34E+06	1.07E+06	1.07E+06	1.42E+06	1.18E+06	1.48E+06	1.32E+06	1.23E+06	9.44E+05
1.29E+06	9.22E+05	1.08E+06	8.21E+05	1.23E+06	1.40E+06	1.10E+06	1.96E+06	8.61E+05
1.82E+06	1.79E+06	2.09E+06	1.07E+06	1.42E+06	1.47E+06	8.86E+05	1.39E+06	1.49E+06
1.51E+06	1.22E+06	1.62E+06	1.31E+06	8.17E+05	1.51E+06	1.05E+06	1.32E+06	1.10E+06
1.09E+06	1.49E+06	9.98E+05	8.98E+05	1.20E+06	1.19E+06	1.36E+06	1.68E+06	1.49E+06
1.32E+06	1.08E+06	1.96E+06	1.66E+06	1.32E+06	9.26E+05	1.19E+06	9.63E+05	1.15E+06
1.06E+06	1.60E+06	1.46E+06	1.01E+06	1.42E+06	1.37E+06	7.31E+05	9.56E+05	7.90E+05
9.82E+05	1.14E+06	1.21E+06	1.47E+06	1.22E+06	1.62E+06	9.61E+05	1.12E+06	1.56E+06
1.07E+06	9.51E+05	1.66E+06	1.06E+06	1.12E+06	1.26E+06	1.31E+06	1.37E+06	7.81E+05
1.07E+06	1.58E+06	1.28E+06	1.42E+06	1.19E+06	1.45E+06	1.10E+06	9.64E+05	1.02E+06
1.27E+06	1.20E+06	1.37E+06	1.04E+06	1.04E+06	1.60E+06	1.08E+06	1.26E+06	7.86E+05
1.09E+06	1.57E+06	7.70E+05	9.87E+05	1.01E+06	1.23E+06	8.81E+05	1.28E+06	1.20E+06
1.45E+06	1.80E+06	1.86E+06	1.31E+06	1.23E+06	1.15E+06	1.39E+06	9.22E+05	9.99E+05
1.25E+06	1.38E+06	1.43E+06	1.03E+06	1.59E+06	1.53E+06	1.74E+06	8.90E+05	8.05E+05
1.13E+06	1.39E+06	1.04E+06	9.80E+05	1.52E+06	1.93E+06	1.00E+06	1.03E+06	1.29E+06
1.37E+06	7.81E+05	1.45E+06	1.99E+06	1.55E+06	1.49E+06	8.98E+05	1.05E+06	1.39E+06
1.13E+06	1.56E+06	1.47E+06	2.08E+06	1.48E+06	1.35E+06	1.65E+06	1.17E+06	1.20E+06
1.62E+06	1.92E+06	1.17E+06	7.01E+05	1.17E+06	1.59E+06	1.34E+06	1.31E+06	7.60E+05
1.75E+06	1.23E+06	1.30E+06	1.18E+06	1.24E+06	1.45E+06	1.50E+06	8.00E+05	1.02E+06
1.18E+06	6.13E+05	1.21E+06	1.31E+06	9.22E+05	1.34E+06	1.52E+06	1.15E+06	1.30E+06
1.52E+06	1.64E+06	1.27E+06	1.20E+06	7.32E+05	1.37E+06	1.28E+06	1.16E+06	1.35E+06
1.38E+06	1.18E+06	1.05E+06	1.08E+06	1.58E+06	1.09E+06	9.70E+05	9.33E+05	1.18E+06
1.46E+06	1.45E+06	1.40E+06	9.46E+05	1.24E+06	1.69E+06	8.08E+05	1.27E+06	1.39E+06
1.52E+06	9.55E+05	1.27E+06	1.15E+06	1.64E+06	1.18E+06	1.79E+06	1.40E+06	1.15E+06
1.12E+06	1.30E+06	1.58E+06	1.08E+06	1.65E+06	9.88E+05	9.44E+05	1.36E+06	1.36E+06
1.22E+06	1.31E+06	1.31E+06	1.15E+06	1.12E+06	1.45E+06	1.28E+06	1.52E+06	1.18E+06
1.27E+06	1.45E+06	1.28E+06	1.03E+06	1.47E+06	9.54E+05	1.04E+06	1.40E+06	1.43E+06
1.37E+06	1.47E+06	1.55E+06	1.27E+06	1.33E+06	1.22E+06	1.34E+06	1.57E+06	1.42E+06

1.58E+06	1.04E+06	1.96E+06	8.79E+05	1.03E+06	1.31E+06	1.42E+06	1.05E+06	1.20E+06
1.46E+06	9.78E+05	9.45E+05	1.30E+06	1.52E+06	1.14E+06	7.21E+05	1.47E+06	1.19E+06
1.41E+06	1.07E+06	1.19E+06	1.15E+06	1.39E+06	1.54E+06	1.38E+06	1.83E+06	1.34E+06
1.63E+06	1.52E+06	1.17E+06	1.10E+06	1.23E+06	1.56E+06	1.48E+06	1.28E+06	1.20E+06
1.66E+06	9.65E+05	1.06E+06	1.66E+06	1.02E+06	1.31E+06	1.40E+06	1.29E+06	1.03E+06
7.28E+05	1.59E+06	1.18E+06	1.28E+06	1.23E+06	1.33E+06	1.52E+06	1.70E+06	1.46E+06
1.35E+06	1.07E+06	1.11E+06	1.59E+06	1.28E+06	1.38E+06	1.36E+06	1.28E+06	1.33E+06
1.27E+06	1.15E+06	1.47E+06	1.65E+06	1.33E+06	1.66E+06	1.56E+06	1.21E+06	1.16E+06
1.91E+06	1.02E+06	1.79E+06	1.20E+06	1.41E+06	1.49E+06	1.17E+06	1.04E+06	1.15E+06
1.76E+06	1.18E+06	1.04E+06	1.09E+06	1.45E+06	1.47E+06	1.38E+06	1.52E+06	1.54E+06
1.40E+06	1.54E+06	1.18E+06	9.35E+05	1.60E+06	9.29E+05	1.35E+06	1.10E+06	1.80E+06
1.42E+06	6.59E+05	1.15E+06	1.27E+06	9.69E+05	1.17E+06	1.23E+06	1.56E+06	1.17E+06
1.31E+06	1.20E+06	1.00E+06	1.34E+06	1.28E+06	8.65E+05	1.48E+06	1.23E+06	1.34E+06
1.17E+06	8.82E+05	1.69E+06	1.36E+06	1.53E+06	1.25E+06	1.19E+06	1.28E+06	9.55E+05
8.77E+05	1.59E+06	1.20E+06	9.66E+05	1.41E+06	1.47E+06	1.03E+06	1.32E+06	1.24E+06
1.33E+06	1.36E+06	1.72E+06	1.14E+06	1.53E+06	1.24E+06	1.05E+06	1.31E+06	1.18E+06
1.36E+06	1.21E+06	1.42E+06	1.33E+06	1.08E+06	1.12E+06	1.53E+06	1.42E+06	8.63E+05
1.13E+06	1.25E+06	1.32E+06	1.47E+06	1.22E+06	1.59E+06	1.09E+06	1.43E+06	1.18E+06
1.30E+06	9.36E+05	1.37E+06	1.55E+06	1.71E+06	1.55E+06	1.54E+06	8.79E+05	8.40E+05
1.10E+06	1.10E+06	1.61E+06	1.31E+06	6.64E+05	1.51E+06	1.43E+06	1.52E+06	1.41E+06
1.16E+06	1.02E+06	1.66E+06	1.26E+06	1.24E+06	1.26E+06	1.59E+06	9.74E+05	8.44E+05
1.38E+06	1.28E+06	1.55E+06	1.09E+06	1.26E+06	1.33E+06	1.34E+06	8.13E+05	1.39E+06
1.46E+06	1.18E+06	1.48E+06	7.70E+05	1.30E+06	1.30E+06	8.91E+05	1.11E+06	8.65E+05
1.34E+06	1.26E+06	1.56E+06	1.42E+06	1.34E+06	1.55E+06	1.15E+06	1.97E+06	1.54E+06
1.41E+06	1.20E+06	1.33E+06	7.48E+05	8.65E+05	1.12E+06	1.30E+06	1.30E+06	1.31E+06
8.98E+05	1.76E+06	1.25E+06	9.01E+05	1.31E+06	1.16E+06	1.70E+06	1.62E+06	1.25E+06
1.29E+06	1.44E+06	1.25E+06	1.41E+06	9.71E+05	1.18E+06	9.06E+05	1.25E+06	1.26E+06
9.66E+05	1.25E+06	1.41E+06	1.14E+06	1.29E+06	1.55E+06	1.22E+06	1.22E+06	8.60E+05
1.29E+06	1.06E+06	1.43E+06	1.34E+06	1.57E+06	1.14E+06	1.84E+06	9.43E+05	1.43E+06
9.85E+05	1.60E+06	1.32E+06	1.26E+06	1.43E+06	1.16E+06	1.45E+06	1.66E+06	1.17E+06
1.25E+06	1.51E+06	1.49E+06	1.37E+06	8.65E+05	1.64E+06	1.16E+06	1.31E+06	8.70E+05
8.52E+05	1.30E+06	1.22E+06	1.43E+06	1.08E+06	1.60E+06	1.30E+06	1.43E+06	1.21E+06
1.49E+06	1.02E+06	1.66E+06	8.09E+05	1.07E+06	1.15E+06	1.43E+06	1.02E+06	1.32E+06
9.82E+05	1.10E+06	1.17E+06	1.20E+06	8.49E+05	1.39E+06	1.15E+06	1.17E+06	1.08E+06
1.10E+06	1.08E+06	1.45E+06	1.19E+06	1.32E+06	1.35E+06	1.39E+06	1.26E+06	1.47E+06
1.10E+06	1.73E+06	1.35E+06	1.02E+06	1.38E+06	1.03E+06	7.45E+05	1.14E+06	1.43E+06
1.67E+06	1.29E+06	1.68E+06	1.16E+06	1.31E+06	1.20E+06	1.01E+06	1.08E+06	9.91E+05
9.83E+05	1.42E+06	1.02E+06	1.35E+06	1.08E+06	1.92E+06	1.18E+06	1.01E+06	1.51E+06
1.61E+06	1.05E+06	1.92E+06	1.74E+06	1.38E+06	1.11E+06	1.39E+06	1.17E+06	1.19E+06
1.15E+06	1.67E+06	9.45E+05	1.44E+06	1.18E+06	1.06E+06	1.51E+06	1.64E+06	1.35E+06
1.41E+06	1.75E+06	1.79E+06	1.87E+06	1.20E+06	1.11E+06	1.73E+06	1.02E+06	1.27E+06
1.24E+06	1.41E+06	1.12E+06	1.40E+06	1.46E+06	1.43E+06	1.09E+06	1.25E+06	1.27E+06
1.06E+06	1.11E+06	1.31E+06	1.21E+06	1.23E+06	1.89E+06	1.43E+06	1.22E+06	1.46E+06
1.23E+06	1.42E+06	1.08E+06	1.48E+06	1.09E+06	7.39E+05	1.23E+06	1.60E+06	1.03E+06

Appendix E: LINGO First Test Run Results

Global optimal solution found at iteration:
Objective value:

5186
1040024.

ASSIGN(P1, B49)	1.000000	151.1345
ASSIGN(P2, B10)	1.000000	38.62214
ASSIGN(P2, B11)	1.000000	36.81607
ASSIGN(P2, B12)	1.000000	35.01000
ASSIGN(P2, B13)	1.000000	33.20393
ASSIGN(P2, B23)	1.000000	33.62071
ASSIGN(P2, B24)	1.000000	35.42679
ASSIGN(P2, B25)	1.000000	37.23286
ASSIGN(P2, B26)	1.000000	39.03893
ASSIGN(P2, B27)	1.000000	40.84500
ASSIGN(P2, B28)	1.000000	42.65107
ASSIGN(P2, B29)	1.000000	44.45714
ASSIGN(P2, B30)	1.000000	46.26321
ASSIGN(P2, B31)	1.000000	48.06929
ASSIGN(P2, B33)	1.000000	32.62043
ASSIGN(P2, B34)	1.000000	34.39871
ASSIGN(P2, B35)	1.000000	36.17700
ASSIGN(P2, B36)	1.000000	37.95529
ASSIGN(P2, B37)	1.000000	39.73357
ASSIGN(P2, B38)	1.000000	41.51186
ASSIGN(P2, B39)	1.000000	43.29014
ASSIGN(P2, B40)	1.000000	45.06843
ASSIGN(P2, B41)	1.000000	46.84671
ASSIGN(P2, B42)	1.000000	48.62500
ASSIGN(P2, B43)	1.000000	37.14950
ASSIGN(P2, B51)	1.000000	33.31507
ASSIGN(P2, B52)	1.000000	34.09307
ASSIGN(P2, B53)	1.000000	34.87107
ASSIGN(P2, B54)	1.000000	35.64907
ASSIGN(P2, B55)	1.000000	36.42707
ASSIGN(P2, B56)	1.000000	37.20507
ASSIGN(P2, B57)	1.000000	37.98307
ASSIGN(P2, B58)	1.000000	38.67771
ASSIGN(P2, B59)	1.000000	39.53907
ASSIGN(P2, B60)	1.000000	40.31707
ASSIGN(P2, B61)	1.000000	41.09507
ASSIGN(P2, B62)	1.000000	41.87307
ASSIGN(P2, B63)	1.000000	42.65107
ASSIGN(P2, B64)	1.000000	43.42907
ASSIGN(P2, B65)	1.000000	44.20707
ASSIGN(P2, B66)	1.000000	44.98507
ASSIGN(P2, B67)	1.000000	45.76307
ASSIGN(P2, B68)	1.000000	46.54107
ASSIGN(P2, B69)	1.000000	47.06900
ASSIGN(P2, B70)	1.000000	47.62471
ASSIGN(P2, B71)	1.000000	48.34714
ASSIGN(P2, B72)	1.000000	49.01400
ASSIGN(P2, B73)	1.000000	49.68086
ASSIGN(P2, B74)	1.000000	50.34771
ASSIGN(P2, B75)	1.000000	51.18129
ASSIGN(P2, B76)	1.000000	50.01429
ASSIGN(P2, B77)	1.000000	48.62500
ASSIGN(P2, B78)	1.000000	47.23571
ASSIGN(P2, B79)	1.000000	45.84643
ASSIGN(P2, B80)	1.000000	44.45714
ASSIGN(P2, B81)	1.000000	43.06786
ASSIGN(P2, B82)	1.000000	41.67857
ASSIGN(P2, B83)	1.000000	40.28929
ASSIGN(P2, B84)	1.000000	38.90000
ASSIGN(P2, B85)	1.000000	37.51071
ASSIGN(P2, B86)	1.000000	36.12143
ASSIGN(P2, B87)	1.000000	34.73214
ASSIGN(P2, B88)	1.000000	33.34286
ASSIGN(P2, B98)	1.000000	41.01171
ASSIGN(P2, B99)	1.000000	41.51186
ASSIGN(P2, B100)	1.000000	42.01200
ASSIGN(P2, B101)	1.000000	42.53993
ASSIGN(P2, B102)	1.000000	49.01400

ASSIGN(P2, B103)	1.000000	47.43021
ASSIGN(P2, B104)	1.000000	45.84643
ASSIGN(P2, B105)	1.000000	44.26264
ASSIGN(P2, B106)	1.000000	42.67886
ASSIGN(P2, B107)	1.000000	41.09507
ASSIGN(P2, B108)	1.000000	39.51129
ASSIGN(P2, B109)	1.000000	37.92750
ASSIGN(P2, B110)	1.000000	36.37150
ASSIGN(P2, B111)	1.000000	34.81550
ASSIGN(P2, B112)	1.000000	33.25950
ASSIGN(P2, B129)	1.000000	33.98193
ASSIGN(P2, B130)	1.000000	35.59350
ASSIGN(P2, B131)	1.000000	37.20507
ASSIGN(P2, B132)	1.000000	38.92779
ASSIGN(P2, B133)	1.000000	45.70750
ASSIGN(P2, B134)	1.000000	44.04036
ASSIGN(P2, B135)	1.000000	43.20679
ASSIGN(P2, B136)	1.000000	42.37321
ASSIGN(P2, B137)	1.000000	41.53964
ASSIGN(P2, B138)	1.000000	40.70607
ASSIGN(P2, B139)	1.000000	39.87250
ASSIGN(P2, B140)	1.000000	39.03893
ASSIGN(P2, B141)	1.000000	38.20536
ASSIGN(P2, B142)	1.000000	37.37179
ASSIGN(P2, B143)	1.000000	36.53821
ASSIGN(P2, B144)	1.000000	35.70464
ASSIGN(P2, B145)	1.000000	34.87107
ASSIGN(P2, B146)	1.000000	34.03750
ASSIGN(P2, B147)	1.000000	33.20393
ASSIGN(P3, B44)	1.000000	120.1290
ASSIGN(P4, B5)	1.000000	78472.04
ASSIGN(P4, B6)	1.000000	82973.96
ASSIGN(P4, B19)	1.000000	55754.63
ASSIGN(P4, B20)	1.000000	51252.70
ASSIGN(P4, B159)	1.000000	51252.70
ASSIGN(P4, B160)	1.000000	49174.89
ASSIGN(P5, B1)	1.000000	71652.30
ASSIGN(P5, B2)	1.000000	77164.01
ASSIGN(P5, B3)	1.000000	82017.61
ASSIGN(P5, B4)	1.000000	87282.53
ASSIGN(P5, B117)	1.000000	0.000000
ASSIGN(P5, B161)	1.000000	53471.86
ASSIGN(P5, B162)	1.000000	50921.67
ASSIGN(P6, B9)	1.000000	29500.08
ASSIGN(P7, B118)	1.000000	0.000000
ASSIGN(P7, B119)	1.000000	0.000000
ASSIGN(P7, B120)	1.000000	0.000000
ASSIGN(P7, B122)	1.000000	0.000000
ASSIGN(P7, B156)	1.000000	12589.15
ASSIGN(P8, B7)	1.000000	39547.82
ASSIGN(P8, B8)	1.000000	42428.58
ASSIGN(P9, B47)	1.000000	512.4040
ASSIGN(P10, B92)	1.000000	1485.060
ASSIGN(P11, B95)	1.000000	1419.159
ASSIGN(P11, B121)	1.000000	0.000000
ASSIGN(P12, B21)	1.000000	683.2543
ASSIGN(P13, B123)	1.000000	13019.84
ASSIGN(P13, B157)	1.000000	12421.23
ASSIGN(P14, B17)	1.000000	8981.629
ASSIGN(P15, B154)	1.000000	6476.718
ASSIGN(P16, B124)	1.000000	9368.675
ASSIGN(P16, B155)	1.000000	9277.913
ASSIGN(P17, B90)	1.000000	469.6083
ASSIGN(P18, B114)	1.000000	588.1057
ASSIGN(P19, B94)	1.000000	2548.756
ASSIGN(P20, B116)	1.000000	3633.660
ASSIGN(P21, B113)	1.000000	164.4371
ASSIGN(P22, B16)	1.000000	2533.758
ASSIGN(P23, B153)	1.000000	1425.169
ASSIGN(P24, B22)	1.000000	138.0959
ASSIGN(P25, B149)	1.000000	210.0708
ASSIGN(P26, B45)	1.000000	592.8071
ASSIGN(P27, B32)	1.000000	416.7587

ASSIGN(P28, B115)	1.000000	1403.213
ASSIGN(P29, B125)	1.000000	2856.699
ASSIGN(P30, B128)	1.000000	57.80202
ASSIGN(P31, B96)	1.000000	497.1487
ASSIGN(P32, B14)	1.000000	269.4226
ASSIGN(P33, B152)	1.000000	722.9786
ASSIGN(P34, B150)	1.000000	354.1519
ASSIGN(P35, B127)	1.000000	436.1327
ASSIGN(P36, B151)	1.000000	449.5792
ASSIGN(P37, B46)	1.000000	408.7452
ASSIGN(P38, B97)	1.000000	330.9746
ASSIGN(P39, B126)	1.000000	1223.271
ASSIGN(P40, B148)	1.000000	64.09070
ASSIGN(P41, B91)	1.000000	822.1125
ASSIGN(P42, B93)	1.000000	4078.073
ASSIGN(P43, B48)	1.000000	369.0816
ASSIGN(P44, B15)	1.000000	698.6842
ASSIGN(P45, B50)	1.000000	32.53854
ASSIGN(P46, B89)	1.000000	119.0988

Appendix F: LINGO Results

F1.1 Option 1

Global optimal solution found at iteration: 2273
Objective value: 1036147.

Variable	Value	Reduced Cost
ASSIGN(P1, B49)	1.000000	151.1345
ASSIGN(P2, B33)	1.000000	32.62043
ASSIGN(P3, B44)	1.000000	120.1290
ASSIGN(P4, B5)	1.000000	78472.04
ASSIGN(P4, B6)	1.000000	82973.96
ASSIGN(P4, B19)	1.000000	55754.63
ASSIGN(P4, B20)	1.000000	51252.70
ASSIGN(P4, B159)	1.000000	51252.70
ASSIGN(P4, B160)	1.000000	49174.89
ASSIGN(P5, B1)	1.000000	71652.30
ASSIGN(P5, B2)	1.000000	77164.01
ASSIGN(P5, B3)	1.000000	82017.61
ASSIGN(P5, B4)	1.000000	87282.53
ASSIGN(P5, B117)	1.000000	0.000000
ASSIGN(P5, B161)	1.000000	53471.86
ASSIGN(P5, B162)	1.000000	50921.67
ASSIGN(P6, B9)	1.000000	16308.14
ASSIGN(P6, B158)	1.000000	16308.14
ASSIGN(P7, B18)	1.000000	12517.21
ASSIGN(P7, B118)	1.000000	0.000000
ASSIGN(P7, B156)	1.000000	12589.15
ASSIGN(P8, B7)	1.000000	39547.82
ASSIGN(P8, B8)	1.000000	42428.58
ASSIGN(P8, B119)	1.000000	0.000000
ASSIGN(P9, B47)	1.000000	512.4040
ASSIGN(P9, B120)	1.000000	0.000000
ASSIGN(P10, B92)	1.000000	1485.060
ASSIGN(P11, B95)	1.000000	1419.159
ASSIGN(P11, B121)	1.000000	0.000000
ASSIGN(P12, B21)	1.000000	683.2543
ASSIGN(P13, B123)	1.000000	13019.84
ASSIGN(P13, B157)	1.000000	12421.23
ASSIGN(P14, B17)	1.000000	8981.629
ASSIGN(P15, B154)	1.000000	6476.718
ASSIGN(P16, B124)	1.000000	9368.675
ASSIGN(P16, B155)	1.000000	9277.913
ASSIGN(P17, B90)	1.000000	469.6083
ASSIGN(P18, B114)	1.000000	588.1057
ASSIGN(P19, B94)	1.000000	2548.756
ASSIGN(P20, B116)	1.000000	3633.660
ASSIGN(P21, B113)	1.000000	164.4371
ASSIGN(P22, B16)	1.000000	2533.758
ASSIGN(P23, B153)	1.000000	1425.169
ASSIGN(P24, B22)	1.000000	138.0959
ASSIGN(P25, B149)	1.000000	210.0708
ASSIGN(P26, B45)	1.000000	592.8071
ASSIGN(P27, B32)	1.000000	416.7587
ASSIGN(P28, B115)	1.000000	1403.213
ASSIGN(P29, B125)	1.000000	2856.699
ASSIGN(P30, B128)	1.000000	57.80202
ASSIGN(P31, B96)	1.000000	497.1487
ASSIGN(P32, B14)	1.000000	269.4226

ASSIGN(P33, B152)	1.000000	722.9786
ASSIGN(P34, B150)	1.000000	354.1519
ASSIGN(P35, B127)	1.000000	436.1327
ASSIGN(P36, B151)	1.000000	449.5792
ASSIGN(P37, B46)	1.000000	408.7452
ASSIGN(P38, B97)	1.000000	330.9746
ASSIGN(P39, B126)	1.000000	1223.271
ASSIGN(P40, B148)	1.000000	64.09070
ASSIGN(P41, B90)	0.000000	861.2607
ASSIGN(P41, B91)	1.000000	822.1125
ASSIGN(P42, B93)	1.000000	4078.073
ASSIGN(P43, B48)	1.000000	369.0816
ASSIGN(P44, B15)	1.000000	698.6842
ASSIGN(P45, B50)	1.000000	32.53854
ASSIGN(P46, B89)	1.000000	119.0988

F1.2: Option 2

Variable	Value	Reduced Cost
ASSIGN(P1, B12)	1.000000	166.6050
ASSIGN(P2, B35)	1.000000	36.17700
ASSIGN(P3, B34)	1.000000	128.2067
ASSIGN(P4, B6)	1.000000	82973.96
ASSIGN(P4, B8)	1.000000	93847.85
ASSIGN(P4, B15)	1.000000	73762.33
ASSIGN(P4, B16)	1.000000	69260.40
ASSIGN(P4, B18)	1.000000	60256.55
ASSIGN(P4, B20)	1.000000	51252.70
ASSIGN(P5, B1)	1.000000	71652.30
ASSIGN(P5, B2)	1.000000	77164.01
ASSIGN(P5, B3)	1.000000	82017.61
ASSIGN(P5, B4)	1.000000	87282.53
ASSIGN(P5, B17)	1.000000	76917.22
ASSIGN(P5, B19)	1.000000	66222.85
ASSIGN(P6, B21)	1.000000	22436.68
ASSIGN(P6, B32)	1.000000	23059.92
ASSIGN(P6, B45)	1.000000	22499.00
ASSIGN(P7, B5)	1.000000	16301.15
ASSIGN(P8, B7)	1.000000	39547.82
ASSIGN(P8, B9)	1.000000	44463.90
ASSIGN(P9, B44)	1.000000	546.8157
ASSIGN(P10, B124)	1.000000	1379.620
ASSIGN(P11, B116)	1.000000	1318.855
ASSIGN(P12, B92)	1.000000	632.6429
ASSIGN(P13, B161)	1.000000	9727.467
ASSIGN(P13, B162)	1.000000	9263.541
ASSIGN(P14, B22)	1.000000	10998.89
ASSIGN(P14, B118)	1.000000	0.000000
ASSIGN(P15, B117)	1.000000	0.000000
ASSIGN(P15, B158)	1.000000	5268.626
ASSIGN(P16, B120)	1.000000	0.000000
ASSIGN(P16, B159)	1.000000	7462.669
ASSIGN(P16, B160)	1.000000	7160.128
ASSIGN(P17, B121)	1.000000	0.000000
ASSIGN(P17, B126)	1.000000	446.9818
ASSIGN(P18, B115)	1.000000	557.7519
ASSIGN(P18, B122)	1.000000	0.000000
ASSIGN(P19, B156)	1.000000	2239.118
ASSIGN(P20, B157)	1.000000	3099.628
ASSIGN(P21, B48)	1.000000	160.6901
ASSIGN(P22, B155)	1.000000	2331.058
ASSIGN(P23, B93)	1.000000	1333.450
ASSIGN(P24, B150)	1.000000	134.4777
ASSIGN(P25, B127)	1.000000	204.7034
ASSIGN(P26, B153)	1.000000	552.8487
ASSIGN(P27, B114)	1.000000	407.3723
ASSIGN(P28, B154)	1.000000	1315.938
ASSIGN(P29, B119)	1.000000	0.000000
ASSIGN(P29, B123)	1.000000	2515.514
ASSIGN(P30, B149)	1.000000	56.26526
ASSIGN(P31, B95)	1.000000	473.6257
ASSIGN(P32, B151)	1.000000	262.2698
ASSIGN(P33, B94)	1.000000	678.0477
ASSIGN(P34, B96)	1.000000	349.0699
ASSIGN(P35, B152)	1.000000	418.7820
ASSIGN(P36, B91)	1.000000	429.1437
ASSIGN(P37, B47)	1.000000	398.8384
ASSIGN(P38, B90)	1.000000	325.6458

ASSIGN(P39, B125)	1.000000	1154.338
ASSIGN(P40, B97)	1.000000	61.50507
ASSIGN(P41, B46)	1.000000	872.2222
ASSIGN(P42, B13)	1.000000	5156.928
ASSIGN(P43, B33)	1.000000	388.6115
ASSIGN(P44, B14)	1.000000	741.3269
ASSIGN(P45, B24)	1.000000	35.42838
ASSIGN(P46, B23)	1.000000	125.3127

Row	Slack or Surplus	Dual Price
1	1142236.	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000

Appendix G: Space Utilization
G 1: Current Layout

Product	Inventory Required	Capacity	Unused Capacity	Unused	4 week cycle
P1	1.388375	54	52.61163	0.974289	yes
P2	0.29175	54	53.70825	0.994597	yes
P3	1.087375	54	52.91263	0.979863	yes
P4	727.2343	744	16.76575	0.022535	no
P5	863.7763	948	84.22375	0.088844	no
P6	218.1344	306	87.86563	0.287143	no
P7	151.0698	270	118.9303	0.440482	no
P8	328.7824	504	175.2176	0.347654	no
P9	4.949625	168	163.0504	0.970538	yes
P10	15.59313	103	87.40688	0.84861	yes
P11	14.23225	103	88.76775	0.861823	yes
P12	6.64275	168	161.3573	0.96046	yes
P13	157.136	192	34.864	0.181583	no
P14	100.8632	192	91.13678	0.474671	no
P15	70.47206	192	121.5279	0.632958	no
P16	105.8892	192	86.11078	0.448494	no
P17	4.482625	120	115.5174	0.962645	yes
P18	5.691346	60	54.30865	0.905144	yes
P19	26.86941	96	69.13059	0.72011	no
P20	39.21216	96	56.78784	0.59154	no
P21	1.513225	96	94.48678	0.984237	yes
P22	26.60446	96	69.39554	0.72287	no
P23	14.81611	96	81.18389	0.845665	yes
P24	1.266382	60	58.73362	0.978894	yes
P25	1.943386	60	58.05661	0.96761	yes
P26	5.747438	96	90.25256	0.940131	yes
P27	3.942313	96	92.05769	0.958934	yes
P28	14.3185	96	81.6815	0.850849	yes
P29	30.35966	96	65.64034	0.683754	no
P30	0.520516	96	95.47948	0.994578	yes
P31	4.749828	96	91.25017	0.950523	yes
P32	2.503484	96	93.49652	0.973922	yes
P33	7.148094	96	88.85191	0.925541	yes
P34	3.335063	96	92.66494	0.96526	yes
P35	4.1405	96	91.8595	0.95687	yes
P36	4.291438	96	91.70856	0.955298	yes
P37	3.852625	96	92.14738	0.959868	yes
P38	3.108438	96	92.89156	0.96762	yes
P39	12.26776	96	83.73224	0.872211	yes
P40	0.577642	96	95.42236	0.993983	yes
P41	8.221125	102	93.77888	0.919401	yes
P42	45.31192	168	122.6881	0.730286	no
P43	3.475657	168	164.5243	0.979312	yes
P44	6.888436	168	161.1116	0.958997	yes
P45	0.291763	168	167.7082	0.998263	yes
P46	1.087424	168	166.9126	0.993527	yes

G2: Option 1

Product	Inventory Required	Capacity	Unused Capacity	Unused	4 week cycle
P1	1.388375	27	25.611625	0.948578704	yes
P2	0.29175	96	95.70825	0.996960938	yes
P3	1.087375	24	22.912625	0.954692708	yes
P4	727.23425	732	4.76575	0.006510587	no
P5	863.77625	864	0.22375	0.00025897	no
P6	218.134375	282	63.865625	0.226473848	no
P7	151.06975	198	46.93025	0.237021465	no
P8	328.782375	336	7.217625	0.021481027	no
P9	4.949625	27	22.050375	0.816680556	yes
P10	15.593125	96	80.406875	0.837571615	yes
P11	14.23225	96	81.76775	0.851747396	yes
P12	6.64275	96	89.35725	0.930804688	yes
P13	157.136	180	22.864	0.127022222	no
P14	100.8632188	102	1.1367812	0.011144914	no
P15	70.4720625	96	25.5279375	0.265916016	no
P16	105.8892188	192	86.1107812	0.448493652	no
P17	4.482625	96	91.517375	0.95330599	yes
P18	5.691345566	60	54.30865443	0.905144241	yes
P19	26.8694125	60	33.1305875	0.552176458	no
P20	39.2121625	60	20.7878375	0.346463958	no
P21	1.513225	60	58.486775	0.974779583	yes
P22	26.6044625	102	75.3955375	0.739171936	no
P23	14.8161125	96	81.1838875	0.845665495	yes
P24	1.266382069	102	100.7336179	0.98758449	yes
P25	1.943386291	9	7.056613709	0.78406819	yes
P26	5.7474375	24	18.2525625	0.760523438	yes
P27	3.9423125	96	92.0576875	0.958934245	yes
P28	14.3185	60	45.6815	0.761358333	yes
P29	30.35965625	96	65.64034375	0.683753581	no
P30	0.520515625	96	95.47948438	0.994577962	yes
P31	4.749828125	96	91.25017188	0.950522624	yes
P32	2.503484375	102	99.49651563	0.975456036	yes
P33	7.14809375	96	88.85190625	0.92554069	yes
P34	3.3350625	96	92.6649375	0.965259766	yes
P35	4.1405	96	91.8595	0.956869792	yes
P36	4.2914375	96	91.7085625	0.955297526	yes
P37	3.852625	24	20.147375	0.839473958	yes
P38	3.1084375	96	92.8915625	0.967620443	yes
P39	12.2677625	96	83.7322375	0.872210807	yes
P40	0.577641544	9	8.422358456	0.935817606	yes
P41	8.221125	96	87.778875	0.914363281	yes
P42	45.31191829	96	50.68808171	0.528000851	no
P43	3.475656731	27	23.52434327	0.871271973	yes
P44	6.888435626	102	95.11156437	0.932466317	yes
P45	0.291763157	27	26.70823684	0.989193957	yes
P46	1.087424036	96	94.91257596	0.988672666	yes

G3: Option 2

Product	Inventory Required	Capacity	Unused Capacity	Unused	4 week cycle
P1	1.388375	102	100.6116	0.986388	yes
P2	0.29175	168	167.7083	0.998263	yes
P3	1.087375	168	166.9126	0.993528	yes
P4	727.2343	744	16.76575	0.022535	no
P5	863.7763	876	12.22375	0.013954	no
P6	218.1344	279	60.86563	0.218156	no
P7	151.0698	168	16.93025	0.100775	no
P8	328.7824	336	7.217625	0.021481	no
P9	4.949625	27	22.05038	0.816681	yes
P10	15.59313	96	80.40688	0.837572	yes
P11	14.23225	60	45.76775	0.762796	yes
P12	6.64275	96	89.35725	0.930805	yes
P13	157.136	192	34.864	0.181583	no
P14	100.8632	102	1.136781	0.011145	no
P15	70.47206	96	25.52794	0.265916	no
P16	105.8892	192	86.11078	0.448494	no
P17	4.482625	96	91.51738	0.953306	yes
P18	5.691346	60	54.30865	0.905144	yes
P19	26.86941	96	69.13059	0.72011	no
P20	39.21216	96	56.78784	0.59154	no
P21	1.513225	27	25.48678	0.943955	yes
P22	26.60446	96	69.39554	0.72287	no
P23	14.81611	96	81.18389	0.845665	yes
P24	1.266382	96	94.73362	0.986809	yes
P25	1.943386	96	94.05661	0.979756	yes
P26	5.747438	96	90.25256	0.940131	yes
P27	3.942313	60	56.05769	0.934295	yes
P28	14.3185	96	81.6815	0.850849	yes
P29	30.35966	96	65.64034	0.683754	no
P30	0.520516	9	8.479484	0.942165	yes
P31	4.749828	96	91.25017	0.950523	yes
P32	2.503484	96	93.49652	0.973922	yes
P33	7.148094	96	88.85191	0.925541	yes
P34	3.335063	96	92.66494	0.96526	yes
P35	4.1405	96	91.8595	0.95687	yes
P36	4.291438	96	91.70856	0.955298	yes
P37	3.852625	27	23.14738	0.85731	yes
P38	3.108438	96	92.89156	0.96762	yes
P39	12.26776	96	83.73224	0.872211	yes
P40	0.577642	96	95.42236	0.993983	yes
P41	8.221125	27	18.77888	0.695514	no
P42	45.31192	102	56.68808	0.555766	no
P43	3.475657	102	98.52434	0.965925	yes
P44	6.888436	102	95.11156	0.932466	yes
P45	0.291763	102	101.7082	0.99714	yes
P46	1.087424	102	100.9126	0.989339	yes