Analysis of Nike Distribution Facility's Outbound Process Flow

by

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Executive Summary

Nike is proud to be associated with the Soccer World Cup 2010 event through the sponsorship of footwear and kits to various teams and high profile players. Being a leading global brand, Nike is expecting extraordinary demand over the duration of the event. The agility and flexibility in which Nike respond to these special orders is what will distinguish them from the competitors in this space. The service levels expected by customers for World Cup related orders add significant pressure to the entire supply chain. The Nike South Africa distribution facility, located in Meadowdale, is currently not operating at its optimal capacity and desired processing flexibility to meet the customer requirements. Barloworld Logistics is contracted to analyse all distribution processes and develop the capabilities needed to achieve and maintain order fulfilment throughout the event.

A simulation study was conducted using Arena® to run different scenarios on processes affected by this event. Along with Microsoft Excel® spreadsheets this simulation proved to be vital in the decision making of the build up for the World Cup. The results obtained showed that not all Key Performance Indicators (KPI's) where at their optimal levels and resource capacity planning had to be reviewed to achieve the desired outcomes. It also indicated that the system was resistant to change and modifications on process logic are needed to create the desired flexibility.

The change in the resources deployment will save Nike labour cost due to increased productivity and utilisation in various departments. The system changes will reduce process cycle time and order lead time, which in turn will result in increased customer satisfaction. Increasing the flexibility indicated that more goods could be delivered in the same period of time, thus increasing overall order fulfilment.

Overall the project was a huge success and once implemented in February 2010, the project will yield significant cost reductions. Preliminary indications are that the project will yield a reduction on unit processing costs and increase throughput capacity. The simulation model is re-usable internally and further studies can be conducted on outbound process flow and planning processes.

Acknowledgments

TO MY FAMILY AND FRIENDS – FOR THEIR UNCONDITIONAL LOVE AND SUPPORT

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1 Introduction

1.1 Background

Nike, Inc. is a global company operating in 4 regions and 6 continents and with global revenue exceeding US $14 billion in 2006. Nike's global headquarters are located in Beaverton in the USA. South Africa is part of the EMEA (Europe, Middle-East and Africa) region which is headquartered in Hilversum, the Netherlands.

Originally managed by a distributor, Nike decided to manage marketing and distribution in South Africa through its own organisation which was implemented in 1995. The office is located in Midrand, Johannesburg with a satellite sales office in Cape Town. The total organisation employs 120 people with a turnover of approximately $100m. Nike's product range can be classified in 3 categories:

- Footwear
    - Categories such as Running, Basketball, Football, Cross-Training and Tennis
- Apparel
    - Products like Shirts, Tank Tops, Jerseys, Track Suits, Windbreakers, Sports Jackets and Caps
- Equipment
    - Items such as Socks, Bags, Back Packs, Gloves, Timing and Balls

Nike enjoys major market shares across all 3 business units'. They compete with Reebok, Adidas, Ellesse and Puma in this space.

In South Africa, product reaches customers through the following distribution channels:

- National and strategic accounts of multi-brand stores
- Franchised Nike only stores
- Nike owned Factory outlets selling close-out (also called aged) inventory and excess inventory

Nike's distribution facility is located in Meadowdale, Johannesburg. During 2009 Barloworld Logistics was contracted by Nike to investigate the local distribution facility in view of an expected increase of sales during the 2010 Soccer World Cup in South Africa. It is estimated that at least 50,000 units per day must be distributed through the distributions facility, to meet the expected demand. The distribution facility is currently running at a level of approximately 30,000 units per day, which is far less than the projected need. Nike is a major sponsor of the Soccer World Cup, which places an important responsibility on the distribution facility to run at its optimal level, thereby insuring a constant availability of products, failing might lead to a reduced share in the market to its various competitors. Nike's ability to respond to a rapid increase and decrease in demand is an important factor in its ability to compete with the main competitors and retain market share.

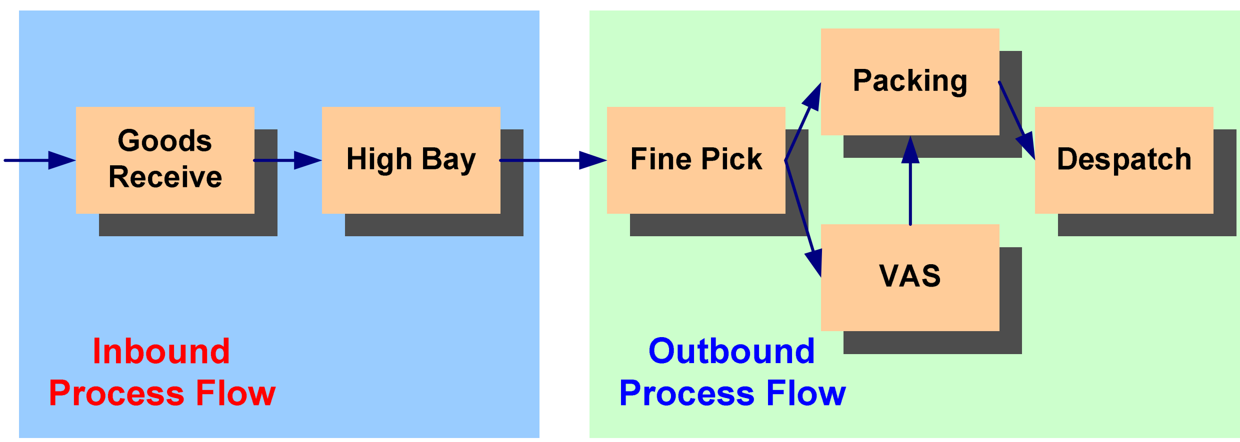
The focus of Barloworld Logistics is on the distribution facility and all the processes it entails. Thus an overview is needed of the facility and the recommendations to ensure that the demand will be achieved for the Soccer World Cup 2010 season.

1.1.1 Overview of Outbound Process Flow

In the distribution facility there are mainly two types of process flows. The first is the Inbound Process Flow (Figure 1); this process flow takes into account all the processes, flow of material and resources in receiving of goods from the suppliers. The departments running the Inbound Process Flow are the Goods Receiving department (the receiving of goods from the supplier) and the High Bay Department (the storing of the goods in bulk storage locations).

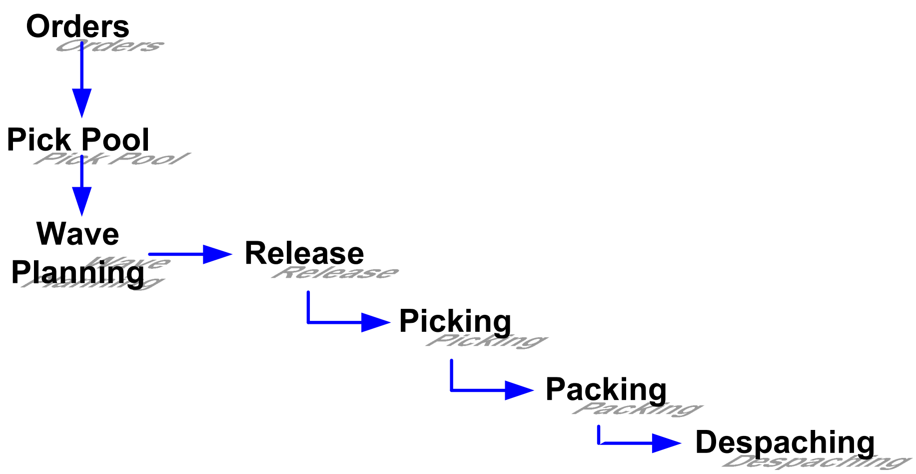
The second process flow is the Outbound Process Flow (Figure 1). This process flow takes into account all the processes, flow of material and resources in despatching specific orders to customers. The departments running the Outbound Process Flow are the Fine Pick department, Value Added Service (VAS), Packing department and the Despatching department.

Figure 1: Process Flow Diagram



On a higher level of detail the Outbound Process Flow consists of an order that comes from a customer. This order contains all the necessary detail from the products to be purchased to the delivery date of the products. After the order is complete it goes to the Pick Pool (Figure 2). From the Pick Pool it is taken to the Wave planning, where the planning occurs of when each order must be picked in order to reach the specified delivery date. This planning takes different constraints into account from the, expedite, which is the most urgent to the Non IDP (Integrated delivery plan) which is the less urgent orders. These orders get released by Wave planning and the picking of the goods takes place. After the goods have been picked it is sent to the Packing department. At the Packing Department the goods are packed into boxes and sent to the Despatch department where it gets despatched to the specific customer (Figure 2).

Figure 2: Outbound Process Flow



1.2 Project Aim

The main objective of this project is to provide Barloworld Logistics with a model to assess if the outbound process flow of the distribution facility would meet the output and flexibility requirements over the Soccer World Cup period. It will also assess if the demand levels can be achieved for the increased sales over the Soccer World Cup season, as well as any changes, if any, which might take place at the distribution facility to run at optimum throughput capacity. The facility was designed to achieve a theoretical output of 50,000 units per day. It is essential due to the expected high demand of the Soccer World Cup that the actual output per day must be as close as possible to the theoretical output per day. The process analysis will include demand variability, seasonality and growth over the next few months, which are Nike's most important and peak demand period.

An effective response to the changes in customer demand is the decisive factor. The demand will increase during the build-up and the occurrence of the Soccer World Cup 2010. With continuous changes comes a need for intuitive and flexible control. A highly flexible system is of great importance for the Soccer World Cup. If a team goes through to the next round in the Soccer World Cup, it is expected that the demand for Nike products of that team will increase. They will be ordered today and need to be despatched the next day, this indicates that some orders are of higher priority and the flexibility of the system will indicate if the demand can be met.

The simulation model will be used in studying accurate information and recommendations to management pertaining to the following decision making parameters:

- Highlight the possible bottlenecks under a certain set of conditions
- Flexibility of the system under changes in demand
- Material flow in the distribution facility
- Number of staff needed at each station
- Increase throughput, as close as possible to the theoretical maximum per day
- Calculate the buffer sizes, if needed, at each station
- Increase resource utilisation
- Inter relationship between processes

The essence of the parameter will entail the following processes:

- Optimising the processes (E.g. Throughput optimisation)
- Material handling, the flow of material through the facility
- Line balancing
- Queuing analysis.

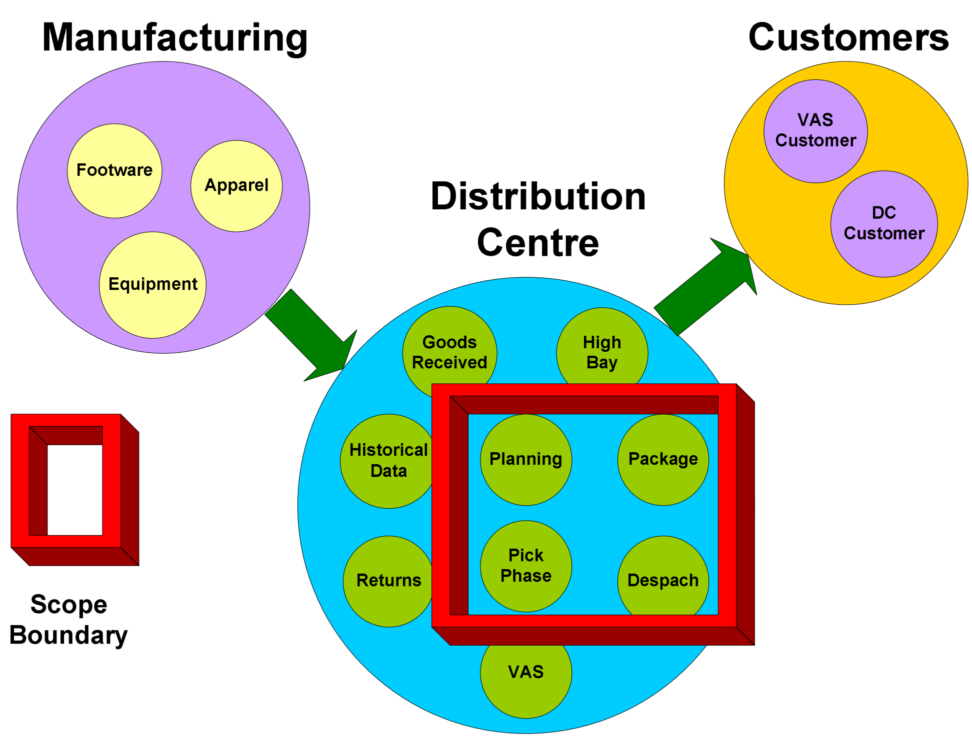
The ultimate goal of the study is to provide Barloworld Logistics with a model, which will indicate the distribution facility's readiness to cope with the peak demand for the Soccer World Cup. The study will also indicate what recommendations and changes must be made in order to achieve that goal.

1.3 Project Scope

All operation activities regarding the Outbound Process Flow are included in this project (Figure 2). The project is seen as a tactical model for the distribution facility. It will look at the facility and its outbound operations on a low level, taking into account smaller details of every station and its operations. The return station is seen as an operation on its own and therefore does not fall in the outbound flow of goods and thus will be not be included in the model.

Historical data are used and not the methods of how those data where collected. In essence all outbound processes are included, from where the orders are made until the despatching of goods (Figure 2). Figure 3 more clearly illustrates the border of the scope.

Figure 3: Scope Boundary



2 Literature Study

2.1 System Analysis Models

2.1.1 Management Decision

It is essential for managers to base their decisions and the extent to which their decisions are made, on the time horizon. The event of the Soccer World Cup takes place in a few months time and in order to satisfy the demand it is important to make informed decisions. According to Buzacott & Shanthikumar (1993:5) it is useful to distinguish between strategic, tactical and operational decisions, which are defined as follows:

- **Strategic** – Strategic decisions are those with long time horizon (more than a year or two) and involve major commitments of the organisation's resources. These decisions must be in alignment with the corporate strategy.
- **Tactical** – Tactical decisions have an intermediate time horizon of between 3 and 18 months or a lesser scope. These tactical decisions, in turn, become the operating constraints under which operational planning and control decisions are made.
- **Operational** – Operational decisions are typically those made every day or every week.

(Chase, Jacobs & Aquilano 2006:9)

2.1.2 Nature of Models

According to Buzacott & Shanthikumar (1993:8) a model is based on a representation of the operation of the system. Buzacott & Shanthikumar (1993:8) states that, the model is either a mathematical formula or a computer programme that when supplied with the numerical values of various parameters will make a numerical prediction of the system performance measures. By changing the values of a parameter the user can gain insight into its influence on performance. Models are intended to support management decisions about the system.

2.2 Basic Approach to Modelling

The process of modelling involves the following steps:

- **Identify the issues to be addressed**

  The needs of management must be established before clarifying the major concerns. The decisions that the model is required to support have to be identified.

- **Learn about the system**

  Buzacott & Shanthikumar (1993:8) said, "Identify the elements of the system, such as the machines, material handling and the data collection and control systems. Determine the characteristics of the job and the target volumes, quality and cost". It is useful to review any existing models to identify their capabilities, shortcomings and the level of familiarity of managers with the use of modelling approaches to help in the system design or operation.

- **Choose a modelling approach**

  "Various types of modelling approaches can be used, ranging from formal mathematical models through computer simulations. The choice of modelling approach is determined by the time and cost budget" said by said by Buzacott & Shanthikumar (1993:8). The level of user interface should also be considered when selecting the modelling approach.

- **Develop and test the model**

  During this step, data on the parameters of the model should be acquired. Decisions on the level of detail, accuracy and the method of collecting data should be made, since it will influence the correctness of the system, Buzacott & Shanthikumar (1993:8).

➢ **Verify and validate the model**

The model should be checked to see that it is a reasonably correct representation of reality; a base case should be established. This includes verification and validation.

- "Verification is to ensure the model results are correct derived from the assumptions made in developing the model" said by Buzacott & Shanthikumar (1993:8).
- "Validation is the process of ensuring that the assumptions of the model and the results are an accurate representation of the real system" said by Buzacott & Shanthikumar (1993:8).

➢ **Develop a model interface for the user**

Buzacott & Shanthikumar (1993:8) said "If the model is to be of value in making decisions it has to be provided with some interface so that it can be used by management". This requires the modeller to either incorporate the model into a decision support system or to present the model and its implications in a way that management can understand. The user has to be convinced that the model is adequate for the decision that the model is required to support.

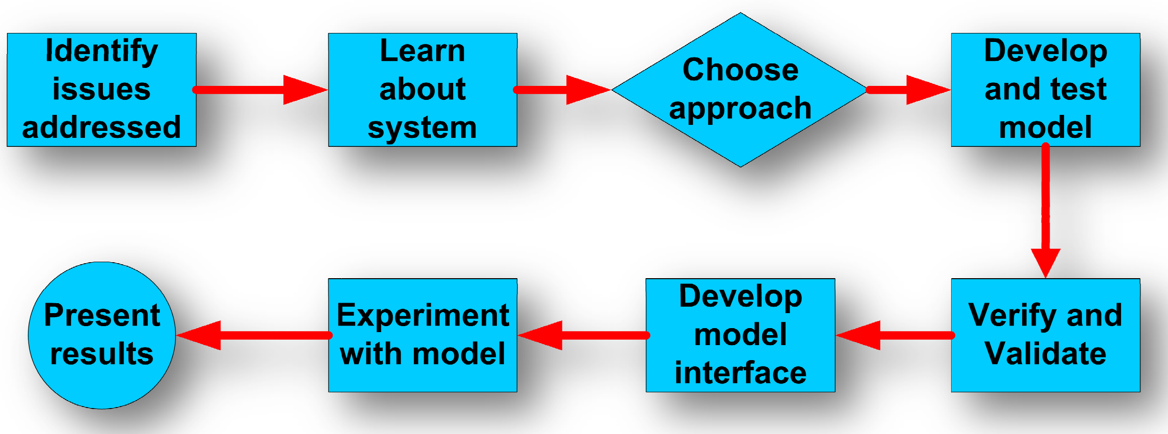
➢ **Experiment with the model**

"This requires exploring the impact of changes in model parameters and developing understanding of the factors influencing performance of the system so that the manager can be confident in the decisions made using the model" said by Buzacott & Shanthikumar (1993:8).

➢ Present the Results

Using the model, the manager should implement the recommended course of action. It is important that the users are informed about the accuracy of the results which will be generated by the model in order to make correct and informed decisions, Buzacott & Shanthikumar (1993:8).

Figure 4: Basic Approach to Modelling



2.3 Types of Models

For discrete part manufacturing there are three types of models in common use:

2.3.1 Physical Models

(Buzacott & Shanthikumar 1993:11) said, "Physical models represent the real system by another physical system, in which parts move from one machine to another and the machines perform processing operations on the parts. The major difference from the real system is that the model uses a different dimensional scale, so a large system will occupy a large amount space. Physical models are excellent as a means of educating production management and workers about the control of the system, but they do not lend themselves to assessing the long run behaviour of the system as it is difficult to represent the statistical properties of events such as machine failures".

2.3.2 Computer Simulation Models

Kelton, Sadowski & Sturrock (2007:5) said that, "Computer simulation refers to methods for studying a wide variety of models of real-world systems by numerical evaluation using software designed to imitate the system's operations or characteristics, often over time. From a practical viewpoint, simulation is the process of designing and creating a computerised model of a real or proposed system for the purpose of conducting numerical experiments to give us a better understanding of the behaviour of that system for a given set of conditions". Simulation models can become quite complicated, if needed to represent the system faithfully and you can still do a simulation analysis.

"The probabilistic nature of many events, such as machine failure, can be represented by sampling from a distribution representing the pattern of occurrence of the event. Thus to represent the typical behaviour of the system it is necessary to run the simulation model for a sufficient long time, so that all events can occur a reasonable number of times", said by Buzacott & Shanthikumar (1993:11). Simulation models can be provided with an interactive graphic display to demonstrate the movement of jobs and material handling devices. This can be of great value in communicating the assumptions of the model to the managers (Buzacott & Shanthikumar 1993:11).

2.3.3 Analytical Models

Analytical models describe the system using mathematical or symbolic relationships. If the model is simple, traditional mathematical tools like queuing theory, differential-equation methods or linear programming can be used (Kelton, Sadowski & Sturrock 2007:5). Buzacott & Shanthikumar 1993:12 said that, "These are then used to derive a formula or to define an algorithm or computational procedure by which the performance measures of the system can be calculated. Analytical models can also be used to demonstrate properties of various operating rules and control strategies".

2.3.4 Analytical versus Simulation Models

Simulation models can be developed in several different ways. One is to try and include all the required detail of the system from the beginning. This tends to result in long development and debugging time, and usually makes the resultant code unreadable to all but the developer. Another approach is to develop models of the system components and after each component model has been debugged, tested and validated, link the components two at a time, test and validate, then three at a time, test and validate and so on. Sometimes there are already existing simulation models of various sub-systems. The problem is that these can be too detailed for the overall system model but often it is possible to devise ways of summarising the performance of the sub-system model and replacing it by a simple sub-system component model. This approach is called the micro-macro approach and is useful in developing models of very large systems.

Simulation models are usually written in a simulation language such as GPSS, SLAM, SIMAN, SIMULA or SMALLTALK and only experts in the simulation language can read the code.

Analytical models typically determine the expected value of some performance criterion, whereas simulation models determine a time-limited sample of performance. Thus some statistical test is required to determine whether the sample is consistent with the analytical results. Analytical models either give a formula or define a computational procedure. If they give a computational procedure then it is necessary to consider the computational complexity of the procedure. It is by no means uncommon for the computational requirements to increase exponentially. This often limits the size of the system and the range of parameter values for which the procedure can be used (Buzacott & Shanthikumar 1993:12).

2.4 Why Model?

Models can be developed for a variety of reasons, in particular:

- **Understanding**

  "The model is used to explain why and how. The model is intended to help develop insight. It also indicates the direction of influence of some variable on performance", said by Buzacott & Shanthikumar (1993:12).

- **Learning**

  "As well as providing insight a model may be intended to teach managers or workers about the factors that determine performance" is said by Buzacott & Shanthikumar (1993:12).

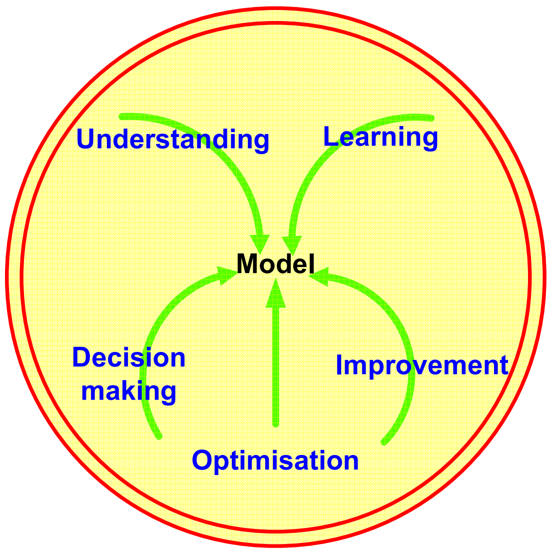
- **Improvement**

  "The model is used to improve system design and operation. Changes in parameters and rules can be explored, and factors critical for achieving performance targets can be identified" said by Buzacott & Shanthikumar (1993:12).

- **Optimisation**

  "The model is to be used to aid decisions about either the design or operation of the system. The model has to be able to differentiate the effect of different courses of action and project their impact over time", is said by Buzacott & Shanthikumar 1993:12.

Figure 5: Areas influenced by modelling



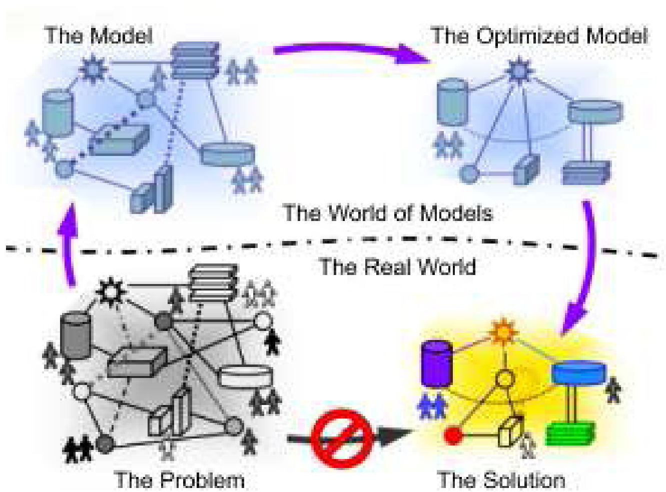
2.5 Simulation Modelling

Simulation may be defined as a technique that imitates the operation of the real-world system as it evolves over a period of time. There are two types of simulation models: Static and dynamic. A static simulation model represents a system at a particular point in time. A dynamic simulation model represents a system as it evolves over time.

Winston (2004:443) said that, “Simulations can be divided into deterministic or stochastic. A deterministic simulation contains no random variables, whereas a stochastic simulation contains one or more random variables”. Finally, simulations may be represented by either discrete or continuous models. A discrete simulation is one in which the state variable change only at discrete points in time. In a continuous simulation, the state variables change continuously over time.

Simulation moves the real world to a virtual world of models, performing experiments with the model of the system in a risk-free environment and map the best possible solution back to the real world see Figure 6.

Figure 6: Illustrating the mapping of simulation between the real world and models



2.5.1 Simulation Language

Computer programming is the basis of simulation. The study and writing of the computer code for a complex problem is a difficult and laborious task. Special purpose simulation languages simplify computer programming. The most widespread and readily available simulation languages include GPPS, GASP, ACSL, SIMSCRIPT, SLAM, SIMAN and many more (Winston 2004:440).

2.5.2 High-Level Simulators

High-Level simulators typically operate by intuitive graphical user interface, menus and dialogs. Selecting from available simulation-modelling constructs connects them and run the model along with a dynamic graphical animation of system components as they move around and change (Kelton, Sadowski & Sturrock 2007:5).

2.5.3 Simulation Modelling Tools

Currently in the markets there are numerous simulating tools available, each of which has its own capabilities. Each tool has a different approach to simulation and their success factors vary in more ways than one. Because of the great number of tools available only a few, which is most applicable to this project will be analysed further.

- **Arena®**

"Rockwell Arena is simulation and automation software acquired by Rockwell Automation almost a decade ago. It uses the SIMAN processor and simulation language. It is currently in version 12.0".

(Arena Rockwell Software – wikipedia.
[online]http://en.wikipedia.org/wiki/Rockwell_Arena,accessed on 14May 2009)

Arena® combines the ease of use found in high-level simulators with the flexibility of simulation languages and accommodates general-purpose procedural languages like the Microsoft® Visual Basic® programming system and even C.

Arena maintains its modelling flexibility by allowing the user to interchange between templates of graphical simulation modelling and analysis modules. Low-level modules can be used at any time and access to simulation language flexibility is unlimited. The Arena® software is completely hierarchical allowing access to a whole set of simulation modelling constructs and capabilities, such as the SIMAN constructs together with higher-level modules from other templates.

(Kelton, Sadowski & Sturrock 2007:10)

Arena® is used most effectively "when analysing complex, medium to large-scale projects involving highly sensitive changes related to supply chain, manufacturing, processes, logistics, distribution, warehousing and service systems".

Applications include:

- "Analysis of Six Sigma implementation, KanBan/Pull or Push systems".
- "Detail analysis of warehousing, logistics or transportation, military and mining applications".
- "Modelling complex customer-handling activities".
- "Detail analysis of complex manufacturing processes that include material-handling intensive operations".

(Arena® Professional Edition. [online] http://www.arenasimulation.com/products/professional_edition.asp, accessed on 14May 2009)

Arena® exploits two Microsoft Windows® technologies that are designed to enhance the integration of desktop applications. The first, ActiveX® Automation, allows applications to control each other and themselves via a programming interface. Programming languages like C++, Visual Basic or Java is used to create the programme that controls the application.

The second technology exploited by Arena® for application integration is Visual Basic (VBA). VBA is the same language that works with Microsoft Office, AutoCAD and Arena®.

These two technologies work together to allow Arena® to integrate with other programmes that support ActiveX Automation. It is possible to write Visual Basic code directly in Arena® that automates other programmes, such as Excel, AutoCAD or Visio.

(Kelton, Sadowski & Sturrock 2007:420)

It has been noted that creating a simulation can require more time at the beginning of a project, but quicker installations and product optimizations can reduce overall project time.

➢ ProModel

“ProModel is discrete event simulation software, used for evaluating, planning or designing manufacturing, warehousing, logistics and other operational and strategic situations.

This easy-to-use software allows you to build computer models of your situation and experiment with scenarios to find the best solution. The software includes animation and graphical reports, providing powerful tools for analysing and optimisation”.

- Develop “what if” scenarios quickly
- Direct data import and export with Microsoft® Excel®
- Capture system randomness and variability by utilising over 20 statistical distribution types or directly import your own data.

- Distribute models to other divisions and department with run-time licensing
- Automatic creation of output reports

ProModel is an easy-to-use and easy-to-implement.

(ProModel Optimisation Software. [online] http://www.promodel.com/products/promodel/features.asp, accessed on 13May 2009)

➢ ACSL

“The Advanced Continuous Simulation Language, or ACSL (pronounced “axle’), is a computer language designed for modelling and evaluating the performance of continuous system described by time-dependent, nonlinear differential equations”.

(Acsl-wikipedia. [online] http://en.wikipedia.org/wiki/advanced_continuous_simulation_language, accessed on 11May 2009)

ACSLX – "ACSLX is the latest software package by ACSL. ACSLX is a modelling, execution and analysis environment for continuous dynamic systems and processes. Simple to learn and easy to use, ACSLXtream provides an intuitive environment for users at all level, is versatile and powerful enough to address the most challenging simulation problems".

The ready-to-use code blocks incorporated in ACSLX enable quick model assembly, while powerful analysis capabilities provide quick and accurate results. Models are specified using either familiar block diagram notation or code-based descriptions using CSSL (Continuous System Simulation Language) modelling language. All model representations are translated into C or FORTRAN language source code for compilation and execution, ensuring the fastest possible performance and support for extremely large or complex models.

(ACSLX. [online] http://www.acslsim.com/products, accessed on 13May 2009)

The Arena® package developed by Rockwell Software will be selected, investigation shows that it is the best software for the project and that a full version of this package can be provided by the University of Pretoria without additional expenses.

3 Conceptual Design of Model

3.1 Structuring the Model

A basic approach will be followed to construct the simulation model. The major phases in the simulation study are illustrated in Figure 7. This flow chart view of the major phases in simulation study, simplifies the modelling process significantly, especially when changes to the model are made as the system is under examination. The goal of the initial model is to create a simulation model that represents the current operation of the distribution facility.

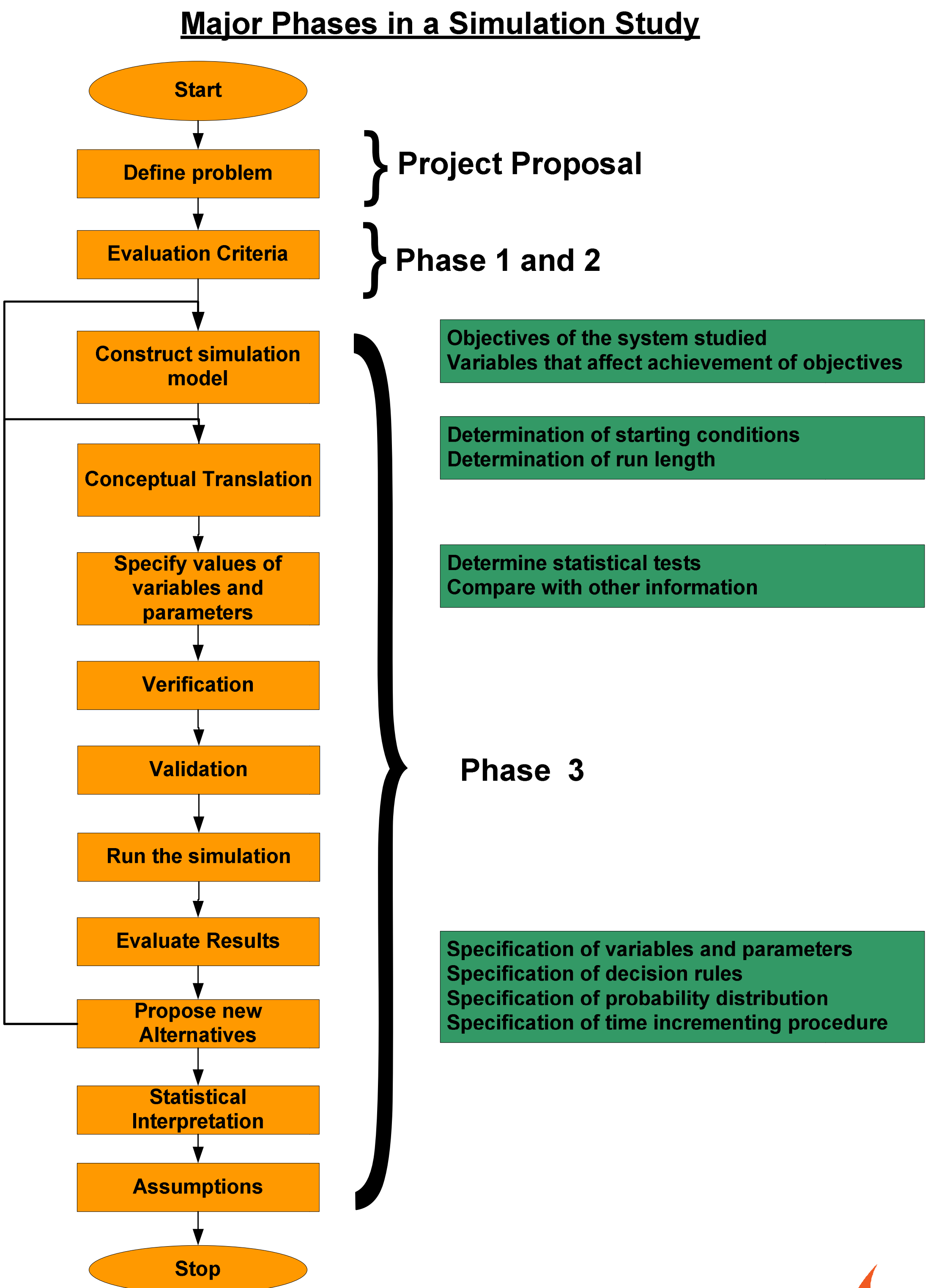
According to Chase, Jacobs and Aquilano (2006:703) a continuous model is based on mathematical equations with values for all points in time.

Discrete models are a process, in which changes to the state of the system occur at isolated points in time (Kelton, Sadowski & Sturrock 2007:465). The modelling of the distribution facility at Nike is a discrete simulation, events occur at specific points in time. Goods arriving at the distribution facility are an example of a discrete event.

In a system, an object of interest is called an entity and any properties of an entity are called attributes (Winston 2004:443). The entity of this simulation is an order from a customer and one of the attributes (one entity may have more than one attribute) attaches to that entity is the type of business units ordered by the customer, i.e. footwear, apparel or equipment.

The simulation model is also a queuing system, with many orders or entities arriving at each station and waiting to be sent through the system. Figure 7 is obtained from Chase, Jacobs and Aquilano (2006:693).

Figure 7: Major Phases in Simulation Study



Chase, Jacobs and Aquilano (2006:291) states a queuing system consists essentially of three major components:

1. The source population and the ways entities arrive at the system.
2. The service system.
3. The condition of the entity exiting the system.

3.2 Conceptual Inputs and Outputs of the Model

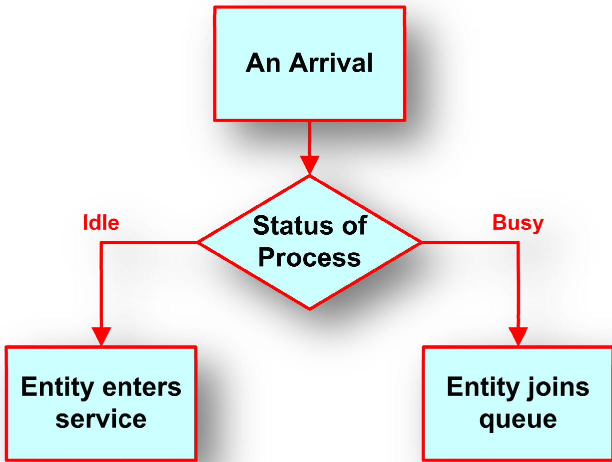
The input analysis specifies the model parameters and distributions. The logic aspect of the model, such as the entity and resource characteristics, the path an entity follows through the system and any other activities is called structural modelling (Kelton, Sadowski & Sturrock 2007:172).

The structural modelling of a system is an arrangement of the fundamental logic that describes the system. The mathematical input that describes the logic is called quantitative modelling. Quantitative modelling specifies the numerical nature of the resources and entities included and not only, the distributions and model parameters modelling (Kelton, Sadowski & Sturrock 2007:172).

The inputs to the queuing model are the arrival process, the process time of each station, the number of entities and the number of lines.

The structural modelling of a simple flow chart for an entity arrival is illustrated by Winston (2004:405) in Figure 8.

Figure 8: Flow chart of an Arrival



The values of the inputs to the simulation are determined by using Microsoft Excel®. Excel® spreadsheets are used as a user-interface tool to assign values to attributes and variables, which will be used in the simulation model.

By linking these spreadsheets with the model, the input values can be altered for different scenarios without having to change the values in the simulation model itself. All the spreadsheets are linked with each other, providing a relationship between interrelated cells. This makes it easier for a person with no knowledge of how Arena® operates to run different scenarios and draw data from the model.

The conceptual outputs of the queuing system are typified by a specific probability distribution, which governs a customer's service time. The random variable input data generates random variability in the output data. The most important output statistic of a simulation model will include the following performance measures (Mehrotra & Fama 2003:137).

- Abandonment Statistics
- Queue Statistics
- Volume Statistics

The system will be measured by several KPI's (Key Performance Indicators). These KPI's are used to measure the performance of the different scenarios against each other. The more important KPI's will include the following as stated by Chase, Jacobs & Aquilano (2006:164).

1. **Resource Utilisation** (Picker Utilisation and Packer Utilisation) – It is the ratio of the time that a resource is truly being used in relation to the time that it is available.
2. **Throughput Time** – It includes the time that the unit is being worked on together with the time that the unit spends waiting in a queue (The average time a unit takes to move through the system).
3. **Time in Process** – The time a unit takes to be completed in a specific process e.g. the time it takes a unit to pass through the picking phase.

4 Data Collection and Analysis

One of the very early steps in planning a simulation project should be to identify what data is needed to support the model. The availability and quality of data can influence the modelling approach taken and the level of detail captured in the model (Kelton, Sadowski & Sturrock 2007:174).

Accourding to Kelton, Sadowski & Sturrock (2007:175) a benefit of developing an early understanding of the quality of your input data is that it can help you decide how much detail to incorporate in the model logic. The results and recommendations present, from the simulation study are only as reliable as the model and its inputs.

Input Data Analyzer is included in the Arena® software, it automatically fits existing data values to the best statistical probability distributions. The Input Data Analyzer fits a distribution to the data and provides an estimate of the parameter values and an expression of the model (Kelton, Sadowski & Sturrock 2007:176).

4.1 Input Data and Analysis

Data will be received by intensive time studies on the relevant stations. The input data is retrieved from the Microsoft Access® data base. It is then transferred to Microsoft Excel®, which is more accessible and the data is analysed.

4.1.1 Order Information

Each order generated by a customer has certain data attached to it. The types of goods that is ordered, the quantity of each item and the delivery date. Each order is then classified into three different channels, the IDP (Integrated Delivery Plan), Non IDP and the Priorities. The channels differ in the delivery dates, how urgent a certain order is. The IDP has a fixed despatch date and planning is done around that date. The Non IDP is the most flexible channel it has a shipping window of delivery date plus 30 days. The Priorities is the most urgent orders, if an order comes in today it must be despatched the next day, making it the least flexible channel. This channel is the most important channel for the world cup season.

4.1.2 Transport Time of a Picker per Order

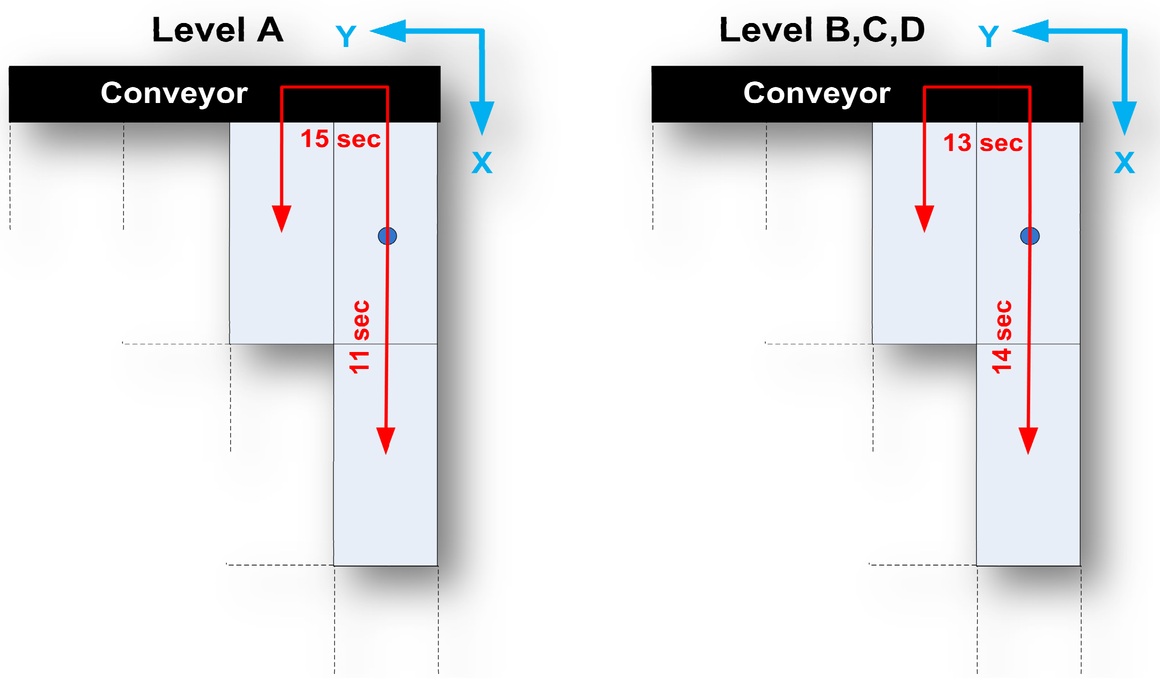
The Transport time of a picker per order is the time a picker takes to walk on a specific level from the one bin location to the next in order to pick the units to fulfil the order. This is time consuming as the order could contain any of the 30,000+ products Nike offer.

Each unit has a specified location that is entered into the system. The levels of the pick face is divided into blocks, level A is divided into 3x9 blocks and levels B,C and D is divided into 3x12 blocks. The blocks are defined by an X-Y co-ordination in order to calculate the size of a block and the distances from one block to the next. The locations of the units are then incorporated into one of these blocks, thus each unit belongs to a specific block on a specific level. The units are linked via there reference to a block.

The time it takes a picker to walk from one block to the next is calculated through time studies (see Figure 9). Level A differs from levels B, C and D because of the greater number of storage locations on these levels.

The time to walk from one block to the next or to any other block is calculated in Microsoft Access®. A formula is used where the times are multiplied if the picker either walks in the x-direction or in the y-direction. The formula differs from level A to the others by; the number the formula is multiplied with. E.g. level A is multiplied in the x-direction with 11 and levels B, C, D is multiplied with 14 (see Figure 9 for the values).

Figure 9: Walking time from one block to next



The travel times are then exported to Microsoft Excel® where the data are pivoted into a table for travel times of level A and a separate table for levels B, C and D (see Appendix 10.1, Table 15 and Table 16). If picking at a certain level does occur, the transport time is calculated in Microsoft Excel® using the Index and Match formulas. The formula is an “if” statement, it looks on what level the picking must occur and uses the level A table or the level B, C, D table. In the “if” statement the Index function is used marking the table that needs to be used. In combination with Index function the Match function is used in order the match, from where and to where (the starting and ending locations), the picker must walk. This value is the transport time from the one block to the next block where the picker must pick next.

After the travel times between the blocks, in order to pick units, are calculated then the travel time to the conveyor is calculated (after all picks is completed and the units must be taken to the conveyor). There are three blocks in the x-direction, the time it takes to walk to the conveyor irrelative in what y-block the picker is, is the block number in the x-direction multiplied with 7.5.

E.g. If the picker stands in the second block in the x-direction then the transport time to the conveyor is 2*7.5 = 15sec. This is calculated for every order on a specific floor.

The total transport time for a picker is the sum of the transport times. These times are then expanded into their different levels (A, B, C, D) by placing them into a matrix form (see Appendix 10.1, Table 17).

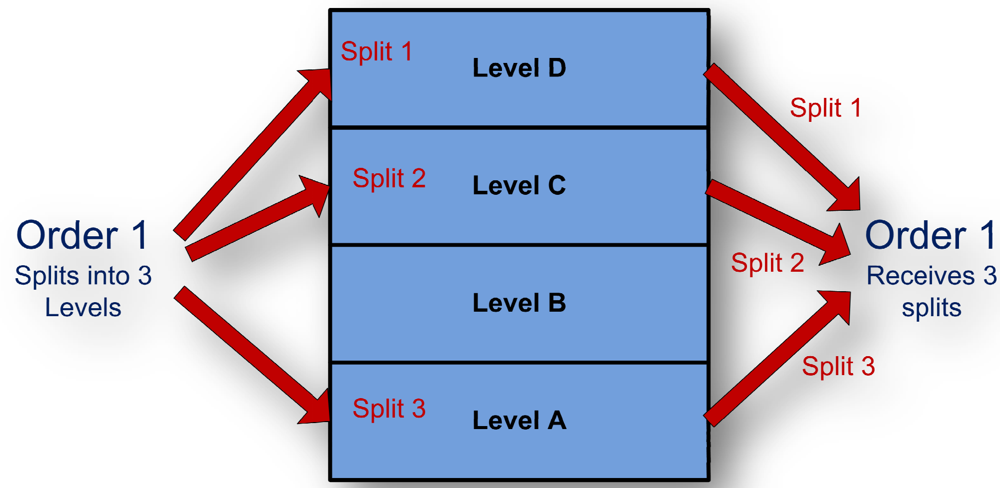
4.1.3 Quantity of a Business Unit Picked

An order contains the quantity of certain products and the type of business units. The Microsoft Access® database then finds the locations of the products that are ordered. It captures the quantity units, type of business unit (footwear or other) and the level it is situated in. A matrix table is then compiled of the information in Microsoft Excel® from the data in the Microsoft Access® database. The matrix table states the order number; the type of business units and the quantity that must be picked on a level (see Appendix 10.1, Table 18). Each order differs and all computation between Microsoft Access® and Excel® is done automatically for each order.

4.1.4 Number to be batched

An order can have units that need to be picked on different levels. If an order has units that need to be picked on different levels, it is then split by the units that need to be picked at different levels. This split in the order must be batched together when the order is packed into boxes. The number to be batched calculates how many splits an order has and the number to be batched must be equal to the number of splits, this is illustrated in Figure 10. The order will not be despatched until the number of splits are all together (see Appendix 10.1, Table 19). It is to assure that all orders are complete when despatched.

Figure 10: Illustration of the split of an Order



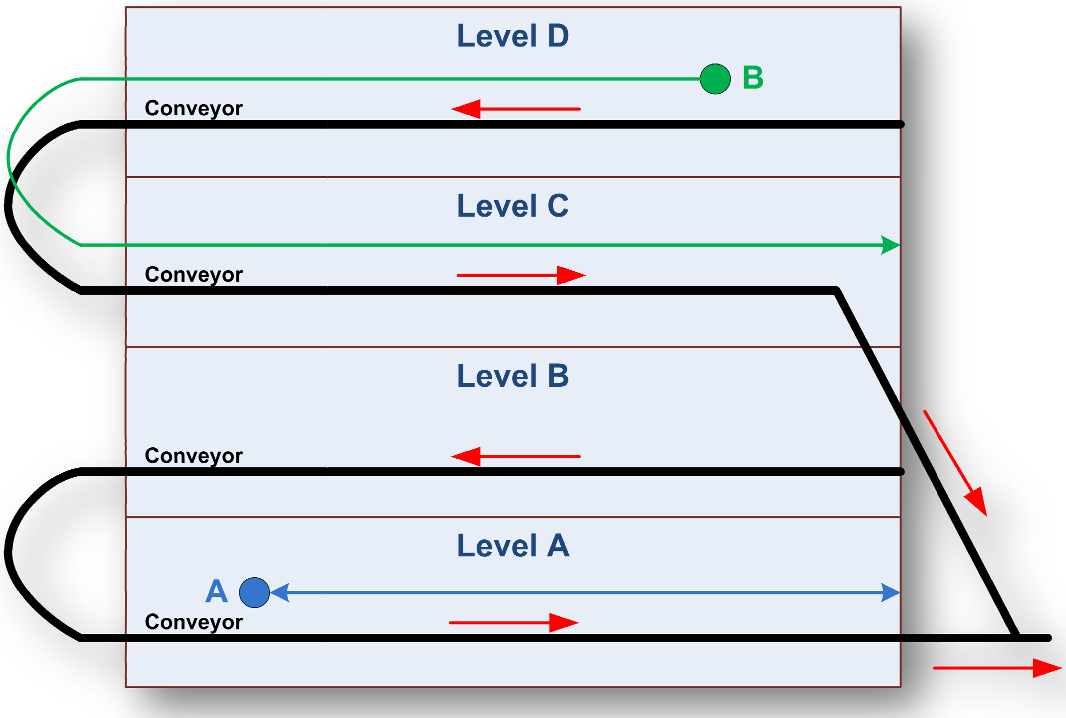
4.1.5 Distance Conveyor travel in Picking

On the side of every level is a conveyor (see Figure 9), when a picker is finished picking an order, the tote (picked units) is then placed on the conveyor. The conveyor conveys the totes to packing. The conveyor moves from level to level as illustrated in Figure 11 by the red arrows.

Each order ends on a different place on a level. The picker then walks straight from the last picked locations to the conveyor. The location of where the totes are placed on the conveyor has an influence on the distance that the tote must travel to packing; this has a direct influence on the time it takes a tote to travel to packing.

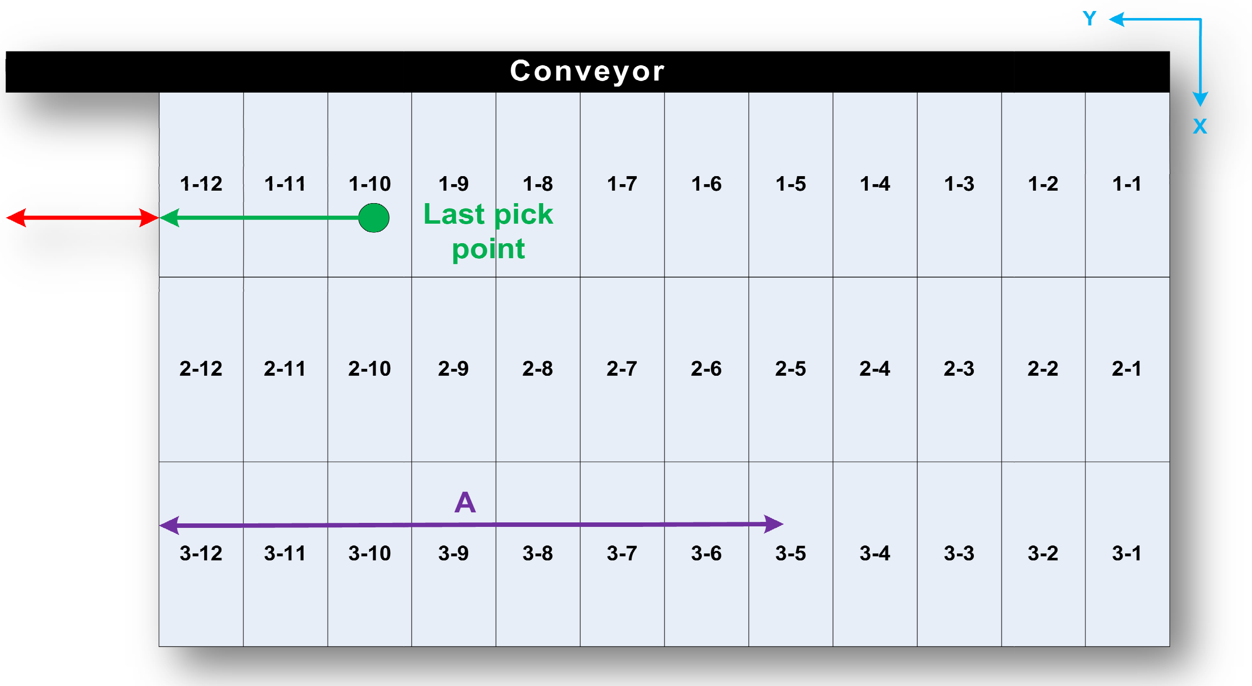
If a tote is placed at position A, in Figure 11, then the tote only has to travel the distance from point A to the end of level A, shown as a blue arrow. If the tote is placed at point B in Figure 11, then the tote must move the distance on level D and the entire distance on level C, shown as a green arrow. Thus the tote at point B will travel longer to get to packing than point A.

Figure 11: Illustration of Conveyor Movement on Picking Levels



The location of the last product on the pick list is used to determine the travelling distance. If on level A the y co-ordination is 9 blocks and on levels B, C, D there are 12 blocks as illustrated in Figure 12, the distance from the last pick point to the end of the level is calculated, which is shown as a green arrow, and the distance of which the conveyor is longer, which is shown as a red arrow, is added together (see Figure 12).In essence the y co-ordinate of the final location is used.

Figure 12: Level Layout



This calculation is done in Microsoft Excel® with 21 "if" statements. It determines the level the picker is situated on. If the picker is on level A then a certain distance is used for the 9 blocks on level A. If the picker is on levels B, C, D then a different distance, than level A is used, because those levels contain 12 blocks. E.g. If the picker is on level C (see Figure 12) in block 3-5 then the distance marked by the letter A is calculate and then added with the distance which the conveyor is longer, marked with the red arrow. The total y co-ordination is calculated from the last pick point to the end of the conveyor.

The distances used in the "if" statements are shown in the Table 1.

Table 1: Distance Conveyor travel from each block

	Distance conveyor travel (m)		
Block Number in y co-ordination	**Level A**	**Level B**	**Level C**
1	6	70	5
2	12	66	9
3	18	61	14
4	24	56	18
5	30	52	23
6	36	47	28
7	42	43	32
8	48	38	37
9	54	33	41
10		29	46
11		24	51
12		20	55

After conducting a few measurements on the conveyors system it was concluded that all conveyor travel at a constant speed. The distance is then multiplied with the speed in order to obtain the time the conveyor takes to move from a level in picking to packing. The distance of the different level is shown in a matrix form and these distances are read into the simulation see Appendix 10.1, Table 20.

4.1.6 Process Time Picking

The process time is the time a picker takes to pick a number of units of a specific business unit (footwear, apparel or equipment). Intensive time studies were done and data was obtained from each station. The time to pick footwear differs to the other business units due to the irregular size difference in apparel and equipment. Apparel and equipment takes the same amount of time to pick thus they are combined into a business unit called "Other". The results obtained from the time studies were analysed.

Table 2: Processing Times for Picking in sec/unit

Process Time (in sec)	Minimum	Average	Maximum
Other	1	19	48
Footwear	3	11	26

Using these results mathematical expressions were developed in Arena® Input Analyzer (Appendix 10.2.1 and 10.2.2) which indicates triangular distributions with the minimum, average and maximum as stated in Table 2. These values may be changed and will automatically change in the simulation model, thus they are user defined.

4.1.7 Process Time Packing

The process packing time includes all the different business units, no distinction can be made between footwear and other. The data obtained for packing follows a mathematical expression developed in Arena® Input Analyzer (Appendix 10.2.3) which is a normal distribution. The average and the standard deviation are indicated in Table 3. These values may be changed and will automatically change in the simulation model, thus they are user defined.

Table 3: Processing Times for Packing

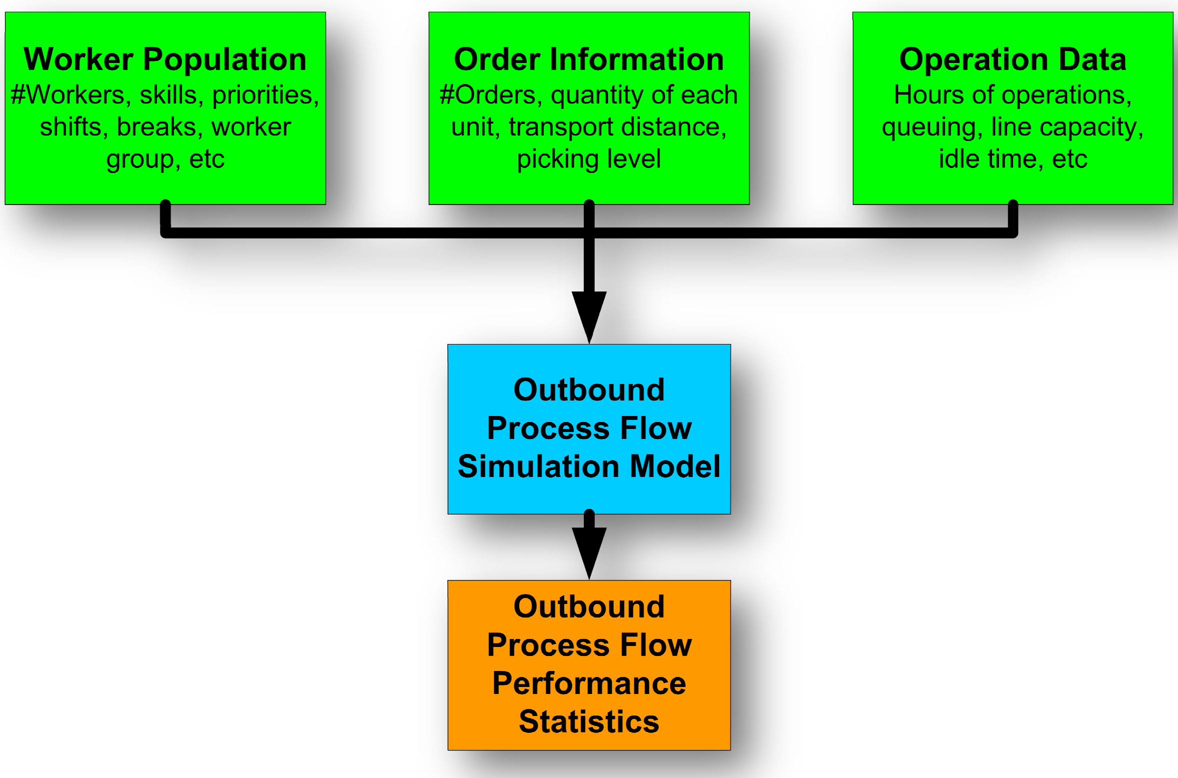
	Average (in sec)	Std Dev
Packing Time	287	98.2

4.2 Soft Data

The soft data include all the data relating to the workforce and personnel. The company policies govern the staffing regulations, such as the number of staff members with their respective skill levels, daily shift hours and weekly schedules.

Figure 13 is adapted in combining information from Buzacott & Shanthikumar (1993), Kelton, Sadowski & Sturrock (2007) and Chase, Jacobs and Aquilano (2006) to illustrate the data involved in the simulation study.

Figure 13: Data input to Simulation Study



5 Depiction of Simulation Model

The development of the simulation model is seen as the most difficult and critical part because of the detailed description and conceptual translation of the system. Logic relations combines with mathematical relations must represent the important attributes of the processes. The simulation model is divided into four activity areas.

5.1 Conceptual Translation

The conceptual translation of a model lays an essential foundation in the progress or design phase and is also referred to as identification or the 'pieces of the model'. Conceptual translating a model is to, formulate the model design and approach before one actually builds the model in Arena®. The justification behind this is to ensure that all mechanisms and 'building components' are considered. Some of the things that one should take into account are the data structure or constraints, the type of analysis to be performed, the type of animation required and replication length, just to name a few.

5.1.1 Entities

Entities are the dynamic objects of the simulation. They move around, change status, affect and are affected by other entities and the state of the system and affect the output performance measures (Kelton, Sadowski & Sturrock 2007:20).

A single entity is created at time zero merely to assign a set of attributes and variables to the model. A Read/Write module is used to obtain all the attributes and variables from the Microsoft Excel® spreadsheets.

The second entity which is created receives the attributes assigned to it. This entity gets replicated and each replication is specified as an order made by a customers.

5.1.2 Attributes

An attribute is a common characteristic of all entities, but with a specific value that can differ from one entity to another (Kelton, Sadowski & Sturrock 2007:21).

By attaching multiple attribute values to each entity, each entity becomes unique. The attributes of each activity will be listed independently, since their values are determined by an Excel® spreadsheet. All the attributes needed to perform the outbound process flow model are listed in Table 4.

Table 4: List of Attributes

Attribute Name	Description	Purpose
TransTime_A **TransTime_B** **TransTime_C** **TransTime_D**	Time (Transport time) it takes the picker to walk from one pick station to the next on a specific level.	To measure the time it takes to walk, a specific distance by that operator for an order.
Order#	Each order has a specific number which is call the order number.	In order to rectify what customer placed what order.
#beBatched	It indicated how many totes must be batched, if the order is split in the picking phase.	To make sure that all the totes that have been split is together for the same order.
Qty_LA_Other **Qty_LA_FW** **Qty_LB_Other** **Qty_LB_FW** **Qty_LC_Other** **Qty_LC_FW** **Qty_LD_Other** **Qty_LD_FW**	The number of Other/FW units that needs to be picked at a specific level (Level A, B, C or D)	It is used to be multiplied by the time to pick that specific unit. In order to get the total processes picking time.
ConvDist_LA **ConvDist_LB** **ConvDist_LC** **ConvDist_LD**	The distance the conveyor needs to travel from where the picker places the units on the conveyor to the end of the level see Figure 12.	To calculate the total time the conveyor takes to transport the units to the next station. The distance is multiplied by the speed of the conveyor.

5.1.3 Variables

A variable is a piece of information that reflects some characteristic of your system, regardless of how or what kind of entities might be around. There can be many different variables in a model (Kelton, Sadowski & Sturrock 2007:21).

Table 5: List of Variables

Variable Name	Description	Purpose
PT_Other_Min **PT_Other_Avg** **PT_Other_Max**	The range of the process time (picking time). The process time, is the time a picker uses to pick a single unit of type Other.	It is used to calculate the time a picker takes to pick a specified number of unit and of type Other. The quantity is multiplied by process time.
PT_FW_Min **PT_FW_Avg** **PT_FW_Max**	The range of the process time (picking time). The process time, is the time a picker uses to pick a single unit of type FW (Footwear).	It is used to calculate the time a picker takes to pick a specified number of unit and of type FW. The quantity is multiplied by process time.
PT_Pack_Avg **PT_Pack_StdDev**	It is the average packing process time and its standard deviation.	The packing follows a normal distribution. The average and the standard deviation are used as inputs for the distribution.
Input_Taller **Input_Taller + 1**	It is a variable that is given when an entity pass.	It is used to form the logic that a specified number of orders are released from the pick pool for picking.
Max#Order	It is the total number of orders placed by the pick pool (the number of the last order).	It is used to find the last entity (order) in the simulation model.

The variables used are user-defined and the values are determined by Excel® spreadsheets. The variables used to perform all the actions in the model are listed in Table 5.

5.1.4 Resources

Resources represent things like personnel or equipment. An entity seizes (a number of units of) a resource when available and releases it (or them) when finished (Kelton, Sadowski & Sturrock 2007:22).

The following resources were identified in the model operations:

Table 6: List of Resources

Resource Name	Description
Picker	It is a person who receives an order that needs to be picked by hand. The picker walks to every station and pick the specific amount of units and place it in a tote, when finished the tote is placed on the conveyor.
Packer A-J	It is a person who packs all the single units from the totes into boxes for shipment.

The current system contains 8 picker resource units for the picking and 2 packers for every pack station, there are 10 pack stations.

5.1.5 Queues

The purpose of a queue is when an entity can not move on because it needs to seize a unit of a resource that is tied up by another entity; it needs to be place to wait. (Kelton, Sadowski & Sturrock 2007:22).That entity will wait in the queue until a resources is available.

The queues defined in the simulation model are listed in Table 7.

Table 7: List of Queues

<table>
<tr><th>Queue Name</th><th>Description</th></tr>
<tr><td>Transport between Station_LA.Queue
Transport between Station_LB.Queue
Transport between Station_LC.Queue
Transport between Station_LD.Queue</td><td>The waiting of a picker resource at a specific level (A, B, C, D). In order to seize it for picking at that level.</td></tr>
<tr><td>Batch Orders same OrderNumb.Queue</td><td>If an order is split at picking it needs to be batched together to ensure that the full order (not just a part of the order) is despatched to the customer. It is the waiting of an entity (part of an order) for the rest of the order to be completed.</td></tr>
<tr><td>Packer Station_A.Queue
Packer Station_B.Queue
Packer Station_C.Queue
Packer Station_D.Queue
Packer Station_E.Queue
Packer Station_F.Queue
Packer Station_G.Queue
Packer Station_H.Queue
Packer Station_I.Queue
Packer Station_J.Queue</td><td>It is the waiting of an entity at the pack station, for a specific resource, in order to pack the complete order.</td></tr>
</table>

5.1.6 Conveyors

Long distance transportation of product is facilitated through the use of belt conveyors systems. The following conveyors are activities on their own. They were identified to convey totes from the picking station to the packing station and then from the packing station to the despatching area. The conveyors in the picking and packing stations move at a constant speed.

Table 8: Conveyors

Conveyor Name	Description
Conveyor Picking	It is the time a conveyor uses to transport totes from the picking stations to the packing stations.
Conveyor Packing	It is the time a conveyor uses to convey the boxes from the packing stations to the despatching station.

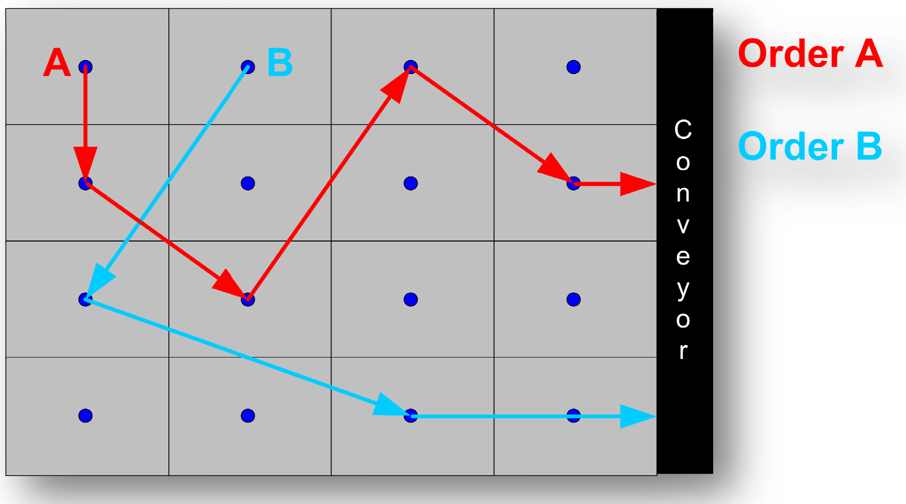
5.1.7 Picker Travel Pattern

Each order that a picker receive has a unique travel pattern on that level (the travel pattern is unique to that specific order) this is shown in Figure 14 and described in section 4.1.2. This pattern is calculated so that the picking of the units occur in the least amount of walking distance. The travelling time is proportional to the distance travelled from one pick location to the next.

To obtain the travel time of the picker from each station, the distance must be calculated as stated in section 4.1.2. The calculation is done in Microsoft Excel® and read in to the simulation model.

Level A is divided into 27 blocks and levels B, C and D is divided into 36 blocks. The distance from the centre of the one block to the next is known and this includes all the blocks on all the levels. This gives the distance travel by the picker from the one block to the next. The system knows what type of units is stored in each block and a walking pattern is developed for the sequential distance for each order. This gives the travelling distance of a picker between stations and that travelling distance is used to calculate the travelling time of the picker.

Figure 14: Picker Travel Pattern



6 Simulation Model Construction

The simulation model construction can be very time consuming, depending on its detail and complexity. The best approach is to start with a simple model and increasing the detail and complexity as system knowledge advance. Verification and validation of the processes and methods used are discussed in this section.

6.1 Model Activity Areas

The simulation model construction is divided into several activity areas to better understand and illustrate the logic of the model. The activity areas are as follows:

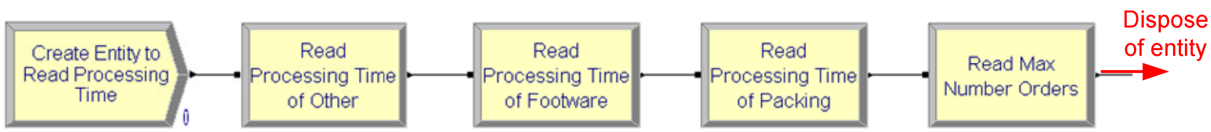
1. Order information generation
2. Pick face
3. Pack stations
4. Despatch and Output transfer

6.1.1 Order Information Generation

In this activity area two entities are generated, the first is created to read all the specified variables and the second entity is specified as an order from a customer.

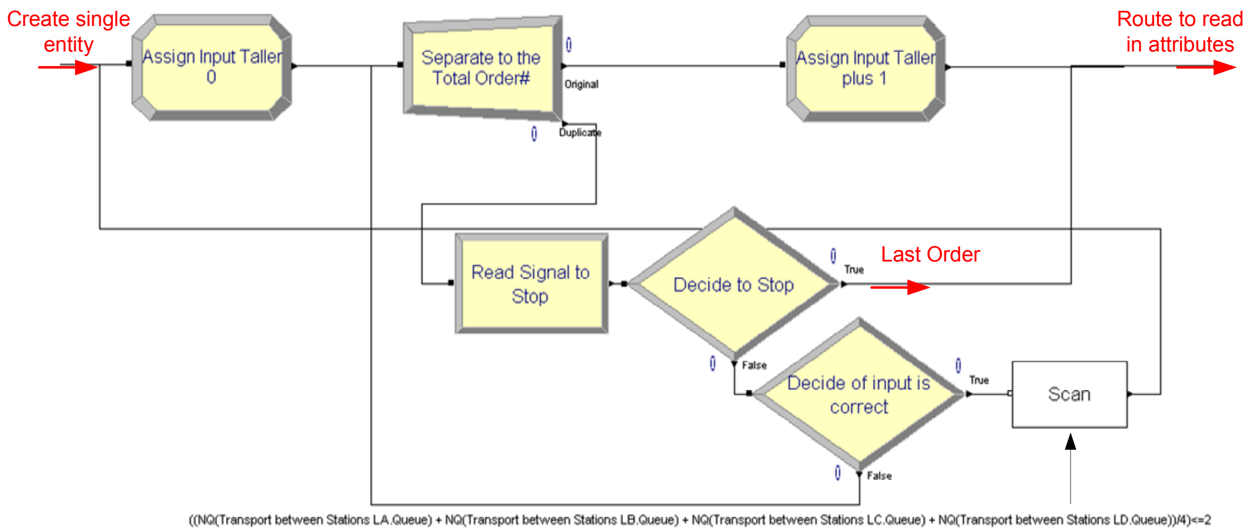
The first entity is created at time zero and runs through the read modules (Figure 15); it reads the different variables as in the picking processing time of the different business units, packing processing time and the total number of orders. Section 5.1.3 describes the different variables that are imported from the Microsoft Excel® spreadsheets. The variables are then incorporated into the different distributions for the picking and packing processing times, these distributions are described in section 4.1.6 and 4.1.7. The variable that indicates the total number of orders is used at the end of the simulation model, so that the last order writes all the required data to the Microsoft Excel® spreadsheet.

Figure 15: Read Simulation Model Variables



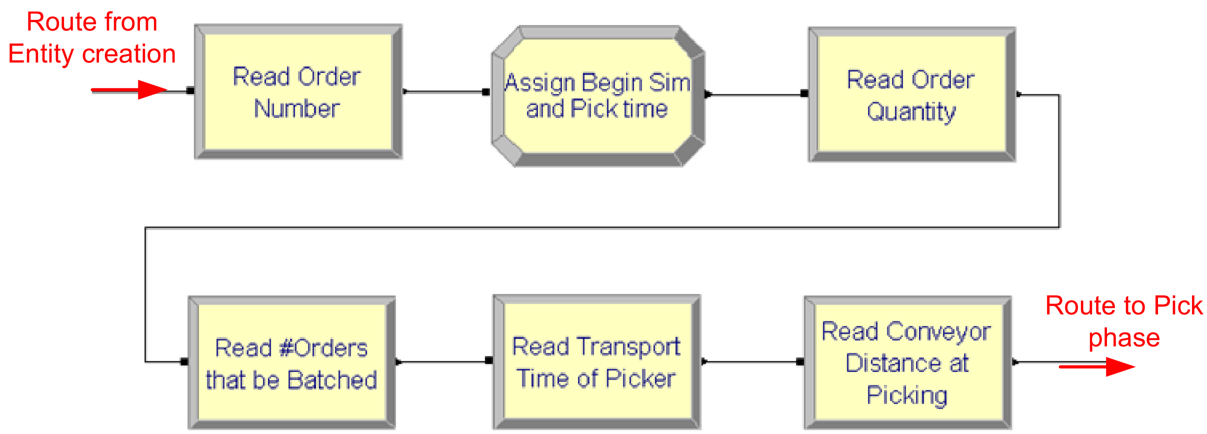
The second entity is described as an order made by a customer and is created at time zero. It enters the first assign module (Figure 16) where "zero" is assigned to a variable (Input_Taller). The entity then enters a separate module and is duplicated. It then enters the second assign module where the variable (Input_Taller) is added with a value of one (Input_Taller + 1). The duplicated entity reads (using read module) from a Microsoft Excel® spreadsheet a value, this value is either a 0 or a 1. If it is a 0 then it means that there are more orders that needs to be send from the pick pool (it is not he last order) and if it is a 1 then it is the last order. The first decide module verify the value of the number (0 or 1) and if that number is 1 then it sends the entity on (the statement is true); no more entities are duplicated as it is the last order from pick pool. If it is not the last entity then it enters the second decide module. The orders are sent from the pick pool to picking in batches that are specified by the user (e.g. 100 orders are sent at a time to picking). The second decide model verify the variable (Input_Taller), if the variable is equal to that value which is specified by the user, the batch size value (e.g. 100). If it is not equal then the entity follows the path explained above and the value of the variable (Input_Taller) is increased with 1. (Input_Taller gets bigger until it equals the batch size value). If the second decide module is true (equal to the user specified value) then it enters a scan module. The scan module scans the queue length at picking (Transport between stations queues). It verifies if the value of the sum of the queue length divided by four is smaller or equal to 2, if not then the scan module waits until the queue is smaller or equal to 2. If that occurs then the entity is released by the scan module. The entity then enters the first assign module, where the variable (Input_Taller) gets assigned the value zero. The same process occur as explained until the last order is send on by the first decide module. See Figure 16 for a graphical presentation.

Figure 16: Duplication of Entity to the Number of Orders



The entity then enters the process of getting assigning different attributes from the Microsoft Excel® spreadsheets. These attributes are order number, quantity and type of business units' etc. description of all the input data is described in section 4.1. These attributes will dictate processing sequence, time and quantity. The attributes are read from the spreadsheet with a read model. Figure 17 illustrates the path of the entity in obtaining the different attributes of each order. As can be seen in Figure 17, when the entity enters the simulation model an assign module is used to assign the current simulation time to that entity, this attribute is later used to analyse the simulation time. It gives the entity a time stamp of when it entered the simulation model.

Figure 17: Assigning and Reading Attributes to Entity

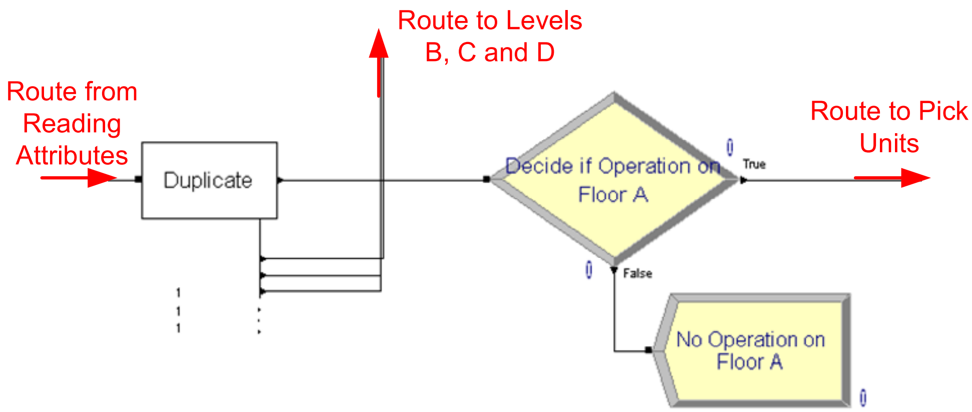


Appendix 10.4.1 illustrates the complete Arena® model for the order information generation activity.

6.1.2 Pick Face

The entity assigned with different attributes also known as an order, gets duplicated and sent to all the different floors of the pick face area. There are four levels of picking as stated previously and the order is send to all four. A decide module checks the attributed value of the transport time on that level, if the number is greater than zero then it means that transportation of business units occur on that level, thus the order is send to that level for picking. If the transport time for that level is zero then it means that no transporting of the business unit occurs on that level and the order is send to the dispose module.

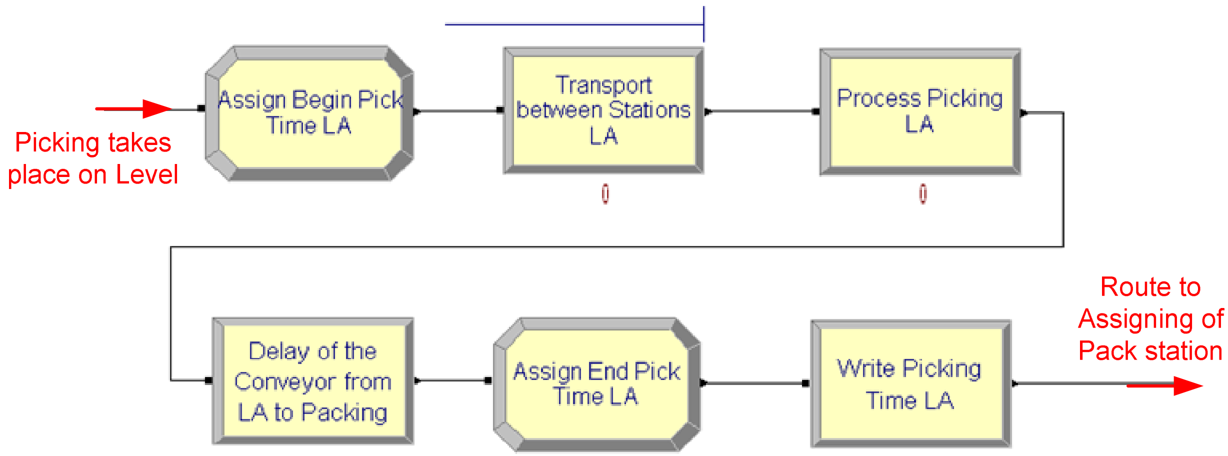
Figure 18: Assigning Orders to different levels for picking



After defining that picking should take place on a level by the decide module, the order is send on for processing of the transport of the picker from each location and the actual picking of the business units.

The order passes an assign node (Figure 19) where the simulation time is stamped on the order as an attribute, this time stamp indicates the time the picking process for an order starts. At the end of the picking process another assign module assigns the simulation time to that same order, thus the beginning and ending times of picking is given to the order as attributes. The write module writes the specified attributes to a Microsoft Excel® spreadsheet for further analysis of the times an order spends in picking.

Figure 19: Picking and Conveying Processes



The order enters a process model called transport between stations LA (or LB, LC, LD) where a resource namely a picker is seized and delayed for a specific period of time. The delay time is the time the picker takes to walk from each location to the next to pick business units for a specific order. The time is calculated in Microsoft Excel® see section 4.1.2 for details in calculation of the transport time of a picker for an order.

After the transportation process, the order then gets delayed from the same resource (picker). The second delay is the process time for the picking of the business units (actual time it takes to pick one unit). The quantity of business units is multiplied with the processing time of that specific business unit. The processing time (picking time) for footwear differs from that of the other business unit, they are added together and form the picking processing time. The processing times is described in section 4.1.3 refer to that section for more information. The picked units are placed in totes (container for transporting the ordered units), these totes are placed on the conveyor and the picker resource is released in order to seize another order.

The conveying of the totes from picking to packing is at a constant velocity, a delay module is used (Figure 19). The time it takes to convey the totes is directly dependant on the location where the tote is placed by the picker on the conveyor. The calculation of the distance is described in section 4.1.5 and the distance the conveyor must travel for that order is read into the model through a read module (Figure 17). The distance which the conveyor must travel is multiplied with the constant velocity of the conveyor which is 4.2sec/meter, giving the total delay time of the conveyor. Appendix 10.4.2 illustrates the complete Arena® model for the pick face activity.

6.1.3 Pack Station

The tote that comes from the picking area via the conveyor passes an assign node where the simulation time is given as an attribute to the tote. It is a time stamp of when the packing process begins. The tote then enter a decide module, the module must assign the tote to a specific packing station. The logic is that there are two packers at each packing station, if a tote enters the packing area it must be assign to a pack station. First the logic checks if packer A is busy (if the number of resources busy are less then 2) then the tote is assign to that pack station otherwise it checks the number of resources (packers) currently busy at pack station B, if that is less than two then it gets assign to pack station B, this is carried on until pack station J. Pack station A will be the first to fill then B and so on.

Figure 20: Decide on packing station

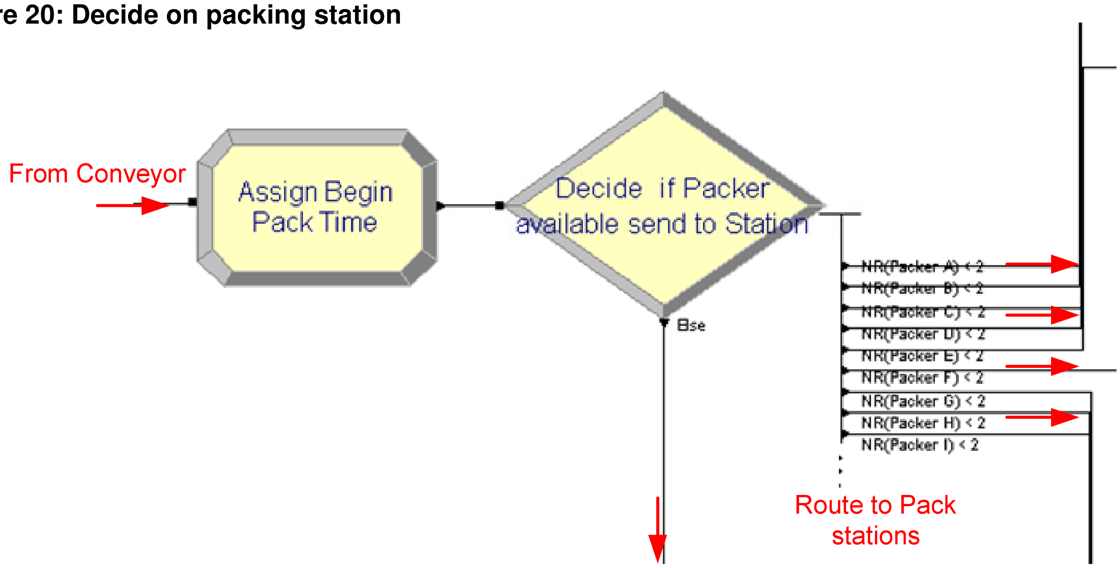
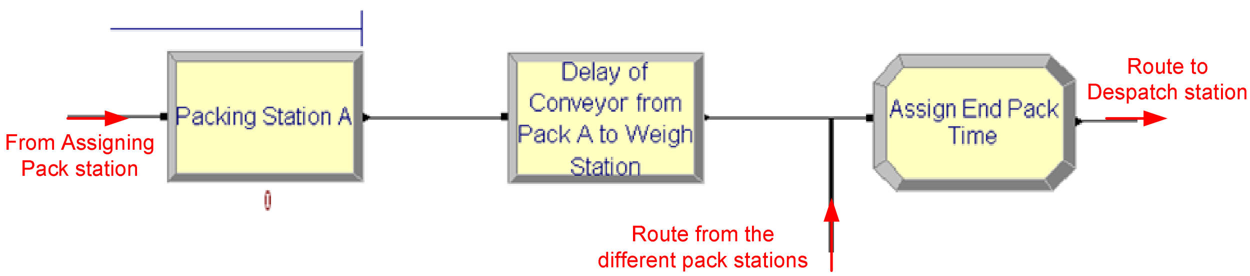


Figure 21 illustrates the actual packing of the units from the totes into boxes for shipment. The tote enters the packing process and seizes a resources call a packer. The resource is seized, delayed and released for a certain period of time. This pack processing time is calculated using a mathematical formula see section 4.1.6 and 4.1.7 on the analysis of the pack processing times and the distributions.

Figure 21: Packing Process



The boxes that have been filled with the units are conveyed to the weigh station. The time the conveyor uses to convey the boxes depend on the location of pack station where the box was packed. The further away the pack station is from the weigh station the longer the time it takes the conveyor to convey the boxes. This distance is calculated and multiplied with the speed of the conveyor, because it moves at a constant speed. The delay module is used as the conveyor from the one station to the next. The boxes enter an assign module where the simulation time of the end of the packing process is stamped on the box as an attribute.

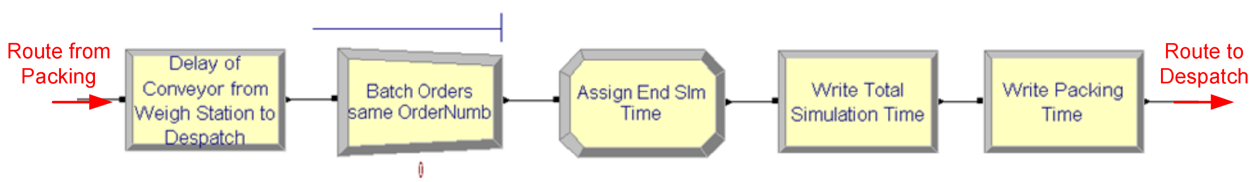
Appendix 10.4.3 illustrates the complete Arena® model for the pack station activity.

6.1.4 Despatch and Output transfer

The distance from the weigh stations to the despatching area is a fixed length, thus the conveying times are constant and the time to weigh a box is constant. Because of the constant time impediment a delay module is used to delay the boxes.

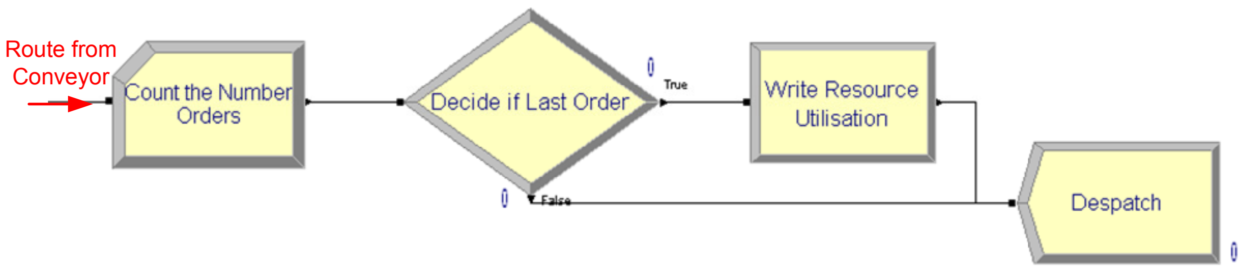
After the delay the boxes are batched together according to their order number, see section 4.1.4 on how many boxes must be batched per order. Next an attribute of the simulation time is assigned to the boxes; it places a time stamp on how long it took for an order to complete all the processes. The different attributes are then exported with a write module to a Microsoft Excel® spreadsheet. These attributes are the time stamps that were placed on the orders to derive the time it takes to complete a specified process.

Figure 22: Delay, Batching and Output transfer processes



The box (order) enter a counter and after that a decide module. The decide module verify if the counter value is equal to the total number of order placed by the pick pool (the variable: Max#Order). If it is true then it is the last order and all the resource utilisations are exported through a write module to the Microsoft Excel® spreadsheet. The order is then despatched.

Figure 23: Despatching of orders



Appendix 10.4.4 illustrates the complete Arena® model for the despatch and output transfer activity.

6.2 Verification and Validation of the Model

6.2.1 Verification

Verification is the process of ensuring that the model behaves in the way it was intended, according to the modelling assumptions made. A thorough investigation on the input parameters is an important aspect in verifying the minor details of the simulation model. Debugging is a major process that is involved in verification; all problems or bugs need to be cleared to ensure that the model runs for the desired duration.

6.2.1.1 Verification Techniques

A single entity is sent to enter the model, that entity is followed (step-by-step) through the model to be sure that the model logic data is correct.

Animation is used as a visual representation of the activities performed by the model. The use of various colours, graphs and assigning different picture to the status of each of the resources (e.g. idle or busy), ensures that the entity flow can be followed.

Counters and Discrete-Change Variables are also measures of entity flow. Verification takes place by consulting the Output Analyzer. These values should resemble the number of entities through counters or variables.

SIMAN code verification is a method of validation. The Experiment Processor (EXP) and Model Processor (MOD) code can be examined for errors.

6.2.2 Validation

Validation is the task of ensuring that the model behaves the same as the physical system. Validation can be described as the process of ensuring that the built simulation model is a good representation of the physical system.

Validation does not mean that the model is exactly as the physical system. It does mean that the model has been built sufficiently, representing, the physical system in order to make decisions concerning the physical system by testing them on the simulation model.

In order to validate a simulation model, the results from the model must be compared with the results from the real system. If the results are similar then the validation is complete. Validation was done by comparing the outputs to the real system outputs.

6.3 Scenario Development

The main objective is to test the flexibility of the current system and to see if the demand levels for the Soccer World Cup season can be met. Future growth in demand and the pressure it will place on the system is also analysed. There are only a few alterations made in the different scenarios to the simulation models itself in terms of logic modifications, merely to the input parameters imported from Microsoft Excel®. Model construction and operational activities are kept roughly the same with minor changes throughout all the scenarios. The scenario development is divided into three different sections and from these sections different scenarios were developed.

6.3.1 Increased growth in forthcoming years

Information gained regarding growth in the quantity of units ordered was received from Nike. The purpose of the scenarios is to indicate the impact of growth of the quantity of units order on the outbound process flow. The growth is in 3 years incremental.

6.3.1.1 Scenario 1: A

System performance and input constraint remains the same as the current year (2009) for the next three successive years. The base model is established.

6.3.1.2 Scenario 1: B

Increase the quantity of the units ordered by the customers with 5%. These changes will be effective within three years, in 2012.

6.3.1.3 Scenario 1: C

Based on the changes made in scenario 2, increase the quantity of the units ordered by the customers with another 5% (a total increase of 10% from the current year 2009). These changes will be effective within three years, in 2015.

6.3.2 Change in the number of resources

The resources (pickers and packers) are one of the key factors, the bottlenecks and queues are closely correlated with the number of resources available for a specific process. Increasing the number of resources will decrease the resource utilisation but will increase the throughput time and this is of more importance to Nike. The Key Performance Indicators (KPI's) will be compared, refer to section 3.2.

6.3.2.1 Scenario 2: A

The picker is the resource that is places the most strain in the model, because of the number of pickers available. The picker resource capacity is increased by three to the total number of picker of eleven.

6.3.2.2 Scenario 2: B

The picker resource capacity is increased further with four making the total capacity of the picker resource to fifteen.

6.3.2.3 Scenario 2: C

The number of packer is underutilised thus a decrease in the number of pack stations will increase the resource utilisation. The number of pack stations is decreased from ten packing stations to seven packing stations. This is an actual decrease of six packers because each pack station has two packers assigned to it.

6.3.3 Change the number of orders released from the pick pool

As explained in section 1.1.1 the orders placed by customers are consolidated in a pick pool before picking tasks are assigned to each picker for processing. The batch size of the number of orders released from the pick pool is equal to 100. Decreasing this value will increase the flexibility of the system. The flexibility of the system is an important factor, thus testing how the system will behave if numerous orders come through of high importance (Expedite orders). These orders will resemble if a team of the Soccer World Cup goes through to the next round, then an increase in sales are expected and must be delivered within the next day. The batch size is changed from 100 order to 50 orders, thus increasing the flexibility of the system and expedite orders can be handled more efficiently.

6.4 Possible follow-up Scenarios

6.4.1 Business unit locations

The distance a picker must walk in the picking station is relative to the classification of the items that must be picked. Fast moving items are assigned to locations as close as possible to the conveyor on the ground floor, level A. Different patterns in the way the units are stored on each level is a way to reduce travel time. Calculating the different travel times for the different patterns will have a positive effect on the throughput time. Thus, optimising pick directives.

6.4.2 Conveyor Speed

The conveyor takes a very long time in conveying the units from pick stations to their assigned pack station and then to dispatching. Thus analysis of the time the conveyor takes can be measured and a trade-off study developed. The trade-off study is between the increases in the throughput time of faster conveyors to the capital cost of new conveyors.

7 Simulation Results and Recommendations

All the scenario runs consisted of one replication for the duration of completion of all the orders. For information regarding the input data refer to section 4. The scenarios are described in section 6.3 and will be evaluated in the following section regarding output parameters attained from reports created by Arena® and data exported to Microsoft Excel® spreadsheets. Reports containing a statistical summary of specified data collection are generated after each simulation run. Additional output date is shown in section Appendix 10.3.

7.1 Increase growth in forthcoming years

The aim is to evaluate yearly throughput time of the orders and utilisation in each section in order to make correct assumptions.

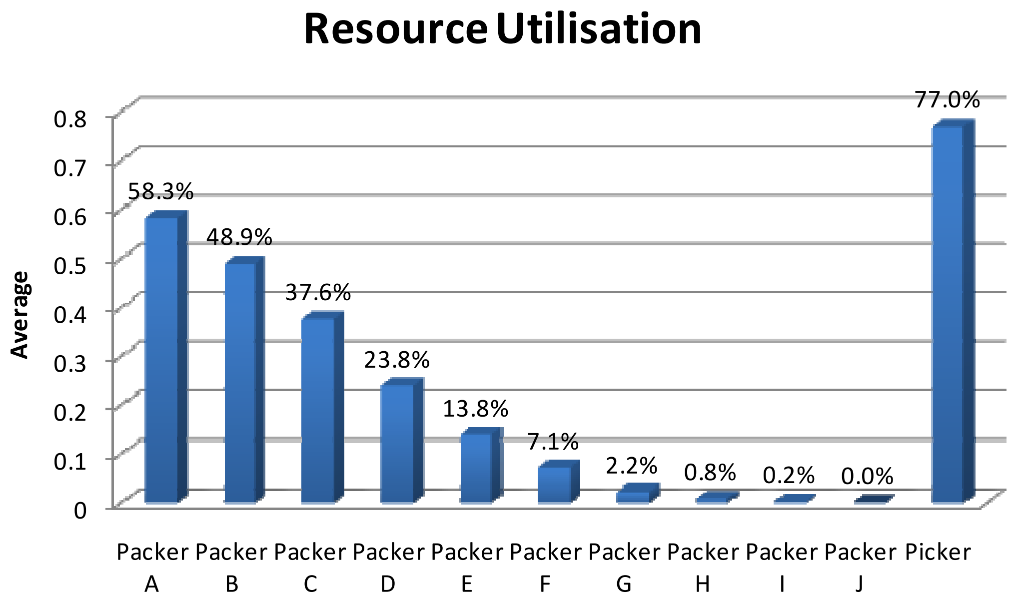
7.1.1 Scenario 1: A

All constraints remain the same, thus the current system results is obtained in Table 9. It states the current output of Nike. It is also referred to the base model.

Table 9: Base model results

Statistics		Output Value (min)
Throughput Time	Average	89.55
Time in Process	Average	79.03
	Picking LA	90.65
	Picking LB	77.62
	Picking LC	54.34
	Picking LD	60.3
	Packing	6.16

Figure 24: Resource utilisation of base model with 8 pickers



The picker is the resource that is utilised the most, indicating that it is the constraint resource (bottle neck).

7.1.2 Scenario 1: B

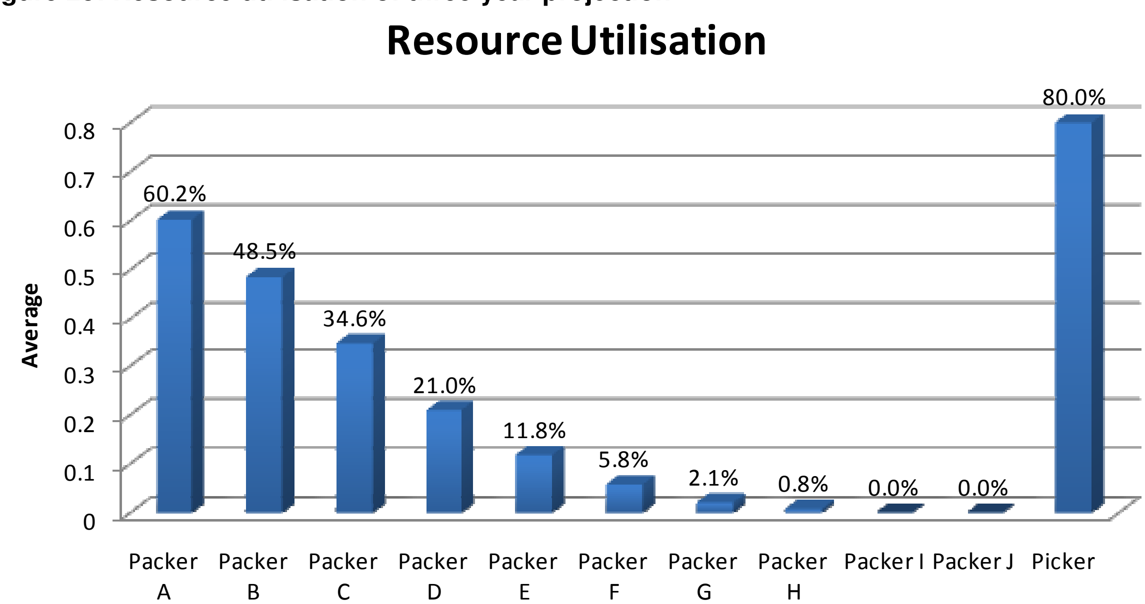
As expected the increase in the number of units ordered by the customers increased the throughput time and also the time in process.

Table 10: Three year projection in quantity of units ordered results

Statistics		Output Value (min)
Throughput Time	Average	95.12
Time in Process	Average	84.41
	Picking LA	64.16
	Picking LB	57.93
	Picking LC	82.52
	Picking LD	97.07
	Packing	6.13

The utilisation of the resources increased, with more work that had to be done because of the 5% increase of the number of units ordered by the customers.

Figure 25: Resource utilisation of three year projection



It is suggested that over the period of three years with an increase of 5% on the number of units ordered by the customer, that the number of the pickers must be increased. Additional studies can be done on the number of picker resources required in order to maintain the current throughput time. It is not necessary to increase the number of packer because the last four packing stations utilisation's is almost zero.

7.1.3 Scenario 1: C

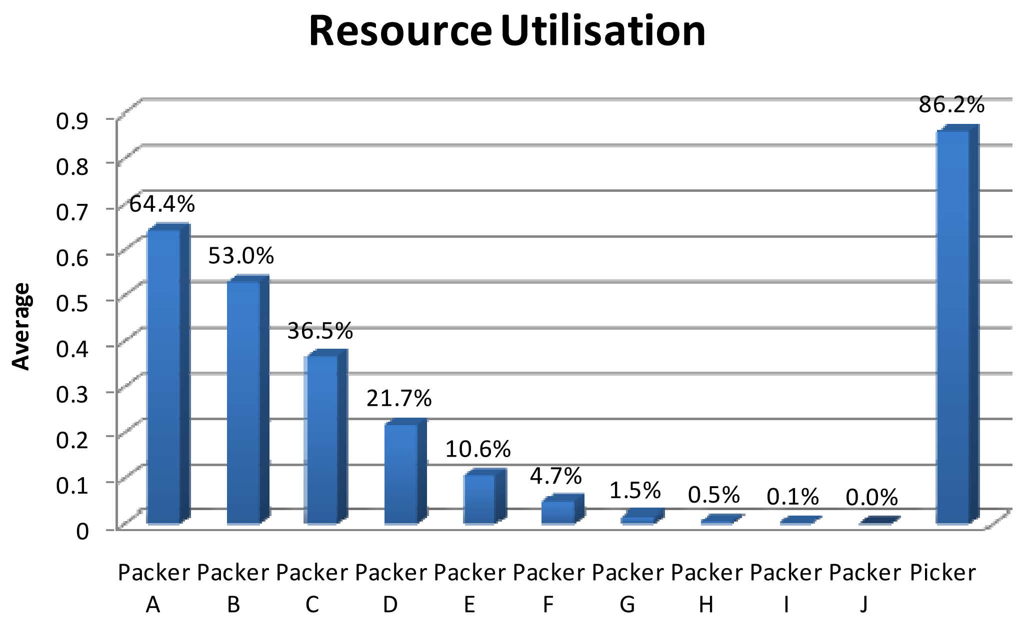
As in the previous scenario the throughput time and the time in process increases with the increase of the number of units ordered from customers.

Table 11: Six year projection in quantity of units ordered results

Statistics		Output Value (min)
Throughput Time	Average	100.15
Time in Process	Average	89.1
	Picking LA	102.65
	Picking LB	86.13
	Picking LC	62.37
	Picking LD	67.49
	Packing	6.15

An increase in volume results in higher resource utilisation.

Figure 26: Resource utilisation of six year projection



As the year pass more units are ordered thus more pickers must be employed to have the same throughput time as the current year. Additional studies can be done on the number of picker resources required in order to maintain the current throughput time.

7.2 Change in resource capacity

The aim is to evaluate the throughput time of the orders and utilisation with the change in resources. Refer to section 7.1.1 for the base case of the simulation model.

7.2.1 Scenario 2: A

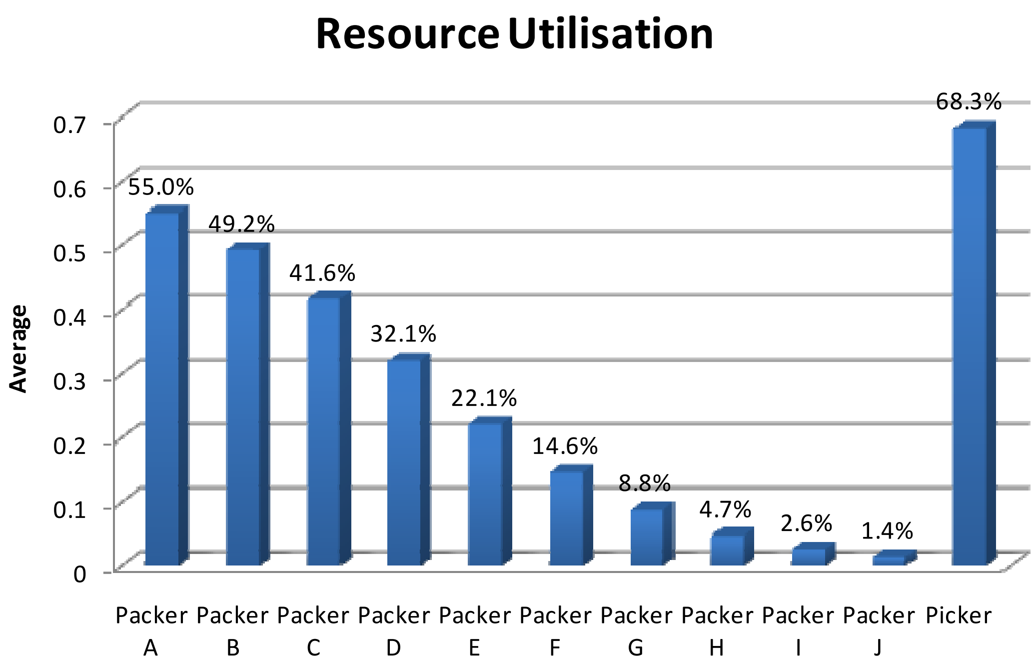
The increase in the number of picker resources greatly reduced the throughput time. This is an indication of the sensitivity of the system related to the number of picker resources. A reduction in all the times is illustrated.

Table 12: Increase picker resource capacity by three results

Statistics		Output Value (min)
Throughput Time	Average	72.78
Time in Process	Average	62.94
	Picking LA	70
	Picking LB	63.49
	Picking LC	44.93
	Picking LD	52.31
	Packing	6.03

The resource utilisation for the picker shows a decrease, but an increase is shown in the utilisation of the packers (except for packer A). This change in the utilisation is as predicted, more picker are available thus more units are pushed through the system. This in turn makes the packers work harder because the units are sent from picking at a much higher rate. It is more important for Nike to decrease the throughput time then to increase all the resource utilisations. In doing this more units can be sold and in turn more revenue.

Figure 27: Resource utilisation with increase of three pickers



7.2.2 Scenario 2: B

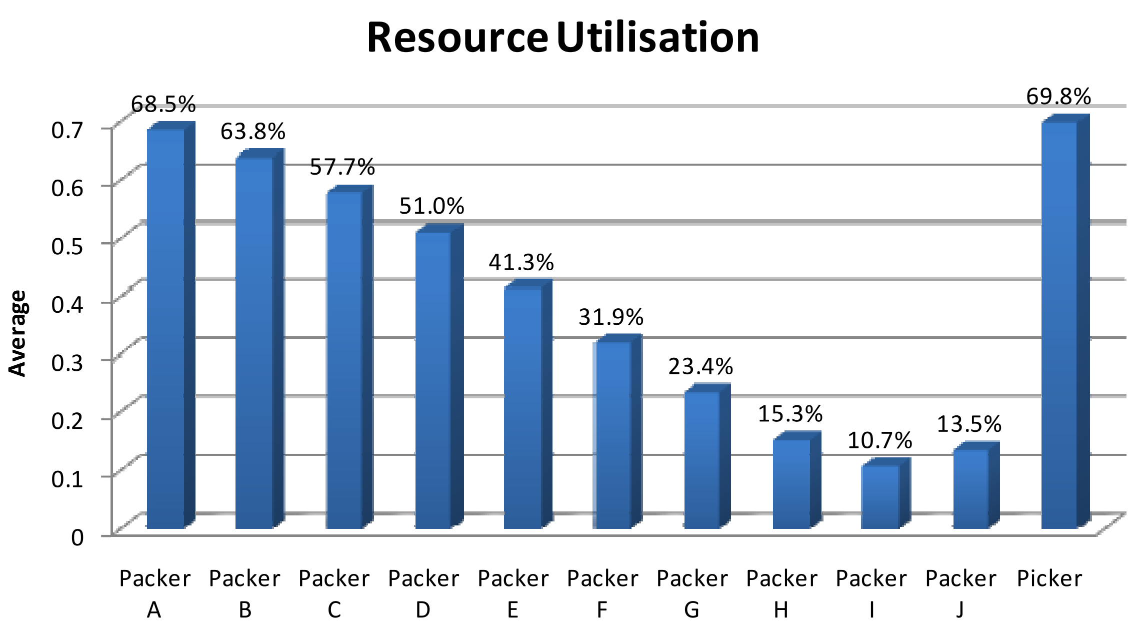
Increasing the picker also indicated a reduction in the throughput time and the time in process. The results indicate a drop in picker utilisation compared to pervious scenarios, but a greater increase in the packer utilisation indicates that more units are pushed through the system.

Table 13: Increase picker resource capacity by seven results

Statistics		Output Value (min)
Throughput Time	Average	57.48
Time in Process	Average	48.88
	Picking LA	52.79
	Picking LB	50.89
	Picking LC	35.68
	Picking LD	43.4
	Packing	6.15

The results obtained behaved as the previous scenario. Increasing the resource capacity decreased the throughput time. The values obtained are lower in the times and increase in the utilisation except for the packer resource.

Figure 28: Resource utilisation with increase of seven pickers



It is suggested that Nike employ more picker. More analysis can be done on the exact number, but increasing the number of pickers shows a considerable decrease in the throughput time and an increase in the utilisation of the packers.

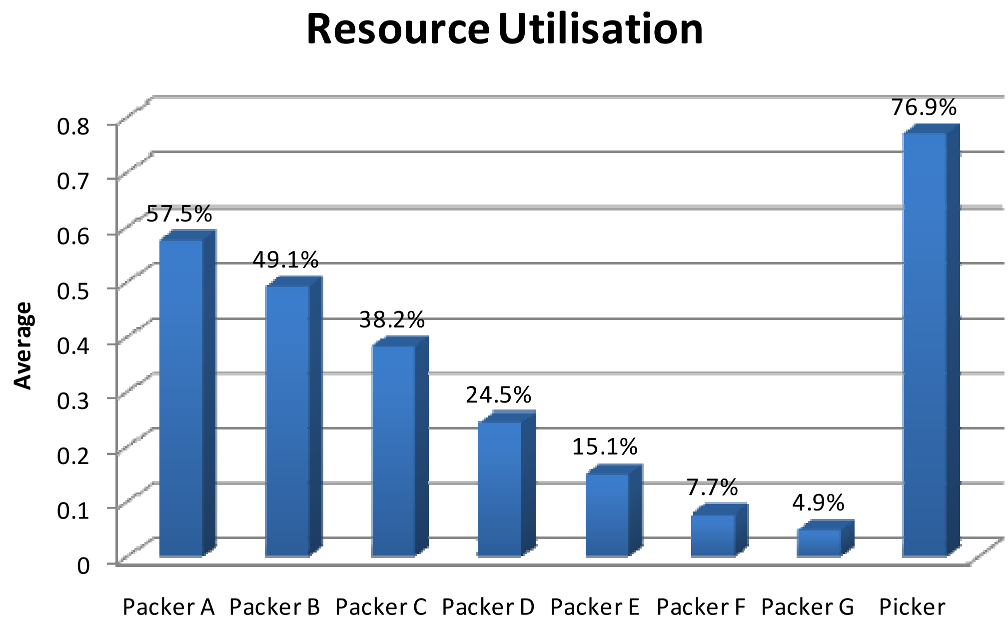
7.2.3 Scenario 2: C

Decreasing the number of packing station by three did not have an adverse effect on the system as predicted. This is because the base case shows that the utilisation for the last packing stations is minimal.

Table 14: Decrease packer resource capacity by three results

Statistics		Output Value (min)
Throughput Time	Average	88.41
Time in Process	Average	78.06
	Picking LA	89.05
	Picking LB	76.59
	Picking LC	54.65
	Picking LD	60.63
	Packing	6.26

Figure 29: Resource utilisation with decrease of three packing stations



This illustrates that the number of packing stations may be reduced with up to as many as three, with very minimal effect on the throughput time and the utilisation of the resources. The rest of the packing station only increases their utilisation with a small percentage to absorb the work of the packing stations that have been taken away.

7.3 Change the batch size of orders send from the pick pool

The aim is to evaluate the throughput time and the utilisation of the orders with the change in the number of orders send from the pick pool; this is done to test the systems flexibility. Smaller batch sizes reduce the total system work in progress

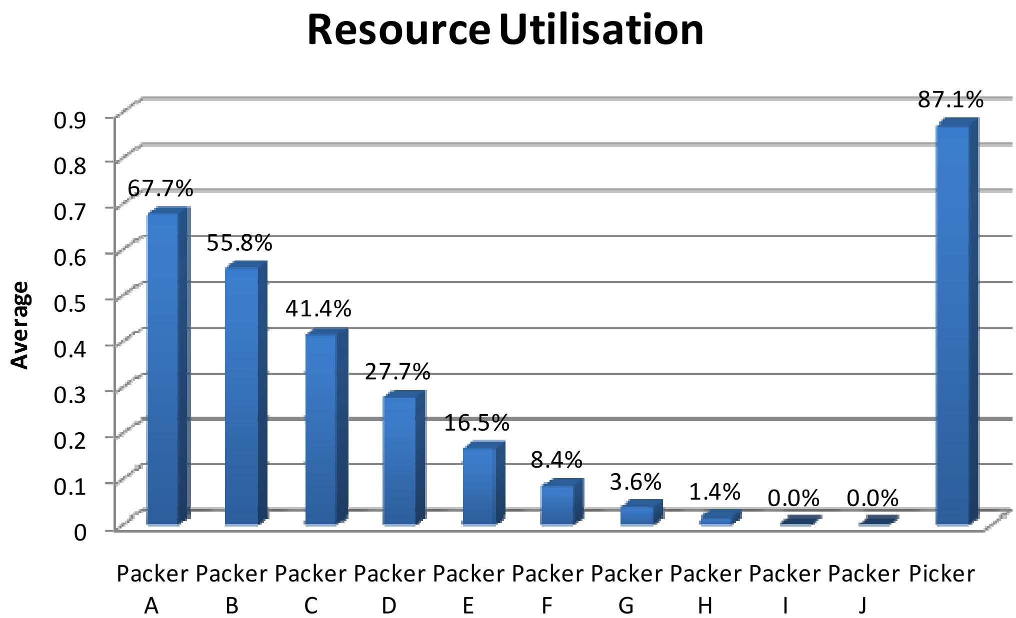
Decreasing the number of orders from, the pick pool that is released for picking, increases the flexibility of the system. Expedite orders are dealt with in a minimal amount of time, increasing the customer satisfaction and meeting with the high needed flexibility of the Soccer World Cup.

Figure 30: Decrease in orders send from pick pool results

Statistics		Output Value (min)
Throughput Time	Average	61.17
Time in Process	Average	52.76
	Picking LA	55.99
	Picking LB	55.56
	Picking LC	39.88
	Picking LD	48.26
	Packing	6.12

The throughput time and the time in process are reduced with the reduction of the number of orders from the pick pool and the utilisation increased considerably. The last number of packers show a zero or very low utilisation, this indicates that less packing stations are required.

Figure 31: Resource utilisation with decrease in orders send from pick pool



It is suggested that Nike reduce the batch size of the number of orders released for picking. This will increase the flexibility which is especially important for the up and coming Soccer World Cup.

As stated previously it is more important for Nike to decrease the throughput time than to increase the utilisation of the resources. If more units are delivered to the customers more units will be sold and so increasing the revenue of Nike.

The results obtained through the scenario development indicate that the simulation model is a true representation of the Nike's outbound process flow. The input parameters influenced the output results as predicted. The simulation model may be used to test and analyse several different scenarios.

8 Conclusion

This project not only satisfied the objectives of increasing plant flexibility, but also proved that the demand of the Soccer World Cup will be met. The managing and understanding of the intricate processes of the Nike distribution facility will lead to higher service levels, satisfied customers and an efficient workforce.

The most suitable industrial engineering tool to assists the management in controlling the factors that affect Nike's performance is the use of simulation modelling. The literature study point out the Arena® simulation model is the most suitable method for completing the project.

The conceptual design combined with the stated input parameter and business decisions ensure that all of the relevant matters are included in the model.

The unstable demand of the Soccer World Cup period is some of the considerations that influence the structure of the simulation model. After verification and validation the model represents the real world and several scenarios are tested. The scenarios generated during the execution of the project can be used to address the initial problems identified. The change in the resources deployment will save Nike labour cost due to high productivity and utilisation in different department. The system changes will reduce process cycle time and order lead time, which in turn will result in increased customer satisfaction. Increasing the flexibility indicated that more goods could be delivered in the same period of time, thus increasing the number of sales.

Through successful identification of the bottlenecks in current operational activities, Nike will be able to recognise and prioritise investment opportunities. By investing in the most appropriate areas, Nike will not only improve their plant utilisation and flexibility, but will also save money by chasing the root cause for the plant utilisation optimisation.

Overall the project is a huge success and will yield significant cost reduction after implementation in February 2010. Preliminary indications are that the project will yield a reduction on unit processing costs and increase throughput capacity. The simulation model is re-usable internally and further studies can be conducted on outbound process flow and planning processes.

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10 Appendices

10.1 Input Data Analysis

Table 15: Picker Transport Time Table for Level A

Sum of Transport Time	Column Labels																											
Row Labels	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	Grand Total
1-1	0	15	30	45	60	75	90	105	120	11	26	41	56	71	86	101	116	131	22	37	52	67	82	97	112	127	142	1917
1-2	15	0	15	30	45	60	75	90	105	26	11	26	41	56	71	86	101	116	37	22	37	52	67	82	97	112	127	1602
1-3	30	15	0	15	30	45	60	75	90	41	26	11	26	41	56	71	86	101	52	37	22	37	52	67	82	97	112	1377
1-4	45	30	15	0	15	30	45	60	75	56	41	26	11	26	41	56	71	86	67	52	37	22	37	52	67	82	97	1242
1-5	60	45	30	15	0	15	30	45	60	71	56	41	26	11	26	41	56	71	82	67	52	37	22	37	52	67	82	1197
1-6	75	60	45	30	15	0	15	30	45	86	71	56	41	26	11	26	41	56	97	82	67	52	37	22	37	52	67	1242
1-7	90	75	60	45	30	15	0	15	30	101	86	71	56	41	26	11	26	41	112	97	82	67	52	37	22	37	52	1377
1-8	105	90	75	60	45	30	15	0	15	116	101	86	71	56	41	26	11	26	127	112	97	82	67	52	37	22	37	1602
1-9	120	105	90	75	60	45	30	15	0	131	116	101	86	71	56	41	26	11	142	127	112	97	82	67	52	37	22	1917
2-1	11	26	41	56	71	86	101	116	131	0	15	30	45	60	75	90	105	120	11	26	41	56	71	86	101	116	131	1818
2-2	26	11	26	41	56	71	86	101	116	15	0	15	30	45	60	75	90	105	26	11	26	41	56	71	86	101	116	1503
2-3	41	26	11	26	41	56	71	86	101	30	15	0	15	30	45	60	75	90	41	26	11	26	41	56	71	86	101	1278
2-4	56	41	26	11	26	41	56	71	86	45	30	15	0	15	30	45	60	75	56	41	26	11	26	41	56	71	86	1143
2-5	71	56	41	26	11	26	41	56	71	60	45	30	15	0	15	30	45	60	71	56	41	26	11	26	41	56	71	1098
2-6	86	71	56	41	26	11	26	41	56	75	60	45	30	15	0	15	30	45	86	71	56	41	26	11	26	41	56	1143
2-7	101	86	71	56	41	26	11	26	41	90	75	60	45	30	15	0	15	30	101	86	71	56	41	26	11	26	41	1278
2-8	116	101	86	71	56	41	26	11	26	105	90	75	60	45	30	15	0	15	116	101	86	71	56	41	26	11	26	1503
2-9	131	116	101	86	71	56	41	26	11	120	105	90	75	60	45	30	15	0	131	116	101	86	71	56	41	26	11	1818
3-1	22	37	52	67	82	97	112	127	142	11	26	41	56	71	86	101	116	131	0	15	30	45	60	75	90	105	120	1917
3-2	37	22	37	52	67	82	97	112	127	26	11	26	41	56	71	86	101	116	15	0	15	30	45	60	75	90	105	1602
3-3	52	37	22	37	52	67	82	97	112	41	26	11	26	41	56	71	86	101	30	15	0	15	30	45	60	75	90	1377
3-4	67	52	37	22	37	52	67	82	97	56	41	26	11	26	41	56	71	86	45	30	15	0	15	30	45	60	75	1242
3-5	82	67	52	37	22	37	52	67	82	71	56	41	26	11	26	41	56	71	60	45	30	15	0	15	30	45	60	1197
3-6	97	82	67	52	37	22	37	52	67	86	71	56	41	26	11	26	41	56	75	60	45	30	15	0	15	30	45	1242
3-7	112	97	82	67	52	37	22	37	52	101	86	71	56	41	26	11	26	41	90	75	60	45	30	15	0	15	30	1377
3-8	127	112	97	82	67	52	37	22	37	116	101	86	71	56	41	26	11	26	105	90	75	60	45	30	15	0	15	1602
3-9	142	127	112	97	82	67	52	37	22	131	116	101	86	71	56	41	26	11	120	105	90	75	60	45	30	15	0	1917
Grand Total	1917	1602	1377	1242	1197	1242	1377	1602	1917	1818	1503	1278	1143	1098	1143	1278	1503	1818	1917	1602	1377	1242	1197	1242	1377	1602	1917	39528

Table 16: Picker Transport Time Table for Level B, C, D

Sum of TransportTime	Column Labels																																			
Row Labels	**1-1**	**1-10**	**1-11**	**1-12**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**2-1**	**2-10**	**2-11**	**2-12**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**3-1**	**3-10**	**3-11**	**3-12**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**Grand Total**
1-1	0	117	130	143	13	26	39	52	65	78	91	104	14	131	144	157	27	40	53	66	79	92	105	118	28	145	158	171	41	54	67	80	93	106	119	132	3078
1-10	117	0	13	26	104	91	78	65	52	39	26	13	131	14	27	40	118	105	92	79	66	53	40	27	145	28	41	54	132	119	106	93	80	67	54	41	2376
1-11	130	13	0	13	117	104	91	78	65	52	39	26	144	27	14	27	131	118	105	92	79	66	53	40	158	41	28	41	145	132	119	106	93	80	67	54	2688
1-12	143	26	13	0	130	117	104	91	78	65	52	39	157	40	27	14	144	131	118	105	92	79	66	53	171	54	41	28	158	145	132	119	106	93	80	67	3078
1-2	13	104	117	130	0	13	26	39	52	65	78	91	27	118	131	144	14	27	40	53	66	79	92	105	41	132	145	158	28	41	54	67	80	93	106	119	2688
1-3	26	91	104	117	13	0	13	26	39	52	65	78	40	105	118	131	27	14	27	40	53	66	79	92	54	119	132	145	41	28	41	54	67	80	93	106	2376
1-4	39	78	91	104	26	13	0	13	26	39	52	65	53	92	105	118	40	27	14	27	40	53	66	79	67	106	119	132	54	41	28	41	54	67	80	93	2142
1-5	52	65	78	91	39	26	13	0	13	26	39	52	66	79	92	105	53	40	27	14	27	40	53	66	80	93	106	119	67	54	41	28	41	54	67	80	1986
1-6	65	52	65	78	52	39	26	13	0	13	26	39	79	66	79	92	66	53	40	27	14	27	40	53	93	80	93	106	80	67	54	41	28	41	54	67	1908
1-7	78	39	52	65	65	52	39	26	13	0	13	26	92	53	66	79	79	66	53	40	27	14	27	40	106	67	80	93	93	80	67	54	41	28	41	54	1908
1-8	91	26	39	52	78	65	52	39	26	13	0	13	105	40	53	66	92	79	66	53	40	27	14	27	119	54	67	80	106	93	80	67	54	41	28	41	1986
1-9	104	13	26	39	91	78	65	52	39	26	13	0	118	27	40	53	105	92	79	66	53	40	27	14	132	41	54	67	119	106	93	80	67	54	41	28	2142
2-1	14	131	144	157	27	40	53	66	79	92	105	118	0	117	130	143	13	26	39	52	65	78	91	104	14	131	144	157	27	40	53	66	79	92	105	118	2910
2-10	131	14	27	40	118	105	92	79	66	53	40	27	117	0	13	26	104	91	78	65	52	39	26	13	131	14	27	40	118	105	92	79	66	53	40	27	2208
2-11	144	27	14	27	131	118	105	92	79	66	53	40	130	13	0	13	117	104	91	78	65	52	39	26	144	27	14	27	131	118	105	92	79	66	53	40	2520
2-12	157	40	27	14	144	131	118	105	92	79	66	53	143	26	13	0	130	117	104	91	78	65	52	39	157	40	27	14	144	131	118	105	92	79	66	53	2910
2-2	27	118	131	144	14	27	40	53	66	79	92	105	13	104	117	130	0	13	26	39	52	65	78	91	27	118	131	144	14	27	40	53	66	79	92	105	2520
2-3	40	105	118	131	27	14	27	40	53	66	79	92	26	91	104	117	13	0	13	26	39	52	65	78	40	105	118	131	27	14	27	40	53	66	79	92	2208
2-4	53	92	105	118	40	27	14	27	40	53	66	79	39	78	91	104	26	13	0	13	26	39	52	65	53	92	105	118	40	27	14	27	40	53	66	79	1974
2-5	66	79	92	105	53	40	27	14	27	40	53	66	52	65	78	91	39	26	13	0	13	26	39	52	66	79	92	105	53	40	27	14	27	40	53	66	1818
2-6	79	66	79	92	66	53	40	27	14	27	40	53	65	52	65	78	52	39	26	13	0	13	26	39	79	66	79	92	66	53	40	27	14	27	40	53	1740
2-7	92	53	66	79	79	66	53	40	27	14	27	40	78	39	52	65	65	52	39	26	13	0	13	26	92	53	66	79	79	66	53	40	27	14	27	40	1740
2-8	105	40	53	66	92	79	66	53	40	27	14	27	91	26	39	52	78	65	52	39	26	13	0	13	105	40	53	66	92	79	66	53	40	27	14	27	1818
2-9	118	27	40	53	105	92	79	66	53	40	27	14	104	13	26	39	91	78	65	52	39	26	13	0	118	27	40	53	105	92	79	66	53	40	27	14	1974
3-1	28	145	158	171	41	54	67	80	93	106	119	132	14	131	144	157	27	40	53	66	79	92	105	118	0	117	130	143	13	26	39	52	65	78	91	104	3078
3-10	145	28	41	54	132	119	106	93	80	67	54	41	131	14	27	40	118	105	92	79	66	53	40	27	117	0	13	26	104	91	78	65	52	39	26	13	2376
3-11	158	41	28	41	145	132	119	106	93	80	67	54	144	27	14	27	131	118	105	92	79	66	53	40	130	13	0	13	117	104	91	78	65	52	39	26	2688
3-12	171	54	41	28	158	145	132	119	106	93	80	67	157	40	27	14	144	131	118	105	92	79	66	53	143	26	13	0	130	117	104	91	78	65	52	39	3078
3-2	41	132	145	158	28	41	54	67	80	93	106	119	27	118	131	144	14	27	40	53	66	79	92	105	13	104	117	130	0	13	26	39	52	65	78	91	2688
3-3	54	119	132	145	41	28	41	54	67	80	93	106	40	105	118	131	27	14	27	40	53	66	79	92	26	91	104	117	13	0	13	26	39	52	65	78	2376
3-4	67	106	119	132	54	41	28	41	54	67	80	93	53	92	105	118	40	27	14	27	40	53	66	79	39	78	91	104	26	13	0	13	26	39	52	65	2142
3-5	80	93	106	119	67	54	41	28	41	54	67	80	66	79	92	105	53	40	27	14	27	40	53	66	52	65	78	91	39	26	13	0	13	26	39	52	1986
3-6	93	80	93	106	80	67	54	41	28	41	54	67	79	66	79	92	66	53	40	27	14	27	40	53	65	52	65	78	52	39	26	13	0	13	26	39	1908
3-7	106	67	80	93	93	80	67	54	41	28	41	54	92	53	66	79	79	66	53	40	27	14	27	40	78	39	52	65	65	52	39	26	13	0	13	26	1908
3-8	119	54	67	80	106	93	80	67	54	41	28	41	105	40	53	66	92	79	66	53	40	27	14	27	91	26	39	52	78	65	52	39	26	13	0	13	1986
3-9	132	41	54	67	119	106	93	80	67	54	41	28	118	27	40	53	105	92	79	66	53	40	27	14	104	13	26	39	91	78	65	52	39	26	13	0	2142
Grand Total	**3078**	**2376**	**2688**	**3078**	**2688**	**2376**	**2142**	**1986**	**1908**	**1908**	**1986**	**2142**	**2910**	**2208**	**2520**	**2910**	**2520**	**2208**	**1974**	**1818**	**1740**	**1740**	**1818**	**1974**	**3078**	**2376**	**2688**	**3078**	**2688**	**2376**	**2142**	**1986**	**1908**	**1908**	**1986**	**2142**	**83052**

Table 17: Extraction from Total Transport Time for Each Level in Picking

Order Number	A	B	C	D	Grand Total
1	0	0	0	75.5	75.5
2	33.5	0	0	0	33.5
3	93.5	0	0	0	93.5
4	59.5	0	0	0	59.5
5	59.5	0	0	0	59.5
6	0	0	74.5	59.5	134
7	0	63.5	0	0	63.5
8	0	75.5	0	0	75.5
9	0	49.5	0	0	49.5
10	63.5	0	75.5	0	139
11	0	101.5	0	0	101.5
12	0	0	49.5	0	49.5
13	37.5	0	0	0	37.5

Table 18: Extraction from Quantity and Business Units per Order on each Level

Order Number	LA_Other	LA_Footware	LB_Other	LB_Footware	LC_Other	LC_Footware	LD_Other	LD_Footware
1	0	0	0	0	0	0	7	0
2	13	0	0	12	0	0	0	0
3	0	12	0	0	0	24	0	0
4	0	15	0	0	0	0	0	0
5	24	0	0	0	0	0	0	0
6	0	0	0	0	134	0	0	0
7	0	0	11	0	0	0	0	0
8	0	0	0	30	0	0	0	5
9	1	0	2	0	0	9	0	0
10	19	0	0	0	0	0	0	0
11	0	0	24	0	0	0	0	0
12	0	0	0	0	0	43	0	0
13	0	3	0	0	0	0	0	0
14	0	1	0	0	0	0	0	0
15	0	0	1	0	108	0	0	0

Table 19: Extraction from Number to be batched on a Level

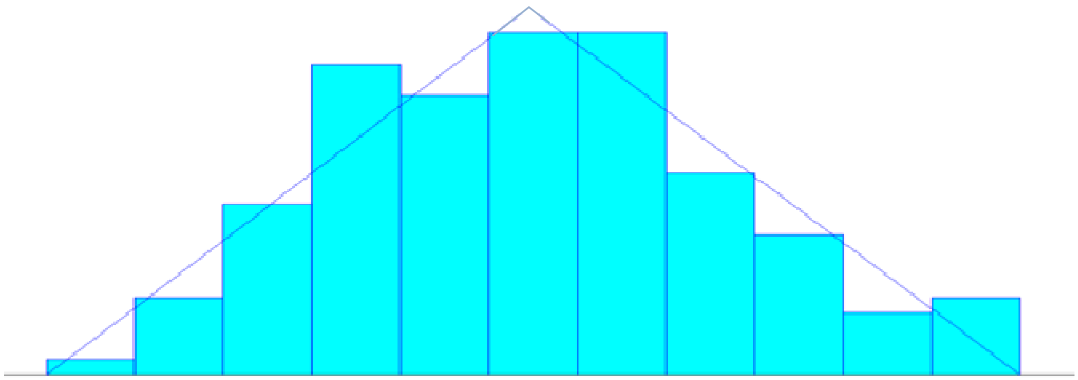
Order Number	A	B	C	D	Batch
1	0	0	0	1	1
2	1	1	0	0	2
3	1	0	1	0	2
4	1	0	0	0	1
5	1	0	0	0	1
6	0	0	1	0	1
7	0	1	0	1	2
8	0	1	0	0	1
9	1	1	1	0	3
10	1	0	0	0	1
11	0	1	0	0	1
12	0	0	1	0	1
13	1	0	0	0	1
14	1	0	0	0	1
15	0	1	1	0	2

Table 20: Extraction Distance the Conveyor travel on a Level

Order Number	A	B	C	D
1	0	0	0	61
2	30	0	0	0
3	54	0	0	0
4	36	0	0	0
5	36	0	0	0
6	0	0	66	0
7	0	43	0	0
8	0	61	0	0
9	0	52	0	0
10	18	0	0	0
11	0	70	0	0
12	0	0	52	0
13	24	0	0	0
14	36	0	0	0
15	0	29	0	0

10.2 Probability Distributions

10.2.1 Picking Process Time for Business Unit "Other" Distribution



Distribution Summary

Distribution: Triangular

Expression: TRIA (1, 19, 48)

Square Error: 0.003419

Data Summary

Number of Data Points = 130

Min Data Value = 1

Max Data Value = 48

Sample Mean = 19

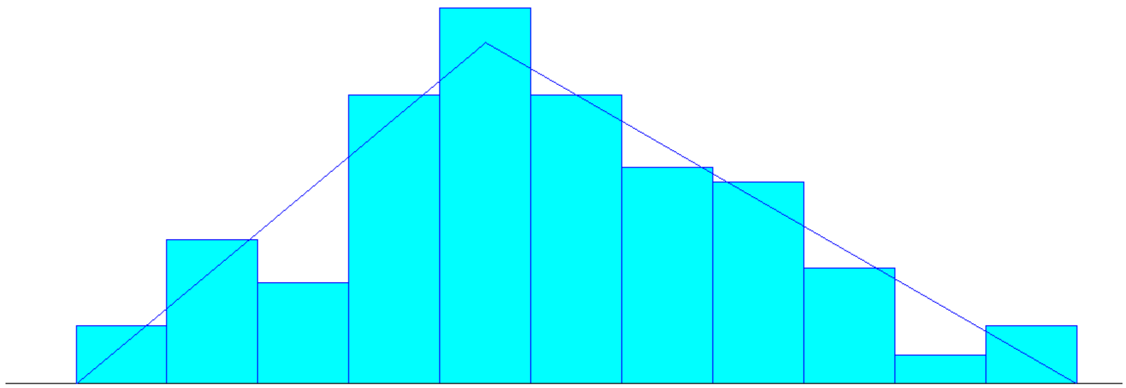
Sample Std Dev = 8.8

Histogram Summary

Histogram Range = 1 to 48

Number of Intervals = 11

10.2.2 Picking Process Time for Business Unit “Footwear” Distribution



Distribution Summary

Distribution: Triangular

Expression: TRIA (3, 11, 26)

Square Error: 0.004735

Data Summary

Number of Data Points = 130

Min Data Value = 3

Max Data Value = 26

Sample Mean = 11

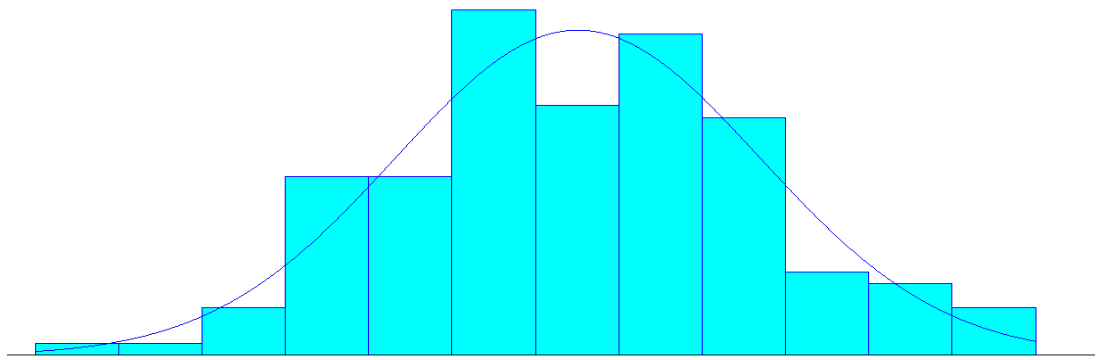
Sample Std Dev = 4.1

Histogram Summary

Histogram Range = 3 to 26

Number of Intervals = 11

10.2.3 Packing Process Time Distribution



Distribution Summary

Distribution: Normal

Expression: NORM (287, 98.2)

Square Error: 0.005179

Data Summary

Number of Data Points	= 150
Min Data Value	= 0.1
Max Data Value	= 542
Sample Mean	= 287
Sample Std Dev	= 98.2

Histogram Summary

Histogram Range	= 0.1 to 542
Number of Intervals	= 12

10.3 Simulation Results

10.3.1 Queue average waiting time per entity

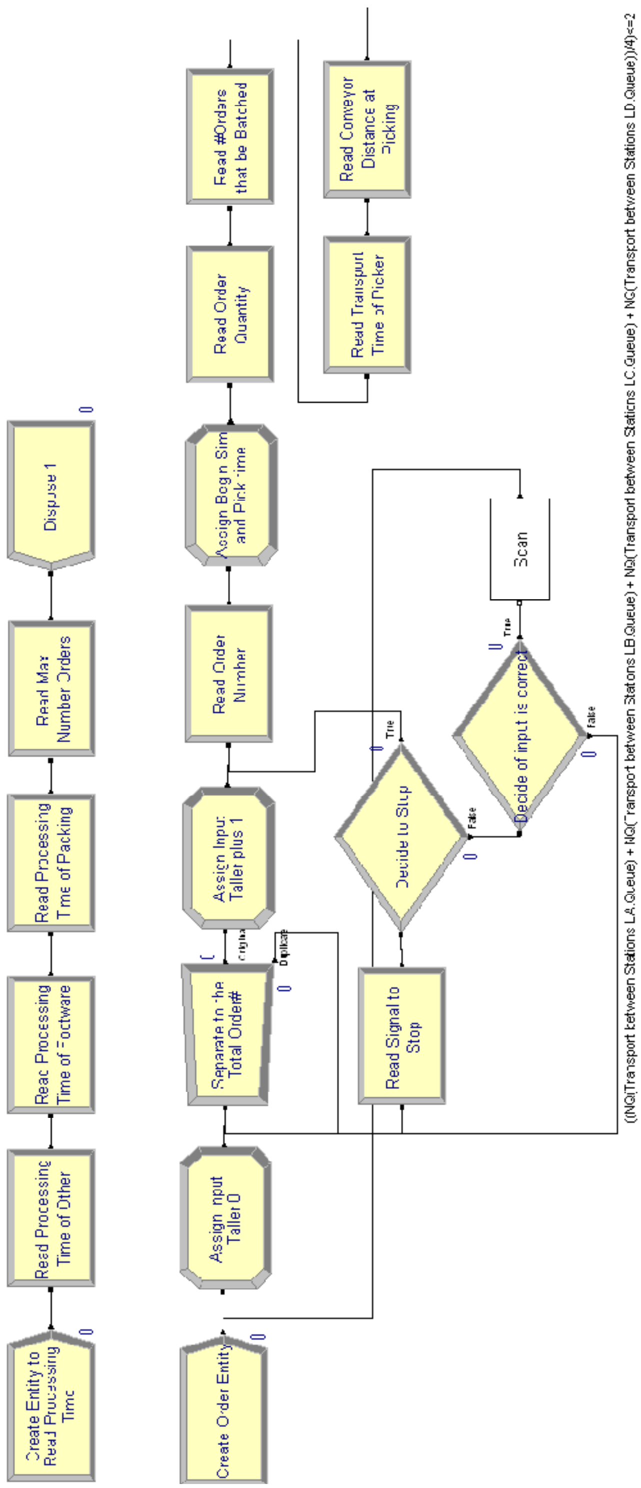
Waiting Time in Queue (Avg)							
		Increase Growth		Change #Resources			Change #Units send
	Base Model	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1
Batch Order same OrderNumber	6.122	6.376	6.767	4.535	3.754	5.654	3.76
Packing Station A	0	0	0	0	0	0	0
Packing Station B	0	0	0	0	0	0	0
Packing Station C	0	0	0	0	0	0	0
Packing Station D	0	0	0	0	0	0	0
Packing Station E	0	0	0	0	0	0	0
Packing Station F	0	0	0	0	0	0	0
Packing Station G	0	0	0	0	0	3.207	0
Packing Station H	0	0	0	0	0	N/A	0
Packing Station I	0	0	0	0	0	N/A	0
Packing Station J	0	0	**0**	1.047	6.161	N/A	0
Transport between Stations LA	76.407	82.43	87.56	55.787	39.232	75.108	41.974
Transport between Stations LB	54.37	58.392	61.944	39.894	27.526	53.391	32.145
Transport between Stations LC	39.336	42.666	46.654	30.353	20.549	39.652	25.499
Transport between Stations LD	35.659	38.735	41.892	27.563	18.953	36.017	24.058

10.3.2 Number of entities entering a process

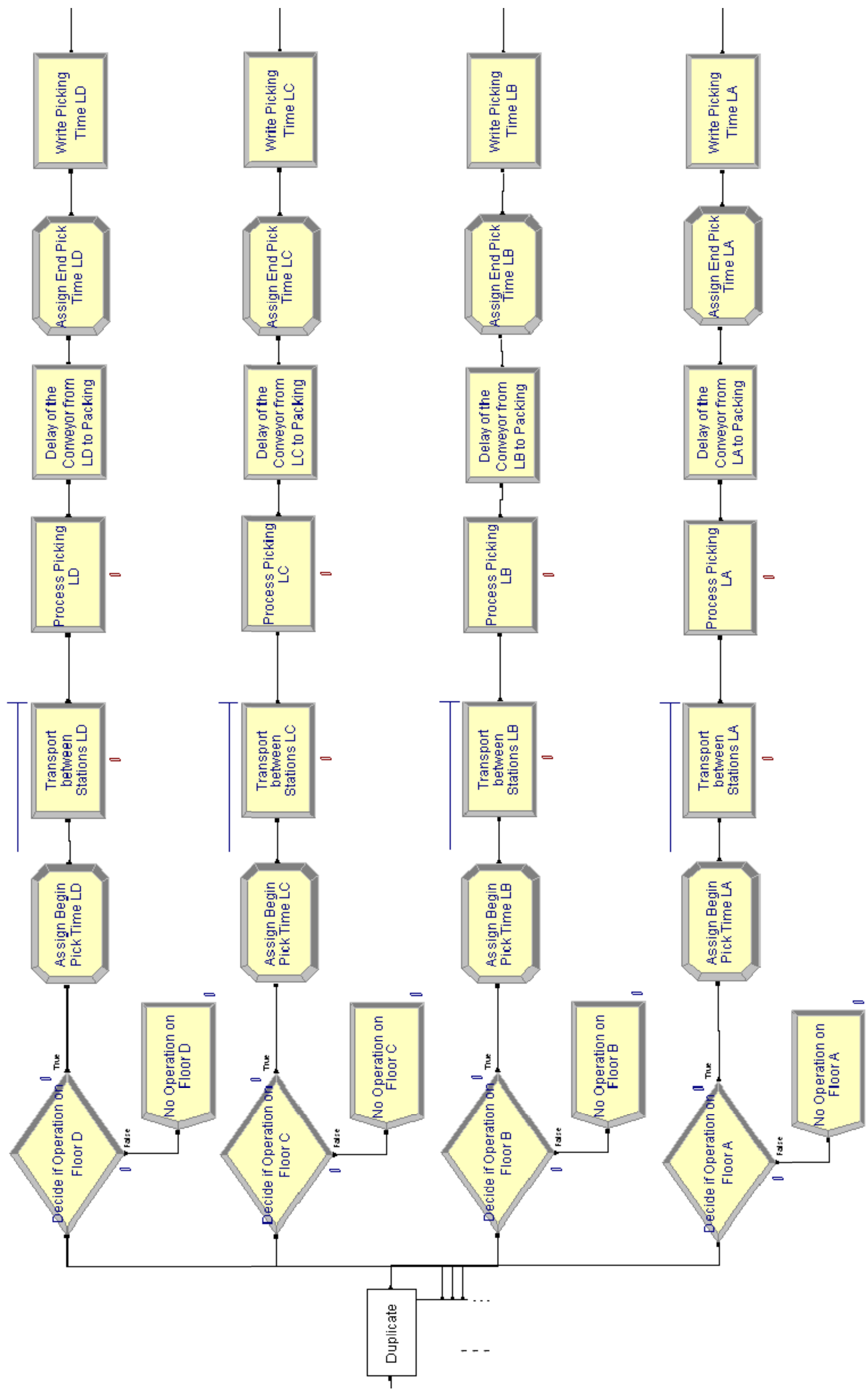
Number in Process (Avg)							
		Increase Growth		Change #Resources			Change #Units send
	Base Model	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1
Packing Station A	841	917	937	663	504	831	856
Packing Station B	704	737	773	592	481	692	690
Packing Station C	548	533	538	511	431	547	526
Packing Station D	362	317	312	388	378	352	340
Packing Station E	202	176	151	267	297	215	216
Packing Station F	102	87	69	180	246	105	114
Packing Station G	34	31	21	104	176	68	49
Packing Station H	14	12	8	57	120	N/A	17
Packing Station I	3	0	1	32	80	N/A	2
Packing Station J	0	0	0	16	97	N/A	0
Picking Process LA	1430	1430	1430	1430	1430	1430	1430
Picking Process LB	669	669	669	669	669	669	669
Picking Process LC	393	393	393	393	393	393	393
Picking Process LD	318	318	318	318	318	318	318

10.4 The Simulation Parts

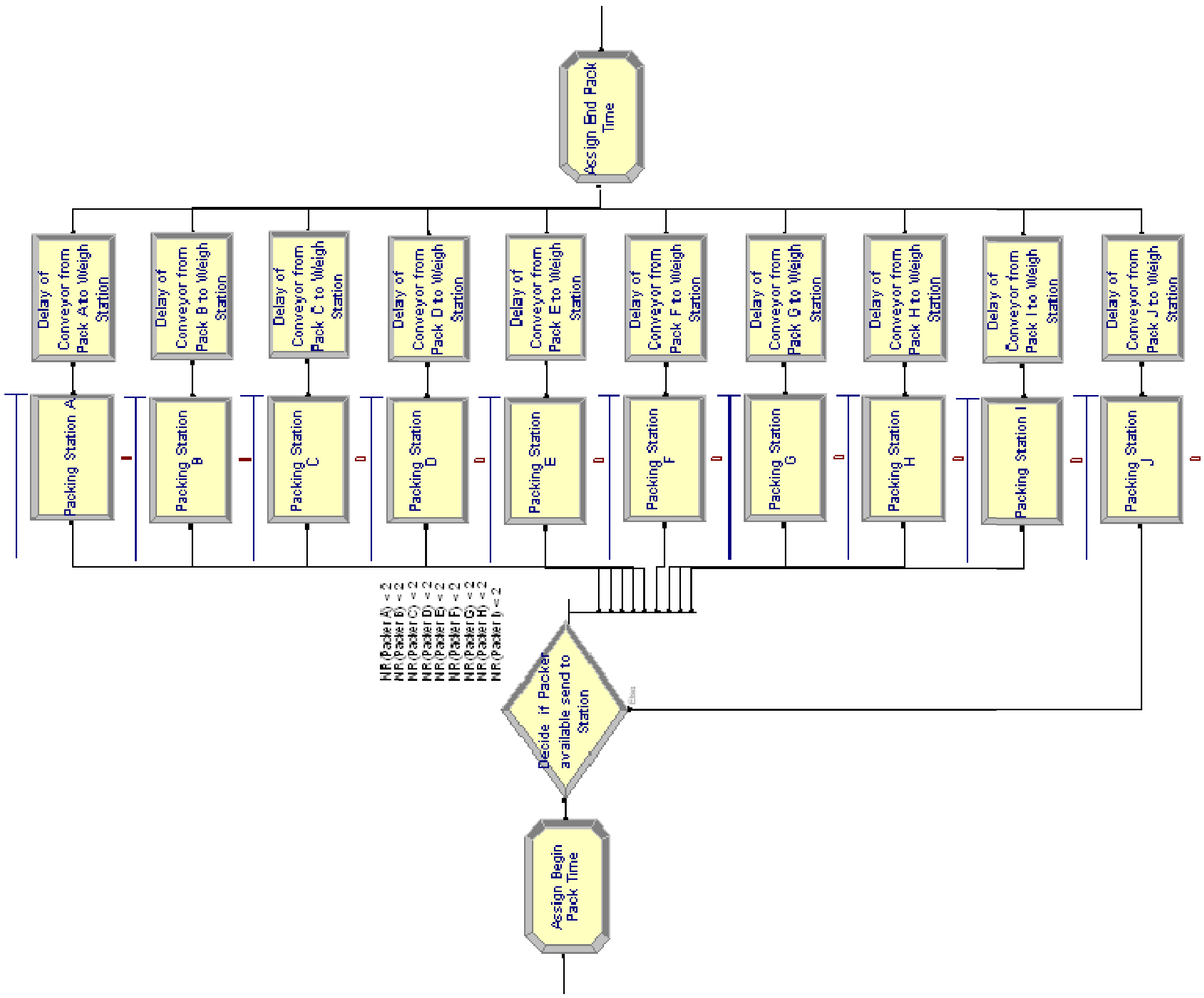
10.4.1 Order information generation phase



10.4.2 Pick Face



10.4.3 Pack Station



10.4.4 Despatch and Output transfer phase