UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

Stellenbosch University

The Development of a Generic Simulation Model of Citrus Packing Lines

October 2011

H.T. Beukes 15456773

Final year project presented in partial fulfillment of the requirements for the degree of Bachelors of Industrial Engineering at the University of Stellenbosch

Study Leader: Prof. C.S.L. Schütte

Acknowledgements

Hereby I would like to express my gratitude to the following people:

- Professor Corne Schütte for his support and guidance throughout the year.
- Noordhoek Packhouse, especially Jacques Umans, for giving me free access to their facility and answering all of my questions.
- Vizier Systems, in particular Bernard van Zyl, who shared his experience and helped me in the right direction.
- The Lord, for helping me when the times were tough.

Declaration

I, the undersigned, hereby declare that the work presented in this report is my own original work and has not previously in its whole or in part been submitted at any university for a degree.

....

Signature **Date**

ECSA Exit Level Outcomes References

Outcome	Chapter	Description
1. Problem Solving	1.1 - 1.4; 4.1; 4.3	The problem has been analysed and defined and criteria for an acceptable solution have been identified.
	3.1 – 3.6	Simulation has been identified as an applicable engineering tool and has been applied as an approach to generate a solution.
	5.1 – 5.5	A possible solution has been generated by developing a simulation model.
	6; 8	The developed model has been evaluated.
	4; 5; 6; 7	The solution has been formulated and presented in the document.
5. Engineering Methods, Skills and Tools, including Information Technology	3; 4; 5	Simulation is a discipline-specific tool and a specific procedure has been followed to develop the model.
	5.5	Simio has been utilised to computerize the simulation model.
	WebEden & DropBox	Computers, networks and information infrastructures have been used to access, process, manage and store information to enhance personal productivity.
6. Professional And Technical Communication:	1; 2; 3; 4; 5; 6; 7; 8	Appropriate structure, style and language have been employed in order to effectively communicate the execution and findings of the project.
	Figures	Figures and tables have been used to provide effective graphical support to complement the text.
9. Independent Learning Ability	References	Various articles and sources have been acquired and evaluated to collect appropriate information.
	2; 3; 4; 5; 6	The knowledge necessary to develop a solution have been acquired and applied.
	4.1 – 4.3; 5.1 – 5.5	Critical assumptions have been made in order to plan and construct the solution.
10. Engineering Professionalism	3; 4; 5; 6; 7	A high level of competence is required to be able to utilise tools and techniques in order to develop a simulation model.
	Declaration	Accepts responsibility for own actions
	5; 6; 7	Own judgement is have been utilised in decision making during problem solving and design.

Synopsis

The design of a citrus packhouse is a time-consuming process and the construction of such a facility is extremely expensive. Most packhouses, however, consist of identical operations. It has been proposed that a generic simulation model can be developed in order to assist engineers in decision-making and evaluation during the design or redesign of citrus packhouses. This project is concerned with the development of such a model.

The report consists of five major phases, namely the problem identification phase, the solution approach identification phase, the solution development phase, the verification and validation phase and the recommendation and conclusion phase. The problem identification phase is focused on the formulation of the problem and a discussion of the major functions and operations within a citrus packhouse. Simulation modelling has been identified as an appropriate tool to develop the solution and a roadmap for the development of such a model has been identified. The solution development phase entails the construction and computerization of the simulation model according to the proposed roadmap. The techniques employed to ensure the validity of the model are described in the verification and validation phase. The recommendations and conclusion phase entails a discussion of how the model can be used to perform experiments and the final remarks regarding the model are discussed.

The model developed during the course of this project can be used to assist engineers to evaluate proposed designs and evaluate the effect of certain parameters on the system. The model is generic and can be used to represent almost any citrus packhouse.

Opsomming

Die ontwerp van ŉ sitrus pakstoor is ŉ tydrowende proses en die konstruksie van so ŉ fasiliteit is verskriklik duur. Die meeste sitrus pakstore bestaan egter uit dieselfde prosesse. Dit is voorgestel dat ŉ generiese simulasie model ontwikkel kan word om ingenieurs by te staan met besluitneming en evaluering tydens die ontwerp of herontwerp van sitrus pakstore. Hierdie projek is vermoeid met die ontwikkeling van so ŉ model.

Die verslag bestaan uit vyf hoof afdelings, naamlik die probleem identifikasie fase, die oplossing benadering identifikasie fase, die oplossing ontwikkeling fase, die verifikasie en validasie fase en die aanbeveling en gevolgtrekking fase. Die probleem identifikasie fase fokus op die formulering van die probleem en ŉ bespreking van die hoof funksies en operasies in ŉ sitrus pakhuis. Simulasie is geïdentifiseer as geskikte gereedskap vir die ontwikkeling van die oplossing en ŉ padkaart vir die ontwikkeling van so ŉ model is geïdentifiseer. Die oplossing ontwikkeling fase bespreek die konstruksie en rekenarisering van die model volgens die voorgestelde roete. Die tegnieke wat aangewend is om die model te valideer is bepreek in die verifikasie en validasie fase. Die aanbeveling en gevolgtrekking fase bevat ŉ bespreking van hoe die model gebruik kan word om eksperimente uit te voer en die finale kommentaar met betrekking tot die model is bespreek.

Die model wat ontwikkel is gedurende die uitvoering van die projek kan gebruik word om ingenieurs by te staan om voorgestelde ontwerpe te evalueer en die uitwerking wat sekere parameters op die sisteem het te analiseer. Die model is ten volle generies en kan ingespan word om byna enige sitrus pakstoor voor te stel.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Food security and agriculture are two very important issues in developing countries such as South Africa. Agro-processing is the division of manufacturing that specializes in the processing of agricultural products and it plays a very important part in the South African economy. South Africa is ranked as number 12 with regard to world citrus production (Siphugu, 2010). The South African citrus industry's main focus is export (Von Broemdsen 1986:171) and South Africa is the most important citrus exporter in the southern hemisphere and second in the world. It is expected that South Africa will produce 1.65 million metric tons of fresh Valencia and Navel oranges in the 2010/11 marketing year from a supply base of about 40.5 million trees (Siphugu, 2011). Roughly 62% of South African citrus produce is exported, while 23% is used for making juice. The rest, about 15%, is packed for the local market (Giles, 2010:6). All of the citrus fruit that are exported have to go through a packinghouse, in order to be prepared for the export market.

The South African citrus industry has shown remarkable growth over the past 40 years. The annual production of oranges in South Africa has increased from 4.6 thousand metric tons in 1970 to 1.6 million metric tons in 2010 (Von Broemdsen 1986:175) (Siphugu, 2011). The South African citrus production base is about 60 000 hectares and the citrus industry employs roughly 60 000 workers, according to the Citrus Growers' Association (Citrus Growers' Association Submission to Agricultural Job Creation Imbizo). Citrus fruit are produced in six of the nine provinces of South Africa and amount to roughly over R 5 000 million of the GDP (Agriculture, Forestry and Land, 2011).

"The marketing of citrus fruits is as important as the actual production of the fruit, as the production itself is carried out in vain unless the fruit can be disposed of profitability." – H. Clark Powell (1930:181). According to Tugwell (1988:1480), the packinghouse's main function is to apply post-harvest technology in such a way that fresh and appealing fruit of the highest possible quality is delivered to the consumer. As the South African citrus industry grows, more packhouses are needed to accommodate the growing supply base.

1.2 General Description of a Citrus Packhouse

A citrus packhouse usually consists of one or more packing lines which consist of several individual operations functioning together in order to accomplish the effective packing of fresh fruit for the export market. The main operations of any packing line consist of cleaning, grading and packaging.

The majority of packhouses handles three grades of fruit. The first two grades are usually packed for the export market, while third grade fruit are bagged to supply fresh fruit for the local market (Grierson, Smith, Thornton & Felsenstein, 1986:288). First grade fruit are packed in cartons that conform to the standards of the export market. Second grade fruit are also packed in cartons, while third grade are usually packed in net bags (Umans, 2011).

Most of the modern citrus packing lines are designed in the same way, consisting of similar operations, even though they might differ in terms of size, layout and efficiency (Kritzinger 2007:19).

1.3 Problem Identification

The current cost of constructing a new packhouse can amount to anything from R 8 million to as much as R 15 million. Thus, it is of utter importance that the design is validated before the packhouse is built. A packhouse consists of facilities, equipment, people and resources and it can be represented as a series of operations functioning as a whole. In order to analyse the system before it is put into operation, a simulation model can be constructed to represent the system. This model can be used to evaluate the design.

Although no two packhouses are identical, all modern packhouses are similar (Wagner & Sauls, (s.a.):3*)*. Since all packhouses are similar, it is possible to create a generic model to assist in the design of such a facility. Such a model can be used to evaluate changes in the packing line and facilitate more effective scheduling (Kritzinger 2007:2). It can also be used to demonstrate and market a specific design.

1.4 Goals and Deliverables

In the design process of a fruit packhouse, throughput, cost and operational convenience are the most important parameters (Bollen, Cox & Riden, 2007:393).

The goals of this project entail the creation of a simulation model of a citrus packing facility, in order to demonstrate the flow of inputs, outputs, materials and resources within the facility. This model should be generic and reusable for a variety of applications and organisations.

The proposed outcome of the project is a functional simulation program which can be used to enter specific constraints of a certain packhouse in order to analyse the flows within the facility in order to evaluate it in terms of throughput and resource utilization.

The package should also enable the user to experiment with the system and to perform a sensitivity analysis in terms of certain constraints.

1.5 Project Methodology

A five step methodology for problem solving has been identified for the execution of the project. This methodology is illustrated at the hand of Figure 1.

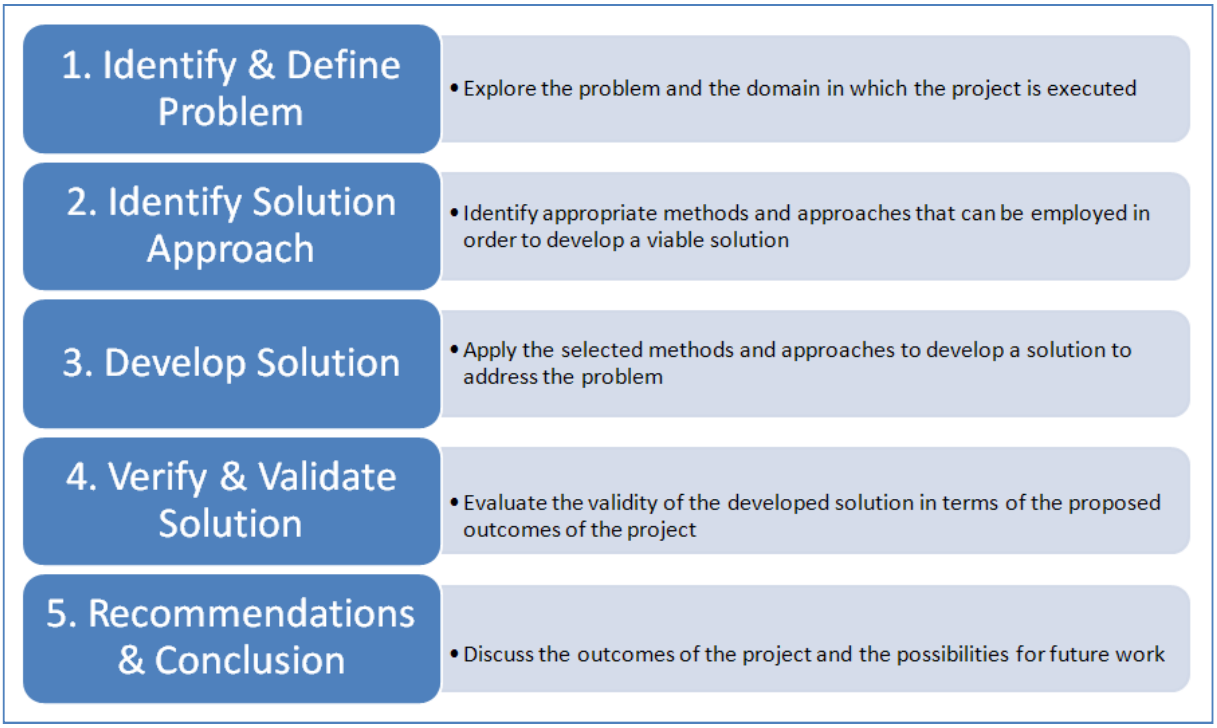


Figure 1: Project Methodology

The steps proposed in the methodology have been applied in a structured manner throughout the execution of the project.

1.6 Document Overview

Chapter 2: Citrus Packhouse Operations

The major functions and operations that take place within a packhouse are described in this chapter. Each operation is discussed individually and a flowchart of the packhouse is given. Furthermore, an illustration of a typical packhouse layout has been provided.

Chapter 3: Simulation Overview

This chapter entails a discussion concerning the basic principles of simulation and its importance. Simulation is defined and the general concepts of simulation are discussed. The advantages and disadvantages of simulation studies are highlighted. The concept of generic simulation is defined and discussed. The practicality of modelling a packhouse with the use of simulation is also discussed. Finally, the chapter describes the simulation modelling process.

Chapter 4: Planning and Definition Phase

The fourth chapter is concerned with the planning and definition of the project. The problem statement is formulated by discussing the need for and the purpose of the simulation project, the various stakeholders of the project, as well as the objective of the project. The project planning is briefly discussed before the system boundary is defined in terms of the inputs, outputs and processes of the system.

Chapter 5: Model Construction Phase

The objective of this chapter is to discuss the procedure that was followed to construct the model. Firstly, the conceptual model of the system is described. Then, the preliminary experiment is described, whereby the system type, the model time span and the various model entities, attributes and resources are defined. The generic process groups are defined and the significant parameters of each process in the system are identified and discussed. After the parameters are defined, the computerization of the model is described.

Chapter 6: Validation and Verification

This chapter entails the details of the techniques employed in order to validate and verify the model. The concepts of validation and verification are briefly defined to lay a foundation from which the different techniques are described. The techniques applied include structured walk-through sessions, animation, degenerate tests and validation by comparison.

Chapter 7: Experimentation

Experimentation is an important part of any simulation study, but it does not fall within the scope of this project. This chapter describes how the user can use the developed model to perform experiments.

Chapter 8: Conclusions

The final chapter concludes the report by discussing the findings and the final remarks regarding the project.

2. Citrus Packhouse Operations

In order to understand the functioning of a packhouse, it is important to understand the various operations of which it consists. As mentioned previously, citrus packing lines consist of a typical sequence of operations. The basic sequence of operations is receiving, waste removal, pre-sorting, pre-sizing, washing, drying, fungicide application, waxing, drying, grading, sizing, final grading, labelling, packing and palletizing. Each of these operations is subject to unique constraints and holds hazards that can affect the quality of the fruit. A flowchart of the typical operations within a citrus packhouse is shown in Figure 2.

Packinghouses tend to become more and more mechanized, whereby most of the operations are automated, if the commercial and economic situations allow it. According to Burdon (1997:4), the degree of mechanization of a packhouse is determined by the yearly throughput, the length of the season, the implementation costs and the degree of available labour. Most citrus packhouses in South Africa is mechanized, since they consist of roller and belt conveyors and sizers. However, although automated sorting systems are available, the high cost associated with the acquisition of optical sizers forces most packhouses to make use of manual grading.

This chapter entails the discussion of each of the standard operations within a citrus packing line that is critical in terms of the throughput of the packinghouse. The purpose of each process is explained, as well as the standard ways in which each operation can be executed.

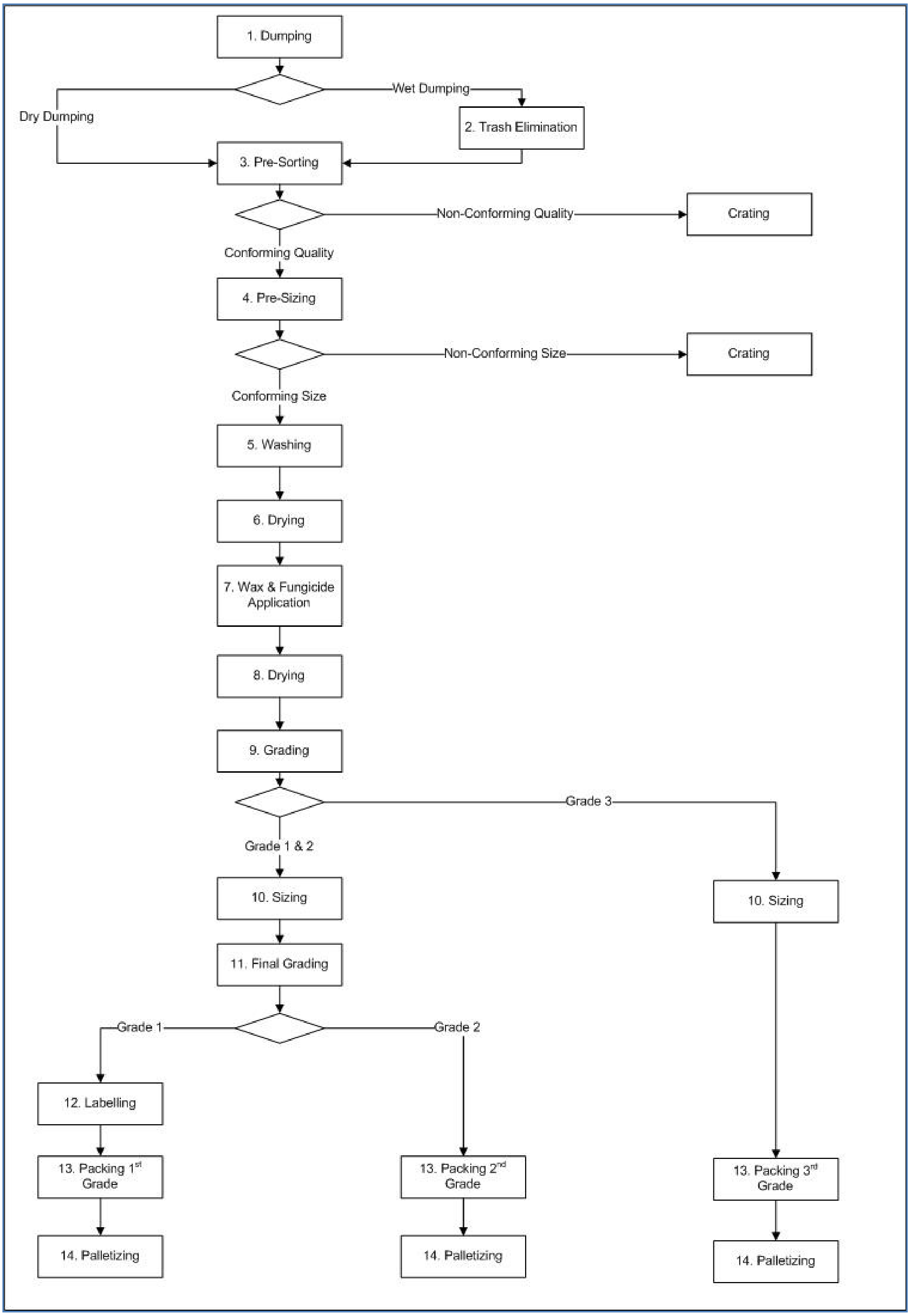


Figure 2: Flowchart of a Typical Citrus Packhouse

2.1 Receiving

Fruit normally comes from the orchard either in crates or in trailers (Umans, 2011). The fruit are received in the packhouse in two basic manners, namely dry dumping or wet dumping.

The fruit are usually dumped onto the packing line by the use of mechanized tippers. Each crate is tipped individually at a constant rate, which creates a continuous flow of fruit at the receiving end of the packing line (personal observation, 2011). The tipping process entails the loading of a full crate onto the tipper, the actual tipping of the crate with the use of hydraulic hoists and the offloading of the empty crate from the tipper. It is common practice to mechanize the entire tipping process, in order to ensure a constant tipping rate. A typical example of such a mechanized tipper is shown in Figure 3.

Figure 3: A Typical Tipper & Dip Tank

Dry dumping is a process whereby fruit are dumped onto a conveyor directly. Although this is a faster method, it increases the risk of causing injuries to the fruit and it requires more intensive cleaning.

Most South African packhouses, however, make use of wet dumping (Grierson, et al. 1986: 291). According to this method, fruit are dumped into a basin of chlorinated water. Wet dumping allows for a softer receiving and lower the risk of injuries to the fruit due to bruising. The water basin can also be used as a buffer for the packing line. However, fruit should pass through the bath as fast as possible, since the water can contain fungal spores and cause fruit decay (Kruger & Penter, 2006:324). The fruit automatically spread across the width of the basin in a single layer and flow at a certain speed towards the next operation in the packing line. The flow speed of the water is regulated by the use of a pump. The fruit are lifted from the dip tank with the use of a roller conveyor elevator, moving at a constant speed.

2.2 Waste Removal

Immediately after the fruit is received in the packhouse, the trash that comes from the orchard should be removed. This trash can include leaves, stems and sand. However, this is only applicable at packinghouses that use wet dumping to receive the fruit (Van Zyl, 2011). Most of the waste stays behind in the dip tank after the fruit are elevated. The waste is removed from the water manually and dumped into a specially assigned crate. When the crate is full, it is removed and the waste is removed from the facility to prevent the contamination of the other incoming fruit (Personal observation, 2011).

2.3 Pre-Sorting

During the pre-sorting step, the quality of each fruit is inspected in terms of quality, size and colour. While the fruit is moving on a roller conveyor, each fruit is examined individually by graders. Non-conforming fruit are removed from the conveyor by the graders, while conforming fruit are left on the conveyor to proceed to the next operation. Figure 4 is a typical example of such a pre-sorting table.

Figure 4: A Typical Pre-Sorting Table

It is important to remove all unmarketable fruit at this step, to prevent spending time and money on fruit that will not generate an income. Rotten and split fruit should be removed before the washing process, in order to prevent further contamination. Oversized and blemished fruit are removed and used for the production of fruit juice (Umans, 2011). The fruit that are removed are crated and the crates are removed from the facility once they are full, usualy by means of a forklift or pallet jack.

2.4 Pre-Sizing

Not all of the fruit that reaches the packhouse are suitable for exporting, and should thus be removed from the packing line. During this stage of the packing line, the under-sized fruit are removed. As with the pre-sorting operation, this is done to prevent spending money on unmarketable fruit.

According to Grierson *et al* (1986:288, 302), pre-sizing can be done mechanically with the use of a pre-sizer. In South Africa, sizing is mostly accomplished with the use of belt-and-roll sizers or pony sizers. Belt-and-roll sizers force the produce into lanes, after which under-sized fruit falls through gaps between rollers and an angled belt. There are specific openings for every fruit size. Pony sizers, however, have rollers arranged in such a way that there are specifically sized gaps between them. The gaps start small and increases gradually towards the end of the sizer. The specific fruit sizes fall through these spaces onto a conveyor (Kritzinger 2007:82).

The concept and basic operation of belt-and-roll and pony sizers is the same in any packhouse, but the width and speed may vary.

2.5 Washing

In order to improve marketability, it is very important to sell clean and attractive fruit (Kaplan, 1986:379). All the fruit that are packed should be washed and cleaned before being packed, in order to appear more appealing and remove fungal spores, dirt and insects.

The fruit proceed from the pony sizer on a roller conveyor and are dropped into the washing unit, where the fruit automatically spread across the width of the unit between two static brushes. Washing is accomplished by applying soap foam unto the fruit while it lies in the gap between two rotating brushes. The fruit remains in the same position until another fruit comes from behind, forcing it over the brush into the next gap. This process is repeated until the fruit has passed all the brushes and exits the washer. It is thus clear that for every fruit that enters the washer, one exits the washer. A washer usually consists of 6 to 12 brushes.

In some instances, water is sprayed at high pressures onto the fruit to improve the washing process. Afterwards, the fruit should be rinsed. The amount of cleaning needed depends on the condition of the fruit. Figure 5 is an illustration of a washing unit showing the brushes and the spray nozzles.

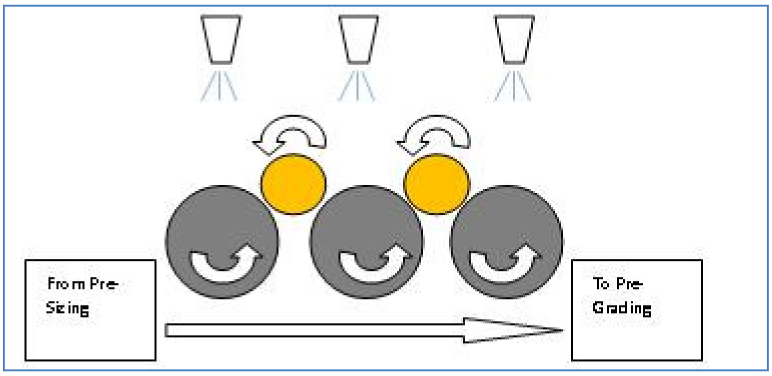


Figure 5: The Washing Operation

After the washing process, the excess water should be eliminated, although the fruit does not have to be completely dry. Grierson *et al* (1986:293) suggests that this stage of water elimination should be done mechanically, by means of horsehair brushes and donut rollers, since it is cheaper than using hot air.

2.6 Drying

After the fruit are washed, it is very important to dry it completely before the wax and fungicide is applied, since the wax cannot be applied to wet fruit (Van Zyl, 2011). Drying is usually accomplished by sending the fruit through a drying tunnel. The primary goal of the drying tunnel is to dry out the excess water on the surface of the fruit after washing (Tarend, 2010).

Fruit is carried on a roller conveyor through a covered tunnel that forces warm air over the surface of the fruit. The tunnels are typically 6 to 8 meters long (Tarend, 2010) and the speed of the conveyor can usually be varied.

2.7 Fungicide Application

The produce passing through the packhouse is treated with fungicide in order to control the spread of post-harvest diseases (Burdon, 1997:6). The fungicide is applied to prevent decay during storage. Fungicide can either be applied by dipping the fruit in a dip tank or it can be sprayed onto the fruit through nozzles (Kruger & Penter, 2006:324).

2.8 Wax Application

Citrus fruit are naturally coated with a wax, which protects the fruit and gives it a natural shine. During the washing process, the natural wax is removed. Synthetic wax is then applied to the fruit, to replace the natural wax. This is done to enhance the appearance of the fruit and it also reduces weight loss during storage.

There are two types of waxes, namely solvent wax and water-based wax. According to Mukhopadhyay (2004:80), water-based wax is preferred. Typically, the wax is sprayed unto the fruit and fungicides can be added to the wax. Thus, the wax and fungicide application is normally done as a single process (Personal observation, 2011).

The wax and fungicide application is also a static brush process, such as the washing operation. Fruit moves over a few static rotating brushes, while wax and fungicide is sprayed onto the fruit through nozzles. The exit rate of fruit is thus equal to the entry rate. Figure 6 depicts a typical wax and fungicide application unit, which consists of a number of static brushes and nozzles.

Figure 6: A Typical Wax & Fungicide Application Unit

2.9 Drying

After the wax and fungicide have been applied, it is important that the fruit are dried again, so that the wax can dry (Tarend, 2010). At this stage, the drying is also accomplished by blowing air at a high velocity over the fruit in a drying tunnel. Both tunnels are basically the same, but the second drying tunnel is usually somewhat longer than the first, ranging between 10 and 12 meters.

2.10 Grading

The next step in the packing procedure is to sort the fruit according to their quality grade. Grading is normally done according to colour, size, shape and weight (Mukhopadhyay, 2004:75). The goal of the grading operation is to grade the fruit as accurately as possible. During this operation, Grade 3 fruit are removed from the main flow of the packing line, so that only Grade 1 and 2 fruit proceed to the next operation. Grade 3 fruit are sized and packed separately (Umans, 2011). Grading can be done by means of manual grading or optical grading. Figure 7 is a depiction of a manual grading table.

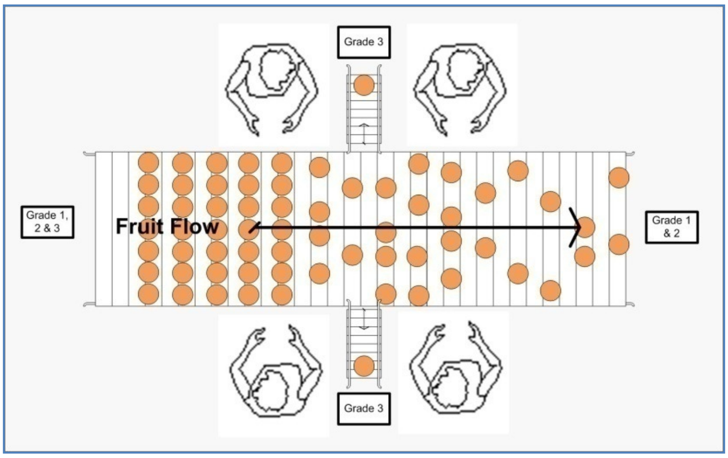


Figure 7: Top View of the Manual Grading Operation

Manual grading consists of the manual inspection of fruit while it is moving on a roller conveyor at a relatively low speed. Each fruit entity is inspected individually and if it is not of conforming quality, it is placed on a different conveyor that escorts it to another location. The fruit automatically spread across the width of the conveyor. Thus, the conveyor cannot be too wide; otherwise the graders will not be able to reach the fruit (Van Zyl, 2011). An example of a typical manual grading table is shown in Figure 8.

Figure 8: A Typical Manual Grading Table

Automatic grading systems employ optical technology to grade the fruit according to size, quality and weight simultaneously. Colour-sorting can also be done optically (Kritzinger, 2007:83). Electronic sizers divide the fruit into different grades automatically and the produce is diverted and transported to the specific grading table according for its quality and size.

2.11 Sizing

The fruit are classified into specific categories according to size. This is done to improve uniformity, aesthetic appeal and to facilitate easier packing (Wagner & Sauls). This classification is done according to the diameter of the fruit. Sizing can be accomplished either manually or electronically.

Citrus fruit are classified into fruit size categories or counts. This count refers to the number of fruit of that specific diameter that can be packed into the standard export carton. There are 10 categories namely Count 144, Count 125, Count 105, Count 88, Count 72, Count 64, Count 56, Count 48, Count 40 and Count 36. Count 144, however, is not a popular count and is nowadays classified as undersized (Umans, 2011). The various fruit counts and corresponding diameters are given in Table 1.

.

Table 1: Sizing Requirements

Size Reference	Count	Diameter Range (mm)	Minimum Recommended Fruit Diameter (mm)
1	144	60 - 68	-
2	125	62 – 70	62
3	105	64 – 73	66
4	88	67 – 76	69
5	72	70 – 80	74
6	64	73 – 84	77
7	56	77 – 88	81
8	48	81 – 92	86
9	40	84 – 96	90
10	36	87 – 100	95

(SAFE, 2010:65)

Mechanical sizing is accomplished by using pull-out belts to divide the different sizes. Belt-and-roll sizers are the most popular sizing equipment in the South African context (Umans, 2011). The fruit is lined up between two rollers, which are moving across a number of lanes. Each lane is destined for a specific fruit count. As the rollers move across the lanes, the gap between them enlarges so that the fruit fall through the gap. Thus, the smallest fruit will fall through at the beginning, while the larger fruit will fall out at the end. The fruit that fall through the gaps are guided by an angled belt into its predestined lane (Personal observation, 2011). Oversized fruit are accumulated at the end of the sizer, crated and sent to juice producers. An illustration of a typical belt-and-roller sizer is shown in Figure 9.

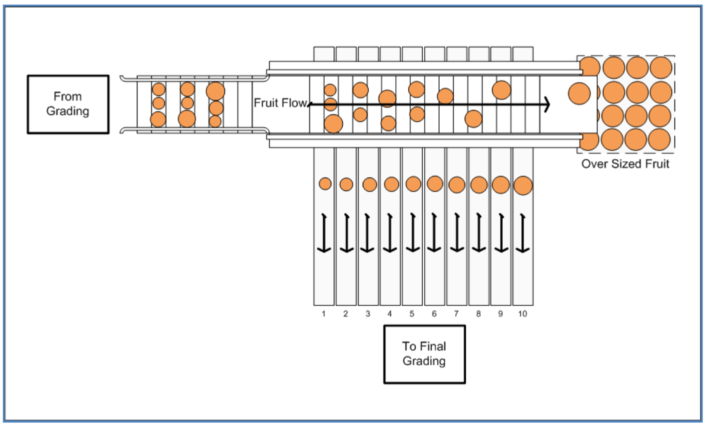


Figure 9: Belt-and-Roll Sizer

Electronic sizing makes use of cameras to size the fruit. Electronic sizing is the preferred sizing method for modern packinghouses, since manual sizing is less accurate and can cause fruit injuries, but it is very expensive to install, so mechanical sizing is still very popular in South Africa.

2.12 Final Grading

After the fruit have been sized, there is a final stage of grading. This step is performed manually, except for when an optical sizer has been installed in the packhouse (Umans, 2011). At this operation, the fruit is spread over a grading table consisting of a roller conveyor. Graders inspect each fruit individually and the main focus of the operation is to separate Grade 1 from Grade 2 fruit. Each of these two classes has a predetermined lane onto which the graders put the fruit after inspection. These lanes usually consist of belt conveyors (Personal observation, 2011).

2.13 Labelling

Usually the market requires that all the first grade fruit passing through the packing line should be labelled (Kritzinger 2007:22). However, this is not always the case and labelling is sometimes not required. According to Grierson *et al* (1986:302), the fruit can be labelled automatically, which is almost always the case.

The fruit is forced into a single lane over which the label applicator is mounted. The fruit moves underneath the label applicator on a relatively slow moving conveyor. The labelling machine applies a single label to every fruit at a certain constant rate. The processing speed of the applicator can be varied and some can even accomplish a throughput as high as 720 fruit per minute per lane (Sinclair, 2009).

2.14 Packing

All the fruit are packed according to their grade and size. Fruit are packed according to count, which means that each carton of a certain grade contains the same number of fruit. It is possible to pack the fruit automatically, but most packinghouses make use of manual packing (Kruger & Penter, 2006:327). Figure 10 is a depiction of a manual final grading and packing unit.

The fruit is transported from the labelling machine to the packing tables that usually consist of bins where the fruit can accumulate. Each fruit class and count has its own predestined packing lane. Packers take an empty carton from an overhead rail and place it on a portable stand. The packers then take fruit from the packing table and pack it into the carton in a specific pattern that depends on the count. Sometimes the packers wrap some of the fruit individually to enhance the aesthetic appeal of the carton (Umans, 2011). The number of fruit per carton that are wrapped is specified either by the market or by the packhouse manager. After a carton has been filled, it is placed on a conveyor and transported to the palletizing area.

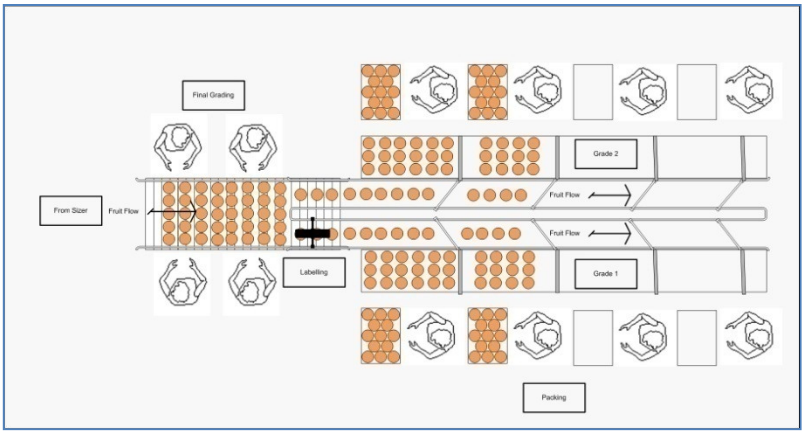


Figure 10: Final Grading and Packing

In every production run there are two or three size counts that are dominant, depending to the fruit size distribution of the run. Thus, all the packing tables are not equally busy and the number of packers at each packing table may vary. More packers are assigned to packing tables that are very active, while only one or two packers are assigned to packing tables for less frequent fruit sizes (Umans, 2011).

2.15 Palletizing

The final operation of a typical packing line is palletizing, where packed cartons are stacked onto pallets, to be stored and transported to the market. The number of cartons per pallet may vary according to market specifications or the preference of the packhouse manager.

2.16 Supporting Operations

There are also various supporting operations within the packhouse. These operations are providing secondary services to the main functions of the packing line.

Bin transport is the first supporting operation in the packhouse. This operation involves the loading of full bins into the tipper and removing empty bins from the tipper, as well as the transport of these bins to and from the tipper.

Fruit that are culled from the packing line, for example the rotten or waste fruit, are collected in crates in the packhouse. As soon as one of these crates is filled, it should be removed and disposed of.

Class 3 fruit that are removed from the packing line at the grading table are sized and packed at a separate packing line. The fruit are normally transported by a conveyor belt to the third class packing line.

Carton folding and transport is the operation that supplies the packing stations with empty cartons. The cartons are folded either manually or automatically by means of a carton folding machine. The empty cartons are then placed on an overhead monorail that transports the cartons to the various packing tables.

The final supporting function is the pallet transportation system. Empty pallets are delivered to the palletizing stations by means of a forklift, which also collects the completed pallets and transported to the docking station from where the full pallets exit the system.

A depiction of the typical layout of a citrus packhouse is provided in Appendix A.

2.17 Summary of Chapter 2

The basic operations within a citrus packinghouse were investigated and explained in this chapter. The function of each operation is discussed and the standard manners in which each one is performed are defined. These operations are discussed in the order in which they occur in the packing line. This chapter creates an understanding of the basic operations that make up a packing line.

Chapter 3 provides a general overview of simulation as a modelling approach to generically represent citrus packing lines. Furthermore, a structured modelling procedure is discussed to construct a roadmap for the development of such a model.

3. An Overview of Simulation

The goal of the project is to develop a model that can assist engineers in the design process of citrus packing lines. This chapter entails an overview of simulation in order to investigate the relevance of this approach to model citrus packing lines.

3.1 Definition of Simulation

Simulation is defined by Winston (2004:1145) as “a technique that imitates the operation of a real-world system as it evolves over time.” A simulation study is used to predict the performance of a system, given a definite set of inputs (Robinson, 2004:4).

A simulation model has to be constructed to perform a simulation study. Such a model consists of assumptions concerning the operation of the system, which are expressed in terms of mathematical or logical relations between the system’s objects of significance. These models are generally constructed with appropriate computer software (Bekker, 2011:8). Simulation studies are usually performed to answer certain “what if” questions.

Robinson (2004:4) highlights the fact that simulation should only be viewed as a structure to support decision-making and should not be used to make decisions on behalf of the user. The user should use the model to explore the behaviour of the system by evaluating the outcomes of various alternative scenarios until he/she understands the system sufficiently to make decisions regarding the actual system.

3.2 General Concepts of Simulation

A system can be defined as the collection of interrelated objects that work together towards a common goal (Bekker, 2011:6). According to the Transaction-Flow World View, a system can be envisaged as the collection of discrete traffic units that flow through the system from point to point, while competing for limited resources (Brunner & Schriber, 2010:152).

Winston (2004:1146) defines the state of a system as the collection of variables required to portray the status of the system.

An entity is a unit of traffic in the system that competes for resources (Brunner *et al*, 2010:152).

A resource is an element in the system with a limited capacity, which supplies a service to entities (Brunner *et al*, 2010:152).

3.3 Advantages & Disadvantages of Simulation

There are ample advantages of using simulation studies to analyse systems. By building simulation models, analysts can investigate systems before the actual system is built (Bekker, 2011:12). Simulators can supply feedback during the design process of the system. The validity of the design can thus be determined beforehand. This allows the user to evaluate various alternative designs and select the best alternative. By selecting the best alternative, the overall cost of the construction of the system can be reduced considerably. Winston (2004:1145) describes the simulation methodology as relatively straight forward and it can be applied with relative ease. One of the most important advantages of simulation, however, is the flexibility of this analytical approach, since simulation models have very little restrictions. Thus, such a model can represent the physical system without making many simplifying assumptions (Winston, 2004:1145). Simulation models can be reusable, which enables the analyst to build one model and use it to analyse different alternatives. A further advantage of simulation is the fact that it can be used to demonstrate the behaviour of a system to stakeholders in order to develop an understanding of the system, especially by using animation. Simulation can also be used to establish consensus among stakeholders regarding certain assumptions or a specific design of a system. Lastly, simulation enables the analyst to study long processes in a relatively short period of time (Bekker, 2011:12).

Even though simulation can be advantageous, it also has some disadvantages. The construction of a simulation model requires a great deal of expertise, exercise and experience. The success of a simulation model depends to a great extent on the capability of the analyst (Bekker, 2011:12). A simulation study is usually extremely time consuming. It can also be very costly, since simulation packages are usually exceptionally expensive. In order to simplify a system, analysts tend to make certain assumptions regarding the system. This can create a misleading sense of confidence regarding the results of the simulation.

3.4 Generic Simulation Modelling

The construction of a simulation model is a very timely process. Modellers can save time and cut costs by using the same model more than once. A model is classified as generic when it is constructed for a specific purpose and it can be used by various organizations (Formoso, Schramm & Silveira, 2008:3) and when it can be used to analyse a large set of systems (Lawrence & Mackulak, 1998:980). Software reuse can be formally defined as “the isolation, selection, maintenance and utilisation of existing software artefacts in the development of new systems” (Robinson, Nance, Paul, Pidd & Taylor, 2004:481).

The main benefits of developing a generic model are the reduction in cost and time of development, increased productivity and the possibility of improved quality.

There are four primary classes of model reuse, namely code reuse, function reuse, component reuse and full model reuse (Robinson *et al*, 2004:481). A reusable model should be easy to configure for a specific application (Lawrence & Mackulak, 1998:979).

3.5 Practicality of Using Simulation for Packhouse Modelling

There are a number of modelling approaches that can be applied to study systems. These include approaches such as spreadsheet models, mathematical programming and queuing theory. However, some systems cannot be represented by these approaches due to their inherent nature. The level of variability, interconnectedness and complexity of a system may pose the need to apply simulation to model it (Robinson, 2004:6). Variability can be either predictable or unpredictable and refers to the changing of conditions within a system. Interconnectedness refers to the fact that operations within a system do not function in isolation, but affect other operations. If one part of a system is changed it may cause a change in another part of the system. Complexity refers to the fact that the functioning of a system is sometimes very intricate and difficult to anticipate. Since simulation is a more flexible modelling approach, simulation models can be constructed to incorporate these factors to a certain degree and can be used to study such systems.

Simulation is typically used to model queuing systems. Such systems consist of entities that undergo a series of operations and queues are formed between consecutive operations if the processing capacity is inadequate (Robinson, 2004:11).

Robinson (2004:2) states that there are four major categories of systems, namely:

i. Natural Systems
ii. Designed Physical Systems
iii. Designed Abstract Systems
iv. Human Activity Systems

Packhouses fall in the category of designed physical systems, since it is the outcome of human design. The nature of the operations within a packhouse is so complex and interconnected that it can only be represented by a simulation model.

3.6 Simulation Modelling Procedure

Bekker (2011:17) and Winston (2004:1185) identified certain steps that an analyst should follow when performing a simulation study. This is a general guideline or roadmap that can be followed to ensure that the model development is carried out in a structured manner. This procedure can be divided into five major phases namely the planning phase, the model construction phase, the verification phase, the experimentation phase and the implementation phase.

The first phase is the planning and definition phase. The purpose of this phase is to formulate and define the problem. The project should be planned during this phase and the boundary of the system should be defined.

The second phase is the model construction phase. This phase is committed to the formulation of the conceptual model, the execution of a preliminary experiment and the establishment of the important parameters. The required input data should also be identified, obtained and analysed. Lastly, the model should be computerized during this phase.

The third phase of a simulation study is concerned with the verification and validation of the model. During this phase, the analyst should determine whether the model represents the physical system accurately or not.

The fourth phase is called the experimentation phase, which consists of the design, performing and analysis of the experiments. The main focus of this phase is the execution of experiments in order to answer certain questions regarding the system.

The fifth and last phase is committed to the implementation of the results of the experiments as well as the maintenance, monitoring and refining of the model. During this phase, the model is reviewed, refined and maintained.

Figure 11 is a depiction of these steps as proposed by Bekker (2011:17) and Winston (2004:1185).

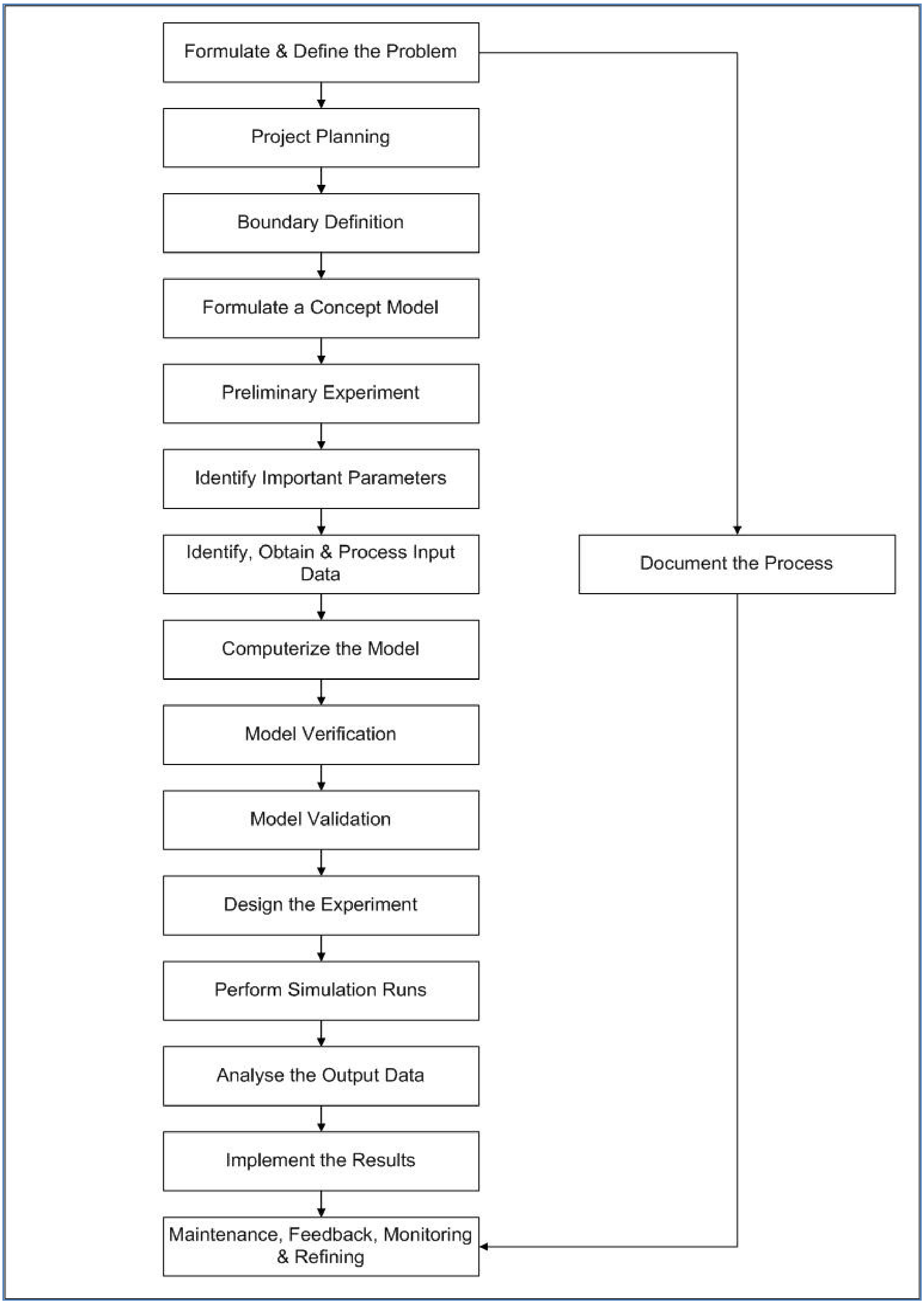


Figure 11: The Simulation Modelling Roadmap (Bekker, 2011:17-26) (Winston, 2004:1185)

3.7 Summary of Chapter 3

The goal of the project is to develop a generic model to represent citrus packing lines. In the next chapter, simulation is investigated as an appropriate modelling approach to develop such a model. An overview of simulation modelling is constructed by defining simulation and discussing the general concepts of simulation. The advantages and disadvantages of simulation are investigated and generic simulation modelling is discussed. The relevance of using simulation for packhouse modelling is investigated. Lastly, a general procedure is defined that can be used as a guideline for the development of the simulation model.

The following chapters entail a description of the model development process by following the proposed procedure as discussed in Chapter 3. The planning phase is discussed in Chapter 4, while the model construction phase is explained in Chapter 5. Chapter 6 consists of the validation and verification phase of the development cycle. The experimentation phase does not fall within the scope of the project, but it is briefly discussed in Chapter 7.

4. Planning and Definition Phase

The previous chapter provided a general overview of simulation as a modelling approach and a modelling procedure was proposed. This chapter entails the discussion of the steps followed to perform the first phase of the procedure, namely the planning and definition phase.

4.1 Formulate the Problem

The process of designing a packhouse is extremely time-consuming, even though all packhouses are essentially the same. It would be desirable to have a simulation model to assist in the design process to reduce the lead time of such a design. This model should be able to assist designers in the process of designing a packhouse or to assist the decision-making process before changing an existing packhouse.

The purpose of the study is to develop a generic simulation model that can be used to evaluate the design of a citrus packhouse against specific criteria. The model should enable the user to compare systems of similar functionality or proposed alternative designs. Furthermore, the user should be able to employ the model to predict the performance of the system under various operating conditions and perform a sensitivity analysis on one or several controlling factors. The model should illustrate the nature of the functional relations in the system and the effects these relationships have on the performance of the system.

The stakeholders of the project are the analyst, the designer and the client for whom the packhouse is designed. Each stakeholder has a different definition for success for the model. In the analyst's perspective, the model would be successful if it can provide useful output data. For the designer, the success of the model lies in its ability to assist in the design or decision process and illustrate the proof of concept. The client would describe a successful model as one that can illustrate the design and layout of the proposed packhouse.

The objective of the study is to develop a generic model by which any or most citrus packhouses can be represented. The model should enable the user to analyse citrus packing lines.

4.2 Project Planning

Project planning is an integral part of any simulation study. A project plan was developed to ensure that the project is finished on time. The plan was updated regularly, in order to keep track of the finished objectives and unfinished milestones. The standard procedure for conducting simulation studies will be followed and the various phases were identified as milestones to be reached.

4.3 System Boundary Definition

According to Bekker (2011:19), system boundaries should be defined in order to simplify the simulation study by reducing the level of detail. The boundaries of the system can be defined by describing the significant inputs, outputs and processes within the system, as depicted in Figure 12.

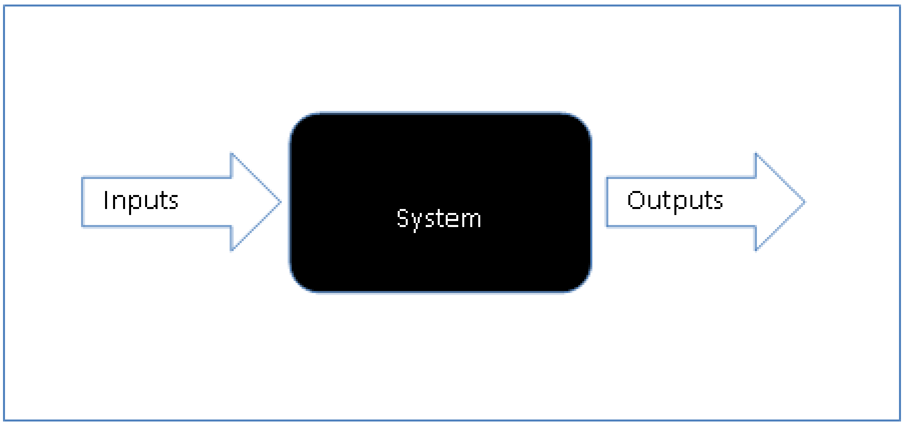


Figure 12: The System as a Black Box

4.3.1 System Inputs

A typical packhouse has numerous inputs, but not all of these inputs are significant when modelling the throughput of the packing line.

Inputs that enter the system, but do not affect the processing capacity of the packing line include the water in the dip tank and washer, the soap in the washer, the wax and fungicide chemicals as well as electricity. It is assumed that these resources are always readily available and the throughput of the system does not depend on these inputs. The labels that are applied at the labelling machine are also assumed to be always available, which means that production will never cease due to a shortage of these labels.

The inputs that do affect the throughput are the fruit and the bins, in which the fruit arrive, as well as the packing material and the pallets. The fruit arrive at the packhouse in the bins, which are dumped at a constant rate. It is assumed that the total amount of bins for a specific production run are always available and that the tipper is never starved. The packing material includes the cartons in which the fruit are packed. The pallets are brought into the packhouse with forklifts, which are also assumed to be readily available.

4.3.2 System Outputs

As with the inputs, there are also a number of outputs of which only a few are significant with regards to the modelling goal.

Outputs such as the trash, waste water and chemicals that exit the physical system fall outside of the scope of this model.

However, outputs such as the nonconforming fruit and stacked unit loads are significant for the purpose of this study. Nonconforming fruit accounts for all the fruit that is not packed in the main packing line of a packhouse, such as the waste fruit, over- and undersized fruit, Class 3 and juice fruit. These fruit are usually crated and removed from the system to be destroyed or processed further at another location. The most important outputs of the system are the stacked pallets. The filled cartons are stacked onto pallets that are transported to the market. Each stacked pallet leaving the system is thus a unit load consisting of a pallet, a number of cartons that are filled with a certain number of fruit.

4.3.3 System Processes

The processes of the system that should be modelled are all the processes within a packing line that transform the significant inputs into the outputs of the system. These processes include the citrus packhouse operations as described previously in the report.

The model should only be developed to represent mechanical packing lines and not electronic sizers.

4.4 Summary of Chapter 4

In this chapter, the first phase of the modelling procedure has been executed. Now that the problem has been defined, the model can be constructed. Chapter 5 provides a discussion of the model construction phase as it was performed to develop the required model.

5. Model Construction Phase

The second phase of the modelling procedure entails the construction of the model. Chapter 5 describes this phase. Firstly, the concept model is constructed, and then the preliminary experiment is performed. Thirdly, the important parameters of the system are identified, the required input data is defined and lastly, the model is computerized.

5.1 Conceptual Model

It is of uttermost importance to plan the proposed model by constructing a conceptual model before starting the computerization. This step is performed to test the analyst's understanding of the system, to identify the lack of information, to establish the first tier logic of the model and to identify the input data that would be required. Concept models can also be used to verify and validate the model and underlying assumptions (Bekker, 2011:20). A concept model illustrates the foundational logic of the model on top of which detail can be added and the computer model can be built.

The conceptual model of a citrus packhouse, shown in Figure 13, has been developed to identify the steps performed on a fruit entity throughout the packing line. The input data required for each step have also been identified. The entities, resources, inputs and outputs of the system have been verified by analysing the concept model.

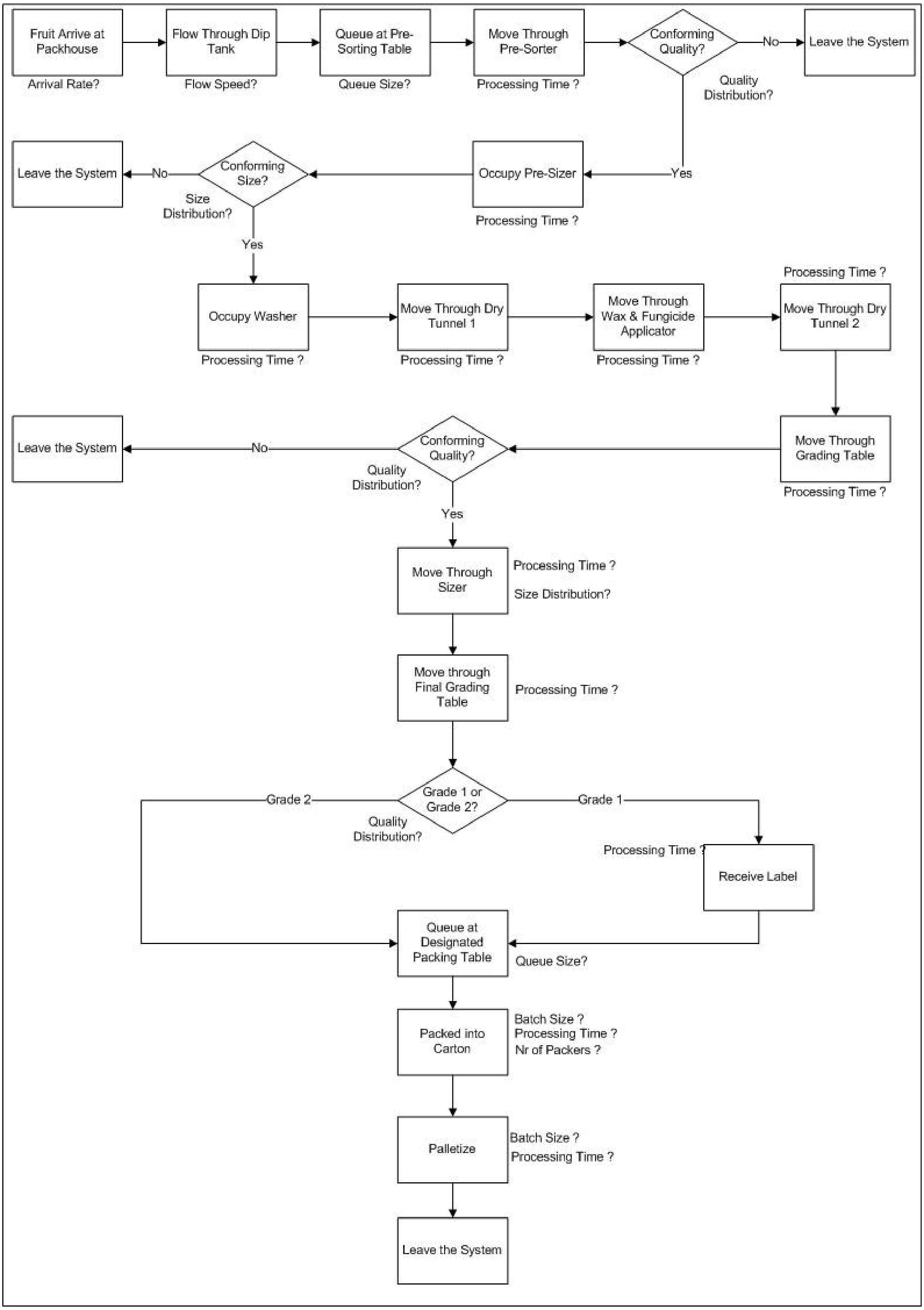


Figure 13: Conceptual Model of a Citrus Packhouse

5.2 Preliminary Experiment

After the concept of the model is established and verified, it is necessary to investigate the system by means of a preliminary experiment, in order to identify the key aspects of the system (Sturrock, 2010:88). These aspects are defined in the following section.

5.2.1 System Type & Model Time Span

The packhouse can be seen as a terminating system, since it operates for a finite length of time during a single production run. This suggests that the system begins a run in an empty state with all its operations in the inactive state and after a series of logical proceedings, the system ends in the empty state with its operations idle again (Bekker, 2011:33). A South African packhouse is normally operational for 9 hours per day. The packing line usually starts at 08:00 in the morning and ends at 18:00 in the evening, with two tea times of 15 minutes each and a 30 minute lunch time. A production run starts as soon as the first bin of fruit is tipped into the packing line and terminates when the last carton is packed. After the termination of a production run, there are usually fruit left on the packing tables of each count, since there is rarely an exactly enough fruit left to fill a carton. The excess fruit are left on the packing tables until the next production run starts, where it is mixed with the new incoming fruit. Thus, the system does not terminate when the last fruit entity exits the packing line, but when the last full carton of the production runs exits the system.

5.2.2 Model Entities & Attributes

As previously defined, an entity is a traffic unit that moves through the system, while competing for resources. In the packhouse there are three basic entities namely fruit, cartons and pallets.

Fruit entities are differentiated by attributes such as quality and size. Each fruit entity that enters the system is of a specific size, namely undersized, oversized or one of the 10 fruit counts. Each fruit can also be one of five quality categories, namely Class 1, Class 2, Class 3, Juice or Waste. Class 1 and Class 2 fruit are of export quality, while Class 3 is for the local market. Juice fruit are fruit that does not have the right colour or have bruises or cut marks. Any fruit that is rotten, cut open or of nonconforming quality is classified as waste.

Fruit are combined into batches and packed in standard cartons. The standard carton used in the South African citrus industry is the 15kg C15 carton. The size of the batch is dependent on the size count of the fruit. For instance, the batch size for Count 56 fruit is 56 fruit per carton. The empty cartons are typically fed to the packing stations by means of a carton rail.

Standard 1000mm x 1200mm pallets are used. Cartons of a specific count are batched on a pallet. The number of cartons per pallet usually varies between 70 and 80, dependent on the preference of the packhouse manager or market specifications.

5.2.3 Model Resources

There are various resources in the model. A resource is an object in the system with a limited capacity that provides a service to the entities. Each operation in the packing line can be seen as a resource in the system. A list of the various resources in the packhouse is provided below.

Table 2: System Resources

Resources	Secondary Resources
Pre-Sorting Table	Graders
Pre-Sizer	-
Washer	-
Drying Tunnel 1	-
Wax & Fungicide Applicator	-
Drying Tunnel 2	-
Grading Table	Graders
Sizer	-
Final Grading Table	Graders
Packing Table	Packers
Palletizers	-

5.2.4 Generic Process Groups

Kritzinger (2007:36) identified 6 generic process groups that exist in a citrus packhouse. Any main operation in a packhouse can be described as one of these groups. These groups are described in detail below.

(a) Fruit Transfer

The fruit transfer group refers to the process whereby fruit enters the packing line. The tipping process is described by this process group. Fruit arrive at the packhouse in bins, which is tipped into the packing line to create a continuous flow of fruit. The fruit transfer process group is illustrated in Figure 14.

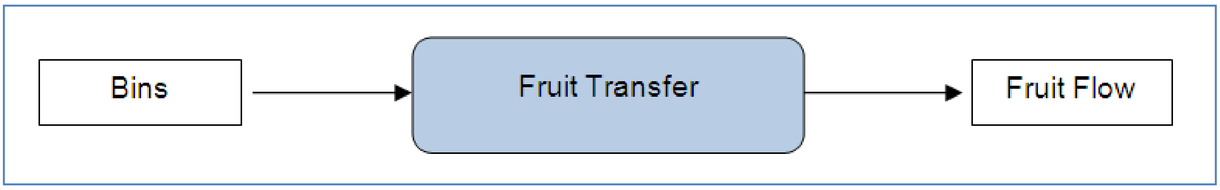


Figure 14: Fruit Transfer

(b) Specific Process

This group represents any process that alters or records aspects of the fruit. In the steady state the output of the process is equivalent to the input of the process. Packing line operations such as washing, wax- and fungicide application, drying and labelling can be represented by this process group. The output flow of fruit from such a process will always be smaller or equal to the input flow.

This process is further divided into three sub-categories namely static roller-, moving roller- and labelling processes. Figure 15 is a depiction of the specific process group.

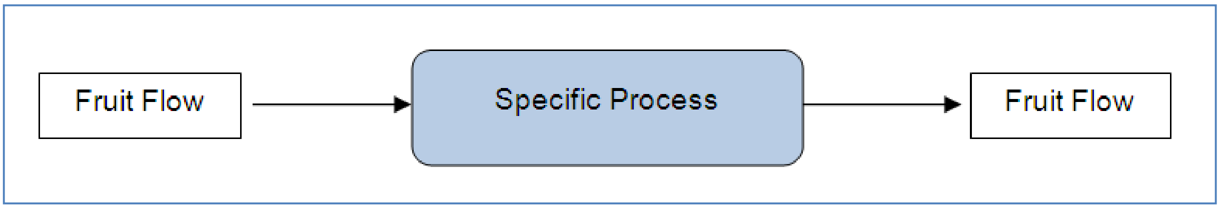


Figure 15: Specific Process

(c) Flow Division

The purpose of a flow division is to split a single flow of fruit into multiple flows according to some process logic. Flow divisions are utilized to represent grading and sizing operations, whereby fruit is divided according to certain fruit attributes, such as quality and size. The total amount of outputs will be equal to the input of the process. The flow division process group is represented in Figure 16.

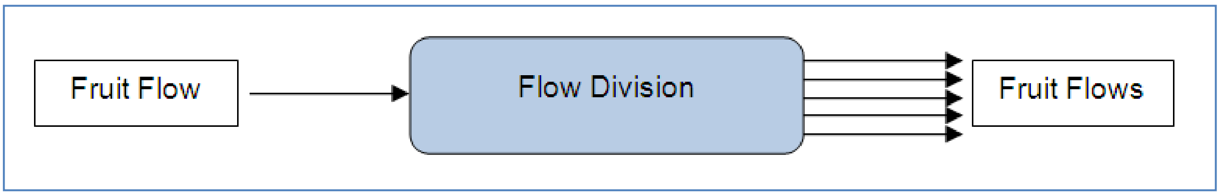


Figure 16: Flow Division

(d) Flow Convergence

The purpose of a flow convergence is to join multiple flows into a single flow of entities. The output of such a process will be equal to the sum of all inputs. Figure 17 illustrates the concept of the flow convergence process group.

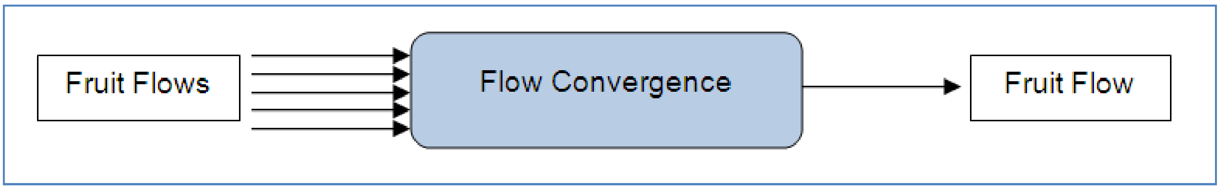


Figure 17: Flow Convergence

(e) Packing

Packing is the process of batches certain number of entities into unit loads. There are two packing processes in a typical packhouse, namely carton packing and palletizing. The capacity of such a process is dependent on the packing rate of the workers and the time required to remove a filled container and replace it with an empty one. The packing process group is illustrated in Figure 18.

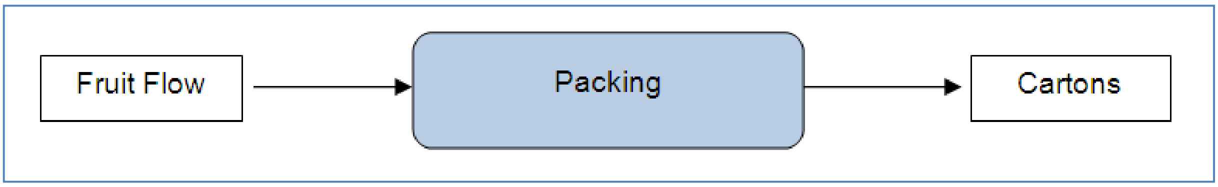


Figure 18: Packing

(f) Flow Control

Flow control processes route entities to specific destinations. An illustration of the flow control process group is shown in Figure 19.

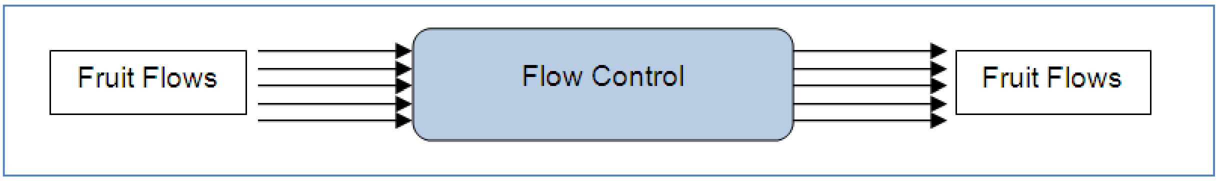


Figure 19: Flow Control

5.3 Parameter Identification

In order to identify the data that will be necessary to build the model, it is crucial to identify all significant parameters in the system, as well as the limits within which these parameters operate. The input variables of the model should also be identified. The outputs of each operation should be determined and the performance measures of those operations should be considered (Bekker, 2011:22).

According to Kritzinger (2007:64), the internal states of the system are represented by the various flows throughout the system.

5.3.1 Fruit Attributes

As previously mentioned, there are two main fruit attributes that influence the performance of the packing line, namely quality and size.

Fruit quality determines the class of the fruit entity. There are five fruit classes, namely Grade 1, Grade 2, Grade 3, Juice and Waste. The quality of the fruit is dependent on the condition of the orchard, the fruit variety and the weather conditions during the season. Fruit quality cannot be improved in the packhouse, but it can be worsened. The quality distribution of each production run can be anticipated by the producer by inspecting the harvest.

Every fruit entity can fall in one of 12 fruit size categories. The distribution of the fruit size of a production run is mainly dependent on the fruit variety and seasonal conditions. The size of the fruit is expressed as the diameter of the fruit and it affects the area covered by the fruit on the rollers and conveyors, as well as the volume of containers that is filled by the fruit. The size distribution can be predicted by the producer beforehand by inspecting the harvest.

The attributes of a certain fruit entity determine the route that it takes through the packing line, since it is graded and sorted according to these attributes.

5.3.2 Fruit Flow Assumptions

In the physical system, fruit are spread across the conveyors and the sizes of fruit vary. For the development of the model it is assumed that the fruit are lined up in a perfect row on the rollers and the average diameter of the fruit is calculated to the amount of fruit that can fit in a row. A graphical illustration of the fruit flow assumption is provided in Figure 20.

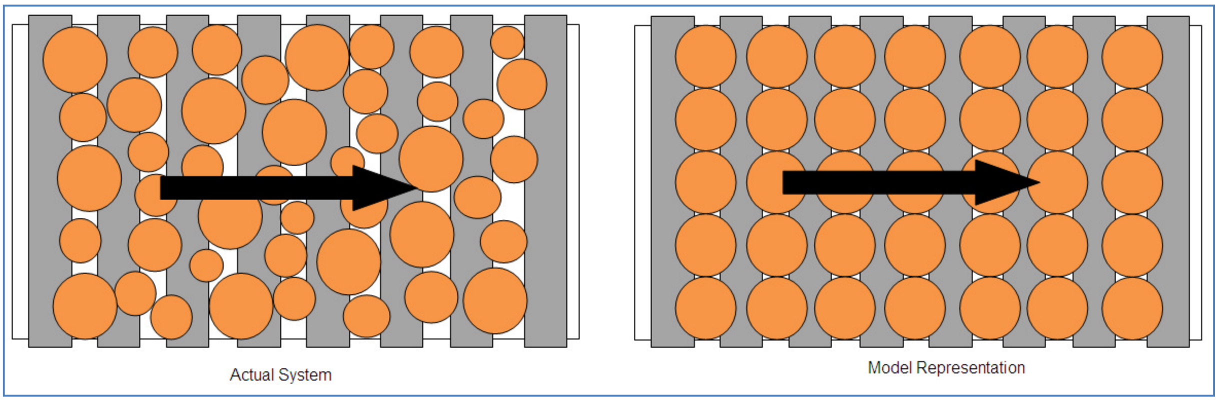


Figure 20: Assumptions Regarding Fruit Flow

5.3.3 Tipping

Fruit arrives at the packing line in bins that are dumped by means of a mechanical tipper. Full bins queue in front of the tipper. As soon as a bin is emptied, it is removed from the tipper and is replaced by a full bin. The fruit are emptied into the dip tank at a constant rate, since the tipping process is automated at modern packhouses. This constant rate creates a continuous flow of fruit into the system until all bins are emptied. Thus, this operation introduces the fruit entities to the system.

As previously mentioned, this process is described by the fruit transfer process group. The significant parameters of this process are the tipping rate, the total number of bins of the production run and the number of fruit per bin.

The tipping rate is dependent on the type of equipment used. Mechanical tippers usually have a constant rate at which bins can be loaded, emptied and unloaded. This tipping rate is crucial in the model, since it would determine the rate at which the fruit entities arrive in the system. The tipping rate should be specified as a certain number of bins per minute or the time to load, empty and unload a bin in seconds.

Any production run consists of a predetermined amount of bins that have to be processed by the packhouse. This parameter is determined by the packhouse manager.

The number of fruit per bin has to be determined in order to calculate the total number of fruit entities that will enter the system during a production run. The total number of fruit can thus be calculated by multiplying the amount of bins with the number of fruit per bin.

5.3.4 Dip Tank

The dip tank at the beginning of the packing line acts as a buffer for the system. The fruit that are dumped are accumulated in the tank and flow at a lower speed towards the first operation, which is pre-sorting.

There are three main parameters that play a role in the throughput of the dip tank, namely the width and length of the tank and the flow speed of the fruit in the tank.

The width and length of the tank are provided by the design engineer or user and is expressed in meters.

The flow speed of the fruit is expressed in meters per minute. The flow speed affects the time that an entity spends in the tank.

5.3.5 Pre-Sorting

The pre-sorting operation is an instance of the flow division process generic group. This process is fundamentally a grading operation, where fruit of nonconforming quality are removed from the system. The sum of the outputs of the pre-sorting process is equal to the input.

The fruit travel on roller conveyors, while graders inspect each fruit individually. Thus, the throughput of the process is determined by the speed at which the conveyor moves and the width of the conveyor and the quality of the fruit.

The speed of the conveyor determines how fast the fruit moves through the grading process. The throughput of the process can be increased by increasing the speed of the conveyor. However, this speed is constrained by the ability of the graders. If the conveyor speed is too high, the graders would be unable to inspect all the fruit before they exit the process. The speed of the conveyor is expressed in meters per second.

The width of the pre-sorting conveyor has a notable effect on the throughput of the process. The amount of fruit that fit in a row on the conveyor is dependent on the width of the conveyor and the average diameter of the fruit at this stage. If the speed is constant, the throughput, in fruit per second, can be increased by increasing the width of the conveyor. The width of the conveyor is constrained by the 5^{th} percentile arm length of the graders. The graders should be able to reach the fruit wherever it is on the conveyor. The width of the conveyor is expressed in millimetres.

The quality of the fruit would have an impact on the flow after the process. If the fruit is of good quality and only a small percentage of fruit has to be removed at the pre-sorting stage, the output flow would be higher than a production run with low quality fruit.

Although the length of the pre-sorting table does not have an effect on the throughput in the steady state, it is necessary to specify this parameter for modelling purposes. This length is expressed in meters.

5.3.6 Pre-Sizing

The pre-sizing operation is also a flow division process, whereby fruit is divided according to size. Undersized fruit are removed from the main flow of fruit. The sum of the outputs of the pre-sizing process is equal to the input.

The throughput of this process is mainly dependent on the width of the unit and the roller speed. The width of the conveyor is expressed in millimetres and the speed in meters per second. The length of the sizer should also be specified in meters.

The size distribution of the fruit determines the output of each possible flow.

5.3.7 Washing

The washing operation can be classified as a static roller specific process. The progress of fruit through the washing unit depends on the arrival of fruit from the pre-sizer. Firstly, the fruit that enter fill the unit. When the process operates in the steady state, one fruit exits the unit for every fruit that enters the unit.

The throughput of the process relies on the time that a fruit entity is required to spend in the unit and the arrival rate of the fruit from the pre-sizer. The capacity of the unit relies on the width of the unit and the number of brushes in the unit.

The time that a fruit entity should spend in the washer is specified by the market. According to Umans (2011), the fruit should spend any time between 30 to 60 seconds in the washing unit.

The arrival rate cannot be specified, since it is only a product of the pre-sizing operation. This rate can be varied by varying the throughput of the pre-sizer.

The unit width and number of brushes determines the capacity of the washer. The number of brushes determines the number of rows of fruit that is present in the unit, while the width determines the amount of fruit per row. The unit width is expressed in terms of millimetres.

5.3.8 Drying 1

The drying operation can be classified as a moving roller specific process. The fruit travels on a roller conveyor through a drying unit. The output flow is equal to the input flow of fruit.

The width of the unit, speed of the rollers and the required drying time are the noteworthy parameters in the drying process.

The width of the unit determines the number of fruit that fit in a row on the conveyor. This parameter is equipment specific and is expressed in millimetres.

The speed of the rollers, in meters per second, influences the throughput of the drying unit. This speed is constrained by the time fruit entities are required to spend in the dryer and the length of the unit. Each fruit entity are required to spend a certain time in the dryer, so the roller speed should be slow enough so that the fruit does not move through the unit in less that the specified time. This time varies between 30 and 60 seconds.

5.3.9 Waxing & Fungicide Application

The wax and fungicide application operation can be classified as a static roller specific process, such as the washing operation.

The important parameters of this process is the time that fruit are required to spend in the unit and the rate at which fruit entities arrive from the drying tunnel. The capacity of the unit relies on the width of the unit and the number of brushes in the unit.

The time that a fruit entity should spend in the unit is specified by the market. This required time is between 30 and 60 seconds.

The arrival rate cannot be specified, since it is only a product of the drying operation. This rate can be varied by varying the throughput of the dryer.

The unit width and number of brushes determines the capacity of the wax and fungicide unit. The number of brushes determines the number of rows of fruit that is present in the unit, while the width determines the amount of fruit per row. The unit width is expressed in terms of millimetres.

5.3.10 Drying 2

The second drying operation is identical to the first drying tunnel, with the same parameters present. However, the values of these parameters are not the same. The time that a fruit entity should spend in this drying tunnel should be between 60 and 90 seconds, thus the second drying tunnel is normally longer than the first, but the steady state throughput is the same.

5.3.11 Grading

Manual grading can be classified as a flow division process. The fruit is transferred on a roller conveyor, while graders inspect each fruit individually. The sum of the outputs is equal to the input.

The throughput of the process is determined by the speed at which the conveyor moves and the width of the conveyor and the quality of the fruit.

The roller speed, in meters per second, is the biggest factor regarding the throughput of the unit and is constrained by the ability of the graders.

The width of the unit, in millimetres, also influences the throughput and is constrained by the maximum reach of the graders.

The quality distribution of the fruit determines the output of each possible flow.

The grading unit is assumed to be 100% accurate.

5.3.12 Sizing

Mechanical sizing, such as belt-and-roller sizers, can be categorised as a flow division process. The incoming flow is divided into multiple flows according to fruit size. The sizer is a moving roller conveyor unit. The number of output flows is dependent on the number of size counts that are packed in the packhouse.

The throughput of the sizer is dependent on the speed of the rollers, the width of the unit and the size distribution.

The speed of the rollers, in meters per second, is equipment specific.

The width of the unit, specified in millimetres, determines the number of fruit that fits in a row of the sizer.

5.3.13 Final Grading

The final grading operation is a roller conveyor flow control process. Grade 1 and 2 fruit come in on a roller conveyor and is separated manually and assigned to a specific lane on the packing table.

The parameters that influence the throughput of the final grader are the speed of the conveyor, the width of the unit.

As with the other grading operations, the speed is constrained by the ability of the graders, while the width is constrained by their reach.

5.3.14 Labelling

The labelling operation is a specific process. The only parameter that is significant is the processing time of the label applicator, which is equipment specific.

5.3.15 Packing

The packing operation is probably one of the most important operations in the packing line. This is the process whereby fruit is packed into cartons for the export market. The fruit accumulates on the packing tables and is packed manually by human packers into the cartons. Each packing table is designated for a specific fruit count and all the fruit of that specific count is assigned to its specific packing table. The packing tables of the predominant size counts for a specific production run are normally the bottleneck of the system (Umans, 2011).

The parameters of the packing operation can be grouped into three major subsets, namely packing table parameters, packing parameters and packer ability.

The packing table parameter group contains parameters such as the capacity of the packing table, in other words, the number of fruit that can accumulate at the packing table and the maximum packing stations at the packing table.

The packer parameters are the time to pack an unwrapped fruit, the time to pack a wrapped fruit and the time to collect and setup an empty carton after one has been filled. All of these parameters are measured in seconds.

The packing parameters are the number of fruit per carton, the number of unwrapped fruit per carton, as well as the number of wrapped fruit per carton. The first parameter is dependent on the specific packing table, while the last two are specified by the market or packhouse manager.

5.3.16 Palletizing

The palletizing operation is a packing process, where a specific number of cartons are stacked on a pallet.

The parameters that influence the palletizing operation are the number of palletizers available and the number of cartons per pallet.

The number of palletizers available refers to the number of people assigned to stack the pallets and is specified by the packhouse manager.

The number of cartons per pallet is determined by the packhouse manager or the market and is usually either 70 or 80 cartons per pallet.

5.3.17 Conveyors

Conveyors are the most popular mode of fruit transport in the packing line. The capacity of the conveyors is determined by the width of the conveyors. The speed of the conveyors is also important and can be expressed in meters per second.

5.4 Determine, Obtain & Analyse Input Data

Due to the generic nature of the model, the required input data is specific to the system to be analysed. There is a set of input data required to set the model up to represent a specific system. This set of data should be obtained before each specific study. The dataset needed is shown in Table 3. If the study is performed to study an existing packhouse, this data can be obtained from the packhouse itself. However, if the purpose of the study is to evaluate a proposed layout, the data can be obtained from the preliminary design.

Table 3: Input Data Required to Model a Packhouse

Operation	Parameter Name	Unit	Type	Source
N/A	Quality Distribution	%	Fruit Info	Producer
N/A	Size Distribution	%	Fruit Info	Producer
N/A	Average Fruit Diameter	mm	Fruit Info	Producer
Tipper	Tipping Rate	containers/min	Equipment	Designer
Tipper	Fruit per Container	fruit	Equipment	Designer
Dip Tank	Average Flow Speed	m/s	Equipment	Designer
Dip Tank	Tank Width	mm	Equipment	Designer
Pre-Sorting	Total Unit Length	mm	Equipment	Designer
Pre-Sorting	Unit Width	mm	Equipment	Designer
Pre-Sorting	Roller Speed	m/s	Equipment	Designer
Pre-Sizing	Total Unit Length	mm	Equipment	Designer
Pre-Sizing	Unit Width	mm	Equipment	Designer
Pre-Sizing	Roller Speed	m/s	Equipment	Designer
Washing	Nr of Brushes	brushes	Equipment	Designer
Washing	Unit Width	mm	Equipment	Designer
Washing	Minimum Time	seconds	Run Info	Packhouse Manager
Drying1	Total Unit Length	mm	Equipment	Designer

Operation	Parameter Name	Unit	Type	Source
Drying1	Unit Width	mm	Equipment	Designer
Drying1	Roller Speed	m/s	Equipment	Designer
Waxing & Fungicide	Nr of Brushes	brushes	Equipment	Designer
Waxing & Fungicide	Unit Width	mm	Equipment	Designer
Waxing & Fungicide	Minimum Time	seconds	Run Info	Packhouse Manager
Drying2	Total Unit Length	mm	Equipment	Designer
Drying2	Unit Width	mm	Equipment	Designer
Drying2	Roller Speed	m/s	Equipment	Designer
Grading	Total Unit Length	mm	Equipment	Designer
Grading	Unit Width	mm	Equipment	Designer
Grading	Roller Speed	m/s	Equipment	Designer
Sizing	Total Unit Length	mm	Equipment	Designer
Sizing	Unit Width	mm	Equipment	Designer
Sizing	Roller Speed	m/s	Equipment	Designer
Final Grading	Total Unit Length	mm	Equipment	Designer
Final Grading	Unit Width	mm	Equipment	Designer
Final Grading	Roller Speed	m/s	Equipment	Designer
Labelling	Labelling Time per Fruit	s	Equipment	Designer
Packing	Time to Pack Unwrapped Fruit	s	Run Info	Packhouse Manager
Packing	Time to Pack Wrapped Fruit	s	Run Info	Packhouse Manager
Packing	Time to Start New Carton	s	Run Info	Packhouse Manager
Roller	Unit Width	mm	Equipment	Designer
Roller	Roller Speed	m/s	Equipment	Designer
Conveyor	Unit Width	mm	Equipment	Designer
Conveyor	Conveyor Speed	m/s	Equipment	Designer
Palletizing	Cartons per Pallet	cartons	Run Info	Packhouse Manager

5.5 Computerize the Model

The fifth step in the model construction phase is to computerize the model. Firstly, a suitable simulation software package should be selected. Simio has been identified as an appropriate package and an overview of Simio is provided. Lastly, the model is constructed in Simio.

5.5.1 Simulation Package Selection

Before the model can be computerized, it is necessary to identify alternative simulation packages and select the most appropriate alternative according to the needs and expertise of the analyst.

In order to make an informed choice regarding the selection of a simulation package, it is essential to understand the functioning of simulation packages. Such packages are normally distinguished in terms of their world views. The simulation modelling world view is a structure used to describe a system. One of the most popular world views is given as “entities having attributes interact with activities or resources under certain conditions creating events that change the state of the system” (Bekker, 2011:13). There are three main approaches to world views, namely event, process and object modelling.

In event modelling, the system is described as a series of instantaneous events that alter the system state over a period of time. The different system events are defined, which are used to model the alteration of the system state at each event (Pegden, 2010:210). Event modelling usually strive to address questions such as how the system state can be defined, what events influence the system state and what is the logic that makes up an event (Pegden, 2010:211).

The movement of inert entities through the system can be described as a process flow, which consists of various steps that model the changes in the system state. Process models are usually in the structure of a flowchart, through which the entities flow. Process modelling identifies the entities that move through the system and the processes that are executed during the movement of the entities (Pegden, 2010:212).

Object modelling is normally easier to use and extremely effective. The system is modelled by the description of the objects that form the system. The behaviour of the system emerges from the interaction between the objects. Object modelling is desirable, since the model relates directly to the physical system that it corresponds to (Pegden, 2010:213).

There are a wide variety of simulation packages available in the market, such as Simio, Arena, ProModel, Simul8, Lingo and Excel.

Simio has been identified as the most viable alternative package for the specific problem, since it is an object-oriented simulation tool (Pegden, 2010:214). The packhouse can be modelled by describing the fruit, machines, conveyors, workers and other objects that make up the system. The interaction between these objects in the packhouse will bring about the performance of the system. Object modelling is considerably more powerful and easier to apply than process modelling (Pegden, 2010:213).

5.5.2 Simio

The Simio simulation package is based on the object modelling approach and enables the user to construct and run three dimensional animated models of a system. This is accomplished by merging and joining objects that corresponds to the real world system. Every object is characterized by its internal model, which is defined to match the events in the physical system. These characteristics include its properties, states, events, external view and logic (Simio LLC, 2010:1), which are described in the table below.

Table 4: Object Characteristics (Simio LLC, 2010:2)

Object Characteristics	Description
Properties	Input values that can be specified by the user
States	Dynamic values that change during the execution of the model
Events	Actions that occur at particular times
External Views	Graphical depiction of the object
Logic	Defined the response of the object to certain events

In the standard library of Simio, there are 15 standard objects. These objects are shown in the table below. Each of these objects has pre-existing properties and external views, which can be changed by the user to fit the physical system.

Table 5: Objects in the Standard Library (Simio LLC, 2010:5)

Object	Description
Source	Generates entity objects of a specific type and arrival pattern
Sink	Destroys entities that have completed processing in the model
Server	Represents a capacitated process
Workstation	Models a complex workstation with setup, processing, and teardown phases and secondary resource and material requirements
Combiner	Combines multiple member entities together with a parent entity
Separator	Splits a batched group of entities or makes copies of a single entity
Resource	A generic object that can be seized and released by other objects
Vehicle	A transporter that can follow a fixed route or perform on demand transport pickups/drop offs. Additionally, an ‘On Demand’ routing type vehicle may be used as a moveable resource that is seized and released for non-transport tasks

Object	Description
Worker	A moveable resource that may be seized and released for tasks as well as used to transport entities between node locations
Basic Node	Models a simple intersection between multiple links
Transfer Node	Models a complex intersection for changing destination and travel mode
Connector	A simple zero-time travel link between two nodes
Path	A link over which entities may independently move at their own speeds
Time Path	A link that has a specified travel time for all entities
Conveyor	A link that models both accumulating and non-accumulating conveyor devices

Entities are the dynamic objects in the model that can be created and destroyed, travel through the system and are processed by fixed objects (Simio LLC, 2010:16). It is thus any unit of traffic within the system.

5.5.3 Computerization

Sturrock (2010:91) describes two approaches to model construction, namely "breadth first" and "depth first." Model construction is considered as "breadth first" if the analyst builds the entire model with a minimal level of detail. "Depth first" modelling is when the analyst constructs the model piecewise by selecting a part of the model and developing it in full detail before moving on to the next part. During the development of the packhouse model, the "breadth first" approach has been followed, since it leads to the immediate development of a semi functional model. The model has thus been developed in an iterative manner, where the first iteration was used to identify the functional specifications. The following iterations involved the further refinement of the model by adding more detail.

The constructed model consists of three basic tiers within Simio. The first tier is constructed in the Facility window, where the basic properties of the objects are defined. The larger part of the model's logic is defined within this level. The second tier is known as the Processes window, which is used to define underlying logic of the objects. The third tier is the Data window. This level consists of several data tables that contain data regarding the model. These tables are referenced by the individual entities and objects in the Facility window and are used to define their properties.

The layout of the model has been constructed in such a way that it represents the typical layout of the physical system.

The majority of the operations within the packhouse can be modelled as roller conveyors. In the physical system, the fruit are spread in rows in the gaps between two consecutive rollers. However, Simio does not allow the entities in the model to spread across the conveyors, but is forced to move in single file. Thus, the speed of the conveyors in the model should be weighted to incorporate this flaw by taking into account the number of fruit that can fit in a row on each specific conveyor.

The construction of the most important parts of the model is discussed in detail in the Chapters 5.5.3.1 to 5.5.3.17. Illustrations of each part of the model are provided in Appendix B.

5.5.3.1 Fruit Entity Definition

There are 24 fruit categories in a citrus packhouse. Each of these categories has been defined as a separate entity, which is specified in the Data window. A table, FruitClassArrivals, has been created that contains all the necessary information regarding the fruit entities. The table consists of 5 columns, namely Fruit Class, Part Mix, Part Mix Unit, Average Fruit Diameter and Diameter Unit. Each row in the table refers to a specific fruit entity. The name of the fruit entity is stated in the Fruit Class column. The average number of each fruit entity in a certain production run is given as a percentage of the total number of fruit in the system in the Part Mix column. The Average Fruit Diameter column contains the diameter of each fruit category.

5.5.3.2 Sequences

It is assumed that graders are totally accurate and that fruit will always be graded correctly. Thus, no Class 1 fruit entities would be graded as Class 2. A specific sequence is assigned to each fruit entity that enters the system and the entity follows that sequence through all the operations to its specific packing table or crate. A sequence table has been created for every fruit entity in the Data window.

5.5.3.3 Hardware Specifications

A data table, Table_HardwareSpecs, has been created that contains the design specifications and parameters of each operation in the system. The operations in the model reference these inputs for the throughput calculations. The table comprises of five columns. The first column states the ID of each parameter, while the operations to which the parameters refer is stated in the second column. The name of each parameter is given in the third column and the values of the parameters are entered in the fourth column. The unit of each parameter is stated in the last column.

5.5.3.4 Tipper

The tipping operation is represented in the Facility window by a Source object from the standard library provided by Simio. The tipper creates the model entities according to the part mix provided in the FruitClassArrivals table.

The arrival mode is defined as inter-arrival time, since an average time between the arrivals of each fruit entity can be calculated. The inter-arrival time is dependent on the tipping ability of the bin tipper, as well as the average amount of fruit per bin.

$$\text{Tipping Rate} = \frac{\text{Bins}}{\text{Minute}} \text{ x } \frac{\text{Fruit}}{\text{Bin}} = \frac{\text{Fruit}}{\text{Minute}} \qquad \text{...(5.1)}$$

$$\text{Inter Arrival Time} = \frac{1}{\text{Tipping Rate}} \qquad \text{...(5.2)}$$

For example, if a tipping unit is capable of tipping 0.5 bins per minute and a bin contains an average of 2000 fruit, the tipping rate is 1000 fruit entities per minute (0.5x2000 = 1000).

5.5.3.5 Pre-Sorting

The pre-sorting unit is basically defined as a roller conveyor and is represented in the model as a Conveyor between two Transfer Nodes. The roller speed of the conveyor is entered by the user in the data table Table_HardwareSpecs. The roller speed of the unit should be weighted.

$$\text{Initial Desired Speed} = \text{Roller Speed x } \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.3)}$$

For instance, if a system's pre-sorting conveyor has a width of 1600mm and is set to a speed of 200mm/s and the average fruit diameter of the specific production run is 80mm, the weighted roller speed of the model's representation of the pre-sorting unit is 4000mm/s (200x1600/80 = 4000). Thus, if 20 fruit entities fit in row on the conveyor in the physical system, the speed of the conveyor in the model should be 20 times faster.

The logical length of the conveyor is the length of the pre-sorting unit and is entered in the Properties

The fruit move from the Input Transfer Node to the Output Transfer Node, from where the waste and juice fruit are deferred to separate sinks and the conforming fruit proceed to the pre-sizing unit.

5.5.3.6 Pre-Sizing

The pre-sizing unit is represented in the model as a Conveyor between two Transfer Nodes, since a pony sizer is a roller conveyor operation. The roller speed of the conveyor is entered by the user in the Hardware Specifications table. The initial desired speed of the unit is the weighted equivalent of the roller speed.

$$\text{Initial Desired Speed} = \text{Roller Speed} \times \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \quad ...(5.4)$$

The length of the unit is entered as the logical length of the conveyor in the model.

The fruit move from the Input Transfer Node to the Output Transfer Node, from where the undersized fruit are deferred to a sink and the fruit with conforming size continue to the washing unit.

Figure 21 is an illustration of the constructed model's representation of the tipping, pre-sorting and pre-sizing units.

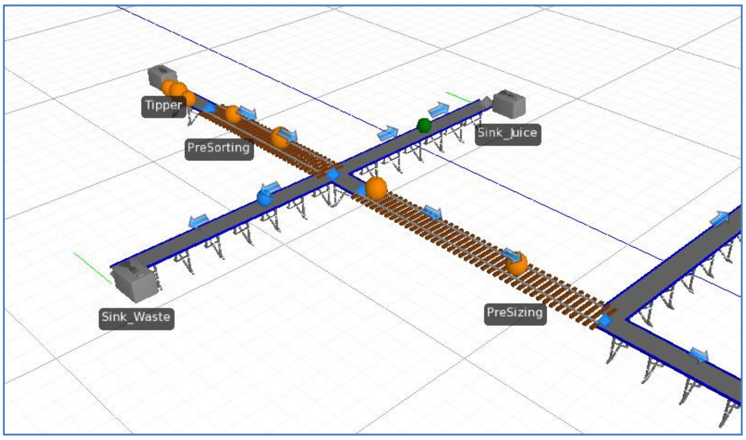


Figure 21: The Model's Tipping, Pre-Sorting & Pre-Sizing Units

5.5.3.7 Washing

The washing process is described in the model as a Server from the standard library. The initial capacity of the server is the number of fruit that fit into the unit, which can be calculated as the number of fruit that fit in a row between the brushes.

$$\text{Capacity} = \frac{\text{Width of Unit}}{\text{Average Fruit Diameter}} \quad ...(5.5)$$

For example, if the washing unit is 1600mm wide and the average fruit diameter of the production run is 80mm, 20 fruit entities will be able to fit in a row (1600/80 = 20), which can be processed simultaneously.

The processing time of the Server is the minimum time that a fruit entity should spend in the washing unit, as defined by the user.

A fruit entity remains between two brushes until it is pushed forward by an incoming fruit. This process is modelled by means of a process in the Processes window with a number of consecutive Wait steps. Each step represents the row between two brushes. Thus, if there are n brushes, there should be n-1 Wait steps in the Process. Thus, the entity waits in the washer until n-1entities enter the unit.

5.5.3.8 Drying 1

The drying unit consists of a roller conveyor moving through a heated tunnel and can be modelled as a Conveyor between two Transfer Nodes. The initial desired speed is a weighted version of the roller speed, which is entered by the user as a hardware specification.

$$\text{Initial Desired Speed} = \text{Roller Speed} \times \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.6)}$$

The logical length of the Conveyor in the model is the length of the drying tunnel in the physical system.

Figure 22 shows the model's representation of the washing unit and the first drying tunnel.

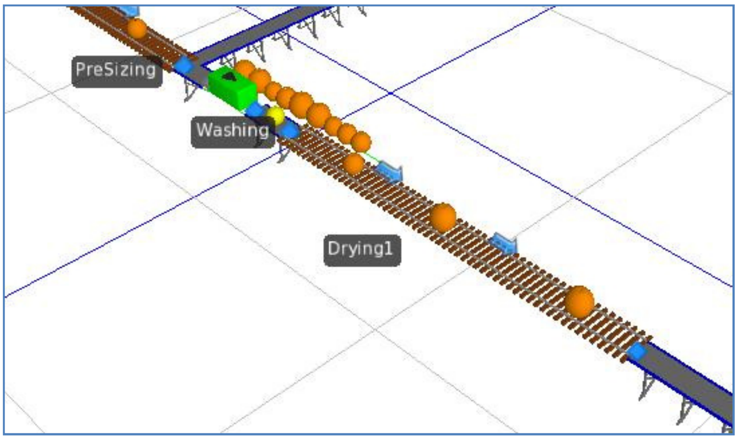


Figure 22: The Model's Representation of the Washing Unit

5.5.3.9 Wax & Fungicide Application

The wax and fungicide application process is described in the model as a Server from the standard library. The initial capacity of the server is the number of fruit that fit in a row in the unit.

$$\text{Capacity} = \frac{\text{Width of Unit}}{\text{Average Fruit Diameter}} \qquad \text{...(5.7)}$$

For example, if the waxing and fungicide application unit is 1600mm wide and the average fruit diameter of the production run is 80mm, 20 fruit entities will be able to fit in a row (1600/80 = 20), which can be processed simultaneously.

The processing time of the Server is the minimum time that a fruit entity should spend in the washing unit, as defined by the user.

As soon as a fruit entity has been processed, it remains in the unit until a new entity arrives at the server from the drying tunnel. This waiting process is modelled in the same manner as the washing unit.

5.5.3.10 Drying 2

The drying unit consists of a roller conveyor moving through a heated tunnel and can be modelled as a Conveyor between two Transfer Nodes. The initial desired speed is a weighted version of the roller speed, which is entered by the user as a hardware specification.

$$\text{Initial Desired Speed} = \text{Roller Speed} \times \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.8)}$$

The logical length of the Conveyor in the model is the length of the drying tunnel in the physical system.

Figure 23 is a depiction of the model's version of the waxing and fungicide application unit, as well as the second drying tunnel.

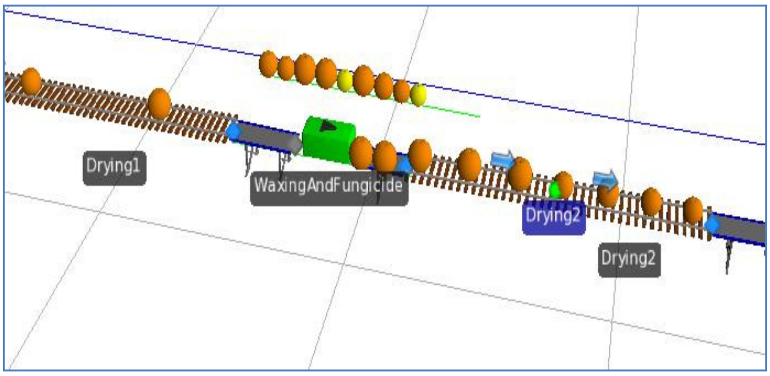


Figure 23: The Model's Waxing & Fungicide Unit

5.5.3.11 Grading

The grading unit can be described as a roller conveyor and is represented in the model as a Conveyor between two Transfer Nodes. The roller speed of the conveyor is entered by the user in the Hardware Specifications table. This speed should then be weighted to give the initial desired speed.

$$\text{Initial Desired Speed} = \text{Roller Speed x } \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.9)}$$

The logical length of the conveyor is the length of the grading table and is entered by the analyst.

The fruit move from the Input Transfer Node to the Output Transfer Node, from where the Grade 3 fruit are deferred to a separate sink and the Grade 1 and Grade 2 fruit proceed to the sizer.

5.5.3.12 Sizing

The sizer is a more intricate unit and is represented in the model by a series of Conveyors between Transfer Nodes. There is one Transfer Node for each size count. The fruit move on the conveyor and is dropped off at its designated Node. The roller speed of the conveyor is entered by the user in the Hardware Specifications table. This speed should then be weighted to give the initial desired speed.

$$\text{Initial Desired Speed} = \text{Roller Speed x } \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.10)}$$

The logical length of the conveyor between the first two nodes in the unit is the length of the sizer and is entered by the analyst. The length of the other conveyors is zero, since they are only a representation of the nodes inside the actual sizer.

An entity moves through the sizer via the various Transfer Nodes to the specific packing table according to its diameter.

5.5.3.13 Final Grading

The final grading unit can be described as a roller conveyor and is represented in the model as a Conveyor between two Transfer Nodes. The roller speed of the conveyor is entered by the user in the Hardware Specifications table. This speed should then be weighted to give the initial desired speed.

$$\text{Initial Desired Speed} = \text{Roller Speed} \times \frac{\text{Unit Width}}{\text{Average Fruit Diameter}} \qquad \text{...(5.11)}$$

The logical length of the conveyor is the length of the grading table and is entered by the analyst.

The fruit move from the Input Transfer Node to the Output Transfer Node, from where the Grade 1 fruit are deferred to the label applicator and Grade 2 fruit are referred to the second grade packing table.

5.5.3.14 Labelling

The labelling process can be represented by a Workstation, which is a constrained resource with a capacity of one. The processing time of the label applicator is equipment specific and is entered by the analyst in the Hardware Specifications table. Only Grade 1 fruit entities move through the labelling machine.

5.5.3.15 Packing

The packing station of each lane can be modelled as a Combiner. The batch quantity of each unit is the count of that lane. The initial capacity is given as the number of packers at the table. The Parent TransferIn Time is specified as the time a packer takes to collect and set up an empty carton after one has been filled. This time is specified in the Hardware Specification table. The processing time of each carton takes into account how many fruit per batch are wrapped or unwrapped.

$$\text{Processing Time} = (\text{Time Wrapped}) \times (\text{Nr Wrapped}) + (\text{Time Unwrapped}) \times (\text{Nr Unwrapped}) \qquad \text{...(5.12)}$$

For instance, consider the Count 80 packing table. The time it takes a packer to pack a wrapped fruit is 0.9 seconds, while only 0.6 seconds is required to pack an unwrapped fruit entity. If it is specified that 40 of the fruit entities of each carton should be wrapped, the processing time per carton would be 60 seconds (0.6x40 + 0.9x40 = 60).

The input buffers of the Combiners should be entered in the Hardware Specifications table, which refers to the designed capacity of the packing tables.

Figure 24 is an illustration of the model's final grading, labelling and packing unit.

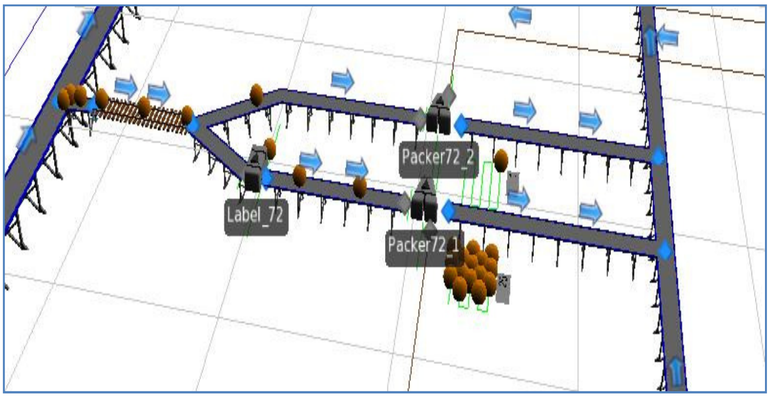


Figure 24: The Model's Packing Table

5.5.3.16 Palletizing

The palletizing operation can be modelled as a Combiner that combines batches of a certain number of cartons on a pallet. The cartons come from the packing stations and the pallets are created by a Source object. The batch quantity is inserted beforehand in the Hardware Specifications table and is referenced by the Combiner. The processing time of the combiner is set to 0 seconds, since it is not of particular value for the study. When a pallet has been erected, it is absorbed and destroyed by a Sink.

It is assumed that pallets are always available and that there are enough palletizing bays. Thus, the palletizing unit is never starved of pallets or workers.

An illustration of the palletizing unit of the constructed model is provided in Figure 25.

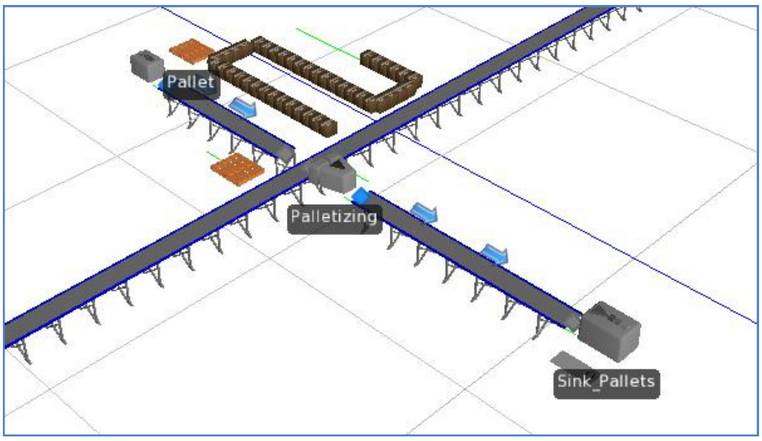


Figure 25: The Palletizing Unit of the Model

5.6 Summary of Chapter 5

The model construction phase consists of the actual design of the model. This design process has been discussed in Chapter 5. Firstly, a conceptual model was created, after which a preliminary experiment has been conducted. The preliminary experiment led to the identification of the important parameters that govern the system. The input data required to study a packhouse were defined.

Lastly, each operation within the model has been computerized. This step encompasses the translation of the concept into a computerized representation of the model.

The next step in the modelling procedure is to verify and validate the model that has been constructed. This step is discussed in Chapter 6.

6. Validation & Verification

In the previous chapter, the proposed model has been constructed and computerized. The next step in the model-development procedure is to evaluate the model by employing various validation and verification techniques.

Verification refers to the confirmation that the model has been built right. Validation, on the other hand, is the confirmation that the right model has been built (Bekker, 2011:24). Every simulation model is built for a specific intention or application and the validity of the model should therefore be determined with regard to that intention (Sargent, 1999:39). There are three central parts of a simulation model, namely the problem entity, the conceptual model and the computerized model. The problem entity is the physical system that is to be modelled. The conceptual model is the logical depiction of the problem entity. The computerized model is the implementation of the concept model on computer software.

With regard to the three model elements given above, Sargent (1999:40) defined four aspects of validity that a model should demonstrate in order to be considered as a valid representation of the system. These validity aspects are conceptual model validity, computerized model validity, operational validity and data validity. The interaction between the three pillars of a model and the four aspects of validity is illustrated in Figure 26.

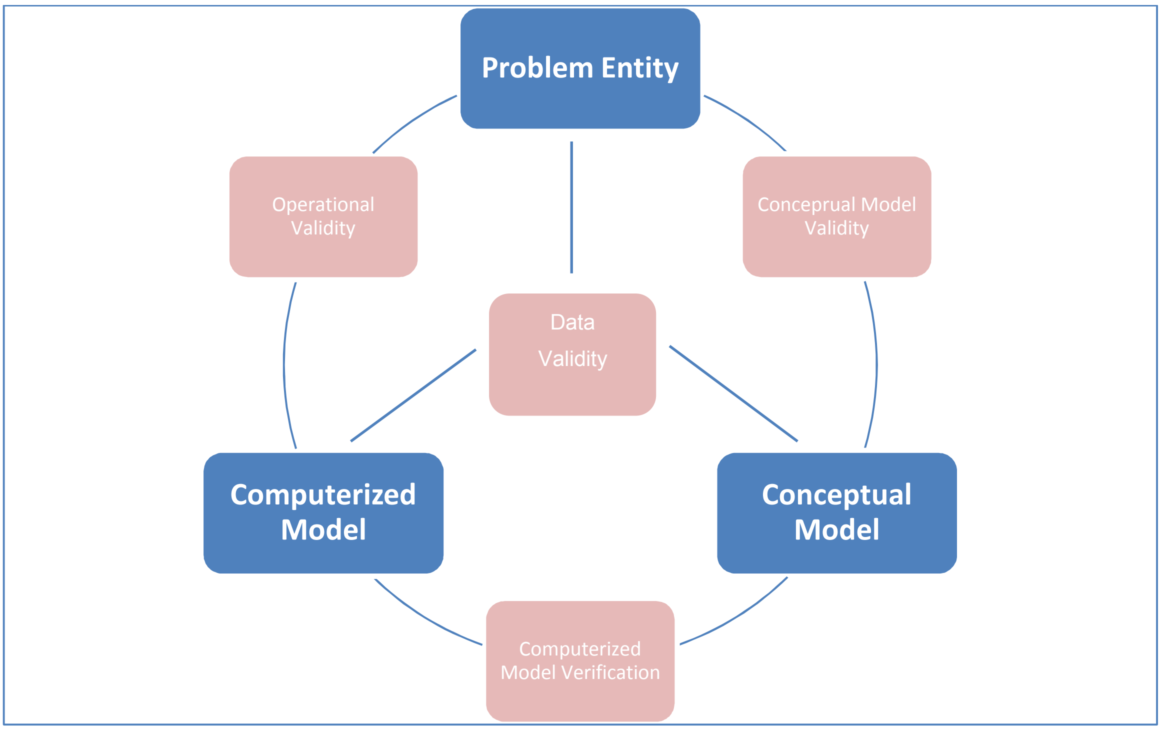


Figure 26: Validation & Verification in the Simulation Process (Sargent, 1999:41)

This chapter entails a discussion regarding the validity of the model in terms of conceptual, computerized model and operational validity.

6.1 Conceptual Model Validity

Conceptual model validity refers to the verification that the concept model represents the problem entity appropriately and that it is accurate with regard to the purpose of the model. The underlying theories, assumptions, structures and logic behind the model have been verified by incorporating the opinions of various experts in the field.

Bernard van Zyl, one of the engineers at Vizier Systems, was asked to verify the flowchart and concept model. Vizier Systems is a company, situated in Somerset West, which specializes in the design and implementation of fruit handling systems. Vizier are experts in the design and operation of citrus packhouses and Although Van Zyl was not involved in the development of the model, he understood the purpose of the study. He evaluated the flowchart of the basic packhouse operations, the various inputs and outputs of the system and the most important parameters that should be incorporated in the model. The basic logic of the operations was verified at various stages throughout the development of the model.

Jacques Umans, the packhouse manager of Noordhoek Packhouse, was also incorporated in the verification process. Noordhoek Packhouse is a citrus packhouse in Citrusdal that specializes in the packing of Navel and Valencia fruits. Even though Umans is not an expert in simulation models, he is an expert in the field of citrus packing. He had a clear understanding of the intention of the model and helped to verify the logic behind the processes within the model. He verified the parameters that affect the throughput capacity of each packhouse operation.

Throughout the process of developing the model, various structured walk-through sessions were conducted to verify the model continuously. By means of walk-through sessions, each process within the model was visited to review its underlying logic. By means of this technique, the conceptual validity of the model has been assured.

6.2 Computerized Model Validity

Computerized model validity entails the assurance that the computer model is a valid representation of the concept model and that the programming is correct. During this stage of verification, the model is checked for errors to determine whether or not the model has been programmed correctly. The model has been verified by performing various structured walk-through sessions and traces. Sargent (1999:43) proposed two approaches for model testing, namely static testing and dynamic testing.

Static testing has been performed by examining the logic and the code of the model during various structured walk-through sessions.

Dynamic testing has been done by examining the behaviour of the model under various controlled conditions to determine whether the model execution is correct.

Firstly, the input-output relations if the model was tested. A hypothetical production run were executed in order to compare the output of the model with anticipated results. A specific part mix was provided and the expected number of each fruit class was calculated for a production run of 10 000 fruit entities. The specific purpose of the test was to ensure that the fruit entities are created according to the provided part mix. The model was executed and the results were compared to the expected outputs. Furthermore, the expected number of cartons packed for each fruit class was also calculated and compared to the results of the production run. This comparison is indicated in Table 6.

Table 6: Comparison of the Expected Results and Actual Outputs

Entities	Part Mix (%)	Expected Entities	Actual Entities	Expected Nr of Cartons Packed	Actual Nr of Cartons Packed
Class1_144	0	0	0	0	0
Class1_125	2	200	212	1	1
Class1_105	4	400	381	3	3
Class1_88	6	600	599	6	6
Class1_72	16	1600	1674	22	23
Class1_64	22	2200	2220	34	34
Class1_56	14	1400	1371	25	24
Class1_48	5	500	522	10	10
Class1_40	2	200	230	5	5
Class1_36	1	100	101	2	2
Class2_144	0	0	0	0	0
Class2_125	0.1	10	7	0	0
Class2_105	0.3	30	26	0	0
Class2_88	0.7	70	73	0	0
Class2_72	1.9	190	179	2	2
Class2_64	3	300	292	4	4
Class2_56	1.7	170	167	3	2
Class2_48	0.9	90	81	1	1
Class2_40	0.4	40	42	1	1

Entities	**Part Mix (%)**	**Expected Entities**	**Actual Entities**	**Expected Nr of Cartons Packed**	**Actual Nr of Cartons Packed**
Class2_36	0	0	0	0	0
Class3	9	900	856	N/A	N/A
Juice	8	800	764	N/A	N/A
Under	0.5	50	52	N/A	N/A
Waste	1.5	150	151	N/A	N/A
Total	100	10000	10000	119	118

It has been found that the outputs of the model correlate to a great extent with the expected outcomes. A graphical representation of the correlation between the expected number of entities and the actual number of entities are provided in Figure 27. From these results, it is evident that the entities are created as expected.

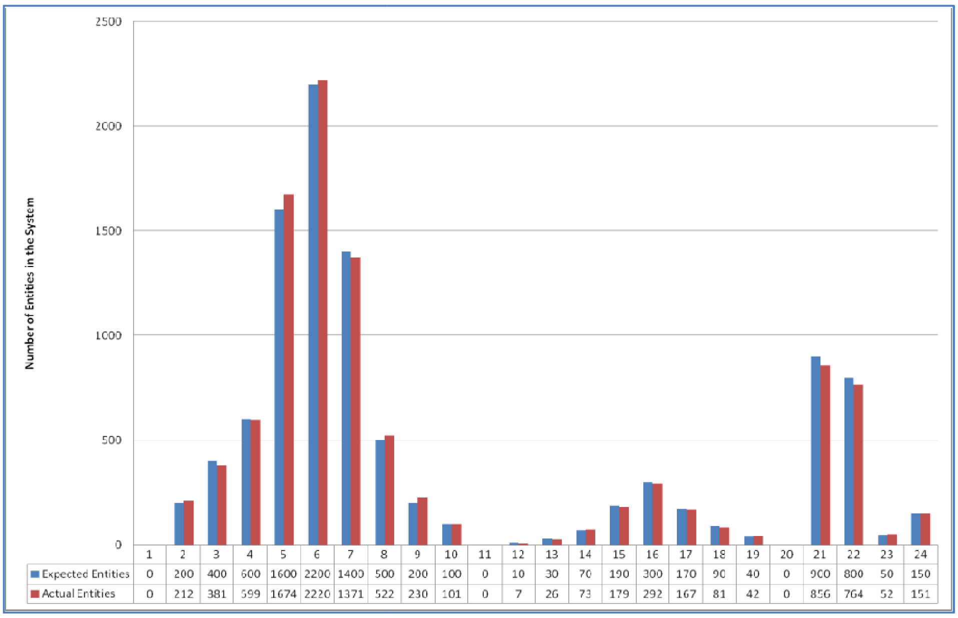


Figure 27: Correlation between Expected Number of Entities and Actual Number of Entities

In order to test the routing logic of the model, the fruit entities of the production run were traced through the system. The model is subject to the assumption that the graders are 100% reliable, so every created fruit entity should reach its specified destination. The number of created fruit entities were compared to the number of entities that actually arrived at the sinks and packing tables. The tabulated results of the test are given in Table 7. It is apparent that all the entities destined for a certain object also arrived at that object and the routing of the entities through the system is correct. An excerpt of the output data generated from these tests is provided in Appendix C.

Table 7: Verification of the Routing Logic

Objects	Number Created	Number Arrived
Packer144_1	0	0
Packer144_2	0	0
Packer125_1	211	211
Packer125_2	7	7
Packer105_1	380	380
Packer105_2	26	26
Packer88_1	598	598
Packer88_2	73	73
Packer72_1	1671	1671
Packer72_2	178	178
Packer64_1	2216	2216
Packer64_2	291	291
Packer56_1	1369	1369
Packer56_2	167	167
Packer48_1	519	519
Packer48_2	81	81
Packer40_1	229	229
Packer40_2	42	42
Packer36_1	101	101
Packer36_2	0	0
Sink_Class3	854	854
Sink_Juice	764	764
Sink_UnderSize	52	52
Sink_Waste	151	151

Lastly, the internal consistency of the model has been verified by testing the model under various sets of input data. The part mix was kept constant, while the conveyor speeds of the units were varied for two scenarios. For the first scenario, all conveyor speeds were set to 100 mm/s while for the second scenario, the speeds were set to 500 mm/s while the average time a fruit entity spends in the system was measured. The average time an entity spends in the system during the first run is expected to be 5 times more than during the second run. The comparison of the output data of the two scenarios are shown in Table 8.

It was expected that the ratio between the average time in the system for entities in scenario A and the average time in the system for entities in scenario B would be 5 times, but the actual ratio is an average of 3.8 times. This is due to the fact that the packing stations in scenario B become the bottlenecks of the system due to the high speeds of the conveyors and are sometimes starved from cartons. This causes a delay and the fruit are not packed immediately after arrival at the packing table.

Thus, it can be concluded that the computerized model is valid. A selected excerpt of the output data of these two scenarios are provided in Appendix D.

Table 8: Comparison of the Average Time in the System

Object Name	A: Time for 100 mm/s	B: Time for 500mm/s	A/B
Class1_105	07:28:44	01:58:11	3.8
Class1_40	07:57:00	02:22:28	3.3
Class1_48	07:20:07	01:54:20	3.8
Class1_56	07:19:13	01:56:28	3.8
Class1_64	07:25:31	01:51:06	4.0
Class1_72	07:24:37	01:52:47	3.9
Class1_88	07:32:00	01:53:47	4.0

By means of these tests, the validity of the computerized model has been confirmed.

6.3 Operational Validity

Operational validity is the proof that the model's output is an accurate representation of the physical system. In order to evaluate the model's operational validity, a trial packing line has been configured to represent an existing packing line. In this manner, the model outcomes can be compared with data from the physical system.

The model was configured to represent Noordhoek Packhouse, a citrus packhouse situated in Citrusdal. The equipment specifications of the packing line were measured and entered into the hardware specifications data table. A production run of 5 bins (10 000 fruit) were executed and the results were compared to the output data of the physical system in order to validate the operational accuracy of the model.

Firstly, the tipping process of the model was compared to data from Noordhoek's actual tipper. The time to load, empty and offload a bin were measured and it was found that the tipper at Noordhoek is capable of tipping an average of 36 bins per hour, which is equivalent to 0.6 bins per minute. Each bin contains an average of 2000 fruit, which means that the tipping rate is 1200 fruit entities per minute (0.6x2000 = 1200). Therefore, the time it takes to tip 10000 fruit entities into the system is 8.333 minutes (10 000/1200 = 8.333). An output statistic element has been defined in the model to record the tipping time of the production run. The recorded tipping time of the model for 10 000 fruit entities is 8.3325 minutes. Therefore, it can be concluded that the tipping unit of the model is an accurate representation of the physical tipper.

Lastly, the time it takes the model to process a batch of 10 000 fruit entities were compared to the time it takes the physical system to do the same. However, Noordhoek does not collect any input or processing data, therefore the validation process was based on approximate data. According to Jacques Umans, manager of Noordhoek, the average time to process a production run of 5 bins (10 000 fruit) varies between 10 and 15minutes from the moment the first bin is tipped until the last carton is palletized. This time, however is dependent on the quality distribution of the incoming fruit. A production run of 10 000 fruit entities were executed and the total processing time was 10 minutes and 53 seconds, which falls within the limits of Umans' estimate. The configuration of the validation model and selected output data of the production run is provided in Appendix E.

6.4 Summary of Chapter 6

After the model has been constructed and computerized, the next step in the model development procedure is to validate and verify the model. A discussion of the measures taken to ensure the validity of the model is provided in Chapter 6. The conceptual, computerized and operational validity of the model has been established.

The next step in the procedure, namely experimentation, is discussed in Chapter 7.

7. Experimentation

Although experimentation and output analysis are important phases within the execution of a simulation study, it does not fall within the scope of this study. The goal of the study was to develop a generic model that can be used by different users for a broad spectrum of experiments. This chapter entails a brief discussion of how the constructed model can be configured to represent a specific system in order to conduct experiments.

7.1 Model Configuration

The generic nature of the model enables the user to investigate the consequences of varying a wide range of parameters with relative ease. In order to conduct an experiment, the user must firstly configure the model to represent the physical system. This can be done by entering the design parameters of the system in the data table, Table_HardwareSpecs, and changing the lengths of the conveyors in the model. Secondly, the specifications of the production run should be specified by entering the expected part mix in the data table, FruitClassArrivals.

7.2 Experimentation

After the model is configured, the user can perform various experiments by varying the design parameters of the system. The intended use of the model may differ from user to user, thus the user should be in control of the design of the experiments. Each user is able to conduct experiments by varying the parameters of the model according to the purpose of that specific study. In this way, the effects of certain changes can be evaluated and the model can be used to answer various “what if” questions. Simio also enables the user to define particular scenarios to perform controlled experiments.

Furthermore, the user is able to perform sensitivity analyses by studying the effects of adding or removing available capacities at the packing tables.

7.3 Summary of Chapter 7

Although experimentation does not fall within the scope of the project, the goal of the project was to develop a generic model that can be used to study citrus packing lines. The model can be used to represent almost any citrus packing line by configuring the only the data tables, after which various experiments can be performed to study the effects of changes in these design parameters.

The final remarks regarding the model and the execution of the project are discussed in Chapter 8.

8. Conclusions

The model has been constructed and in the previous chapter it is explained how the model can be used to perform experiments. This chapter, as the final chapter, provides the final comments on the model, the way forward, an overview of the methodology that has been followed as well as the experience gained during the course of the project.

8.1 Final Comments on the Model

The model developed during the course of this project is fully reusable in the sense that it can be configured to represent almost any citrus packhouse. The model provides a valid representation of the major operations within such a packing line. A typical citrus packing line consists of a series of roller and belt conveyors and the throughput capacity of the system is mainly dependent on the speeds and widths of these conveyors, as well as the packing capability of the packers. These design parameters are the constraints that form the foundation of the model and the system can be evaluated by varying these parameters.

The model is limited in the sense that it only considers the design parameters of the physical equipment and it does not take the personnel scheduling into account. For example, the model does not consider the amount of grading personnel present at the grading table, but only the speed to which the conveyor is set. Furthermore, the model does not take machine failures into account and human error at the grading operations is ignored.

The purpose of the model is to assist engineers in the design and evaluation of citrus packhouses. Analysts can utilise the model in the decision-making process before changing an existing packhouse or to compare alternative designs. Furthermore, the model can be used to market a specific design and to establish consensus amongst stakeholders. The model is also perfect for demonstrating the flow of fruit and material through the system and presenting proposed layouts.

8.2 The Way Forward

There are many ways in which the model can be refined. The following examples of refinement can be considered:

- Equipment failures can be incorporated.
- Personnel requirements and scheduling functions can be included.
- The model can be extended to accommodate other fruit types.
- Supporting functions, such as water and chemical consumption, can be added to the model.

8.3 Experience Gained During the Execution of the Project

Valuable knowledge and experience have been gained during the execution of the project and the development of the model. One of the most important lessons learnt is the amount of expertise required to perform a simulation study. Even though Simio is object orientated and is marketed as a fairly straight-forward package, the successful development of a simulation study requires extensive expertise. Problem solving, analytical and project management skills were improved and systems thinking have been developed.

8.4 Methodology

The project has been executed according to the structure proposed by the problem-solving methodology introduced in Chapter 1. Each chapter of the project addresses a phase of the methodology. An overview of the methodology and the project is given in Figure 28 and discussed further.

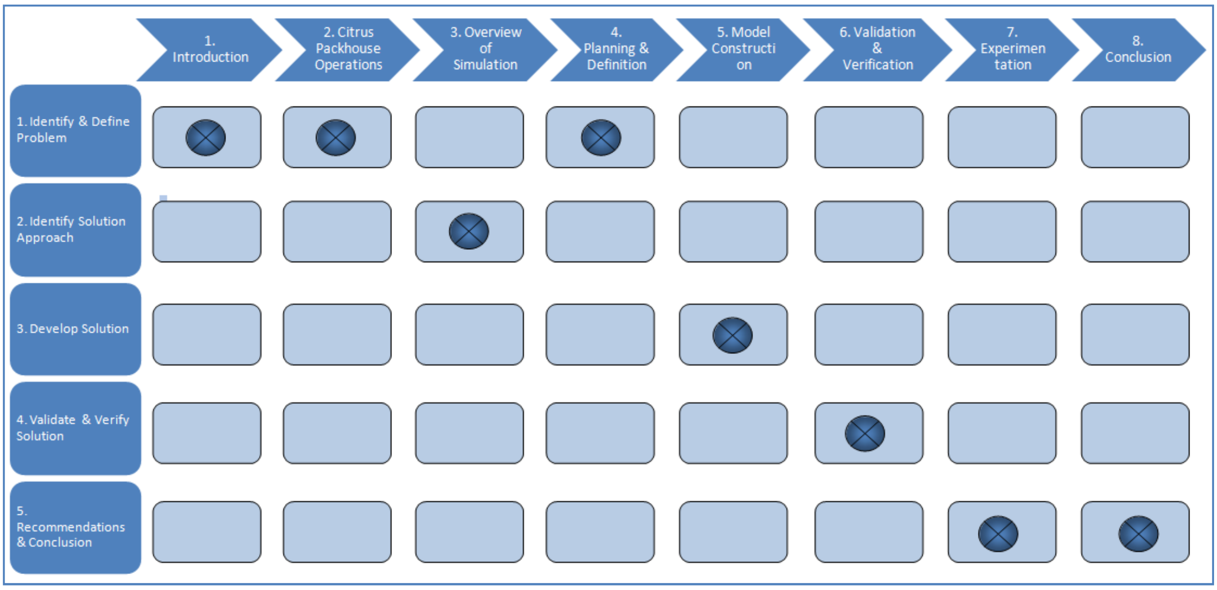


Figure 28: Methodology Overview

In the first chapter the importance of the South African citrus industry has been highlighted. The design of a new packhouse is a timely process and the construction of such a facility is very expensive. This poses the need to develop a model that can be used to assist in the design and validation of such a packhouse.

Before a model can be developed, it is important to understand the system first. Chapter two describes the main functions and operations within a typical citrus packhouse. A flowchart of such a packhouse has been developed.

The third chapter provides an overview of simulation and simulation is evaluated as an alternative approach to model a citrus packhouse. This evaluation is performed by discussing the advantages and disadvantages of simulation as well as defining the concept of generic simulation. Simulation is proved to be a practical way of representing a packhouse and the procedure for conducting a simulation study is outlined.

The first phase of the simulation modelling procedure, namely Planning and Definition, is discussed in the fourth chapter. The problem is formulated and clear objectives are identified. The importance of project planning is highlighted and the system boundaries are defined.

The next phase of the procedure is the model construction phase. The fifth chapter is committed to the discussion of this particular phase. The conceptual model of a citrus packhouse is developed and the preliminary study is performed. The important parameters are defined and the model is computerized.

After the model is computerized, it should be validated and verified. This process is described in the sixth chapter of the report. The model is verified by conducting structured walk-through sessions, incorporating outside doubters, applying animation, performing degenerate tests and comparing it to similar models.

Although experimentation is not included in the scope of the project, it is briefly discussed in chapter seven by explaining how analysts can use the model to analyse a proposed design or perform sensitivity analyses.

In the eighth and final chapter of the project, the final conclusions and recommendations are discussed.

9. Bibliography

1. *Agriculture, Forestry and Land*. [Online]. Available: http://www.southafrica.co.za/about-south-africa/environment/agriculture-forestry-and-land/ [2011, June 09].

2. Bekker, J. 2011. *Short Notes on the Aspects of Discrete-Event Simulation.* Stellenbosch: University of Stellenbosch.

3. Beukes, R. 2011. Personal interview. 12 July. Goede Hoop Citrus, Citrusdal.

4. Bollen, A.F., Cox, N.R., Riden, C.P. 2007. *Agricultural Supply System Traceability, Part I: Role of Packing Procedures and Effects of Fruit Mixing.* [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1537511007001833 [2011, September 18].

5. Brunner, D.T. & Schriber, T.J. Inside Discrete-Event Simulation Software: How It Works and Why It Matters, in Johansson, B., Jain, S., Montoya-Torres, J., Hugan, J. & Yucesan, E. (eds.). *Proceedings of the 2010 Winter Simulation Conference.* 151-165.

6. Burdon, J.N. 1997. Postharvest Handling of Tropical and Subtropical Fruit for Export, in Mitra, S.K. (ed). *Postharvest Physiology and Storage of Tropical and Subtropical Fruits.* Wallingford: CAB International. 1 - 20.

7. *Citrus Growers' Association Submission to Agricultural Job Creation Imbizo*. [Online]. Available: http://academic.sun.ac.za/agric/Standardbank%20sentrum/downloads/Imbibizo%20III/CITRUS.pdf [2011, June 09].

8. Formoso, C.T., Schramm, F.K., Silveira, G.L. 2008. A Proposal for Reusing Simulation Models in the Design of Production Systems in Construction, in *International Conference on Information Technology in Construction.* Santiago. [Online]. Available: http://itc.scix.net/data/works/att/w78-2008-6-05.pdf [2011, September 19].

9. Giles, R. 2010. *1-Citrus: Citrus Packhouse to Port Transportation Harmonisation.* [Online]. Available: http://www.cga.co.za/site/files/5438/1Citrus%20_%60Vision%20and%20Scope%20_%20Final%2002Nov10.pdf [2011, June 12].

10. Grierson, W., Cohen, E., Kitagawa, H. 1986. Degreening, in Wardowski, W.F., Nagy, S., & Grierson, W. (eds.). *Fresh Citrus Fruits*. New York: Van Nostrand Reinhold Company Inc. 253 – 274.

11. Grierson, W., Smith, A.F.G., Thornton, F., Felsenstein, G. 1986. Packingline Machinery, in Wardowski, W.F., Nagy, S., & Grierson, W. (eds.). *Fresh Citrus Fruits*. New York: Van Nostrand Reinhold Company Inc. 287 – 313.

12. Kaplan, H.J. 1986. Washing, Waxing and Color-Adding in Wardowski, W.F., Nagy, S., & Grierson, W. (eds.). *Fresh Citrus Fruits*. New York: Van Nostrand Reinhold Company Inc. 379 – 395.

13. Kelton, W.D., Sadowski, R.P., Sturrock, D.T. 2004. *Simulation with Arena.* New York: McGraw-Hill.

14. Kritzinger, C. 2007. The Development of Generic Modelling Software for Citrus Packing Processes. Unpublished master's dissertation. Stellenbosch: University of Stellenbosch.

15. Kruger, F.J. & Penter, M.G. 2006. Packing of Citrus, in De Villiers, E.A. & Joubert, P.H. (eds). *The Cultivation of Citrus.* Nelspruit: ARC-Institute for Tropical and Subtropical Crops. 319 – 336.

16. Lawrence, F.P., Mackulak, G.T. 1998. Effective Simulation Model Reuse: A Case Study for AMHS Modelling, in Medeiros, D.J., Watson, E.F., Carson, J.S., Manivannan, M.S. (eds.). *Proceedings of the 1998 Winter Simulation Conference.* 979-984.

17. Mukhopadhyay, S. 2004. *Citrus: Production, Postharvest, Disease and Pest Management*. Enfield: Science Publishers.

18. Pegden, C.D. 2010. Advanced Tutorial: Overview of Simulation World Views, in Johansson, B., Jain, S., Montoya-Torres, J., Hugan, J. & Yucesan, E. (eds.). *Proceedings of the 2010 Winter Simulation Conference.* 210-215.

19. Powell, H. Clark. 1930. *The Culture of the Orange and Allied Fruits*. Pretoria: Central News Agency.

20. Robinson, S., Nance, R.E., Paul, R.J., Pidd, M., Taylor, S.J.E. 2004. *Simulation Model Reuse: Definition, Benefits and Obstacles.* [Online]. Available: http://www-sciencedirect-com.ez.sun.ac.za/science/article/pii/S1569190X04000760 [2011, September 24].

21. Robinson, S. 2004. *Simulation: The Practice of Model Development and Use.* [Online]. Available: http://books.google.co.uk/books?hl=en&lr=&id=DapH9XLwN4kC&oi=fnd&pg=PR7&dq=how+to+build+a+simulation+model&ots=I2_cXIEYXB&sig=26y4QtXcr-aNALz8R6ml57AsNYg#v=onepage&q=how%20to%20build%20a%20simulation%20model&f=true [2011, September 24].

22. SAFE. 2010. *Citrus Guide: Export Quality Standards.* [Online]. Available: http://www.safe.co.za/protocols_files/SAFE_Citrus_Guide_F_2010.pdf [2011, September 23].

23. Sargent, R.G. 1999. Validation and Verification of Simulation Models, in Farrington, P.A., Nembhard, H.B., Sturrock, D.T., Evans, G.W. (eds.) *Proceedings of the 1999 Winter Simulation Conference.* 39-48.

24. Simio LLC. 2010. *Introduction to Simio.*

25. Sinclair. 2009. *RM6 High Speed Labelling.* [Online]. Available: http://www.jtechsystems.com.au/wp-content/uploads/2010/06/RM6.pdf [2011, September 24].

26. Siphugu, L. 2010. *USDA Foreign Agricultural Service GAIN Report* [Online]. Available: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Citrus%20Semi-annual_Pretoria_South%20Africa%20-%20Republic%20of_7-1-2010.pdf [2011, June 09].

27. Siphugu, L. 2010. *USDA Foreign Agricultural Service GAIN Report* [Online]. Available: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Citrus%20Annual_Pretoria_South%20Africa%20-%20Republic%20of_1-21-2011.pdf [2011, June 09].

28. Sturrock, D.T. 2010. Tips for the Successful Practice of Simulation, in Johansson, B., Jain, S., Montoya-Torres, J., Hugan, J. & Yucesan, E. (eds.). *Proceedings of the 2010 Winter Simulation Conference.* 87-94.

29. Tarend. 2010. *Drying Tunnel.* [Online]. Available: http://www.tarend.com/en/13_Drying_Tunnel.html [2011, September 23].

30. Tugwell, B.L. 1988. The Application of Postharvest Technology to Packinghouse Operations, in Citriculture: Proceedings of the Sixth International Citrus Congress Volume 3. Tel Aviv: Margraf Scientific Publishers.

31. Umans, J. 2011. Personal interview. 11 July. Noordhoek Packhouse, Citrusdal.

32. UniSA. 2011. *Problem Solving.* [Online]. Available: http://www.unisa.edu.au/counsellingservices/balance/problem.asp [2011, September 24].

33. Von Broembsen, L. 1986. Southern Africa, in Wardowski, W.F., Nagy, S., & Grierson, W. (eds.). *Fresh Citrus Fruits*. New York: Van Nostrand Reinhold Company Inc. 171 - 179.

34. Van Zyl, B. 2011. Personal interview. 09 June, Somerset-West.

35. Wagner, A.B., Sauls, J.W. *Harvesting and Pre-Pack Handling.* [Online]. Available: http://aggie-horticulture.tamu.edu/citrus/l2294.htm [2011, June 09].

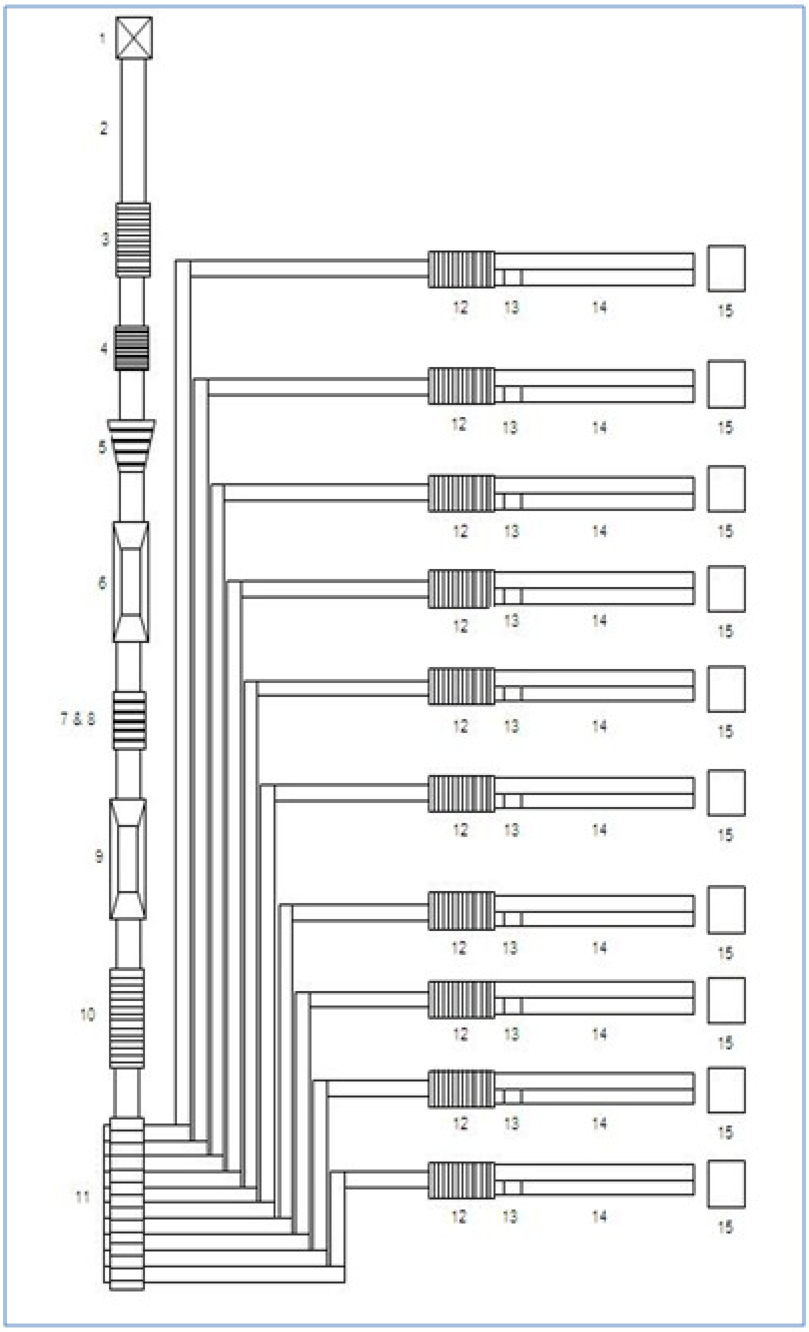
36. Whitt, W. 2005. *Analysis for the Design of Simulation Experiments.* [Online]. Available: http://www.columbia.edu/~ww2040/designPaper.pdf [2011, September 26].

37. Winston, W.L. 2004. *Operations Research: Applications and Algorithms, Fourth Edition.* Canada: Brooks/Cole. Bl. 1145-1184.

Appendix A: Typical Layout of a Citrus Packhouse

Typical Illustration of a Citrus Packhouse

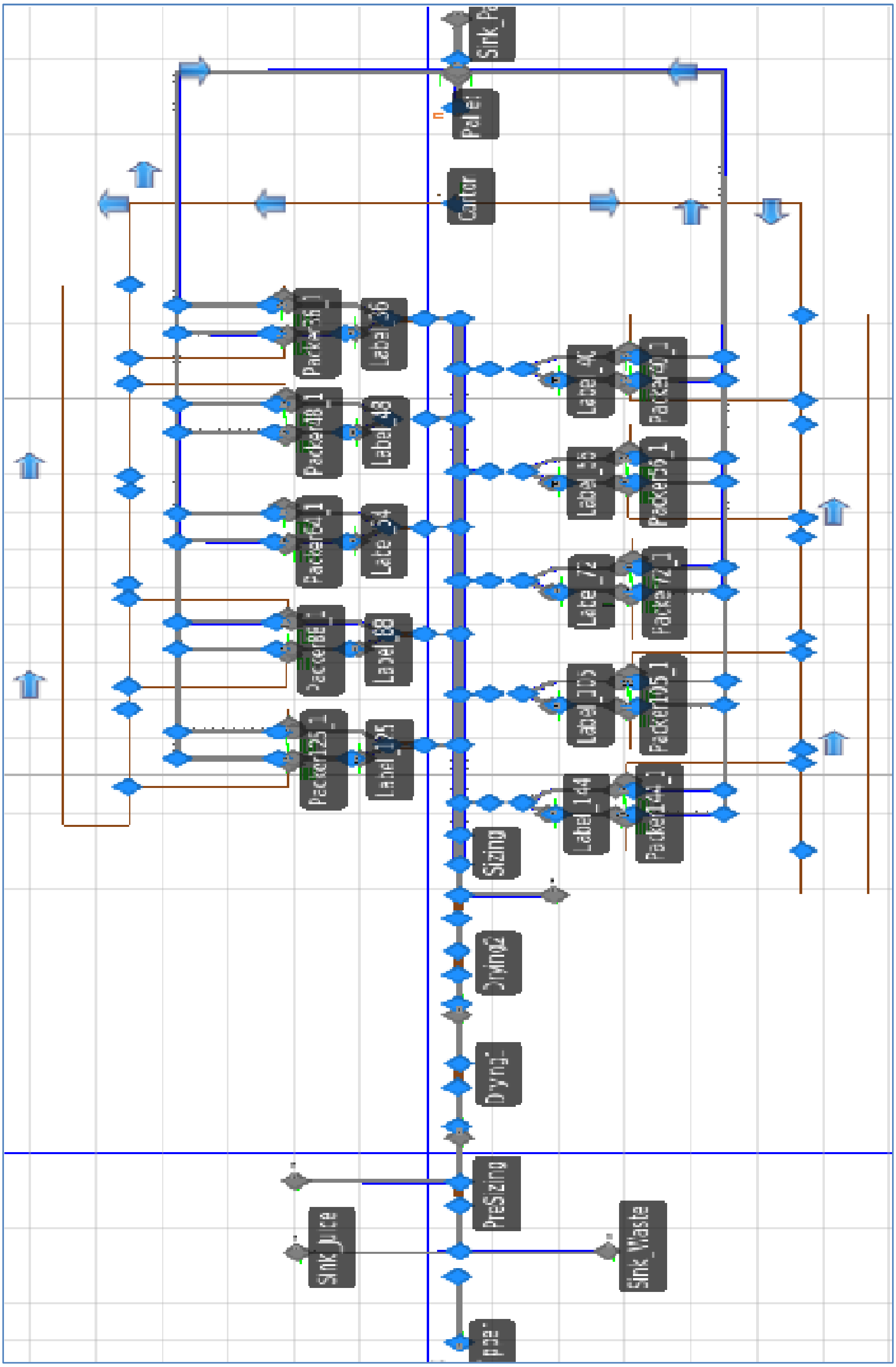
The figure shown below is a depiction of the typical layout of a citrus packhouse. The numbers on the figure correspond to the packhouse operations as indicated in the table. The fruit flow from 1 to 15 through the system. The fruit are routed from the sizer according to their size.



Nr.	Operation
1	Tipping
2	Dip Tank
3	Pre-Sorting
4	Pre-Sizing
5	Washer
6	Dry Tunnel 1
7	Fungicide Application
8	Wax Application
9	Dry Tunnel 2
10	Grading Table
11	Sizer
12	Final Year
13	Labelling Machine
14	Packing Table
15	Palletizing

Appendix B: Computer Model

Complete Model



FruitClassArrivals (Table)

The table shown below is an illustration of the data table FruitClassArrivals. The part mix of the fruit entities and the average diameter of each count are specified in this data table.

Fruit Class	Part Mix	Part Mix Unit	Average Fruit Diameter	Diameter Unit
Class1_144	0	%	64	mm
Class1_125	0.6	%	66	mm
Class1_105	3.3	%	68	mm
Class1_88	8.8	%	72	mm
Class1_72	14.5	%	75	mm
Class1_64	16.3	%	78	mm
Class1_56	14.5	%	82	mm
Class1_48	4.5	%	86	mm
Class1_40	0.8	%	90	mm
Class1_36	0	%	94	mm
Class2_144	0	%	64	mm
Class2_125	0.1	%	66	mm
Class2_105	0.4	%	68	mm
Class2_88	1.2	%	72	mm
Class2_72	1.9	%	75	mm
Class2_64	2.1	%	78	mm
Class2_56	1.9	%	82	mm
Class2_48	0.6	%	86	mm
Class2_40	0.1	%	90	mm
Class2_36	0	%	94	mm
Class3	18.8	%	77	mm
Juice	5	%	60	mm
Under	0.1	%	55	mm
Waste	4.5	%	77	mm

Fruit Entities

There are 24 fruit entities defined in the model. Each entity has a specific size and quality.

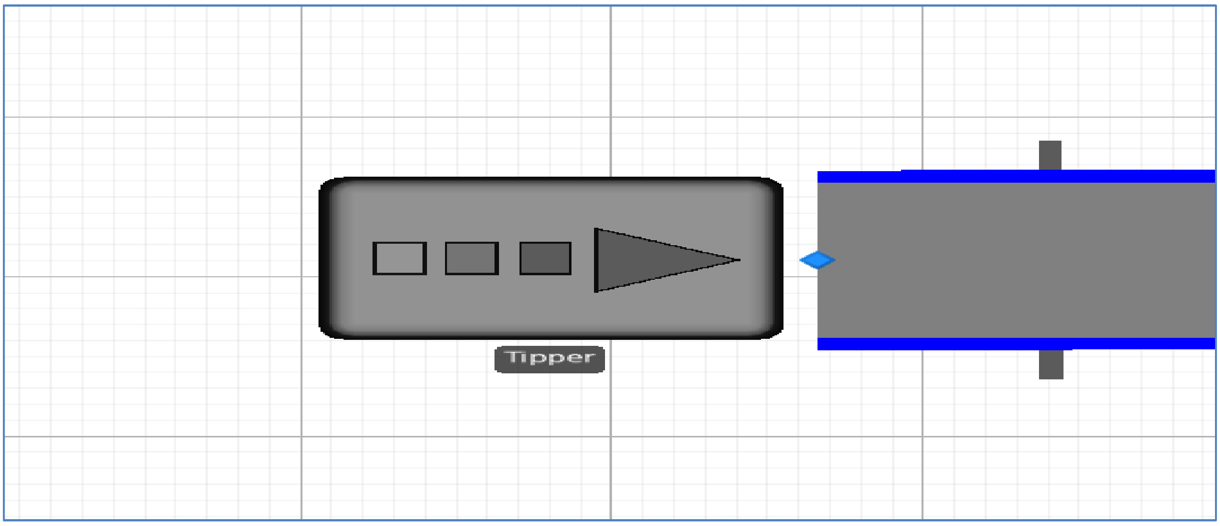
Table_HardwareSpecs

The table shown below is the data table named Table_Hardware_Specs, which contains the significant design parameters of all the operations within the model.

ID	Operation	Parameter Name	User Input	Unit
1	Tipper	Tipping Rate	0.75	containers/min
2	Tipper	Fruit per Container	2000	fruit
3	DipTank	Average Flow Speed	0.2	m/s
4	DipTank	Tank Width	1540	mm
5	PreSorting	Total Unit Length	2500	mm
6	PreSorting	Unit Width	1350	mm
7	PreSorting	Roller Speed	0.11	m/s
8	PreSorting	Single/Double Grading	2	
9	PreSorting	Max Graders	6	people
10	PreSorting	Available Hands per Grader	1	hands
11	PreSorting	Removal Time per Hand	0	s/fruit
12	PreSizing	Total Unit Length	1500	mm
13	PreSizing	Unit Width	1350	mm
14	PreSizing	Roller Speed	0.15	m/s
15	Washing	Nr of Brushes	10	brushes
16	Washing	Unit Width	1500	mm
17	Washing	Minimum Time	30	seconds
18	Drying1	Total Unit Length	5500	mm
19	Drying1	Unit Width	1950	mm
20	Drying1	Roller Speed	0.2	m/s
21	Waxing & Fungicide	Nr of Brushes	10	brushes
22	Waxing & Fungicide	Unit Width	1500	mm
23	Waxing & Fungicide	Minimum Time	30	seconds
24	Drying2	Total Unit Length	5950	mm
25	Drying2	Unit Width	1950	mm
26	Drying2	Roller Speed	0.2	m/s
27	Grading	Total Unit Length	3800	mm
28	Grading	Unit Width	1250	mm
29	Grading	Roller Speed	0.167	m/s
30	Grading	Single/Double Grading	2	
31	Grading	Max Graders	6	people
32	Grading	Available Hands per Grader	1	hands
33	Grading	Removal Time per Hand	0	s/fruit
34	Sizing	Total Unit Length	3000	mm
35	Sizing	Unit Width	1250	mm
36	Sizing	Roller Speed	0.2	m/s
37	Final Grading	Total Unit Length	2000	mm
38	Final Grading	Unit Width	1200	mm
39	Final Grading	Roller Speed	0.16	m/s
40	Final Grading	Single/Double Grading	2	
41	Final Grading	Max Graders	6	people
42	Final Grading	Available Hands per Grader	1	hands
43	Final Grading	Removal Time per Hand	0	s/fruit
44	Labelling	Labelling Time per Fruit	1	s
45	Packing	Time to Pack Unwrapped Fruit	0.6	s
46	Packing	Time to Pack Wrapped Fruit	0.9	s
47	Packing	Time to Start New Carton	20	s
48	Roller	Unit Width	1200	mm
49	Roller	Roller Speed	0.2	m/s
50	Conveyor	Unit Width	300	mm
51	Conveyor	Conveyor Speed	0.1	m/s
52	Palletizing	Cartons per Pallet	80	cartons

Tipper

The tipper is represented by a Source object as shown below. The entities are created according to the part mix defined in the table FruitClassArrivals and the entities are created at a constant rate with a constant interarrival time. The maximum number of arrivals is specified as the number of fruit in every production run.

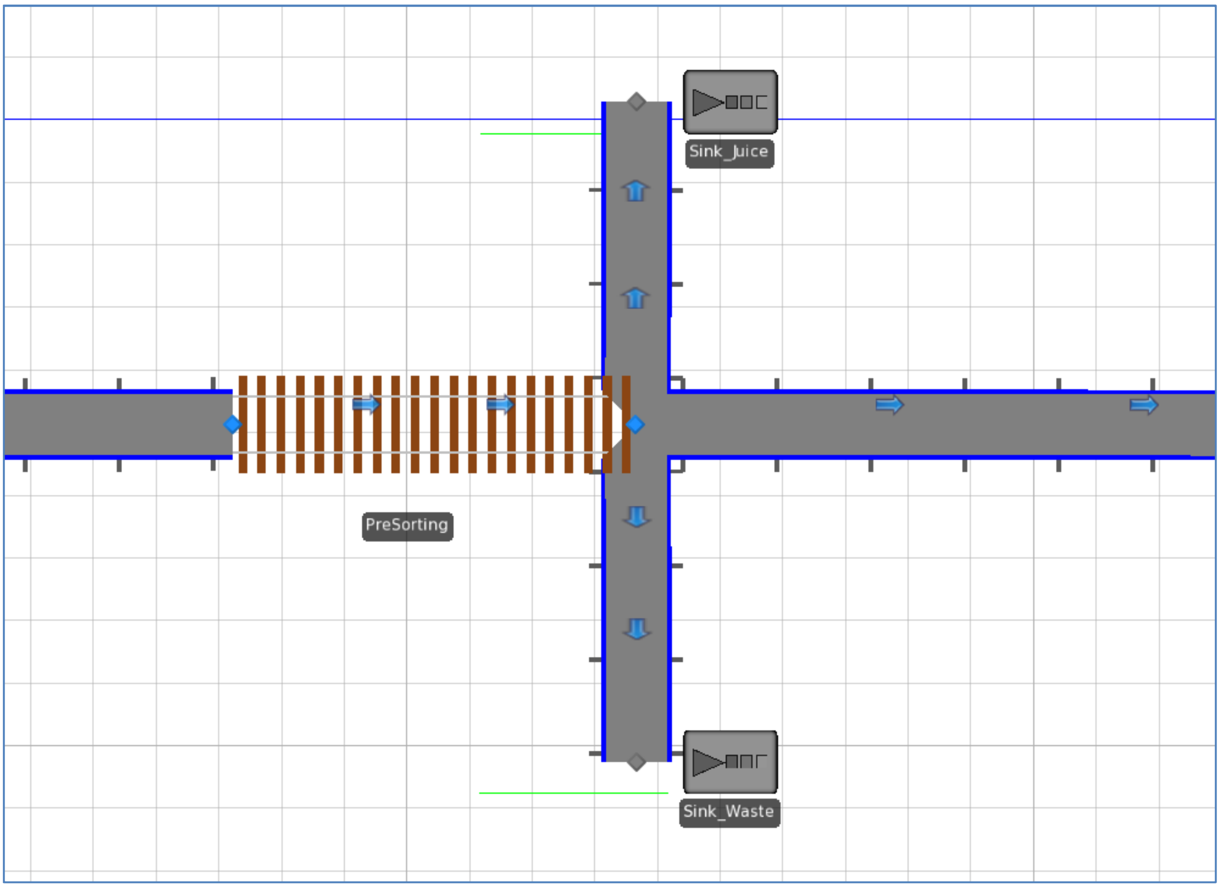


Properties: Tipper (Source)

⊟ Arrival Logic	
Entity Type	FruitClassArrivals.FruitClass
Arrival Mode	Interarrival Time
⊞ Time Offset	0.0
⊟ Interarrival Time	**1/(Table_HardwareSpecs[1].UserInput*Table_HardwareSpecs[2].UserInput)**
Units	Minutes
Entities Per Arrival	1
⊟ Stopping Conditions	
Maximum Arrivals	**10000**
⊞ Maximum Time	Infinity
Stop Event Name	
⊟ Table Reference Assignments	
⊟ Before Creating Entities	
Table Name	**FruitClassArrivals**
Row Number	**FruitClassArrivals.PartMix.RandomRow**
⊞ On Created Entity	
⊞ State Assignments	
⊞ Add-On Process Triggers	
⊟ Advanced Options	
Display Name	
Transfer-In Constraints	Default
Transfer-Out Constraints	**Disable**
⊟ General	
Name	Tipper
Description	
Public	True
Report Statistics	True
⊞ Size and Location	
⊟ Animation	
Current Symbol Index	Tipper.Capacity.Allocated > 0
Random Symbol	False

Pre-Sorting

The pre-sorting unit is a roller conveyor process and is represented by a Conveyor between two Transfer Nodes. The fruit moves through the unit, from where it is directed to one of three nodes according to the quality of the fruit entity. The juice fruit are sent to Sink_Juice and the waste fruit are sent to Sink_Waste. The conforming fruit continue to the pre-sizer.

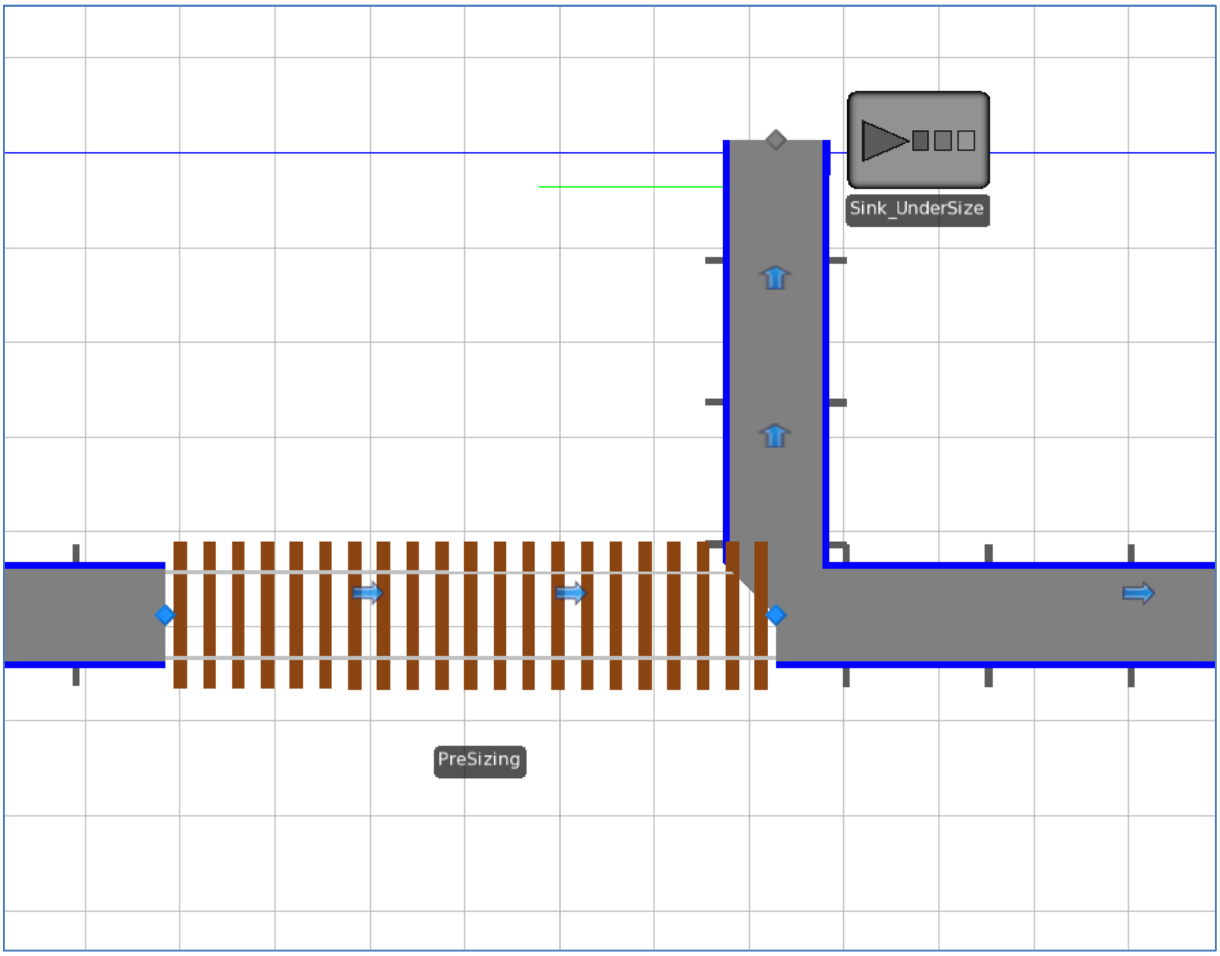


Properties: PreSorting (Conveyor)

⊟ **Travel Logic**	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**Table_HardwareSpecs[7].UserInput*Table_HardwareSpecs[6].UserInput/Table_FruitData[1].UserInput**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	**False**
⊞ Logical Length	**2.5**
Accumulating	True
⊟ **Routing Logic**	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Add-On Process Triggers**	
⊟ **Advanced Options**	
Display Name	
⊟ **General**	
Name	PreSorting
Description	**Remove Juice & Waste fruit**
Public	True
Report Statistics	True
⊞ Size and Location	

Pre-Sizing

The pre-sizing unit is a roller conveyor process and is represented by a Conveyor between two Transfer Nodes. The fruit moves through the unit, from where it is directed to one of two nodes according to the size of the fruit entity. Undersized fruit are deferred to Sink_UnderSize, while other the fruit continue to the washing unit.

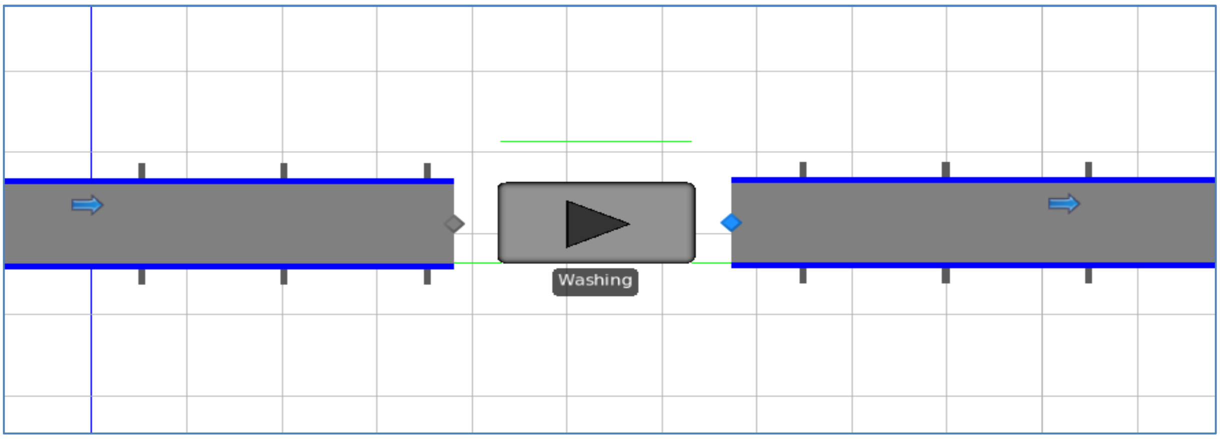


Properties: PreSizing (Conveyor)

⊟ **Travel Logic**	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**Table_HardwareSpecs[14].UserInput*Table_HardwareSpecs[13].UserInput/Table_FruitData[1].UserInput**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	**False**
⊟ Logical Length	**1.5**
Units	Meters
Accumulating	True
⊟ **Routing Logic**	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Add-On Process Triggers**	
⊟ **Advanced Options**	
Display Name	
⊟ **General**	
Name	PreSizing
Description	**Remove Undersized Fruit**
Public	True
Report Statistics	True
⊞ Size and Location	

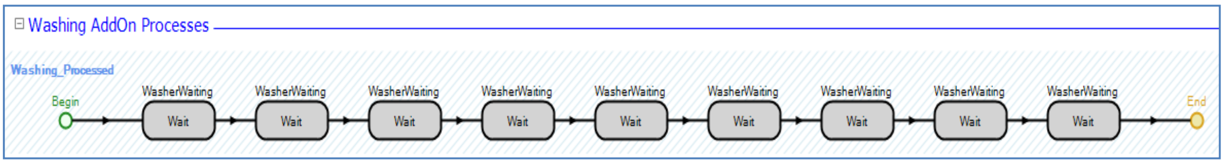
Washing

The washing unit is represented by means of a Server. The capacity refers to the number of rows of fruit that can fit in the unit. The AddOn Process regulates the time a fruit entity remains in the unit. A fruit entity waits in the gap between two brushes until it is pushed over to the next gap. This process is continued until the entity has been pushed over all the brushes in the unit.



Properties: Washing (Server)

⊟ Process Logic	
Capacity Type	Fixed
Initial Capacity	**(Table_HardwareSpecs[16].UserInput/Table_FruitData[1].UserInput)**
Ranking Rule	First In First Out
Dynamic Selection Rule	None
⊞ TransferIn Time	0.0
⊟ Processing Time	**30**
Units	**Seconds**
⊞ Buffer Capacity	
⊞ Reliability Logic	
⊞ State Assignments	
⊞ Secondary Resources	
⊟ Add-On Process Triggers	
Run Initialized	
Run Ending	
Entered	
Processing	
Processed	**Washing_Processed**
Exited	

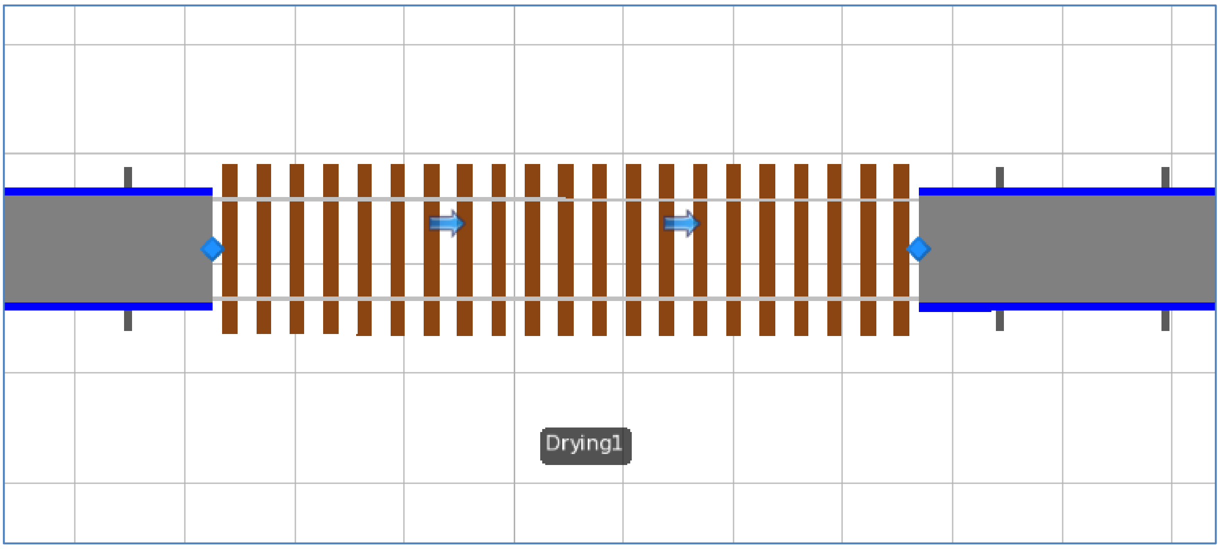


Properties: WasherWaiting (Wait Step Instance)

⊟ Basic Logic	
Event Name	**Input@Washing.Entered**
⊞ Advanced Options	
⊟ General	
Name	**WasherWaiting**
Description	**Fruit Wait In Washer Until Next Fruit Comes In**

Drying 1

The drying tunnel is modelled as a Conveyor. The fruit is only transferred through the unit at a constant speed.

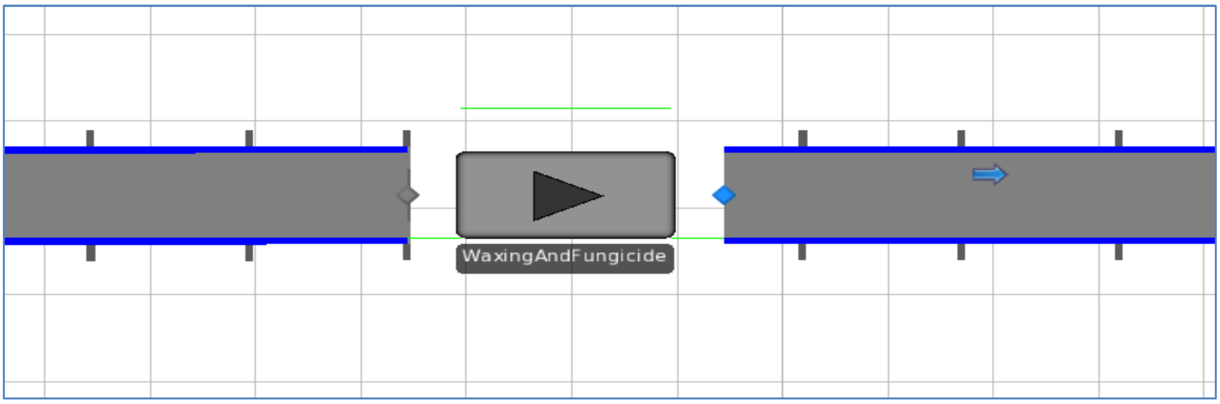


Properties: Drying1 (Conveyor)

⊟ Travel Logic	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**Table_HardwareSpecs[20].UserInput*Table_HardwareSpecs[19].UserInput/Table_FruitData[1].UserInput**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	**False**
⊟ Logical Length	**5.5**
Units	Meters
Accumulating	True
⊟ Routing Logic	
Selection Weight	1.0
⊞ Reliability Logic	
⊞ State Assignments	
⊞ Add-On Process Triggers	
⊟ Advanced Options	
Display Name	
⊞ General	

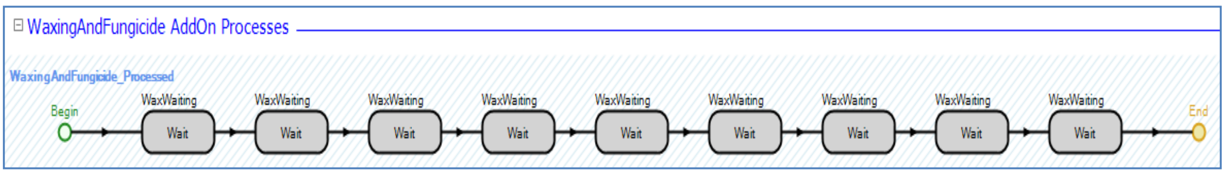
Wax & Fungicide Application

The waxing and fungicide application unit is represented by means of a Server. The capacity refers to the number of rows of fruit that can fit in the unit. The AddOn Process regulates the time a fruit entity remains in the unit. A fruit entity waits in the gap between two brushes until it is pushed over to the next gap. This process is continued until the entity has been pushed over all the brushes in the unit.



Properties: WaxingAndFungicide (Server)

Process Logic	
Capacity Type	Fixed
Initial Capacity	**Table_HardwareSpecs[22].UserInput/Table_FruitData[1].UserInput**
Ranking Rule	First In First Out
Dynamic Selection Rule	None
TransferIn Time	0.0
Processing Time	**30**
Units	**Seconds**
Buffer Capacity	
Reliability Logic	
State Assignments	
Secondary Resources	
Add-On Process Triggers	
Run Initialized	
Run Ending	
Entered	
Processing	
Processed	**WaxingAndFungicide_Processed**
Exited	

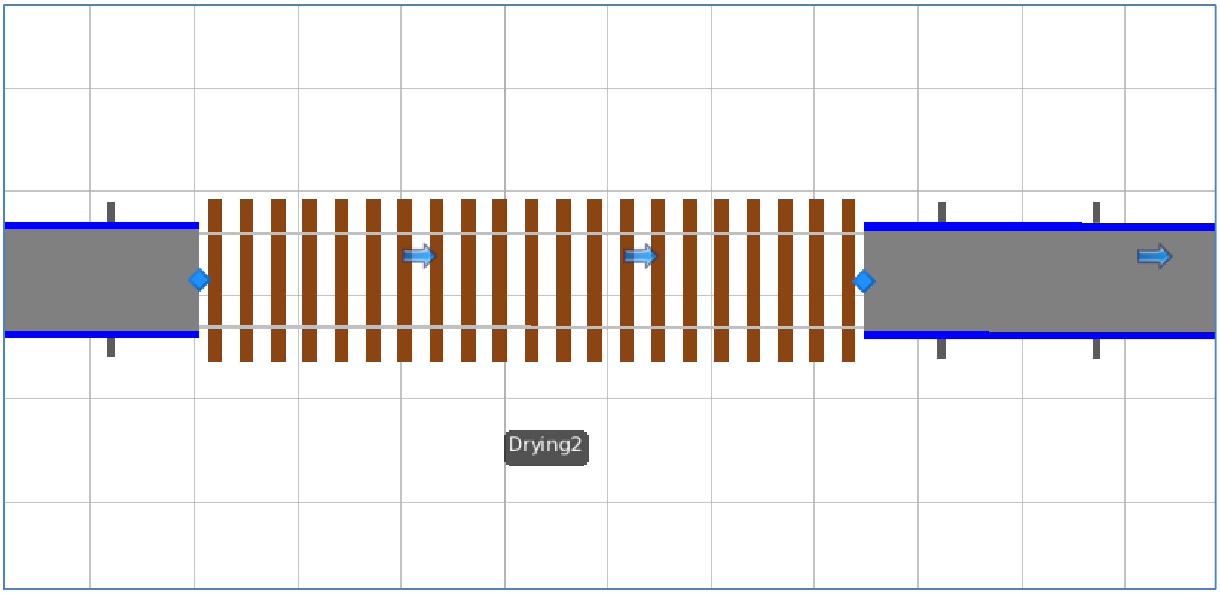


Properties: WaxWaiting (Wait Step Instance)

Basic Logic	
Event Na...	**Input@WaxingAndFungicide.Entered**
Advanced Options	
General	
Name	**WaxWaiting**
Description	**Fruit Entity Waits in Unit Until Next Entity Arrives**

Drying 2

The drying tunnel is modelled as a Conveyor. The fruit is only transferred through the unit at a constant speed.

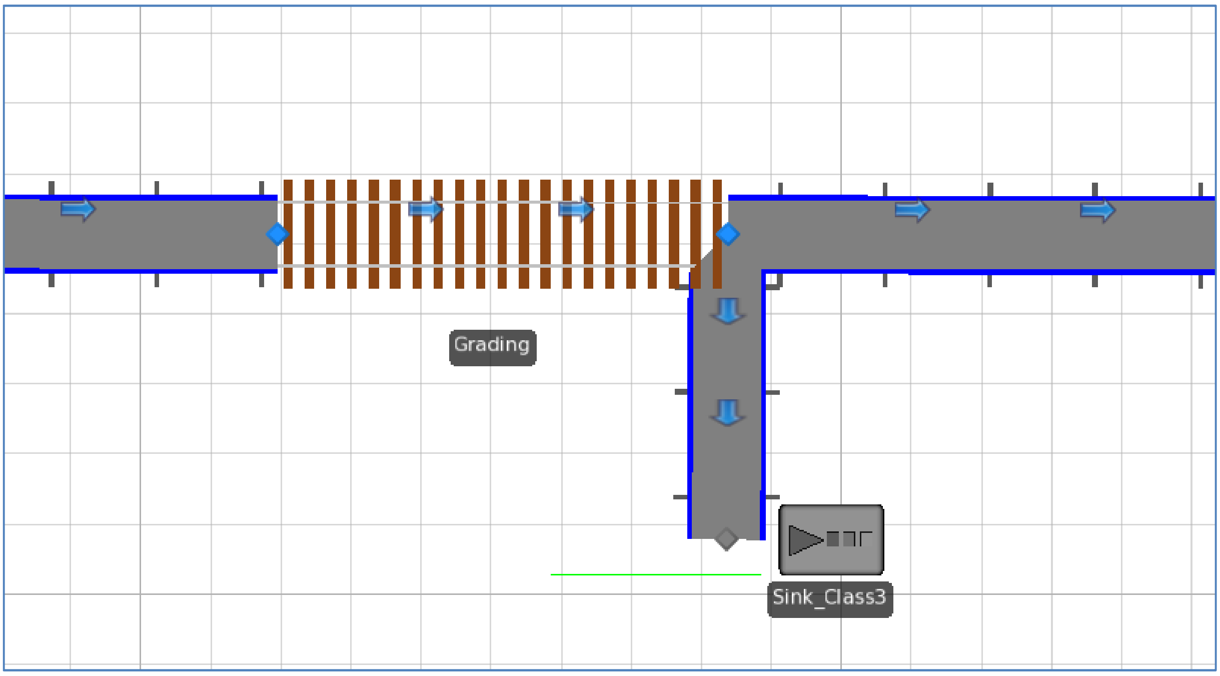


Properties: Drying2 (Conveyor)

⊟ **Travel Logic**	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
⊞ Initial Desired Speed	**Table_HardwareSpecs[26].UserInput*Table_HardwareSpecs[25].UserInput/Table_FruitData[1].UserInput**
Entity Alignment	Any Location
Drawn To Scale	**False**
⊞ Logical Length	**5.95**
Accumulating	True
⊟ **Routing Logic**	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Add-On Process Triggers**	
⊟ **Advanced Options**	
Display Name	
⊞ **General**	

Grading

The grading table is a roller conveyor process and is represented by a Conveyor between two Transfer Nodes. The fruit moves through the unit, from where it is directed to one of three nodes according to the quality of the fruit entity. Class 3 fruit are sent to Sink_Class3, while the conforming fruit continue to the sizer.

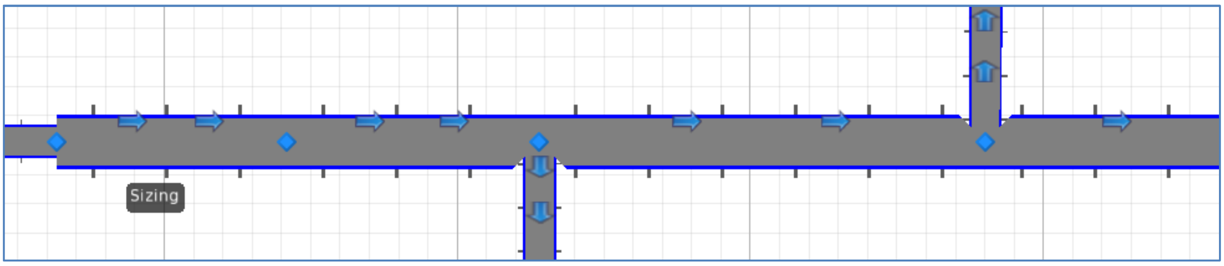


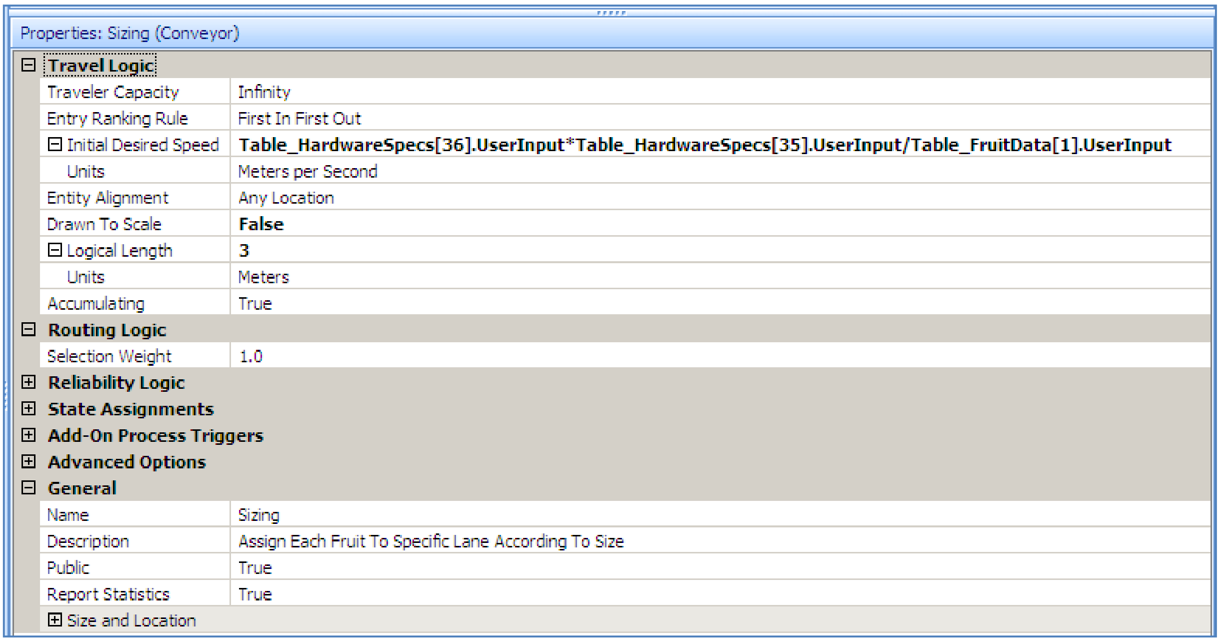
Properties: Grading (Conveyor)

⊟ Travel Logic	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
⊞ Initial Desired Speed	**Table_HardwareSpecs[29].UserInput*Table_HardwareSpecs[28].UserInput/Table_FruitData[1].UserInput**
Entity Alignment	Any Location
Drawn To Scale	**False**
⊞ Logical Length	**3.8**
Accumulating	True
⊟ Routing Logic	
Selection Weight	1.0
⊞ Reliability Logic	
⊞ State Assignments	
⊞ Add-On Process Triggers	
⊞ Advanced Options	
⊟ General	
Name	Grading
Description	Separate Grade 3 from Grade 1 and 2
Public	True
Report Statistics	True
⊞ Size and Location	

Sizing

The sizer is represented by 12 Transfer Nodes connected with conveyors. The first two nodes represent the actual sizer and the conveyor is assigned a length. The other ten nodes represent the inside of the sizer and have a logical length of zero. Each node represents a specific size count. Every fruit entity travels through the sizer until it reaches its node, from where it is directed towards the final grading table.



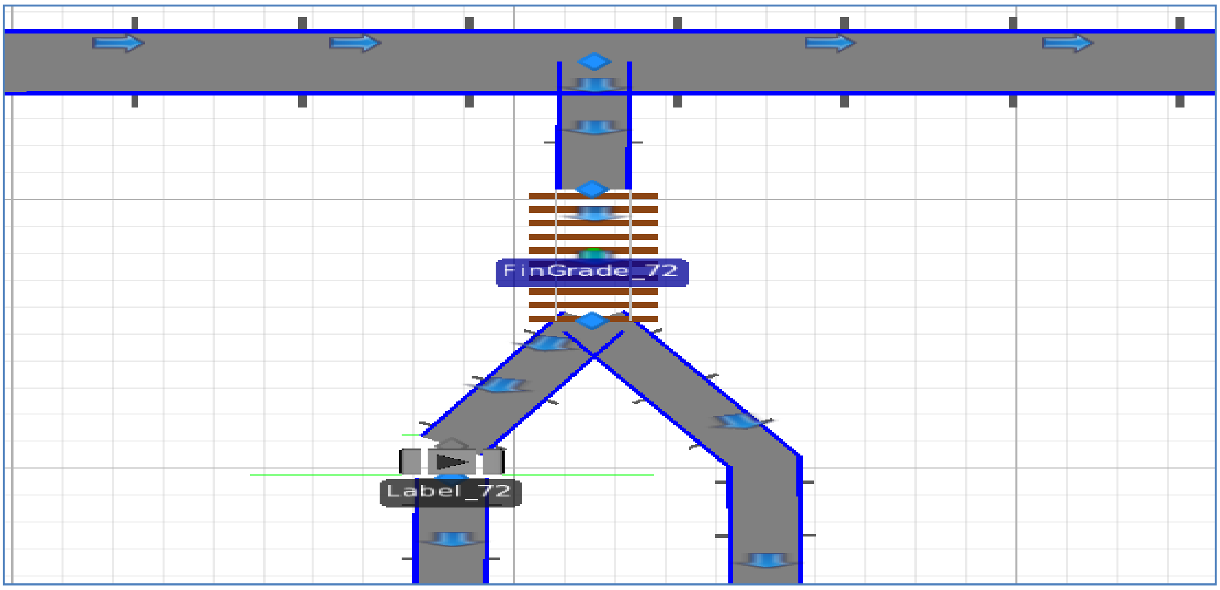


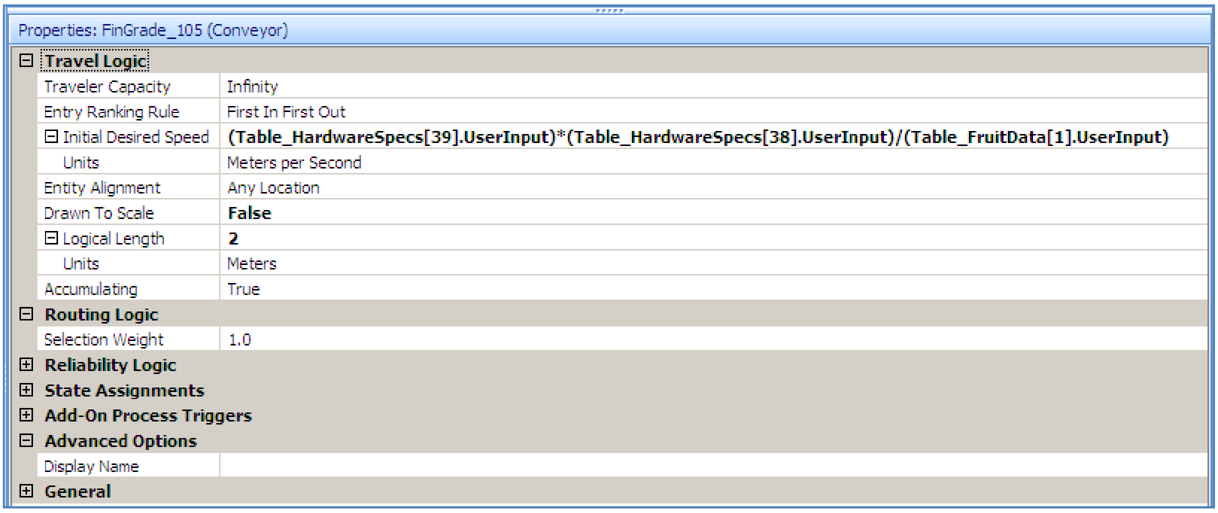
Properties: Sizing (Conveyor)

Travel Logic	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
Initial Desired Speed	**Table_HardwareSpecs[36].UserInput*Table_HardwareSpecs[35].UserInput/Table_FruitData[1].UserInput**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	**False**
Logical Length	**3**
Units	Meters
Accumulating	True
Routing Logic	
Selection Weight	1.0
Reliability Logic	
State Assignments	
Add-On Process Triggers	
Advanced Options	
General	
Name	Sizing
Description	Assign Each Fruit To Specific Lane According To Size
Public	True
Report Statistics	True
Size and Location	

Final Grading

The final grading unit is represented with the use of a Conveyor between two Transfer Nodes. The fruit flow through the entire unit and each entity is routed from the second node according to its quality. Class 1 fruit are directed to the labelling machine, while Class 2 fruit are sent to the packing table.



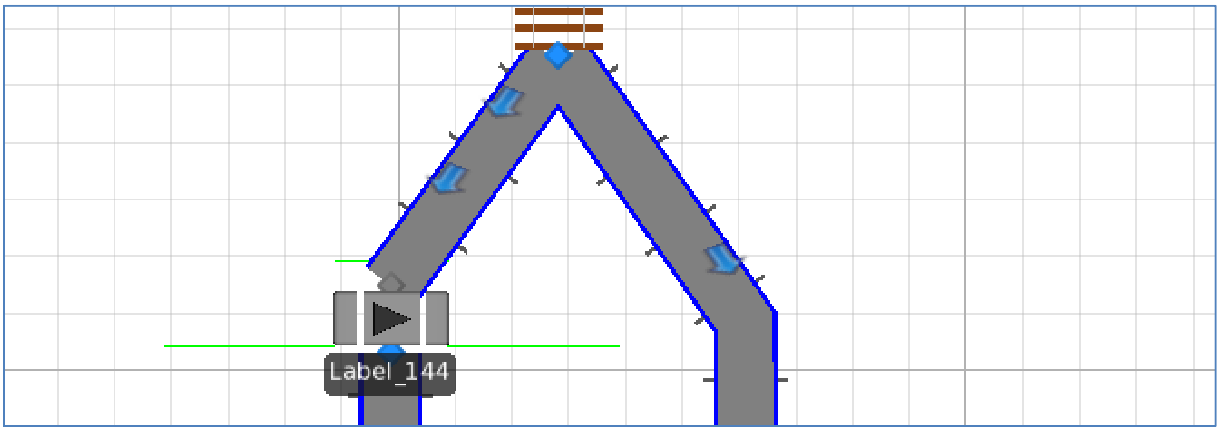


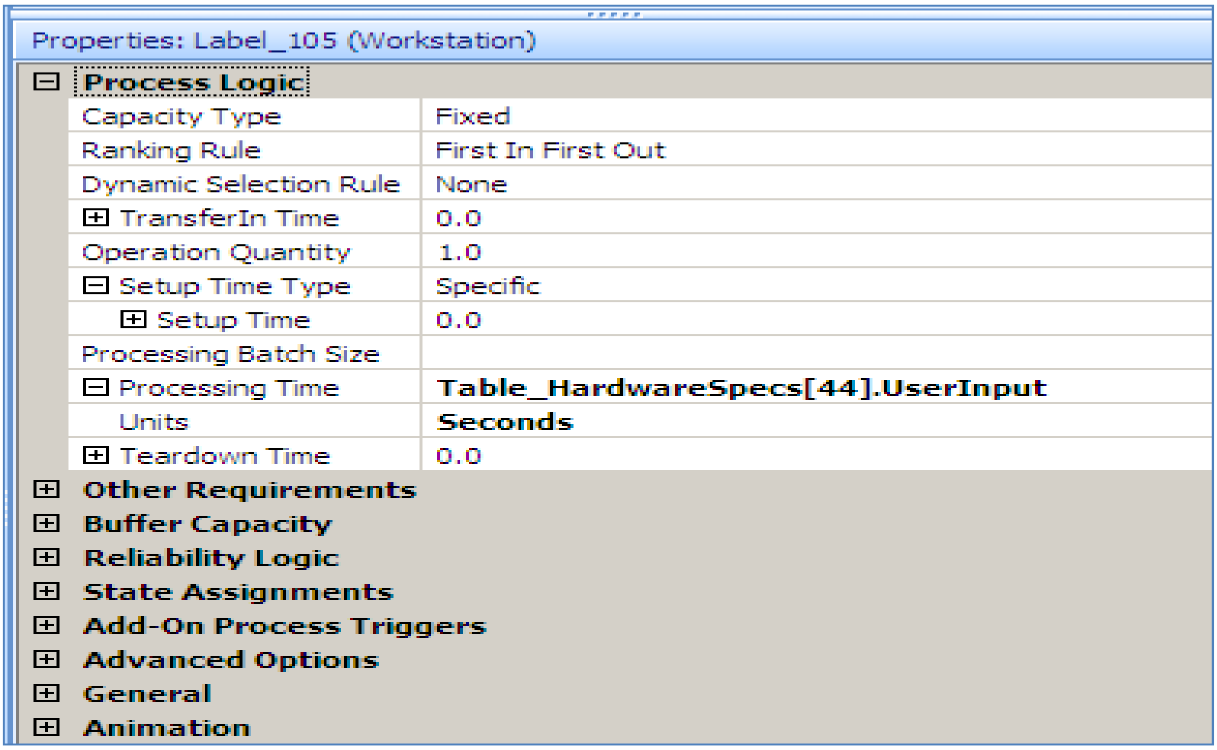
Properties: FinGrade_105 (Conveyor)

Travel Logic	
Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
Initial Desired Speed	**(Table_HardwareSpecs[39].UserInput)*(Table_HardwareSpecs[38].UserInput)/(Table_FruitData[1].UserInput)**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	**False**
Logical Length	**2**
Units	Meters
Accumulating	True
Routing Logic	
Selection Weight	1.0
Reliability Logic	
State Assignments	
Add-On Process Triggers	
Advanced Options	
Display Name	
General	

Labelling

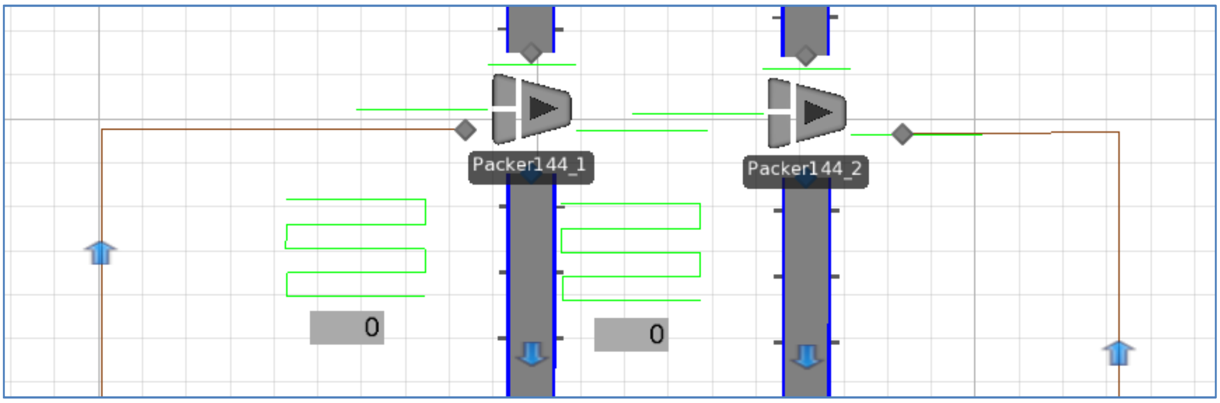
The labelling machine is modelled as a Workstation. The Class 1 fruit entities are processed by the labeller at a constant processing time.

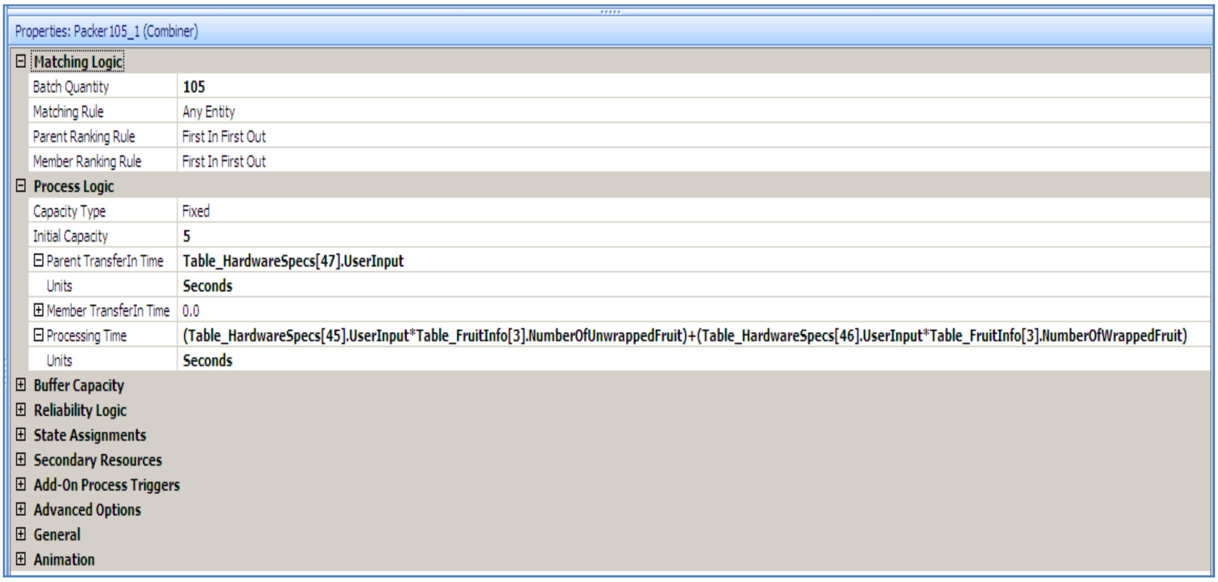




Packing

The packing tables are modelled as Combiners. The capacity refers to the number of packers stationed at the unit. Each packing table has a specific batching quantity that refers to the size count of the table. The processing time is dependant on the number of fruit in the carton that have to be wrapped before packing.





Properties: Packer105_1 (Combiner)

⊟ Matching Logic	
Batch Quantity	105
Matching Rule	Any Entity
Parent Ranking Rule	First In First Out
Member Ranking Rule	First In First Out
⊟ Process Logic	
Capacity Type	Fixed
Initial Capacity	5
⊟ Parent TransferIn Time	Table_HardwareSpecs[47].UserInput
Units	Seconds
⊞ Member TransferIn Time	0.0
⊟ Processing Time	(Table_HardwareSpecs[45].UserInput*Table_FruitInfo[3].NumberOfUnwrappedFruit)+(Table_HardwareSpecs[46].UserInput*Table_FruitInfo[3].NumberOfWrappedFruit)
Units	Seconds
⊞ Buffer Capacity	
⊞ Reliability Logic	
⊞ State Assignments	
⊞ Secondary Resources	
⊞ Add-On Process Triggers	
⊞ Advanced Options	
⊞ General	
⊞ Animation	

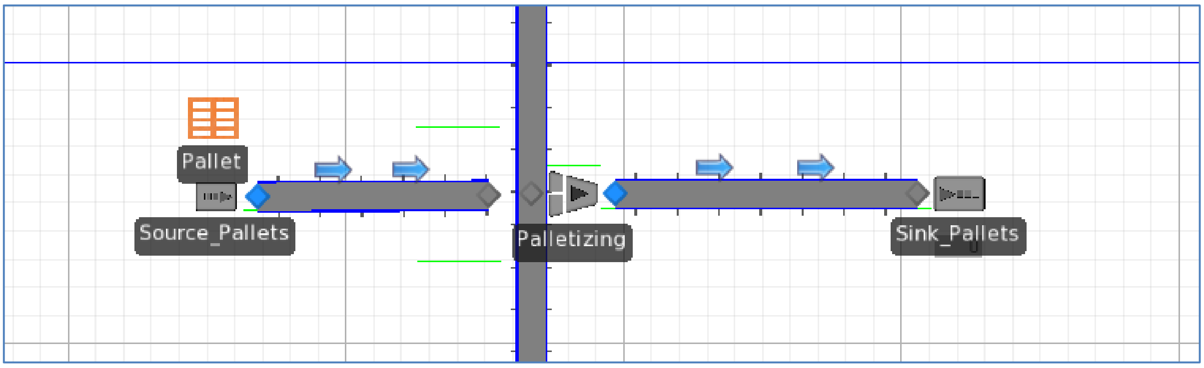
Table_FruitInfo

The packhouse manager specifies the number of wrapped fruit per carton before the commencement of a production run.

ID	Fruit Count	Number Of Unwrapped Fruit	Number Of Wrapped Fruit
1	144	100	44
2	125	75	50
3	105	60	45
4	88	50	38
5	72	50	22
6	64	45	19
7	56	30	26
8	48	25	23
9	40	20	20
10	36	18	18

Palletizing

The palletizing unit is represented by a Combiner. A certain number of cartons are batched and stacked on a pallet.



Properties: Source_Pallets (Source)

Arrival Logic	
Entity Type	**Pallet**
Arrival Mode	Interarrival Time
⊞ Time Offset	0.0
⊟ Interarrival Time	**5**
Units	Minutes
Entities Per Arrival	1
⊞ **Stopping Conditions**	
⊞ **Table Reference Assignments**	
⊞ **State Assignments**	
⊞ **Add-On Process Triggers**	
⊞ **Appearance**	
⊞ **General**	
⊞ **Animation**	

Properties: Palletizing (Combiner)

Matching Logic	
Batch Quantity	**Table_HardwareSpecs[52].UserInput**
Matching Rule	Any Entity
Parent Ranking Rule	First In First Out
Member Ranking Rule	First In First Out
Process Logic	
Capacity Type	Fixed
Initial Capacity	1
⊞ Parent TransferIn Time	0.0
⊞ Member TransferIn Time	0.0
⊞ Processing Time	0.0
⊞ **Buffer Capacity**	
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Secondary Resources**	
⊞ **Add-On Process Triggers**	
⊞ **Advanced Options**	
⊞ **General**	
⊞ **Animation**	

Appendix C: Selected Output Data for Routing Validation

Output Data for Validating the Routing Logic

An excerpt of the Interactive Detail Report of the trail production run for the verification of the routing logic of the model.

Interactive Detail Report			
Project: Validation			**2011/10/23 13:55**
Model: Model (Academic, COMMERCIAL USE PROHIBITED)			**Analyst Name: HendriBeukes**
Scenario: [Interactive Run]			
NumberCreated - Total			
Object Name	**Data Source**	**Category**	**Value**
Carton	[Population]	Throughput	496
Class1_105	[Population]	Throughput	381
Class1_125	[Population]	Throughput	212
Class1_36	[Population]	Throughput	101
Class1_40	[Population]	Throughput	230
Class1_48	[Population]	Throughput	522
Class1_56	[Population]	Throughput	1371
Class1_64	[Population]	Throughput	2220
Class1_72	[Population]	Throughput	1674
Class1_88	[Population]	Throughput	599
Class2_105	[Population]	Throughput	26
Class2_125	[Population]	Throughput	7
Class2_40	[Population]	Throughput	42
Class2_48	[Population]	Throughput	81
Class2_56	[Population]	Throughput	167
Class2_64	[Population]	Throughput	292
Class2_72	[Population]	Throughput	179
Class2_88	[Population]	Throughput	73
Class3	[Population]	Throughput	856
Juice	[Population]	Throughput	764
Pallet	[Population]	Throughput	5
Under	[Population]	Throughput	52
Waste	[Population]	Throughput	151
NumberDestroyed - Total			

Object Name	Data Source	Category	Value
Carton	[Population]	Throughput	80
Class1_105	[Population]	Throughput	210
Class1_125	[Population]	Throughput	125
Class1_36	[Population]	Throughput	72
Class1_40	[Population]	Throughput	120
Class1_48	[Population]	Throughput	336
Class1_56	[Population]	Throughput	952
Class1_64	[Population]	Throughput	1472
Class1_72	[Population]	Throughput	1080
Class1_88	[Population]	Throughput	352
Class2_105	[Population]	Throughput	0
Class2_125	[Population]	Throughput	0
Class2_40	[Population]	Throughput	0
Class2_48	[Population]	Throughput	0
Class2_56	[Population]	Throughput	112
Class2_64	[Population]	Throughput	192
Class2_72	[Population]	Throughput	72
Class2_88	[Population]	Throughput	0
Class3	[Population]	Throughput	854
Juice	[Population]	Throughput	764
Pallet	[Population]	Throughput	1
Under	[Population]	Throughput	52
Waste	[Population]	Throughput	151
NumberEntered - Total			
Object Name	**Data Source**	**Category**	**Value**
Packer105_1	MemberInputBuffer	Throughput	380
Packer105_1	OutputBuffer	Throughput	3
Packer105_1	ParentInputBuffer	Throughput	6
Packer105_1	Processing	Throughput	3
Packer105_2	MemberInputBuffer	Throughput	26
Packer105_2	ParentInputBuffer	Throughput	1
Packer125_1	MemberInputBuffer	Throughput	211
Packer125_1	OutputBuffer	Throughput	1
Packer125_1	ParentInputBuffer	Throughput	7

Packer125_1	Processing	Throughput	1
Packer125_2	MemberInputBuffer	Throughput	7
Packer125_2	ParentInputBuffer	Throughput	2
Packer144_1	ParentInputBuffer	Throughput	1
Packer144_2	ParentInputBuffer	Throughput	1
Packer36_1	MemberInputBuffer	Throughput	101
Packer36_1	OutputBuffer	Throughput	2
Packer36_1	ParentInputBuffer	Throughput	9
Packer36_1	Processing	Throughput	2
Packer36_2	ParentInputBuffer	Throughput	1
Packer40_1	MemberInputBuffer	Throughput	229
Packer40_1	OutputBuffer	Throughput	5
Packer40_1	ParentInputBuffer	Throughput	7
Packer40_1	Processing	Throughput	5
Packer40_2	MemberInputBuffer	Throughput	42
Packer40_2	OutputBuffer	Throughput	1
Packer40_2	ParentInputBuffer	Throughput	6
Packer40_2	Processing	Throughput	1
Packer48_1	MemberInputBuffer	Throughput	519
Packer48_1	OutputBuffer	Throughput	10
Packer48_1	ParentInputBuffer	Throughput	18
Packer48_1	Processing	Throughput	10
Packer48_2	MemberInputBuffer	Throughput	81
Packer48_2	OutputBuffer	Throughput	1
Packer48_2	ParentInputBuffer	Throughput	3
Packer48_2	Processing	Throughput	1
Packer56_1	MemberInputBuffer	Throughput	1369
Packer56_1	OutputBuffer	Throughput	24
Packer56_1	ParentInputBuffer	Throughput	27
Packer56_1	Processing	Throughput	24
Packer56_2	MemberInputBuffer	Throughput	167
Packer56_2	OutputBuffer	Throughput	2
Packer56_2	ParentInputBuffer	Throughput	9
Packer56_2	Processing	Throughput	2
Packer64_1	MemberInputBuffer	Throughput	2216

Packer64_1	OutputBuffer	Throughput	34
Packer64_1	ParentInputBuffer	Throughput	39
Packer64_1	Processing	Throughput	34
Packer64_2	MemberInputBuffer	Throughput	291
Packer64_2	OutputBuffer	Throughput	4
Packer64_2	ParentInputBuffer	Throughput	9
Packer64_2	Processing	Throughput	4
Packer72_1	MemberInputBuffer	Throughput	1671
Packer72_1	OutputBuffer	Throughput	23
Packer72_1	ParentInputBuffer	Throughput	26
Packer72_1	Processing	Throughput	23
Packer72_2	MemberInputBuffer	Throughput	178
Packer72_2	OutputBuffer	Throughput	2
Packer72_2	ParentInputBuffer	Throughput	6
Packer72_2	Processing	Throughput	2
Packer88_1	MemberInputBuffer	Throughput	598
Packer88_1	OutputBuffer	Throughput	6
Packer88_1	ParentInputBuffer	Throughput	10
Packer88_1	Processing	Throughput	6
Packer88_2	MemberInputBuffer	Throughput	73
Packer88_2	ParentInputBuffer	Throughput	3
Palletizing	MemberInputBuffer	Throughput	118
Palletizing	OutputBuffer	Throughput	1
Palletizing	ParentInputBuffer	Throughput	4
Palletizing	Processing	Throughput	1
NumberExited - Total			
Object Name	**Data Source**	**Category**	**Value**
Packer105_1	MemberInputBuffer	Throughput	315
Packer105_1	OutputBuffer	Throughput	3
Packer105_1	ParentInputBuffer	Throughput	3
Packer105_1	Processing	Throughput	3
Packer105_2	MemberInputBuffer	Throughput	0
Packer105_2	ParentInputBuffer	Throughput	0
Packer125_1	MemberInputBuffer	Throughput	125
Packer125_1	OutputBuffer	Throughput	1

Packer125_1	ParentInputBuffer	Throughput	1
Packer125_1	Processing	Throughput	1
Packer125_2	MemberInputBuffer	Throughput	0
Packer125_2	ParentInputBuffer	Throughput	0
Packer144_1	ParentInputBuffer	Throughput	0
Packer144_2	ParentInputBuffer	Throughput	0
Packer36_1	MemberInputBuffer	Throughput	72
Packer36_1	OutputBuffer	Throughput	2
Packer36_1	ParentInputBuffer	Throughput	2
Packer36_1	Processing	Throughput	2
Packer36_2	ParentInputBuffer	Throughput	0
Packer40_1	MemberInputBuffer	Throughput	200
Packer40_1	OutputBuffer	Throughput	5
Packer40_1	ParentInputBuffer	Throughput	5
Packer40_1	Processing	Throughput	5
Packer40_2	MemberInputBuffer	Throughput	40
Packer40_2	OutputBuffer	Throughput	1
Packer40_2	ParentInputBuffer	Throughput	1
Packer40_2	Processing	Throughput	1
Packer48_1	MemberInputBuffer	Throughput	480
Packer48_1	OutputBuffer	Throughput	10
Packer48_1	ParentInputBuffer	Throughput	10
Packer48_1	Processing	Throughput	10
Packer48_2	MemberInputBuffer	Throughput	48
Packer48_2	OutputBuffer	Throughput	1
Packer48_2	ParentInputBuffer	Throughput	1
Packer48_2	Processing	Throughput	1
Packer56_1	MemberInputBuffer	Throughput	1344
Packer56_1	OutputBuffer	Throughput	24
Packer56_1	ParentInputBuffer	Throughput	24
Packer56_1	Processing	Throughput	24
Packer56_2	MemberInputBuffer	Throughput	112
Packer56_2	OutputBuffer	Throughput	2
Packer56_2	ParentInputBuffer	Throughput	2
Packer56_2	Processing	Throughput	2

Packer64_1	MemberInputBuffer	Throughput	2176
Packer64_1	OutputBuffer	Throughput	34
Packer64_1	ParentInputBuffer	Throughput	34
Packer64_1	Processing	Throughput	34
Packer64_2	MemberInputBuffer	Throughput	256
Packer64_2	OutputBuffer	Throughput	4
Packer64_2	ParentInputBuffer	Throughput	4
Packer64_2	Processing	Throughput	4
Packer72_1	MemberInputBuffer	Throughput	1656
Packer72_1	OutputBuffer	Throughput	23
Packer72_1	ParentInputBuffer	Throughput	23
Packer72_1	Processing	Throughput	23
Packer72_2	MemberInputBuffer	Throughput	144
Packer72_2	OutputBuffer	Throughput	2
Packer72_2	ParentInputBuffer	Throughput	2
Packer72_2	Processing	Throughput	2
Packer88_1	MemberInputBuffer	Throughput	528
Packer88_1	OutputBuffer	Throughput	6
Packer88_1	ParentInputBuffer	Throughput	6
Packer88_1	Processing	Throughput	6
Packer88_2	MemberInputBuffer	Throughput	0
Packer88_2	ParentInputBuffer	Throughput	0
Palletizing	MemberInputBuffer	Throughput	80
Palletizing	OutputBuffer	Throughput	1
Palletizing	ParentInputBuffer	Throughput	1
Palletizing	Processing	Throughput	1

Appendix D: Selected Output Data for Consistency Test

Output Data for the Validation of Internal Consistency

An excerpt of the Interactive Detail Report of the trail production run for the verification of the model's internal consistency.

Roller Speed 100mm/s				
TimeInSystem - Average (Hours)				
Object Name	**Data Source**	**Category**	**Value**	**Actual Time**
Class1_105	[Population]	Flow Time	0.3116162	07:28:44
Class1_40	[Population]	Flow Time	0.3312443	07:57:00
Class1_48	[Population]	Flow Time	0.3056408	07:20:07
Class1_56	[Population]	Flow Time	0.3050153	07:19:13
Class1_64	[Population]	Flow Time	0.3093923	07:25:31
Class1_72	[Population]	Flow Time	0.3087569	07:24:37
Class1_88	[Population]	Flow Time	0.313888	07:32:00

Roller Speed 500mm/s				
TimeInSystem - Average (Hours)				
Object Name	**Data Source**	**Category**	**Value**	**Actual Time**
Class1_105	[Population]	Flow Time	0.0820694	01:58:11
Class1_40	[Population]	Flow Time	0.0989339	02:22:28
Class1_48	[Population]	Flow Time	0.0794005	01:54:20
Class1_56	[Population]	Flow Time	0.0808748	01:56:28
Class1_64	[Population]	Flow Time	0.0771482	01:51:06
Class1_72	[Population]	Flow Time	0.0783252	01:52:47
Class1_88	[Population]	Flow Time	0.0790106	01:53:47

Appendix E: Noordhoek Validation Production Run

Configuration of Noordhoek's Hardware Specifications

The data table containing Noorhoek's equipment configuration is shown below.

ID	Operation	Parameter Name	User Input	Unit
1	Tipper	Tipping Rate	0.6	containers/min
2	Tipper	Fruit per Container	2000	fruit
3	DipTank	Average Flow Speed	0.2	m/s
4	DipTank	Tank Width	1540	mm
5	PreSorting	Total Unit Length	2500	mm
6	PreSorting	Unit Width	1350	mm
7	PreSorting	Roller Speed	0.11	m/s
8	PreSorting	Single/Double Grading	2	
9	PreSorting	Max Graders	6	people
10	PreSorting	Available Hands per Grader	1	hands
11	PreSorting	Removal Time per Hand	0	s/fruit
12	PreSizing	Total Unit Length	1500	mm
13	PreSizing	Unit Width	1350	mm
14	PreSizing	Roller Speed	0.15	m/s
15	Washing	Nr of Brushes	10	brushes
16	Washing	Unit Width	1500	mm
17	Washing	Minimum Time	30	seconds
18	Drying1	Total Unit Length	5500	mm
19	Drying1	Unit Width	1950	mm
20	Drying1	Roller Speed	0.2	m/s
21	Waxing & Fungicide	Nr of Brushes	10	brushes
22	Waxing & Fungicide	Unit Width	1500	mm
23	Waxing & Fungicide	Minimum Time	30	seconds
24	Drying2	Total Unit Length	5950	mm
25	Drying2	Unit Width	1950	mm
26	Drying2	Roller Speed	0.2	m/s
27	Grading	Total Unit Length	3800	mm
28	Grading	Unit Width	1250	mm
29	Grading	Roller Speed	0.167	m/s
30	Grading	Single/Double Grading	2	
31	Grading	Max Graders	6	people
32	Grading	Available Hands per Grader	1	hands
33	Grading	Removal Time per Hand	0	s/fruit
34	Sizing	Total Unit Length	3000	mm
35	Sizing	Unit Width	1250	mm
36	Sizing	Roller Speed	0.2	m/s
37	Final Grading	Total Unit Length	2000	mm
38	Final Grading	Unit Width	1200	mm
39	Final Grading	Roller Speed	0.16	m/s
40	Final Grading	Single/Double Grading	2	
41	Final Grading	Max Graders	6	people
42	Final Grading	Available Hands per Grader	1	hands
43	Final Grading	Removal Time per Hand	0	s/fruit
44	Labelling	Labelling Time per Fruit	0.3	s
45	Packing	Time to Pack Unwrapped Fruit	0.6	s
46	Packing	Time to Pack Wrapped Fruit	0.9	s
47	Packing	Time to Start New Carton	20	s
48	Roller	Unit Width	1200	mm
49	Roller	Roller Speed	0.2	m/s
50	Conveyor	Unit Width	300	mm
51	Conveyor	Conveyor Speed	0.25	m/s
52	Palletizing	Cartons per Pallet	80	cartons

Noordhoek Output Data

An excerpt of the output data of the Noordhoek validation production run is shown below. The tipping time of the model is highlighted.

Object Type	Object Name	Data Source	Category	Data Item	Statistic Type	Value
Model	Model	TippingTime	MyOutputs	Output	Value	8.3325
Source	Tipper	OutputBuffer	Throughput	NumberEntered	Total	10000
Source	Tipper	OutputBuffer	Throughput	NumberExited	Total	10000
Source	Tipper	OutputBuffer	Content	NumberInStation	Average	3773.410338
Source	Tipper	OutputBuffer	Content	NumberInStation	Minimum	0
Source	Tipper	OutputBuffer	Content	NumberInStation	Maximum	8719
Source	Tipper	OutputBuffer	HoldingTime	TimeInStation	Average (Hours)	0.471676292
Source	Tipper	OutputBuffer	HoldingTime	TimeInStation	Minimum (Hours)	0.000105827
Source	Tipper	OutputBuffer	HoldingTime	TimeInStation	Maximum (Hours)	0.943186811