Volume 21 (1), pp. 63–75
http://www.orssa.org.za

ORiON
ISSN 0529-191-X

Simulation of fruit pallet movement in the port of Durban: A case study

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Received: 1 February 2005; Revised: 31 March 2005; Accepted: 5 April 2005

Abstract

This paper gives an overview of a discrete-event simulation study that was performed on pallet movement at Fresh Produce Terminals in the port of Durban, South Africa. The study formed part of an extended study of the logistics infrastructure of the South African fresh fruit industry and its export supply chain. The focus in this paper is on pallet movement in the terminal and its requirement on the storage capacity of the cold store facility. Specifics pertaining to input data analysis are provided, as well as a discussion of simulation model validation and output data analysis.

Key words: Discrete-event simulation, pallet movement, logistics infrastructure.

1 Introduction

A study on the South African fruit logistics infrastructure was conducted from March 2003 to April 2004. The study consisted of four phases and involved several institutions and contributors [6]. The first phase entailed the development of a Supply Chain Information and Communication Procedure (ICP), which contains a code of best practice for information sharing amongst the sub-sectors in the fruit export supply chain. The remainder of the study focused on the requirements for logistics infrastructure. Extensive data gathering took place in Phase 2 to determine, amongst others, infrastructure capacities, as the fruit industry was lacking consolidated datasets. Phase 3 included the development of optimisation and simulation models as well as a crop estimate methodology, a transaction cost analysis and an investigation into developments and trends in the supply of infrastructure and in overseas markets. The last phase entailed the forecasting of fruit production and export volumes and the analysis of various scenarios in order to determine whether investment in logistics infrastructure would be required in the foreseeable future.

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An overview of the study was given in a previous paper [6], while the complete study is reported in [5].

In this paper a simulation study of fruit pallet movement at Fresh Produce Terminals (FPT) in the port of Durban, which formed part of Phase 3 of the logistics infrastructure study, is described. The main aspects of this simulation study [5] are discussed from a practical point of view. A detailed discussion of the simulation model may be found in [5] and [6].

A simulation study is usually conducted according to a formal methodology [1], which includes identification of the scope and objectives of the study, input data analysis, model validation and output analysis. The structure of this paper is based on these steps, while specific issues of the input data analysis will be discussed. We show that the base model is valid, and future storage capacity needs can be determined by increasing pallet arrivals in the simulation model.

The structure of this paper is as follows: In §2 the fruit pallet movement process is described, followed by the scope and objectives of the study in §3, while the major assumptions made during the simulation study are listed and briefly motivated in §4. We discuss input data analysis in §5, model validation in §6 and present the results in §7 and conclusions in §8.

2 Description of the fruit pallet movement process

Although citrus fruit is exported through a number of South African ports, the largest volume is exported through FPT in the port of Durban. Fruit is exported in cartons on pallets, either in refrigerated (reefer) containers or in "bulk", *i.e.* the pallets are loaded into the hold of a specialised refrigerated vessel in a dedicated fruit terminal such as FPT. The refrigerated containers may be loaded onto a container vessel at the container terminal or onto the deck of a specialised refrigerated vessel at the fruit terminal.

Pallets of fruit are transported from the production areas to Durban either by truck or by train. In order to reduce congestion at the port and the (cold) stores, the trucks first go to a truck stop where they wait until they can be received at their destination. There are three possible destinations for trucks, namely the ambient store outside the port (where the citrus fruit "wilts" for a couple of days before proceeding to cold storage), one of the cold stores outside the port or the cold store at FPT. The term "ambient pallets" refers to pallets with fruit that are stored in a protected, but not cooled environment ("ambient store"), while the term "refrigerated pallets" refers to pallets with fruit that are stored in a cold store at a predetermined temperature. The trains go to FPT and/or a cold store outside the port.

FPT receives refrigerated pallets from cold stores outside the port (by truck) and ambient pallets from the ambient store outside the port (by truck) or directly from the production areas by truck (via the truck stop) or train. On arrival, the barcodes on the pallets are scanned before the pallets are off-loaded. The refrigerated pallets are loaded directly from the trucks onto the vessels. These pallets are referred to as "directs." The ambient pallets (also referred to as "cold store pallets") are received into a temporary ambient buffer from where they are put into cold storage. The cold storage consists of "chambers" and "tunnels." The chambers are larger than the tunnels, so it takes longer to cool the fruit to the required temperature in the chambers.

Pallets destined for the USA and the Far East undergo a cold sterilisation ("steri") treatment and must be kept separate from pallets for non-"steri" markets at all times. Also, "steri" pallets may not be transported more than 50m between the cold store and the vessel, so they cannot be kept in cold stores outside the port. "Steri" pallets have to undergo a quality inspection before being put into cold storage. If they fail the inspection, they can either be exported to non-"steri" markets or sent to the local market, depending on the circumstances.

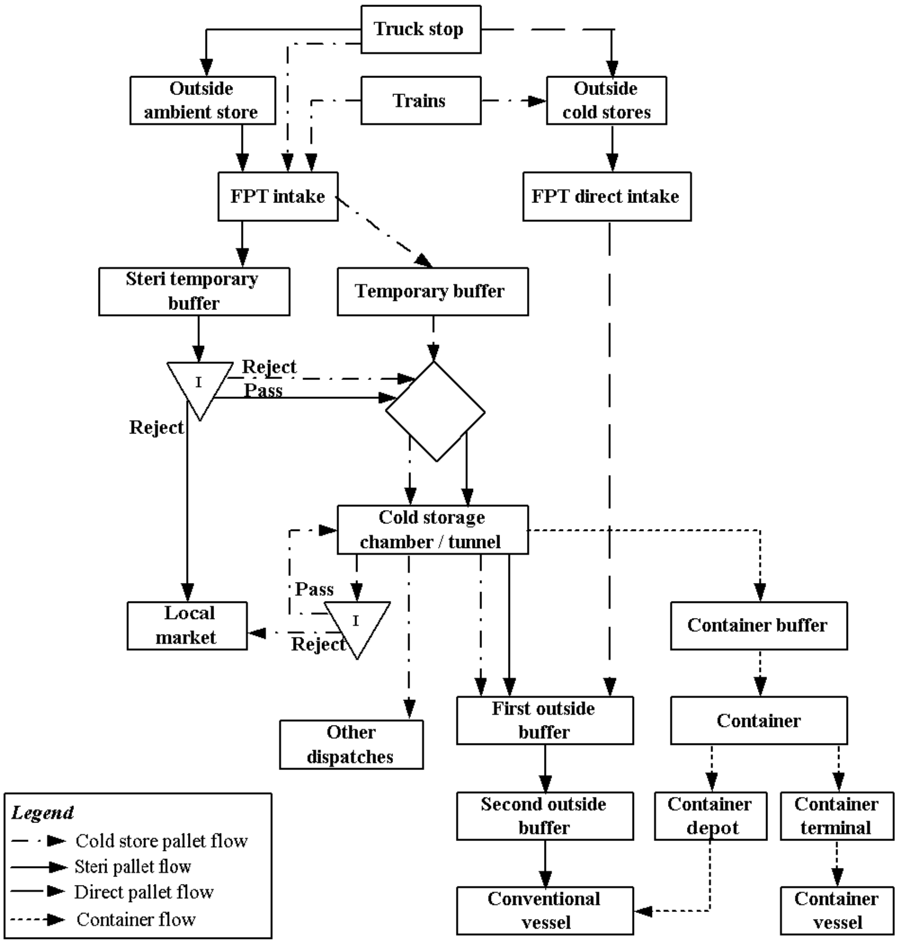

Figure 1: *Schematic of pallet movement at FPT.*

All pallets that have been in cold storage for 21 days or more have to undergo a quality inspection. (Theoretically, no "steri" pallets should be in cold storage for this long as they should be loaded onto a vessel as soon as they have been cooled to the required temperature.) Pallets that fail the inspection are sent to the local market.

From the cold stores pallets are loaded onto vessels via buffers on the quayside. However, some of the pallets are loaded into refrigerated containers for loading on deck of the specialised refrigerated vessels at FPT or to be loaded onto container vessels in the container terminal. A schematic of the pallet movement is shown in Figure 1.

3 Scope and objectives of the simulation study

The following pallet-related activities were included in the simulation model: The trucks arrive at the terminal. The pallets are then scanned and off-loaded. The off-loading is done either into the cold storage facility or directly onto a vessel. In the cold storage facility, the cold store pallets are cooled in tunnels or chambers to the desired temperature and then loaded onto the designated ship when it arrives. Only a certain number of berthing bays are available at the terminal. The flow of containers is excluded from the model, since container use for citrus fruit export is currently small. In future the situation might change, because new reefer vessels can carry more containers on deck.

The objectives of the simulation study were to

- develop a valid model that can be used with confidence as a predictor when evaluating scenarios;
- estimate future demand on fruit logistics infrastructure when imposing increased fruit exports;
- determine the need (if any) to invest in additional port infrastructure and equipment.

The output parameters were identified and their values estimated to support these objectives as indicated in Table 1.

Output parameter	**Type**	**Purpose**
Number of direct pallets received per season	Expected value	Validation Scenario analysis
Number of cold store pallets received per season	Expected value	Validation Scenario analysis
Annual duration of export season (period since first pallets are received until last pallets are shipped)	Expected value	Validation Scenario analysis
Maximum capacity of tunnels	Expected maximum value	Scenario analysis
Maximum capacity of chambers	Expected maximum value	Scenario analysis
Utilization of forklifts	Expected value	Scenario analysis

Table 1: *Output parameters estimated in the simulation study.*

The following scenarios were simulated, namely (I) the effect of an increase in fruit exported through the port and (II) the effect of an investment in additional equipment. This paper focuses on estimating the cold storage capacity for pallets via the simulation model in order to determine whether an investment is required for additional capacity. Thus only scenario I is discussed in this paper.

4 Model assumptions

The following main assumptions were made during the study:

- It was assumed that there is always at least one vessel available for loading. The terminal is not supposed to absorb fruit pallets due to external inefficiencies, although some capacity allowances should be made for unforeseen events, *e.g.* bad weather.
- The forklifts, cranes and other equipment were assumed to be ideal, *i.e.* no equipment failures occur.
- It was assumed that the required work force is always available and able to execute the required tasks.
- It was assumed that there are no significant loading delays due to bad weather.
- No seasonal trend in pallet arrivals was assumed over any 24-hour period. This means that trucks arrive according to a homogeneous process on each day throughout the season.
- The simulation transient phase was assumed to be negligible. This means that the simulation model starts "empty" (there are no trucks or containers present in the model), but builds up to a steady state quickly. In the steady state, the rate of container arrivals is on average equal to the rate of container departures.

5 Input data analysis

The following are the main input parameters to the model: (i) Average forklift speed (250 m/min), (ii) number of forklifts used, (iii) inter-arrival times of incoming trucks, (iv) the number of pallets on a truck (v), scanning times, (vi) transportation times between all the locations, (vii) times pallets spend in a tunnel, a chamber and in ambient storage, (viii) the proportion of cold store pallets assigned to a tunnel and the proportion assigned to a chamber, (ix) the proportion of "steri"-pallets rejected, (x) the proportion of pallets rejected when they are inspected after remaining in the terminal for more than 21 days, and (xi) the time it takes for a crane to load a cage with four pallets into the hatch of a vessel.

The inter-arrival times of the trucks, as well as the number of pallets on a truck, are stochastic parameters and require further discussion. Historic data from FPT's warehouse management system were obtained and analysed to determine arrival models for the two types of pallets (direct and cold store). Both these models consist of three elements each: specifying whether or not bulk arrivals occur, the time between arrivals of a group of pallets (resembling a truck), and assigning the number of pallets in the group. These elements are discussed next.

5.1 Bulk arrivals

Raw data for cold store pallets, totalling 8 054 records for the 2003 season, showed that bulk arrivals occur, *i.e.* more than one truck was registered at the same time. Single arrivals account for 90%, while the remaining 10% represent simultaneous arrivals of two trucks. No more than two trucks arrived simultaneously. These proportions (90% and 10%) also apply to the direct pallets based on analysis of 7 335 records (2003 season).

5.2 Time between arrivals of pallet loads

All historic records with single arrivals were analysed to determine the time between arrivals of pallet loads (trucks). The time between arrivals for the majority of arrivals of direct pallets (98%) is less than 170 minutes. The same proportion of arrivals for cold store pallets has a time between arrivals of less than 125 minutes. Extreme values as high as 5 500 minutes were included in the arrival models because they occurred on several occasions in the data set provided.

The recommended strategy [4] when developing stochastic input data specifications for simulation models is to use the observed data values directly in the model (trace-driven), or to develop an empirical distribution from the data, or to specify a theoretical statistical distribution, estimate its parameters and evaluate the fit by means of a hypothesis test, *e.g.* a chi-squared goodness-of-fit test. These alternatives are listed in order of increasing desirability.

Since no suitable theoretical statistical distribution could be found for the times between arrivals of trucks carrying pallets (direct and cold store pallets), empirical distributions were developed. These are shown in Figures 2 and 3. Note that the cumulative values of the relative frequencies (which form a stepwise continuous function) are used as the empirical distribution.

5.3 Number of pallets per load

Every truck arrival represents a varying number of pallets. Empirical distributions are again used to specify the number of pallets per truck, for both types (direct and cold store pallets). The distributions are shown in Figures 4 and 5.

6 Model validation

During model validation the analyst determines whether the simulation model is an adequate representation of the real-world system being simulated, *i.e.* whether the right model has been developed (see p. 336 in [1] and p. 264 in [4]). Validation must be conducted throughout a simulation study (see p. 345 in [1]), but only the major model validation aspects of this particular study are discussed here. These directly concern the pallet flow,

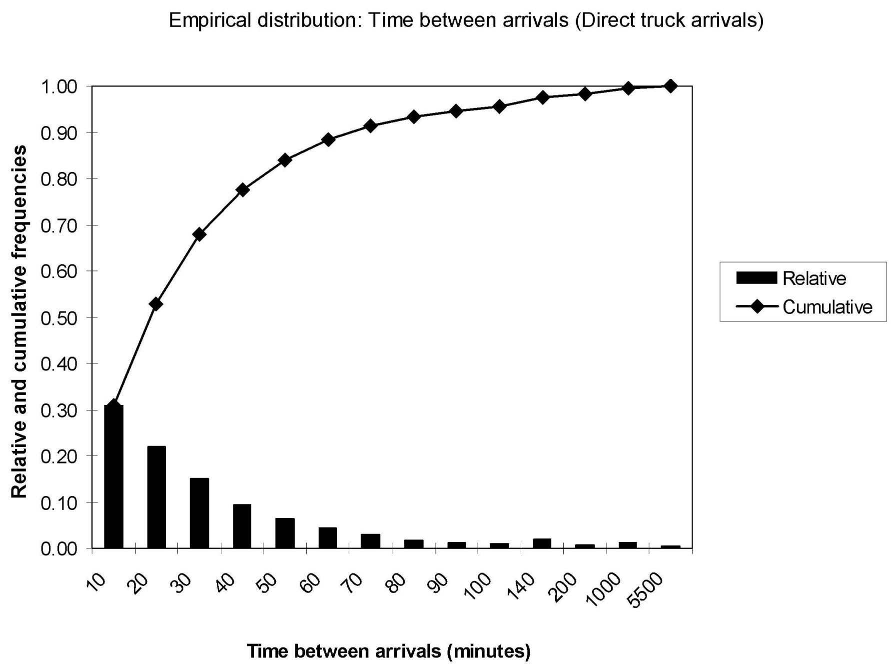

Figure 2: *Histogram and empirical distribution: Time between arrivals (Direct).*

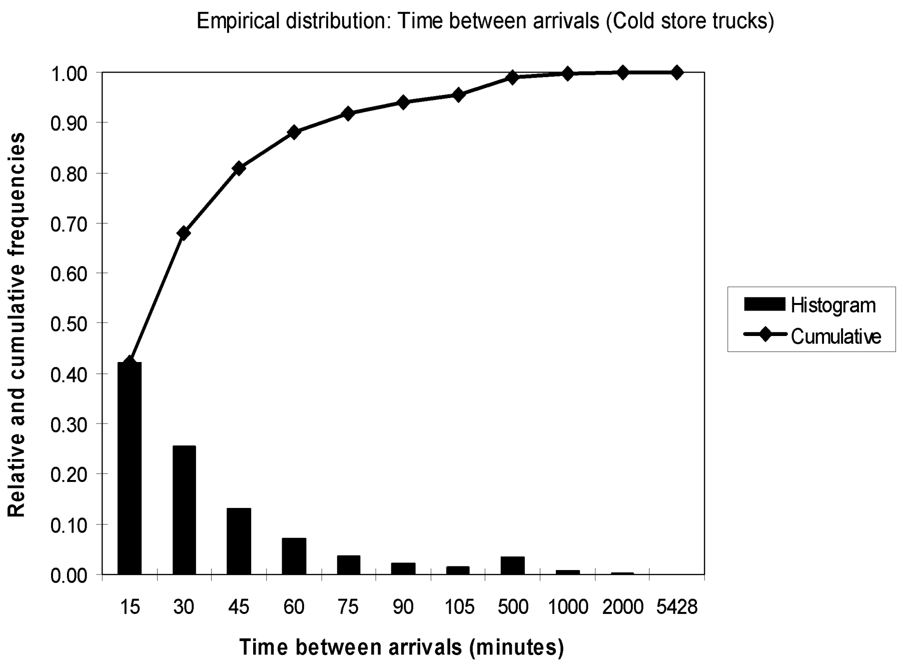

Figure 3: *Histogram and empirical distribution: Time between arrivals (Cold store).*

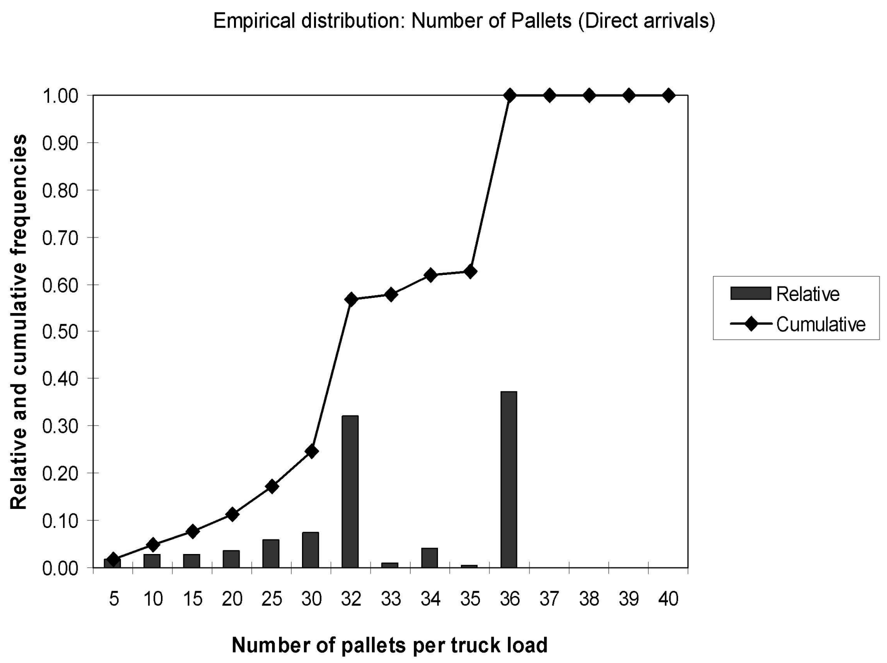

Figure 4: *Histogram and empirical distribution: Number of pallets (Direct).*

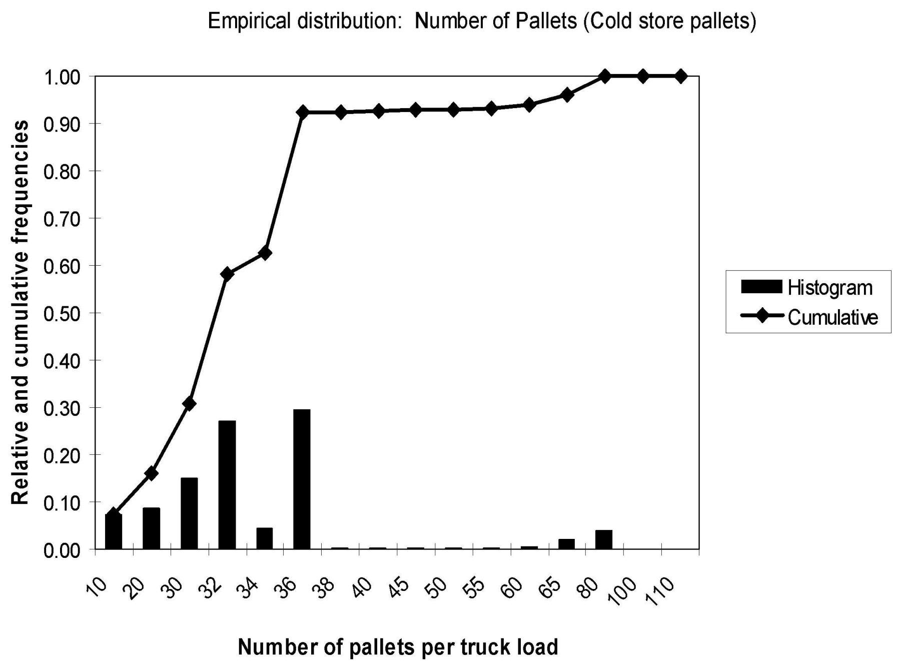

Figure 5: *Histogram and empirical distribution: Number of pallets (Cold store).*

and include the validation of the pallet arrival models and the length of the season, *i.e.* annual duration of pallet handling at the port. There are at least 75 validation techniques available (see pp. 354-356 in [1]), of which *Face validation* is best known and widely used. Briefly, it comprises the (subjective) comparison of system and model behaviour by the simulation analyst(s) as well as the people involved in the system (owner, operator, subject-matter expert). If results are reasonable, the model may be accepted as sufficiently valid. Face validation was applied in this study.

6.1 Pallet arrival models

The proposed pallet arrival models were implemented in the simulation model, and the number of truck arrivals, as well as the number of pallets delivered, was compared to the corresponding values from historical data. One replication of the simulation model is equivalent to a season of export activities, and 20 independent replications were made to obtain reasonably small confidence intervals on response parameters (see pp. 505–515 in [4]). A sequential approach was followed where the number of replications was increased until the calculated confidence intervals (for the output parameters) were small. It was found that 20 replications were sufficient, and the results (expected values compared to real-world values) are shown in Tables 2 and 3.

	Model (expected value)	**FPT** (2003)	**Difference** (δ)[1]
Direct pallets	6 282	6 443	2.5%
Cold store pallets	6 476	6 496	0.3%

Table 2: *Comparison of number of truck arrivals at FPT for validation.*

	Model (expected value)	**FPT** (2003)	**Difference** (δ)
Direct pallets	188 790	196 495	3.9%
Cold store pallets	205 050	205 248	0.1%

Table 3: *Comparison of parameter "Number of pallets received" at FPT for validation.*

6.2 Annual duration of the pallet handling season

Pallets start to arrive at the port of Durban early each year, and the last pallets are received during November. The last pallets are shipped no later than December. The simulation model should not only create pallet arrivals according to the models discussed earlier, but it should also finish processing the pallets according to the real-world system at the port. This means that all pallets should eventually be removed from the terminal, and it should happen at a time that can be associated with the real-world system. Specific dates of these events for 2003 are shown in Table 4.

[1] $\delta = \left(1 - \frac{\text{Model}-FPT}{FPT}\right) 100\%$

Date when first pallets arrived (D_A)	24 April 2003
Date when last pallets arrived (D_L)	3 November 2003
Date when last pallets were shipped (D_S)	12 December 2003
Season duration (days) ($D_S - D_A$)	233

Table 4: *Event dates of pallet arrivals and departures at FPT (2003).*

The simulation model thus had to create pallet arrivals for the period $D_L - D_A$ (194 days), while the period $D_S - D_A$ was measured in the simulation model and compared to the value of 233 days. However, the simulation model was run for consecutive processing days, while the period $D_L - D_A$ above includes some days on which no pallets were processed (*e.g.* some weekends or part thereof). Analysis of data records showed that 39 days out of the 233 days were lost due to no processing. The effective number of days that FPT processed pallets during 2003 is thus 194 days (233–39 days), and this number had to be compared with the total processing time as reported by the simulation model.

To verify that the simulation model processed the pallets correctly in terms of throughput, pallets were allowed to enter the model for a simulated period of 194 consecutive days (the period $D_L - D_A$ in Table 4). The model was allowed to run until the last pallet had been processed, and the simulated time (per replication) was recorded. The mean time duration, based on 20 replications, was found to be 199 days with a 95% confidence interval half-width of 0.35 days. This value compares reasonably well with the value of 194 days of the real-world system (2.5% deviation).

It follows from the discussion above that there was no reason to believe that the model is invalid, and production runs were consequently made. The results are presented and discussed in the following section.

7 Results

The following output parameters were estimated with the simulation model for Scenario I (see §3):

- Number of direct pallets received per season (expected value)
- Number of cold store pallets received per season (expected value)
- Maximum capacity of tunnels (expected maximum value)
- Maximum capacity of chambers (expected maximum value)

The expected maximum values of the latter two parameters were estimated, because these values represent storage areas. Estimating the means will result in storage areas that are insufficient for approximately 50% of the time (assuming a symmetric distribution of the output response values).

To determine future capacity requirements, the arrival rates of pallets were increased as a percentage of the current rate. This was achieved by scaling the times between arrivals of the original empirical arrival distribution. The results, based on 20 independent replications, are shown in Table 5. The symbol h in Table 7 represents the confidence

Arrival rate scale factor	1	1.11	1.25	1.33	1.67
Expected number of direct arrivals	188 790	212 420	239 650	250 870	318 480
h_D	5 190	5 589	6 983	6 044	7 028
Expected number of cold store arrivals	205 050	227 650	256 590	272 940	340 050
h_L	2 341	2 444	3 430	3 748	3 371
Expected maximum tunnel capacity	2 900	3 074	3 347	3 682	4 287
h_T	155	112	71	120	108
Expected maximum chamber capacity	1 403	1 503	1 681	1 782	2 140
h_C	65	62	43	60	56
Expected maximum capacity (tunnels + chambers)	4 303	4 577	5 028	5 464	6 426

Table 5: *Estimated values for the output parameters with different arrival rates.*

interval half-width, based on the t-distribution.

While the Central Limit Theorem is applied in estimating expected values, it usually cannot be applied when estimating expected maximums ("Expected maximum tunnels capacity" and "Expected maximum chamber capacity"). The *jack-knife method* (see, for example, pp. 201–203 in [3]) was used to analyse these two parameters.

The various capacity estimations in Table 5 may be used to determine future capacities via regression. Table 6 shows regression functions fitted to the "Tunnel" and "Chamber" capacity values of Table 5. The form of the regression function was guessed initially, and then through iteration it was found that the form $y = ax^b + c$ yields the highest R^2 value.

The regression functions are shown in Table 6. Here x is the pallet arrival rate expressed as a factor of the current value, where the current value is 1, and y is the required "Tunnel" or "Chamber" capacity, measured in number of pallets.

Output parameter	**Regression function**	R^2 **value**
Expected maximum tunnels capacity	$y = 2\,865x^{0.790\,9}$	0.986 5
Expected maximum chamber capacity	$y = 1\,392x^{0.841\,2}$	0.997 9

Table 6: *Regression functions for capacity requirements.*

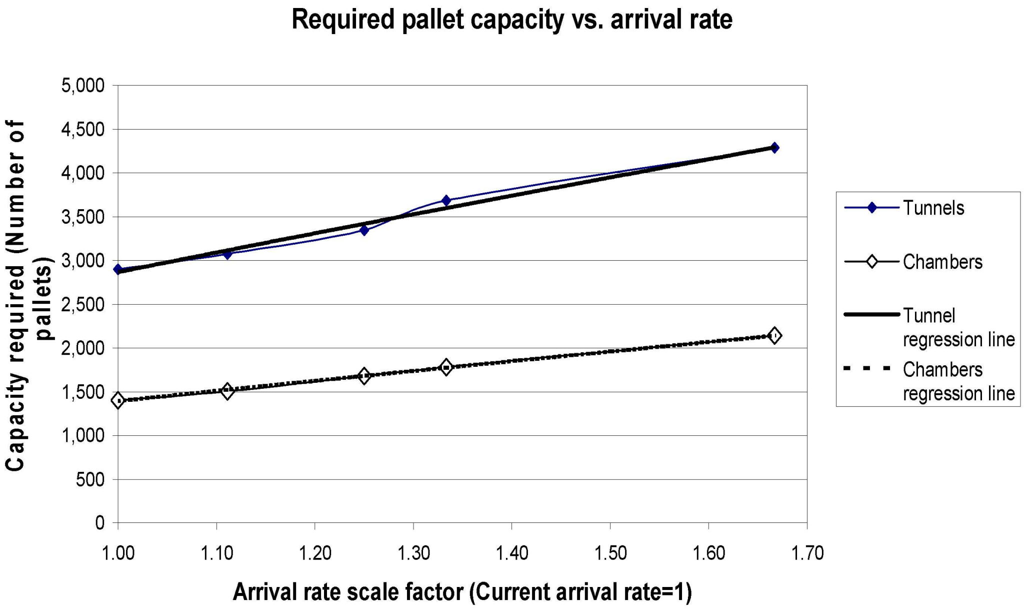

Figure 6: *Required capacities as functions of arrival rates.*

Immediate future capacities may be determined with these functions, given that the pallet arrival rates are known. The functions should, however, not be used for extrapolating with too high arrival rate scale factors, since many additional factors must be considered at higher arrival rates, *e.g.* appointment of additional personnel and hiring more forklifts.

The current capacity at the FPT is 17 500 pallets for "Tunnels" and "Chambers" (collectively). If an occupation ratio of 0.85 is used to prevent congestion, the capacity is 14 875 pallets. At the current arrival rate (scale factor = 1), the occupation ratio of Tunnels:Chambers is approximately 2:1 (see Table 5). Assuming the same occupation ratio for the future, the arrival rates may be increased by factor values of approximately 4.8 (Tunnels) and 4.5 (Chambers), before the respective capacities are exceeded. These factors thus indicate that there is no need for any immediate expansion of cold storage capacity, while they also quantify the current cold storage capacity.

8 Conclusions

In this paper a simulation study of pallet flow at the Fresh Produce Terminals in the port of Durban was discussed. The simulation model was validated against various criteria and could therefore be used to quantify the existing cold store capacities, to determine whether an investment in additional capacity would be required.

It was shown that the current and immediate future cold store capacities are adequate. However, this must be seen in context — the model did not take into account that fruit might have to wait in the cold store until the vessel on which the particular fruit has to be loaded, is available. This can happen when the vessel has been delayed *en route* or when there are no free berths, because other vessels are in the process of loading. Vessels may also be delayed during the loading process. For example, during the peak season some of the cold stores outside the port are not always able to load the trucks at the time and in the sequence required to supply FPT with a continuous supply of the right fruit for a particular vessel, hatch and deck at the time that the pallets are required for direct loading, thus causing delays. This contributed 53% of the total delays experienced at FPT in Durban during the 2003 citrus season [6]. These delays cause the cold stores to fill up with fruit that is ready to be loaded. This prevents FPT from accepting additional fruit for cold storage. The solution, however, does not lie in expanding the FPT cold store facilities, but in addressing the causes of the delays.

If pallet exports increase, other parameters should also be evaluated, *e.g.* increasing the number of forklifts. The simulation model can be refined and with more historical data it can be used to determine other capacity requirements in the terminal.

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