

ANALYSIS OF THE USE OF SPACE AND MODULE-CONFIGURED PACKAGING TO IMPROVE FRUIT EXPORT MASS IN A REFRIGERATED CONTAINER

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ABSTRACT

The South African fruit export industry is a key contributor to the country's economy, and must be managed efficiently to that ensure its vital role is maintained. Significant increases in reefer freight rates have placed substantial pressure on the fruit export industry to find new and innovative ways of improving the space / volume use of fruit in these reefer containers. Improvements must adhere to key constraints to ensure that fruit quality and shelf life are not compromised. This paper analyses the current potential for increasing the mass of stone and pome fruit that is exported in reefer containers. The study indicates that pome fruit has the greatest opportunity for improvement, whereas stone fruit has less room for improving the use of space / volume. Proposed improvement methods are: optimal packing arrangements of fruit; improved packaging and pallet dimensions (special pallet sizes); improved stacking arrangements of cartons on pallets and pallets in reefers; and lastly, the use of slip sheets instead of pallets.

OPSOMMING

Die Suid-Afrikaanse vrugte uitvoer industrie is 'n belangrike bydraer tot die land se ekonomie, en moet doeltreffend bestuur word om te verseker dat hierdie rol volhou word. Beduidende toenames in koelhouer vragkoste het aansienlike druk op die vrugte uitvoer industrie geplaas om nuwe en innoverende maniere te vind om die spasie / volume benutting binne die koelhousers te verbeter. Verbeteringe moet voldoen aan belangrike beperkings om te verseker dat die kwaliteit en raklewe van vrugte nie benadeel word nie. Hierdie studie ontleed die potensiaal om die uitvoer massa van steen- en kernvrugte in verkoelde housers te verhoog. Die studie dui aan dat kernvrugte die grootste geleentheid bied vir verbetering, terwyl met steenvrugte daar minder potensiaal is om spasie / volume benutting te verbeter. Die voorgestelde verbeteringsmetodes is soos volg: optimale verpakkingsreëlins van vrugte; verbeterde verpakking en palletafmetings (spesiale pallet-groottes); verbeterde stapelreëlins van kartonne op palette en palette in koelkashousers; en laastens, die gebruik van 'slip sheets' in plaas van palette.

1 INTRODUCTION

South Africa's fruit industry is one of the key contributors to the country's economy. In 2013, the export value was around R19.8 billion, accounting for 50 per cent of all agricultural exports from South Africa (Goedhals-Gerber, et al. 2015). The fruit industry employs about 460 000 people, which includes direct employment on farms and at pack houses, but excludes logistics personnel (Hortgro 2012). Because almost 45 per cent of the total deciduous fruit production is exported, it is imperative that the fruit industry's export cold chain, with all of its intricacies, is efficiently and optimally managed (Hortgro 2012). According to Rodrigue and Notteboom (Rodrigue and Notteboom 2014), the term 'cold chain' refers to a temperature-controlled supply chain that involves the

movement of products (fruit, in this case) that are sensitive to temperature and physical strain, from point of origin to point of consumption. Movement takes place through thermal and refrigerated packaging and storage methods. For fruit export, the products / shipments are stored in refrigerated containers (also known as reefers) and transported by cargo ships or air cargo. These reefers are used universally across various parts of the cold chain and, as a result, must be used effectively (Rodrigue and Notteboom 2014).

Steep increases in reefer freight rates introduced in 2013 have placed great strain on the profitability of the fruit export supply chain (Bouwer and Dodd, Reefer Volume Utilisation 2016). As stated by Bouwer (Bouwer, Reefer rate increases 2016), freight costs account for about 15 per cent of the entire supply chain costs; it is thus imperative to try and extract as much value out of this service as possible. One way to achieve this is to ensure that the maximum mass of fruit is exported in each container. Currently it is difficult to achieve this goal, as there are several internationally entrenched paradigms in place, such as the pallet and carton dimensions. There are also constraints relating to the mass of fruit the cartons can carry due to the strength or cost of the corrugated board. However, the existing literature about the cold chain (and specifically about reefers) is focused more on the technological aspects than on the managerial aspects (Arduino, Carrillo Murillo and Parola 2015).

However, very little work has been done to improve the mass of fruit to be exported in a container. A review of the existing literature on the maximum mass of fruit that can be exported in containers revealed no results. A search was performed on SCOPUS, Web of Science, and Google Scholar using the keywords 'maximum' AND 'mass' AND 'fruit' AND 'container', but no relevant papers were found. A study by Van Dyk and Maspero (Van Dyk and Maspero 2004) conducted an analysis of the South African fruit logistics infrastructure. However, their study focused more on infrastructure capacity, and not on the use of capacity in a reefer. In the operational research field, studies have focused on the container loading problem, where the objective is to maximise the loading of 3-D boxes within a 3-D rectangular container (Bortfeldt and Wäscher 2012). The problem is viewed as a geometric assignment problem to maximise the use of space. Some of these studies also investigate the weight distribution constraints as part of the problem formulation (Egeblad, et al. 2010), (Liu, et al. 2011). These studies, however, do not specifically focus on fruit and the current box sizes used for fruit; neither do they investigate the theoretical maximum mass of fruit that can be packed in a container.

A need was therefore identified to better understand the current constraints that reduce the use of space / volume within such containers, and to identify potential areas to improve the use of the space / volume, thereby increasing the amount and the mass of pome and stone fruit being exported.

The purpose of this paper is to investigate current fruit export standards, to calculate theoretical reefer container capacities, to analyse constraints, and then to provide recommendations about improving the use of space / volume in reefers to increase fruit export mass (specifically from a South African perspective). The paper first provides a literature and industry analysis of the most exported cartons, carton / pallet stacking patterns, the number of pallets per container, and the export quantities found in industry for pome and stone fruit. This is followed by a calculation of the theoretical unconstrained maximum capacity of a 12 m high cube reefer for the different fruit types (apples, pears, peaches, nectarines, apricots, and plums). This theoretical unconstrained capacity is then reduced by adding the container payload and pallet weight / dimension constraints currently found in practice. This provides a more realistic maximum fruit export capacity. Current fruit export capacities found in practice (expressed in terms of weight) are then compared with these constrained maximum capacities to determine how effective the current use of weight / volume is inside the reefer container. Finally, potential improvements to increase the amount or mass of fruit that can be exported in a 12 m high cube reefer are investigated, using a commercial software solution to optimise the arrangement of cartons on pallets and pallets in containers, and changing the dimensions of the cartons.

2 ANALYSIS OF CURRENT FRUIT EXPORT STANDARDS

This section focuses on the analysis of the most exported cartons, carton / pallet stacking patterns, the number of pallets per container, and the export quantities found in the industry. This includes a review of the information available in the literature and of information obtained from industry experts.

2.1 Current carton information

The type of packaging used in the export handling of fresh fruit, such as pome fruit and stone fruit, is primarily ventilated corrugated cartons (Berry, et al. 2015). A recent survey conducted by Berry *et al.* (Berry, et al. 2015) identified the dimensions, weight, average count, and percentage use of the cartons that are mostly used in the export of pome fruit. The survey showed that open display (MK7 and MK9 subtypes) and telescopic cartons (MK4 and MK6 subtypes) are the main cartons used (refer to Table 1). These specific cartons account for 69.81 per cent and 89.74 per cent of apple and pear exports respectively. Due to this high usage, the focus of this analysis will be on these four cartons types (MK9 is used for both apples and pears).

Table 1: Pome fruit carton information: Different carton types and dimensions (Berry, et al. 2015)

	Apples		Pears		
	Open display	Telescopic	Open display	Telescopic	Open display
(mm or kg)	MK9	MK4	MK7	MK6	MK9
Length	600	500	600	400	600
Width	400	330	400	300	400
Height	139	287	91	247.5	139
Weight	12.5	18.25	6.5	12.5	12.5
Average count	83	128	30	72	80
Total % of exported apples	21.61%	48.20%	-	-	-
Total % of exported pears	-	-	22.16%	56.63%	10.96%

Table 2 presents the dimensions, weight, and percentage use of the cartons most used for stone fruit. Estimated percentage use values for the most-used cartons were obtained from an industry expert (Saunders 2016) as no data could be found in the literature. According to Saunders (Saunders 2016), the two cartons (named in Table 2) account for 60 per cent of the cartons used in stone fruit export.

Table 2: Stone fruit carton information: Different carton types and dimensions (Saunders 2016) & (Harrison 2015)

(mm or kg)	D051	M051
Length	400	400
Width	300	300
Height	104	120
Weight	7.5	7.5
Total % of exported fruit	30%	30%

2.2 Pallet characteristics

A pallet is the structural foundation of a unit load (made from either wood or plastic) that facilitates handling and storage efficiencies (Le Blanc 2015). Because pallets are universally used throughout the fruit industry, it is quite evident that they play a noteworthy role in the material handling process of fruit (Trevisani, et al. 2014). Not only are pallets plentiful in the industry: there is also a wide variety of pallet types. Table 1 shows the six different pallet dimensions as set out by the International Organization for Standardization (ISO) (International Organization for Standardization 2003).

Table 3: Pallet dimensions according to ISO standards (Pieterse 2015)

Pallets according to ISO code	Countries where mostly used	Length (mm)	Width (mm)	Height (mm)
ISO pallet 1 (known as Euro pallet)	Europe	1200	800	160
ISO pallet 2 (known as standard pallet)	South Africa	1200	1000	162
ISO pallet 3	American regions	1219	1016	142
ISO pallet 4	North America, Europe & Asia	1067	1067	140
ISO pallet 5	Asia Pacific region	1100	1100	160
ISO pallet 6	European	1140	1140	138

The type of pallet used will influence the loading capacity for several reasons. First, different pallets have different weight capacities, meaning that some pallets can support more fruit than others. The actual weight of the pallet will also impact the loading capacity. Second, the dimensions of a pallet will have an impact on the number of pallets that can be loaded into a container. Last, the height of the pallet will also influence the number of fruit cartons that can be packed on top of it, because there is a load line inside the container that indicates the maximum height to which goods can be stacked.

2.3 Current carton stacking patterns and number of cartons per pallet

Four different pallet-packing configurations are most often used in the pome fruit export cold chain (Berry, et al. 2015). Figure 1 shows these different stacking configurations for different numbers of cartons per layer. Figure 1 (a), (b), and (d) use the standard 1.2 x 1.0 m (ISO 2) pallet, while (c) uses the 1.2 x 0.8 m pallet (ISO 1) (Berry, et al. 2015).

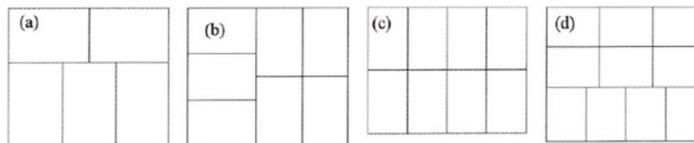


Figure 1: Pallet stacking arrangements showing a) 5, b) 7, c) 8, and d) 10 cartons per layer (Berry, et al. 2015)

Berry *et al.* (Berry, et al. 2015) estimated the number of pome fruit cartons that can be stacked on top of a standard pallet, and the number of cartons per pallet layer. These results are presented in Table 4 for different carton types for both apples and pears. These values are used in section 2.5 to calculate the total number of cartons currently exported, on average, per container.

Table 4: Number of pome fruit cartons per pallet and pallet layer (Berry, et al. 2015)

	Carton	# cartons per pallet	# cartons per layer
Apples	MK9	72	5
	MK4	49	7
Pears	MK7	110	5
	MK6	90	10
	MK9	72	5

The South African pome fruit industry publishes packaging material guidelines for pome fruit (Harrison 2015). The number of stone fruit cartons that can be stacked on top of a standard pallet was extracted from their guidelines; this is presented in Table 5. No information about the number of cartons per pallet layer was available.

Table 5: Number of stone fruit cartons per pallet (Harrison 2015)

Carton	# cartons per pallet
D05L	200
M05L	180

2.4 Current number of pallets per container and stacking arrangements

It is possible to load 24 to 25 ISO 1 (Euro) pallets into a 12 m high cube reefer, or 20 to 21 ISO 2 (standard) pallets (JFHillebrand n.d.). The typical pallet stacking arrangements found inside reefers are presented in Figure 2. These values for loaded pallets will differ from one reefer to another owing to dimensional differences. The standard pallet was used as part of the analysis owing to its relatively high usage, especially when compared with the Euro pallet. The number of pallets per container was also assumed to have a value of 20, as this is considered the industry norm [3].

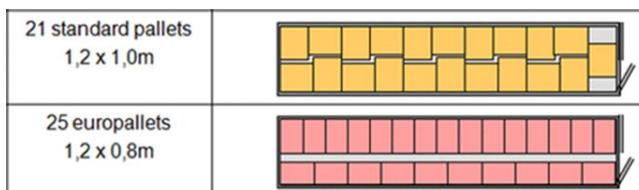


Figure 2: Pallet stacking arrangements in container (JFHillebrand n.d.)

2.5 Current export mass and quantities

In order to calculate the total number of cartons currently exported on average per container, the number of cartons of both pome and stone fruit, which are stacked on top of a standard pallet (as presented in section 2.3), was multiplied by the average number of pallets per container. The total weight of the cartons exported could then be calculated by multiplying the number of cartons by the average weight per full carton (weight information as in section 2.1). The weight of the pallets also had to be added to the cargo. The ISO 2 (standard) pallet weighs 28kg, and is used predominantly in the South African fruit industry (Berry, et al. 2015). Thus the total weight contributed by the pallets could be calculated by multiplying this average weight of an ISO 2 pallet by the average number of pallets per container, which was estimated as 20 (refer to section 2.4). The total pallet weight per container was therefore 560 kg. The calculated current total cargo weight and estimated number of pome fruit cartons that are exported in a 12 m high cube reefer are summarised in Table 6. Bruwer (Bruwer 2015) conducted a study in which he compared the weight restrictions of the containers of different shipping lines. The average maximum payload of thirteen reefer containers used in the industry was calculated as 29 714 kg. If one compares the total cargo weights for the different carton types for both apples and pears (as seen in Table 6) with this maximum payload restriction per reefer container, one can see that the total cargo weight values are far less than the average maximum payload of a 12 m high cube reefer (29 714 kg). This indicates an opportunity for improvement (trying to increase the export mass). The estimated average number of fruits in Table 6 is calculated by multiplying the average count (found in Table 1) by the total number of cartons per container.

Table 6: Total number of cartons and weight exported in container (pome fruit)

	Apples		Pears		
	Open display	Telescopic	Open display	Telescopic	Open display
	MK9	MK4	MK7	MK6	MK9
Total # of cartons per container	1 440	980	2 200	1 800	1 440
Total weight of cargo in kg (cartons + pallets)	18 560	18 445	14 860	23 060	18 560
Estimated average number of fruits	119 520	125 440	66 000	129 600	115 200

Performing the same type of calculations for stone fruit, the current total weight of cargo that is exported in a 12 m high cube reefer may be seen in Table 7. Here the total weight values are close to the average maximum payload restriction of 29 714 kg. The D05l carton exceeds the limit, which may be attributed to inaccurate data. Still, little or no room for improvement (trying to increase the export mass) can therefore be expected for stone fruit. The M05l is slightly under the limit, indicating some potential for export weight improvement.

Table 7: Total number of cartons and weight exported in container (stone fruit)

	D05I	M05I
Total # of cartons per container	4 000	3 600
Total weight of cargo in kg (cartons + pallets)	30 560	27 560

3 ANALYSIS OF UNCONSTRAINED MAXIMUM THEORETICAL EXPORT CAPACITIES

The previous section aimed to determine the current total cargo weight per exported container for both pome and stone fruit. In this section, the theoretical unconstrained maximum capacity (in terms of cargo weight) of a 12 m high cube reefer is determined for the different fruit types (apples, pears, peaches, nectarines, apricots, and plums). By comparing the current export weights with the theoretical maximum possible export weights, opportunities can be identified to increase the cargo export weight per container. The export capacity per container is expressed in terms of number and weight of fruit, and serves as a reference point for further calculations and analysis. The calculations are unconstrained at first, meaning that practical constraints such as the container’s maximum payload limit and the impact of the carton and pallet (volume and unused volume) will all initially be ignored. These calculations therefore provide the theoretical best-case scenario. Section 4 of this paper will focus on incorporating the relevant constraints in order to determine the impact of each constraint, and potentially to identify opportunities for improvement.

3.1 Assumptions

The following analysis of the fruit is only possible when making the key assumption that the different types of fruit (except pears) are modelled as spheres. This assumption seems reasonable, as most fruits bear a close resemblance to a sphere’s shape. Another key assumption pertains to the packing density of the fruit inside the reefer. The packing density of randomly packed spheres can range from 55 per cent to 63.4 per cent, depending on whether the spheres are *randomly loose-packed* or *randomly close-packed* (Nectoux 2015). Note that ‘random’ only refers to the use of no particular packing arrangement (such as, e.g., *face-centred cubic* or *hexagonal close-packed*). To calculate the reefer capacity, an assumption is made that the packing density is 55 per cent, as it seems impractical to assume that the reefer can be shaken to improve packing density. The packing density of optimal packing arrangements (*face-centred cubic* or *hexagonal close packed* – see Figure 3 for a comparison of the packing arrangements) is 74.048 per cent (Nectoux 2015). Airflow / cooling requirements are not fully included within the scope of the project; thus an assumption is made that, regardless of the packing arrangement, the gaps between the individual pieces of fruit are sufficiently large to allow cool air to flow through.

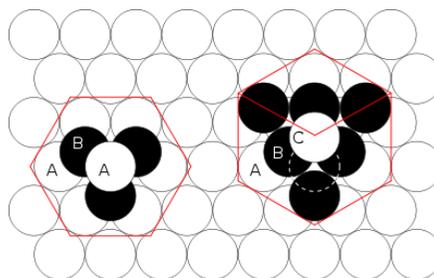


Figure 3 : Comparison of hexagonal close-packed (HCP) (left) and face-centred (FCC) cubic arrangement (right) (Redston 2011)

3.2 Parameters

The average diameter, volume, and mass for each of the analysed fruit types were first collected. These values can be found in Table 8 (as extracted from Harrison (Harrison 2015)).

Table 8: Average fruit diameter, volume, and mass (Harrison 2015)

Fruit	Average diameter (m)	Average volume per piece of fruit (m ³)	Average mass per piece of fruit (kg)
Apples	0.0666	0.0001547	0.128
Nectarines	0.0720	0.0001954	0.442
Peaches	0.0720	0.0001954	0.451
Plums	0.0525	0.0000758	0.088
Apricots	0.0515	0.0000715	0.085
Pears	-	0.0001896	0.190

Due to the physical shape of a pear, its diameter cannot be derived using the formula of a sphere's volume. These values only represent a specific cultivar from each type of fruit, as there are more than a hundred cultivars in total, which would make analysing them an arduous process. The specific values are not necessarily the essential part of the analysis; the true importance comes from the concepts and insights that will be conveyed during the subsequent calculations and analysis.

3.3 Calculations and results

The average internal dimension of a 12 m high cube reefer was used to calculate the volumetric capacity of a typical reefer. These average dimension values are as follows: length = 11 584.92mm, height = 2 525.85mm, and width = 2 287.38 mm (extracted from Bruwer (Bruwer 2015)). However, to calculate the volumetric capacity of a reefer, the height value used should not be the container height but the red load line inside the reefer, which indicates the maximum stacking height that should not be exceeded due to airflow requirements [4]. Subsequently, the actual height value used is 2 409 mm (the red load line height). The reefer's volumetric capacity is determined by calculating the internal volume. The usable volumetric capacity equates to 63.60 m³ and is, subsequently, multiplied by the random loose packing density of 55 per cent to determine the volume occupied by the fruit itself. This is done to account for the air gaps between the packed fruit. Thus the total effective volume is 34.98 m³ for random packing, and 47.09 m³ for FCC / HCP packing .

For the stated parameters, the maximum number of fruits that can be inserted in a 12 m high cube reefer is calculated by dividing the total effective volume by the volume of the individual fruits. The maximum unconstrained number of fruits that can theoretically be loaded in a container for both the random packing and the optimal arrangement (FCC and HCP) is given in Table 9. The total weight is calculated by multiplying the number of fruits by the weight per fruit. There is a significant increase when using optimal packing arrangements. These values represent the theoretical maximum number of fruits that can be inserted in a 12 m high cube reefer, and when compared with the values found in Table 6 (values in practice), there is a noteworthy difference. Note that the total weight of all the fruit types (except the randomly packed apples) exceeds the reefers' average maximum payload limit of 29 714 kg. This indicates that the reefer's payload limit is the limiting factor, and not the reefer's volumetric capacity – i.e. the payload limit would be reached before the reefer is fully loaded.

Table 9: Maximum unconstrained number of fruits and their weight (kg)

	Random		FCC / HCP	
	Number	Weight	Number	Weight
Apples	226 143	28 850	304 463	38 841
Nectarines	178 982	79 067	678 027	106 450
Peaches	178 982	80 638	691 497	108 565
Plums	461 667	40 723	2 433 513	54 827
Apricots	489 086	41 658	2 024 007	56 085
Pears	184 488	35 119	248 381	47 282

4 ANALYSIS OF MAXIMUM THEORETICAL EXPORT CAPACITIES WITH CONSIDERATION OF CONSTRAINTS

This section focuses on the analysis of the impact of adding relevant constraints on the theoretical maximum number of fruits and their weight that can be inserted in the reefer (as calculated in section 3). Constraints such as the container's maximum payload limit and the impact of the pallet (volume and unusable volume) and carton were incorporated in order to analyse the impact of each constraint.

4.1 Container payload constraint

The payload constraint is given by the container's maximum payload limit, which was determined as 29 714 kg (Bruwer 2015). From Table 9, one can see that the theoretical maximum number of fruits per container (calculated in section 0) exceeds the payload limit of 29 714 kg for all scenarios, except for random-packed apples (resulting weight of 28 850kg, which is below the payload limit). When one adds the payload limit to the other scenarios, and then calculates the total number of fruits that can be loaded in a container without exceeding the payload limit, the results seen in Table 10 are obtained. The percentage difference column in this table indicates the percentage reduction in the number of fruits that can be loaded in a container due to the payload limit. As presented in Table 10, all fruit types, except apples, exceed this maximum payload limit when the packing is done randomly, and therefore experience a significant reduction in the maximum number of fruits that can be loaded per container. It is important to note that for other cultivars of the same fruit type, different results may be found, perhaps due to cultivars differing substantially in terms of size and weight.

Table 10: Capacity for random packing with reefer payload constraint

	Maximum number of fruits / container	Number of fruits with payload constraint	% Difference	Weight (kg)
Apples	226 143	226 143	0%	28 850
Nectarines	178 982	67 262	-62%	29 714
Peaches	178 982	65 951	-63%	29 714
Plums	461 667	336 851	-27%	29 714
Apricots	489 086	348 852	-29%	29 714
Pears	184 488	156 091	-15%	29 714

The results in Table 11 were obtained for optimal packing (FCC and HCP). All the total weight values exceed the payload limit, so the number of fruits that can be loaded per container is significantly reduced by the payload limit. This is expected, as the fruit is packed more densely, and thus more fruit is loaded into the reefer. To conclude, it is noteworthy that the reefer weight limit has a considerable impact on the number of fruits packed inside the reefer. For almost all fruit types, the payload limit will inhibit the loading capacity and not the reefer's volumetric size. This can be seen by all the weight values equating to the payload limit.

Table 11: Capacity for optimal packing with reefer payload constraint

	Maximum number of fruits / container	Number of fruits with payload constraint	Difference	Weight (kg)
Apples	304 463	232 913	-24%	29 714
Nectarines	678 027	189 258	-72%	29 714
Peaches	691 497	189 258	-73%	29 714
Plums	2 433 513	1 318 840	-46%	29 714
Apricots	2 024 007	1 072 301	-47%	29 714
Pears	248 381	156 091	-37%	29 714

4.2 Pallet constraint

The pallets will also have an impact on the reefer's loading capacity due to their weight, size, and accompanying inefficiencies. The ISO 1 (Euro) pallet weighs about 22.5 kg, and the ISO 2 (standard) pallet weighs 28 kg (Pieterse 2015). Assuming that there are 24 Euro pallets and 20 standard pallets inserted in a reefer, the theoretical maximum number of fruits will decrease to ensure that the reefer's payload limit is not exceeded. This is true for all fruit types, except the randomly packed apples, as there is a sufficient difference between the payload limit and the current weight of apples: $29\,714\text{ kg} - 28\,850\text{ kg} = 864\text{ kg}$, which is less than both the total weights of either the Euro (540 kg) or the standard (560 kg) pallets. The volume occupied by the pallets will also have an impact on the loading capacity, but only if the reefer is already fully loaded (only for the randomly packed apples). Finally, due to the pallets not being able to fit perfectly within the reefer, there will also be lost space / volume.

The weight factor loss is calculated as the total weight of all the pallets in the container expressed as a percentage of the payload limit of the container. The volume factor loss is calculated as the volume of all the pallets in a container expressed as a percentage of the total volume of a container. The unused area / volume factor is calculated by subtracting the total area requirement for all the pallets in a container from the total area in a container, and expressing it as a percentage of the container area. The two volume-related losses are added to obtain the total volume loss due to the pallets.

To summarise, Table 12 indicates the different percentage losses due to weight and volume restrictions from adding pallets to the container. These findings are considered in the next section, where the theoretical values are compared with those found in practice. Depending on the packing arrangement, and on whether the reefer is at its payload limit or fully loaded in terms of volume, the impact of the pallet can be significant. The volume of the pallet, and the inefficiencies associated with the current pallet stacking patterns, can result in a total loss of 18.85 per cent for the Euro pallet and 15.544 per cent for the standard pallet.

Table 12: Summary of pallet-related losses

	Weight factor loss	Volume factor	Unused area / volume factor	Total volume loss
Euro	1.817%	5.796%	13.054%	18.85%
Standard	1.885%	6.113%	9.431%	15.544%

5 COMPARISON OF THEORETICAL MAXIMUM WEIGHT AND PRACTICAL WEIGHT

This section compares the current capacities found in practice (expressed in terms of weight) with the calculated theoretical maximum capacities, to determine how effective the use of space / volume currently is inside the reefer.

5.1 Theoretical vs current

Table 13 provides a comparison of the maximum theoretical weight values (for random packing) and the current weight values found in practice for pome fruit. From the utilisation values (current weight compared with net theoretical weight), it is clear that the use of some of the current cartons results in relatively low reefer fill. Considerable opportunity for improvement exists for the MK4, MK7, and MK9 (pears) cartons. The MK6 carton (used for pears) and MK9 carton (used for apples) have higher weight utilisation levels than the MK4 and MK7, but the levels are still low.

Table 14 provides a similar comparison for stone fruit. Here one can see that the practical weight value for the D05l carton exceeds the theoretical maximum. This may be attributed to inaccurate data or invalid assumptions. From the utilisation values, one can conclude that the cartons used for stone fruit result in high reefer fill. One would not expect any great opportunity for improvement in increased volume for these two cartons.

Table 13: Theoretical vs current weight values per container for pome fruit

	Apples		Pears		
	MK9	MK4	MK7	MK6	MK9
Theoretical weight (kg)	28 849.80	29 714	29 714	29 714	29 714
% Weight / volume losses	15.54% (volume loss)	1.885% (weight loss)	1.885% (weight loss)	1.885% (weight loss)	1.885% (weight loss)
Net theoretical weight (kg)	24 365	29 153	29 153	29 153	29 153
Current weight (kg)	18 000	17 885	14 300	22 500	18 000
Utilisation	73.88%	61.35%	49.05%	77.18%	61.74%

Table 14: Theoretical vs current weight values per container for stone fruit

	D05I	M05I
Theoretical weight (kg)	29 714	29 714
% Losses	1.885%	1.885%
Net theoretical weight (kg)	29 153.36	29 153.36
Current weight (kg)	30 560	27 560
Utilisation	104.82%	94.53%

6 INVESTIGATION OF POTENTIAL IMPROVEMENTS IN USE OF SPACE

This section focuses on the investigation of potential improvements to increase the amount or mass of fruit that is exported in the 12 m high cube reefer. The use of optimisation software and some miscellaneous improvements are discussed. These miscellaneous improvements include the omission of pallets, the use of slip sheets, and the use of special pallet sizes.

6.1 Optimisation software

This section discusses the use of the optimisation software (*PALLETMANAGER* and *CARGOMANAGER*) developed by Gower Optimal Algorithms Ltd (GOAL) (Gower Optimal Algorithms Ltd n.d.). To investigate potential improvements in pallet loading, pallet sizes, carton sizes, and container loading of cartons, optimisation software developed by GOAL was used. This software allows for the efficient packing / loading of packaged goods to reduce logistics, transportation, and packaging costs. Optimal packaging sizes, pallet sizes, packaging layout on top of pallets, and the layout of pallets within the container were all outputs from this software. The main goal of using *PALLETMANAGER* is to enable a more efficient way of packing cartons on pallets to minimise logistics, transportation, and packaging costs. On the other hand, *CARGOMANAGER* is used to find more efficient ways of packing the reefer container with the pallets.

6.1.1 Input data

The dimensions used as input data for the pome fruit were the MK4, MK6, MK7, and MK9 cartons (open display and telescopic) (refer to Table 1 in section 2.1). These specific cartons were chosen as they accounted for most of the apple and pear exports. For the stone fruit, the dimensions of the D05I and M05I cartons were used as input data (Table 2 in section 2.1). The characteristics of the pallet used in the analysis are that of the standard white block pallet, which is found abundantly in industry. The white block pallet was chosen because certain data (for example, the number of cartons per pallet layer) was specifically available for this pallet. The average load line, the maximum allowable height, and the reefer height dimensions of thirteen different reefers used in the industry were used as input data for the software (see Table 15).

Table 15: Reefer characteristics (values in mm)

Load line	2409
Max. allowable height	2247
Reefer height	2525

6.1.2 Optimising the packing of cartons on a pallet

The *PALLETMANAGER* optimisation software was used to determine the most efficient way to pack the fruit cartons on to a pallet. The software has a mode that allows one to pack the fruit cartons in the most efficient way on to a pallet while adhering to the relevant constraints, such as space and weight limitations. The carton's dimensions and weight must be inserted into the software, as well as the pallet dimensions, the weight capacity, and the maximum stacking height on the pallet. The software also has a '+1 layer' function, which is a built-in function that calculates the extra

height (or, if applicable, weight) required to insert an extra layer of cartons. It also contains a ‘do better’ function, which is also a built-in function that proposes small changes in carton dimensions (either length or width) that would result in a higher area and volume fill / utilisation.

The optimal number of cartons obtained for both apples and pears is presented in the first row of Table 17. The resulting optimal packing arrangement for apples with the MK9 carton is presented in Figure 4. When comparing the optimal number of cartons (or cases) with the number of cases typically packed in practice, it is evident that there is a noteworthy improvement for the MK7 and MK9 cartons (9.09% and 11.11% respectively) when packing the cartons according to the arrangements specified by the optimisation software. The only room for further improvements that can be gained through a packaging reconfiguration lies with the MK4 telescopic carton. Table 16 indicates the changes that can be made to either the length or the width of the carton that would result in an additional four per cent area utilisation, and an additional 3.4 per cent volume utilisation on top of the pallet (from the ‘do better’ function of the software).



Figure 4: Optimal stacking pattern on pallet for apples with MK9 carton

In terms of inserting an extra layer of cartons on a pallet, the required additional heights are provided in Table 17. Taking MK7 carton as an example, if one were to increase the allowable stacking height (currently constrained by the red load line) or reduce either the pallet height or the individual height of each carton by a total of 28 mm (or 1.17 mm per layer), it would be possible to insert an extra five cartons. It would seem more realistic / feasible rather to reduce the individual carton height by reducing the flute thickness, or the pallet height by reducing the slat thickness, to obtain this additional layer, instead of increasing the red load line, as this will affect airflow.

Table 16: MK4 alternate dimensions

New carton dimensions (mm)
600 × 250 × 287
500 × 300 × 287
400 × 333 × 287
500 × 240 × 287
400 × 300 × 287
400 × 250 × 287

When following the software’s recommendations, the area percentage and volume fill percentage seen in Table 17 can be obtained. For MK4 and MK6, there are more than one option; and the one resulting in the best airflow capability and structural stability must be chosen, based on the alignment of carton holes and carton edges. When implementing these changes, the maximum payload constraint is still adhered to, with room for further improvement.

Table 18 summarises the results found for the stone fruit. From the results, it is evident that the current configuration of stone fruit packaging is optimal, as no reconfiguration of the dimensions would result in the use of additional area and volume, based on the software’s analysis. It is possible, however, to insert an additional layer of D05l cartons if the maximum pallet weight limit (1500 kg) is exceeded by five per cent (or 75kg). An additional layer of M05l cartons can be inserted if the height of the load line is increased by 1.375 per cent (33 mm), or if the carton and pallet height is reduced by 33 mm (1.83 mm per layer). These relatively small improvements are to be expected, as it was mentioned previously that stone fruit cartons are already close to optimal (maximum payload limit). When implementing these changes, the total weight of the stone fruit cargo is very close to the maximum payload, indicating that there is no real room for improvement (as predicted earlier).

Table 17: Results from PALLETMANAGER for apples and pears (values in mm or kg)

	Apples		Pears		
	Open display	Telescopic	Open display	Telescopic	Open display
	MK9	MK4	MK7	MK6	MK9
Proposed # of cases	80	49	120	90	80
# cases in practice	72	49	110	90	72
Improvement	11.11%	0%	9.09%	0.00%	11.11%
% Area fill	100.00%	96.00%	100.00%	100.00%	100.00%
% Volume fill	98.00%	86.00%	97.00%	99.00%	98.00%
Weight	1 000	894.25	756	1 125	1 000
	+1 layer				
Additional height required	116	49	28	228	116

Table 18: Result from palletised mode for stone fruit (values in mm or kg)

	D05I	M05I
Proposed # of cases	200	180
Cases in practice	200	180
Improvement	0%	0%
% area fill	100.00%	100.00%
% volume fill	92.00%	96.00%
	+1 layer	
Additional height required	-	33
Additional weight required	75	-
Remaining height	n/a	-
Required reduction per layer	3.75	1.83

6.1.3 Optimising the loading of pallets in a container

As mentioned earlier, the CARGOMANAGER software allows one to fill the reefer with pallets in the most efficient manner. An optimal packing arrangement obtained using the software may be seen in **Error! Reference source not found.** This arrangement is specifically for apples packed in the MK9 carton. As one can see, there is unused volume at the front of the reefer, which is undesirable. A total of 20 pallets are inserted inside the container using this arrangement, which corresponds with what is currently found in practice for the standard pallet. This software may be used by various stakeholders in the fruit export supply chain when deciding on new pallet sizes, as it will provide visual feedback and quantitative data on the proposed implementation of a new pallet size.

6.2 Miscellaneous improvements

This section focuses on miscellaneous improvements to increase the space / volume use of fruit that is exported in the reefer container. These improvements include the omission of pallets, the use of slip sheets, and the use of special pallets.

6.2.1 Pallet omission

The pallet's impact on the number of fruits inserted in the reefer is quite substantial. If one were to remove the pallets entirely and only load the individual fruit cartons inside the reefer, the percentage gains seen in Table 12 could be achieved. Depending on the situation (i.e., the payload limit is reached or the reefer is fully loaded), a total increase of either 18.85 per cent or 15.544 per cent in volume fill could be achieved for the Euro and standard pallets respectively. To illustrate the potential improvements graphically, Figure 6 provides a comparison of omitting pallets and using pallets.

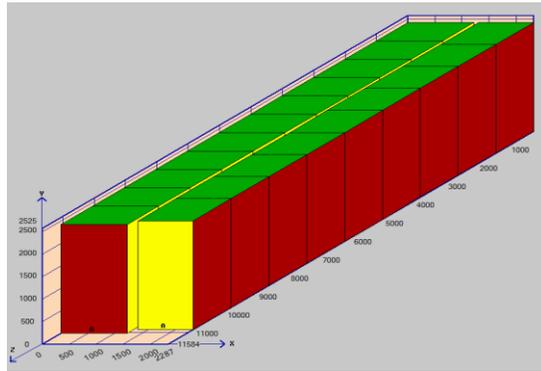


Figure 5: Packing arrangement of pallets in reefer

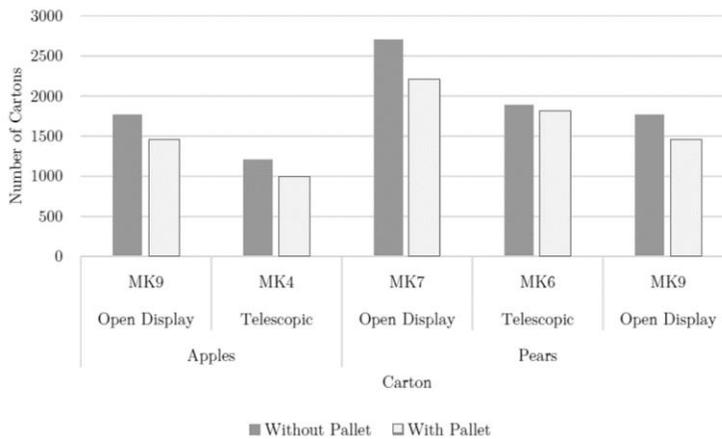


Figure 6: Bar chart illustrating improvements when pallets are omitted

Omitting the pallets will result in a significant increase in material handling time for various stakeholders in the fruit export supply chain. These increases are, arguably, too great for this improvement to be implemented. Palletisation is done for a good reason. Thus, further investigation of alternatives to pallets is warranted.

6.2.2 Slip sheets

Omitting pallets may make noteworthy improvements to the increased volume fill, but the impact on the material handling times will be too great to make this improvement feasible. Slip sheets may thus be considered as a potential solution to improve volume fill while still adhering to material handling constraints. Slip sheets often replace the use of traditional pallets. Due to the significantly smaller form factor and weight, slip sheets allow for considerably more products to be loaded into a container (Sebastian 1999). Slip sheets are about 85 per cent smaller and 20 times lighter than a traditional wooden pallet (Sebastian 1999). Thus a large fraction of the gains illustrated in Section 6.2.1 may be achieved.

Due to the specific airflow requirements of the fruit during export, it would be necessary to perforate the slip sheets to facilitate the flow of cool air through the supported load. It is vital that these perforated holes be aligned with the holes on the fruit cartons to maximise the cooling process's effectiveness. Another aspect to consider when perforating these slip sheets is to ensure that the strength of the sheet is not compromised by the perforated holes. Additional mechanical strength tests will be required to determine the extent of the structural weakness after perforation.

Another benefit of using slip sheets is the level of customisation they offer for their size (mentioned earlier). This feature allows one to have *special* sizes for situations where the regular or standard size (1.2m x 1.0m) sheet is not sufficient. One can see an example of the usefulness of this feature in the situation presented in Figure 5, where there is unused area at the front end of the reefer that could be filled by a pallet or sheet that is smaller in size. This would allow a further increase in the

use of the space / volume within the reefer, as more fruit can be loaded. The analysis and discussion of special sized pallets in the next section (6.2.3) also holds true for slip sheets.

The use of slip sheets will have an impact on the material handling process, as specific forklift truck attachments are required. This would require additional financial investments by various stakeholders in the fruit export cold chain to facilitate the use of the slip sheets. This negative financial impact would be mitigated by the recyclability and cheaper nature of these slip sheets, and by the increased cargo that could be exported in the reefers.

6.2.3 Special pallet sizes

If pallets were redesigned to accommodate the loading arrangements seen in Figure 7, considerable improvements would be possible. Take the MK9 carton as an example. If a new special pallet were to be designed, with a length of 2 200 mm and a width of 1 200 mm, the resulting number of cartons inserted in the reefer would be 1 666. These dimensions were obtained from the PALLETMANAGER software, and the arrangement in Figure 7 illustrates how the pallets would be packed (except for the very first stack of 4 cartons by 17 layers). When compared with the actual value found in practice (1440 cartons), a noteworthy improvement of 15.69 per cent is achievable. This special pallet would have 11 MK9 cartons per layer, and a total of 17 layers. This results in a total of 187 cartons with a mass of 2 337.5 kg. A standard pallet (1 200 mm by 1 000 mm) can carry a load of 1 500 kg, but only if the load is evenly distributed. It is unknown whether this new special pallet with the above-mentioned dimensions could carry this much-increased weight (55.83% more). Future studies and tests are required to determine this; and if it were not possible, it is recommended that the pallet be constructed with stronger materials to support this load, as the 15.69 per cent increase is quite significant. A forklift can transport a maximum load of 4 500 kg. Thus there would not necessarily be a problem of the material handling equipment being unable to support the load. Alternative forklift attachments may be considered for the wider (or longer) pallet.

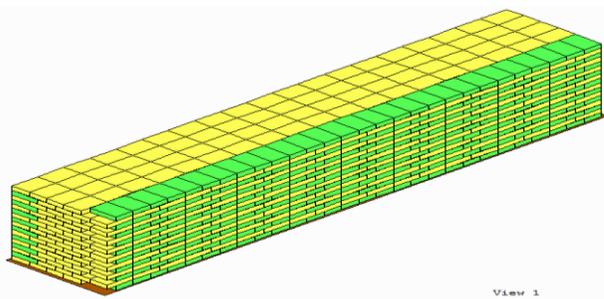


Figure 7: Alternative stacking pattern for MK9 carton inside reefer

An important aspect to consider when introducing a new pallet to the fruit industry is that it will likely have a noteworthy impact on the day-to-day operations at various points in the cold chain, such as in fruit pack houses and product destinations (e.g., wholesalers and retailers). One potential reason may be the current setup at warehouses (e.g., the layout of their premises), and not allowing forklifts carrying 2 200 mm wide loads to pass through certain parts at pack houses and wholesalers and retailers. Another impact of using a new pallet is the cost associated with manufacturing a non-standard pallet size. The manufacturing cost would be expected to increase if adjustments were made to the methods used to manufacture and store standard pallet sizes. The analysis of this impact would also form part of any future study.

When using the software to analyse the MK4 carton, it was found that there are no special pallet redesigns that would still be reasonable in size (relatively similar to the current pallets) and improve the number of cartons to be loaded in the reefer. The MK7 carton has potential when using a special pallet. The special pallet will have the same dimensions as the MK9 (2 200 mm by 1 200 mm). This new pallet would allow a total of 2 574 cartons to be inserted in the reefer – a 17 per cent improvement over the current 2 200 cartons. The stacking arrangement would look similar to the one seen in Figure 8, but without the very first stack of 5 x 26 cartons. Using the 2200 mm x 1 200 mm *special* pallet for the MK6 carton would result in 1 792 cartons – eight cartons fewer than found in practice.

For stone fruit, the D05L carton could benefit from the *special* pallet mentioned above, but with one caveat. The number of cartons would improve from 4 000 to 4 554 (a 13.85 % increase), but the total weight of the cargo would increase by 4 135 kg. This is not feasible, as the current arrangement, using the standard pallet, is already at the payload limit. Using this *special* pallet for the M05L carton would result in 40 fewer cartons. It is thus not worth it.

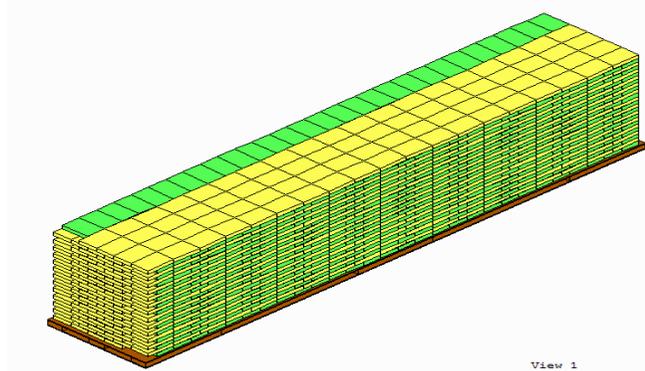


Figure 8: Stacking pattern for MK7 carton inside reefer

7 CONCLUSION

In conclusion, it is evident that there is opportunity for improving the use of space / volume in the 12 m high cube reefer. Pome fruit has the greatest opportunity for improvement, whereas stone fruit has less room to improve the use of space / volume. Proposed improvement methods are as follows: optimal packing arrangements of fruit; improved packaging and pallet dimensions (special pallet sizes); improved stacking arrangements of cartons on pallets and pallets in reefers; and, lastly, the use of slip sheets instead of pallets. Using the recommended stacking patterns provided by the optimisation software, 9.09 per cent more MK7 cartons and 11.11 per cent more MK9 cartons could be loaded inside the reefer. And small changes to the dimensions of the popular MK4 carton could result in a four per cent and 3.4 per cent improvement in the use of space and volume respectively. Omitting pallets could result in a 15 to 19 per cent improvement in the use of volume. However, omitting pallets would be accompanied by substantially increased material handling times, which could be mitigated by using slip sheets, while still maintaining the gains. Special pallet (or slip sheet) sizes for the MK7 carton and the MK9 carton result in a 17 per cent and 15.69 per cent volume utilisation improvement respectively. For special sizes for stone fruit cartons, 13.85 per cent more D05L cartons can be loaded. If stakeholders in the South African fruit export industry were to investigate the proposed methods further and implement some (if not all) of them, it would likely lessen the financial strain of the increased reefer rates imposed by shipping companies. This study, however, did not include a financial analysis of the potential improvements suggested in this study. It is recommended that a cost-benefit analysis be conducted to determine what the benefits would be of improving the use of space / volume using the proposed methods discussed in this paper, and what the associated costs would be. Such a study could also investigate the opinions and views of different stakeholders involved in the full supply chain.

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