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Package Optimisation Model

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Bernd Mueller

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Abstract

A bulk export orientated company has to optimise their packaging to be able to compete in a globalised world. Therefore it is important to maximise the container load to save shipping costs. This can be done in different ways,

- by changing the product weight,
- the packaging material or size,
- the pallet/container size or, for some products,
- the bulk density.

With so many parameters affecting the container load finding the best packaging solution is difficult.

To solve the problem an Add-on to for the existing packaging optimisation software Cape Pack called SADIE was developed. SADIE automates the process of data input into Cape Pack and allows browsing of different packaging combinations in a short time.

Main feature of SADIE is that it allows testing complete weight and/or bulk density ranges in one Query. For that it takes the weight and the bulk density combination that is going to be tested and calculates the start dimension for a regular slotted case (RSC) with a 2:1:2 ratio, which, for a RSC, is the ratio that uses a minimum quantity of board. Those dimensions are then, with many other parameters, transferred into the Cape Pack Design mode where the new packaging solution is calculated and transferred back to SADIE. The data coming from SADIE was tested for consistency and was also used for physical pack size validations, both successfully.

Packaging solutions for products with higher bulk densities could be optimised. A new packaging solution calculated for salted butter could save 231 container per annum. Depending on the destination of the butter cost savings from 184,000 US\$ to 577,500 US\$ would be possible.

The results show that there are improvements in container load possible, especially for products in a higher bulk density range, like butter and cheese. An increase in container load for Whole milk powder (WMP) might be possible if

another packaging system is used whereas for Skim milk powder (SMP), with its higher densities compared to WMP, the program can calculate improved container load without a change to the packaging system used.

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First and foremost I wish to thank my mother. If she would not have pushed me 13 years ago to get a degree that allows me to study I would not write these lines at the moment. Thank you very much, without you I would have missed all the experiences and friends I got over the last years. Your advice shaped my future.

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“Always forward, never backwards.”

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1. Introduction

New Zealand is an export-orientated nation. The dairy company Fonterra represents 96% of all dairy farmers in the country and as the world fifth-largest dairy company and the world's biggest dairy exporter, earned 25% of New Zealand's export earnings and recorded total revenue of \$NZ19 billion in 2008 (Fonterra 2006; Wallace 2008). Fonterra produces a wide range of products, from well known dairy products like butter and cheese to specialised milk and whey protein products and clinical products like paediatric hydrolysates (Fonterra 2009).

A company that depends on exporting their products, especially the long distances Fonterra does, should always try to reduce their distribution costs. One way to do this is to optimise the packaging size to achieve a maximum utilisation on a pallet and in a container. Modern packaging optimisation software is able to provide solutions for this problem but they can do this only based on an initial value. For example, they are able to provide an improved solution for a specific weight (e.g. 25 kg) or, for powder products, a specific weight/bulk density combination (e.g. 25 kg, 550 kg/m³), but they cannot tell if that is the best weight or weight/bulk density combination possible for the product. A weight of e.g. 23.8 kg or a bulk density change of 750 kg/m³ might improve the loading capacity of a container significantly.

1.1 Aim

Aim of this thesis is to develop and evaluate software that determines the best product weight/bulk density and packaging size to optimise the pallet/container capacity.

1.2 Objectives

1. The software should be an add-on to the packaging optimisation software Cape Pack (CapeSystem 2009) that runs without human interfering and gives as many options as Cape Pack itself provides.
2. The results should be easily accessible and analysable to give an overview over the whole Query.

3. The overview should allow making a decision in which direction best to go.
4. These directions are mainly the change of product weight or, where possible, the change of the products bulk density to improve the pallet/container load.
5. Most important, they have to be usable in real life situations.
6. A cost benefit analyses for SMP, WMP, and butter should show if the gained solutions are an improvement compared to the solution in use at the moment.

1.3 Benefits

The results from this developed software program could reduce packaging and transportation cost and would also lead to a drop in pallets/containers necessary to export the products. Furthermore, it would reduce the global carbon footprint of the company which could be exploited for various marketing reasons.

2. Literature review

New Zealand, and in this case Fonterra, is the worldwide leading dairy exporter for butter and whole milk powder (WMP) and the runner up for cheese and skim milk powder (SMP) (Cluff 2008), but to be capable of further competing with other companies it is necessary to provide always the best packaging solution for their products. Although all of these products are important for the company, this literature review will only concentrate on the current packaging of WMP and SMP, the multiwall paper bag.

2.1 The multiwall paper bag

The majority of the dairy powder is packed in multiwall bags with up to five layers. There are two types of bag construction: one in which the Polyethylene (PE) liner is glued onto the innermost paper ply; the other is the cap sac bag in which the inner liner is separate from the paper bag. This bag style is also called bag-in-bag. The inner LDPE layer varies in thickness from 0.076 mm to 0.304 mm. For high milk fat powder products, like WMP, the inner polymer liner also includes an oxygen barrier of ethylene vinyl alcohol (EVOH). Common bag sizes are 15, 20 and 25 kg, whereas the 25 kg bag has now become the global standard for packaging dairy powder (Bylund 1995; Rehman, Farkye et al. 2003; Hartwell 2008). Even though the 25 kg multiwall paper bag is the global standard packaging for milk powder, there are other powder packaging in use, for example, bulk bags, bulk wooden bins, corrugated bins, and plastic bags. Figure 2.1 shows a multiwall paper bag.

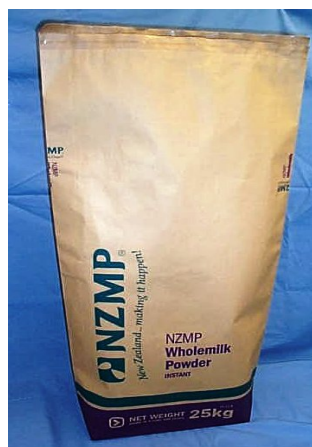


Figure 2.1 Multiwall paper bag

2.1.1 Packaging and powder flaw

1996, two years before the New Zealand Dairy Board introduced the current 25 kg multiwall paper bag with their new dimensions (900 x 530 x 140 mm compared to formally 900 x 505 x 140 mm), Fitzpatrick (1996) wrote about packaging related problems with sacks of dairy powder. He focused on two problems, the “drunken sack” problem and the packaging of low bulk density powder, both explained in detail in the following sections. In addition, other problems, mostly related to economic shipping of dairy powder will be discussed.

2.1.1.1 “Drunken sack” problem

Fitzpatrick (1996) found out that filled powder bags contain a specific amount of air, depending on the production, storage and filling method. Powder bags which have too much air entrapped after closing tend to be unstable when stacked because of the ability of air to move around within the sack when subjected to an external force. Tests showed that everything above four litres of removable air inside the powder packaging deemed to be problematic. As described in the research of Nielsen and Hansen (1982) milk powder contains between 10 and 30 ml of entrapped air per 100 g of powder. This means that for a 25 kg sack four litre of entrapped air could be easily reached, strongly depending on the production process of the powder. Nozzle atomisation typically results in 10 to 15 ml of entrapped air per 100 g, while centrifugal atomisation (disk) under the same conditions will give 20 to 25 ml. By using different disk styles it is possible to reduce the amount of entrapped air. Furthermore, a significant decrease in the content of entrapped air in powders is obtained when using steam swept atomisation. This is based on the principle of adding steam to the acceleration chamber in the atomiser disk which reduces the air whipped in the concentrate during the atomisation process. It is shown in table 1 that using steam for the atomisation process results in a decrease of 65% of entrapped air during the production of SMP and of 75% during the production of WMP (Nielsen and Hansen 1982). Section 2.1.1.2 goes a little deeper into procedures during the atomisation.

Table 1 Entrapped air in milk powder with and without steam atomisation

(Nielsen and Hansen 1982)

| Product | Type of atomisation | Entrapped air (ml/100g) | | Decrease (%) |
|------------------|---------------------|-------------------------|------------|--------------|
| | | without steam | with steam | |
| Skim milk | standard wheel | 23 | 8 | 65 |
| Skim milk | cup wheel | 15 | 7 | 53 |
| Whole milk | standard wheel | 16 | 4 | 75 |
| Whole milk | cup wheel | 10 | 3 | 70 |
| Whey | standard wheel | 21 | 10 | 52 |
| Sodium caseinate | standard wheel | 150 | 85 | 43 |

A potential source of air entrapment is, apart from to the air embedded inside and between the powder particles, the formation of a headspace during bag forming and heat sealing through a sealing element that is well above the powder level during the closing process. This can easily be minimized through machine settings that close the sack at powder level. Another potential source of air entrapment is the use of incorrect sized packaging (Fitzpatrick and O'Callaghan 1996).

The problem is not widespread, but if it occurs it causes a major problem in handling and storage of the product. The ability of the air to move around within the sack when subjected to an external force tends to an unstable pallet.

2.1.1.1.1 Modified atmosphere packaging

While low fat products, like SMP, allow the use of micro perforated bags to prevent air entrapments in the packaging, high fat products, like WMP, are a different matter. To avoid oxidative changes of fat and other components WMP is packed in an atmosphere of inert gas, mostly a combination of N₂ and CO₂. The combination of both gases is related to the properties of CO₂, as it

dissolves in both water and fats. Whereas water is not a problem as most of the powders packaged have moisture contents below 4%, when packaging WMP the high fat content is. If too much CO₂ is absorbed the reduction in gas pressure inside the packaging could cause a collapse of the pack. That is why N₂ is added as a filler to prevent pack collapse. The use of inert gas and therefore the reduction of oxygen has also positive effects on the product. Some examples are:

- Microbial growth, so far not a very big issue for dairy powder, can be suppressed
- Lipid oxidations where the breakdown of unsaturated fatty acids results in the production of malodorous compounds like aldehydes, ketones, and short-chain fatty acids are prevented
- The shelf life of the product can be extended

Additionally, the relative volume of gas and product is important to ensure the effectiveness of modified atmosphere packaging (Hui 1993; Fellows 2000; Zeuthen and Bogh-Sorensen 2003).

2.1.1.1.2 Packaging in high altitude

Entrapped air is a problem as soon as the product is designated to be transported in a high altitude environment like high mountain passes and non- or partial pressurised cargo holds in an aircraft. The entrapped air inside the package expands and could lead to the packaging bursting. If there, as written in section 2.1.1.1, is more air than necessary entrapped in the package the possibility of a package failure is even higher.

Singh (2003) discovered that in terms of a packaging breakdown altitude is more important than the time the product spend there and that higher altitude is worse than lower altitude. Furthermore, high altitude must not mandatory lead to a package breakdown but the combination of high altitude and vibration increase the possibility of a breakdown significantly. Approximately 50% of all packages he tested experienced leaks failure during tests that combined low pressure of 59.5 kPa (4267 m) and truck/air vibrations.

2.1.1.2 Bulk density

The most economical way to sell powder products is to sell powder with a high bulk density. A high bulk density has less volume and therefore lesser demand of packaging material and storage space (Bylund 1995; Fitzpatrick and O'Callaghan 1996).

The equation to calculate the bulk density of a powder is

$$\rho = \frac{m}{V}$$

where

ρ [kg/m³] is the density,

m [kg] is the powder mass and

V [m³] is the volume occupied by the powder.

The bulk density of a powder changes tremendously depending on the way particles are packed, so there is no unique value for a given powder. Bulk density distinguished between aerated bulk density (random loose packaging) and tapped bulk density (random dense packaging).

The aerated bulk density is determined by allowing the dispersed powder to settle in a container under the influence of gravity. A powder with a low bulk density will resist collapse when dispersed in a container because of its structural strength, whereas a structurally weak powder will collapse more easily and therefore have a higher bulk density. Furthermore, friction between the particles results in a low apparent bulk density while a decrease in friction results in a bulk density increase (Abdullah and Geldart 1999).

The tapped bulk density is obtained by tapping the container holding the powder sample. As the sample is tapped the structure of the powder will collapse significantly while the weak or free-flowing powder has little scope for further consolidation. The tapping forces the powder particles to jump and to lose contact with the other particles. Tapping increases the bulk density which, on one hand, results in improved packaging conditions and on the other hand, could destroy the agglomerated structure on agglomerated powder. The ratio

between aerated and tapped bulk density is called Hausner ratio, which is a useful measure of cohesion, which is the molecular force between particles that acts to unite them (Abdullah and Geldart 1999). The standard method to measure aerated and tapped bulk density is described in “ISO 8967- Dried milk and dried milk products: determine of bulk density” and is shown in Appendix 1.

In general, the bulk density is basically influenced by the absolute density (the measured volume excluding the pores as well as the void spaces between particles within the bulk sample), but also the particle geometry and size. The particle shape plays a main role in making denser packaging because the maximum packaging density always occurs when there is a smaller mass fraction of fine particles in a mixture compared to larger particles as shown in figure 2.2 (Abdullah and Geldart 1999).

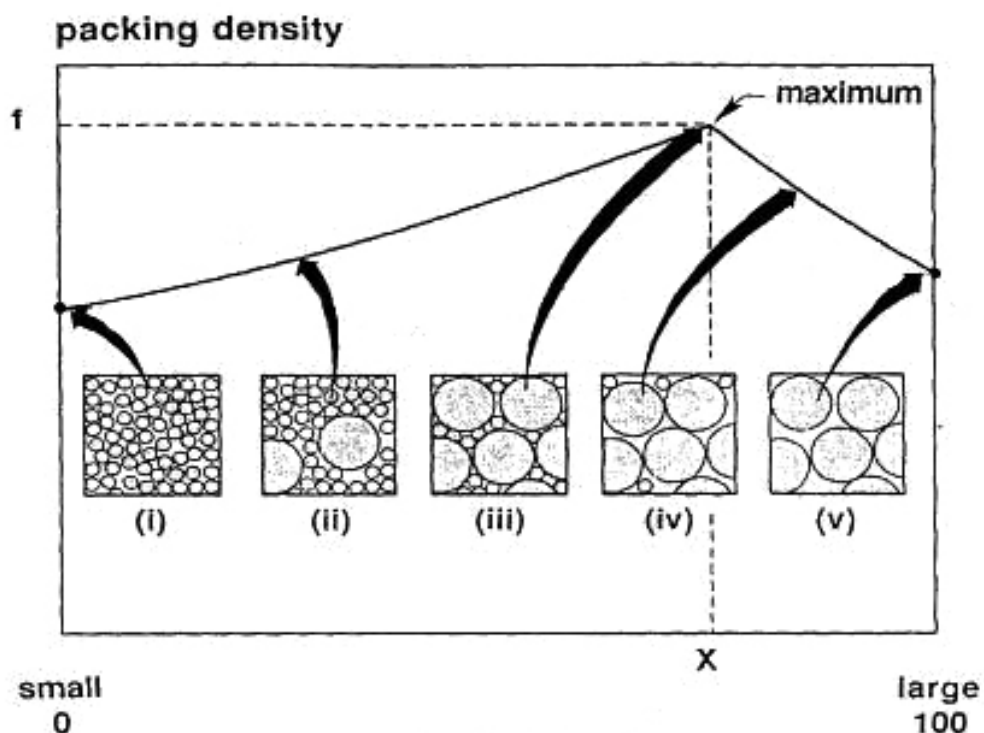


Figure 2.2 Impact of particle sizes on packaging density - modified -

(Abdullah and Geldart 1999)

Another major factor that influences the bulk density is the number of pores in the powder. They are built during the atomizing of the liquid feedstock through air that is trapped inside the droplets. The number of vacuoles varied depending on the atomisation process. When an atomisation disk is used the numbers go

from 10 to 100 air bubbles per droplet, whereas the use of a nozzle produces zero to one air bubble per droplet. More air incorporated in the particle leads to a lower density of the powder and a higher inlet air temperature shows also lower densities as shown in figure 2.3.

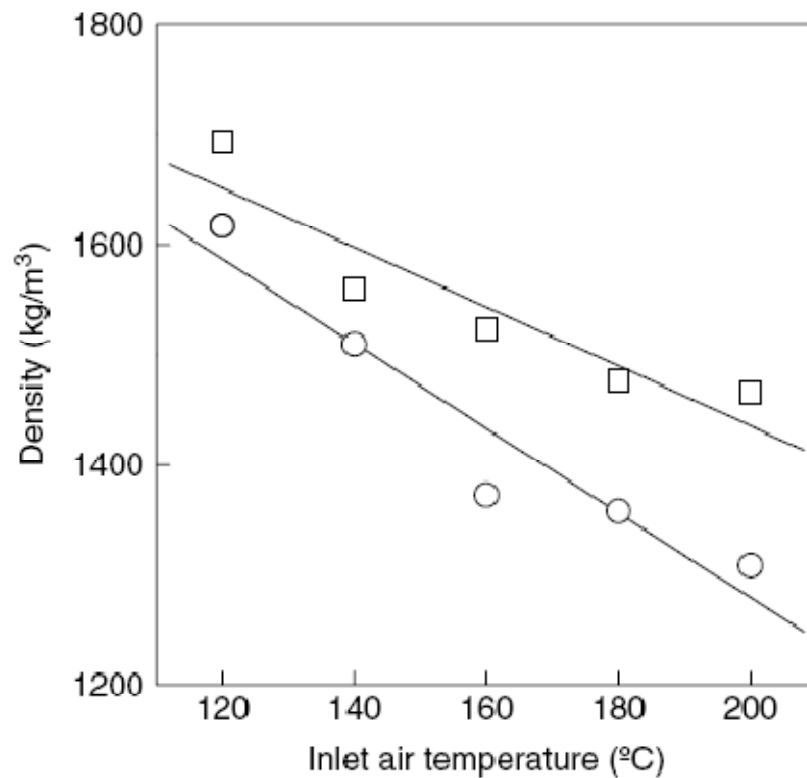


Figure 2.3 Absolute powder density as the function of air inlet temperature and atomization speed: □, 10000 rpm; ○30000 rpm

(Soottitantawat, Peigney et al. 2007)

Water vapour enters the air bubbles, causing them to expand, which happens because the water vapour is able to more easily diffuse to the vacuoles than across the external layer of the drying droplets, which becomes rigid faster than the inside of the droplet (Finney, Buffo et al. 2002; Walstra, Wouters et al. 2006; Soottitantawat, Peigney et al. 2007).

The content of entrapped air in powder is influenced by following process parameters:

- Total solids in milk feed
- Nozzle atomisation versus centrifugal atomisation
- Nozzle pressure

- Disk form (Table 1)
- Steam swept disk atomisation (Table 1)
- Velocity of centrifugal wheel
- Inlet and outlet air temperature (Nielsen and Hansen 1982).

The figures 2.4 to 2.8 show how the different processes above influence the amount of air entrapped inside the powder particle. They all come out of the research from Nielsen & Hansen (1982).

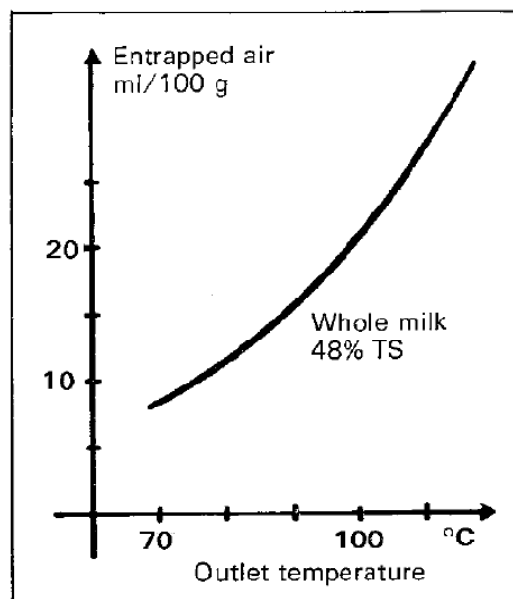


Figure 2.4 Correlation between outlet air temperature and entrapped air in milk powder

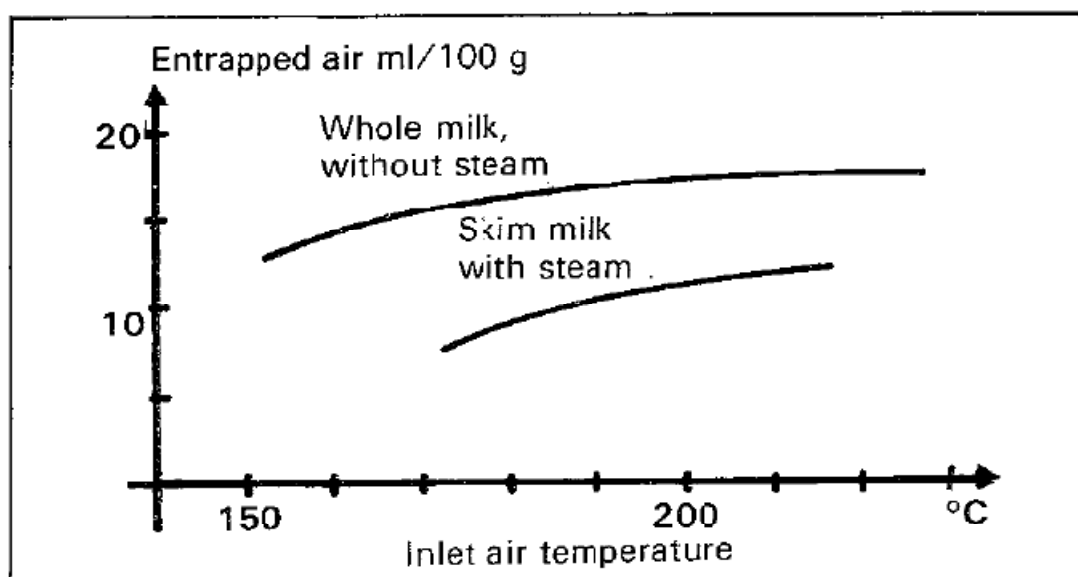


Figure 2.5 Entrapped air as a function of inlet air temperature

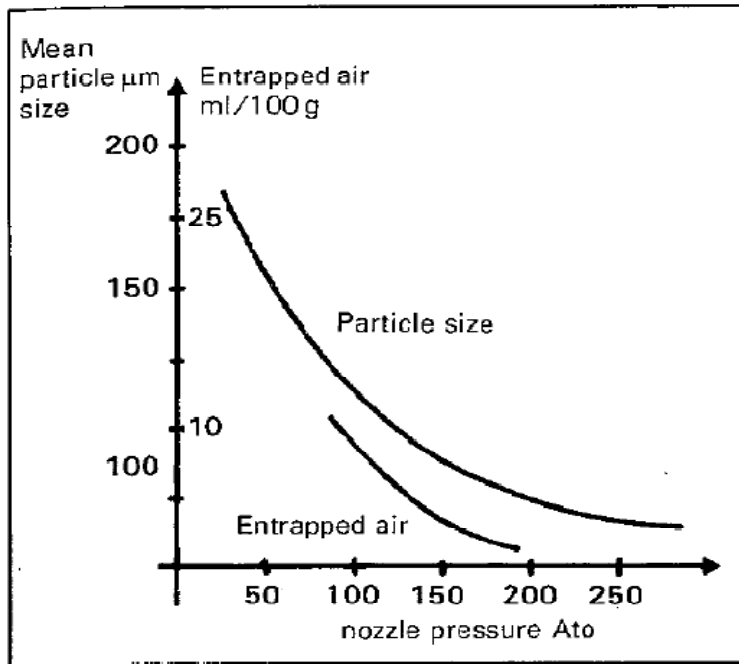


Figure 2.6 Correlation between entrapped air pressure to nozzles, using nozzle atomisation

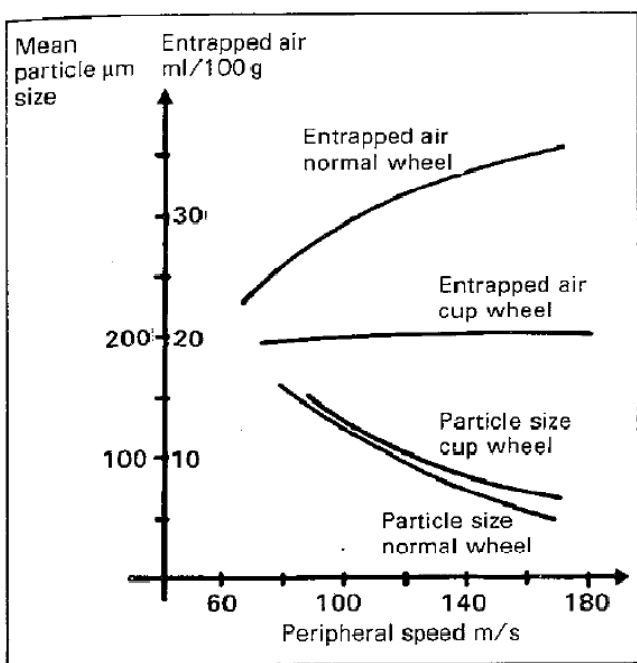


Figure 2.7 Correlation between peripheral speed and entrapped air and particle size

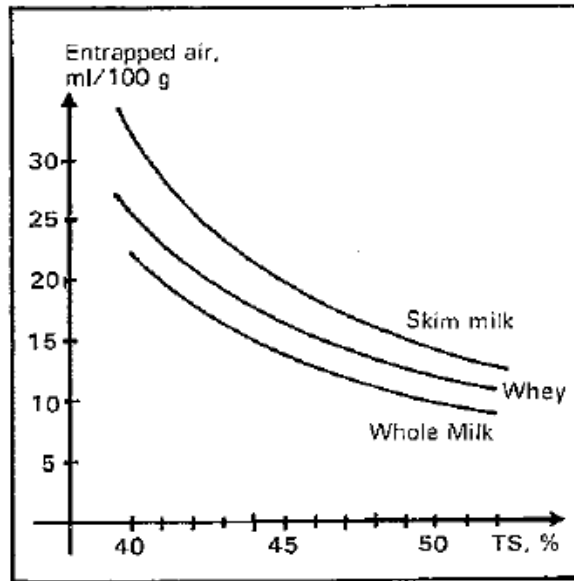


Figure 2.8 Correlation between total solids in feed and entrapped air

Small adjustments during the production process can change the bulk density of a product significantly.

Other factors, other than production process, also play a role in modifying the bulk density. The same product produced with the same equipment in different locations can have different bulk densities. Through experience gained in all the different locations Fonterra is producing milk powder Hartwell and Meijer (2009) found out that the bulk density also depends on the location of the plant, day time, humidity, and season (Hartwell and Meijer 2009). Additionally, further changes occur after the production process, as explained in the next section. Table 2 shows the BD mean and range of different milk powders produced in different Fonterra plants.

Table 2 Variations of bulk density of the same product in different Fonterra plants

| Bulk Density [kg/m³] | | | | | | | | | | |
|--|-----------------|--------------|----------------|--------------|----------------|--------------|-----------------|--------------|----------------|--------------|
| | SMP INST | | SMP REG | | WMP AGG | | WMP INST | | WMP REG | |
| | mean | range | mean | range | mean | range | mean | range | mean | range |
| Plant 1 | 480 | 430 - 550 | 740 | 670 - 780 | | | 480 | 450 - 540 | 600 | 570 - 620 |
| Plant 2 | 520 | 500 - 560 | 740 | 710 - 790 | | | 480 | 440 - 530 | | |
| Plant 3 | 490 | 400 - 530 | | | 490 | 490 - 510 | 490 | 450 - 600 | 570 | 500 - 660 |
| Plant 4 | | | 710 | 680 - 720 | | | 490 | 450 - 520 | 580 | 540 - 680 |
| Plant 5 | | | 720 | 690 - 740 | 530 | 500 - 560 | 500 | 470 - 520 | 590 | 520 - 640 |
| Plant 6 | | | | | 520 | 460 - 590 | 480 | 430 - 550 | 540 | 470 - 590 |
| Plant 7 | | | | | | | | | 600 | 550 - 650 |
| Plant 8 | | | | | | | | | 590 | 540 - 630 |
| range overall | 400 - 560 | | 670 - 790 | | 460 - 590 | | 430 - 600 | | 470 - 680 | |

2.1.1.3 Changes of physical properties

The bulk density of a processed powder is influenced by its chemical composition, particle size and to an even greater extent by moisture as well as its processing and handling history. It is known that powders are compressible and therefore an increase in bulk density can be caused by mechanical compaction, static pressure and the exposure to vibration as it happens during the packing process and the distribution of the product (Malave, Barbosa-Canovas et al. 1985; Barbosa-Canovas, Malave-Lopez et al. 1987; Schubert 1987). The modified figure 2.9 shows the bulk density change of granular material of different sizes after a specified number of taps. ρ is the volume packing fraction and T is the ratio of peak acceleration applied during a tap to gravitational acceleration g.

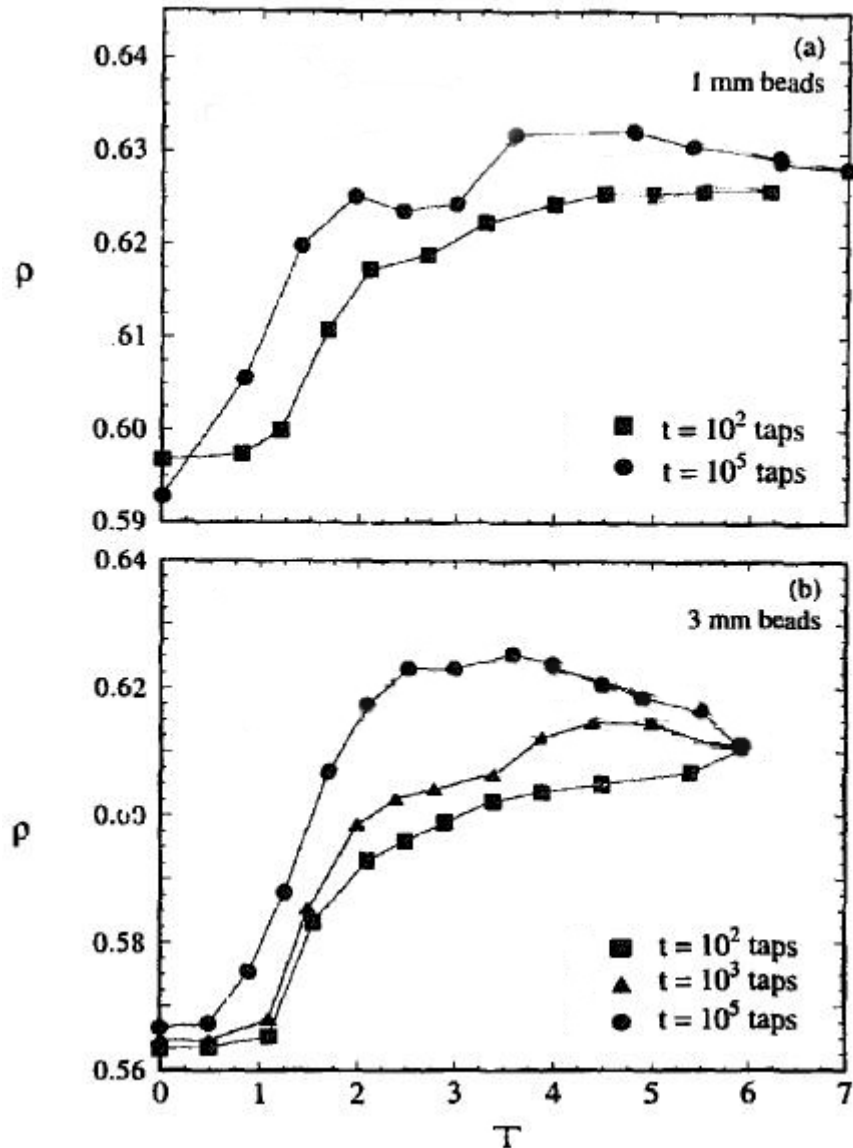


Figure 2.9 Change of volume fraction for different sized granular material after specific amount of taps -modified-

(Nowak, Knight et al. 1997)

Finer (1993) found out that the bulk density of both, unagglomerated and agglomerated powders, underwent changes on its way through the factory to the packaging process, whereas powder with a lower density, in this case agglomerated powder, experienced greater changes. These changes went in both directions. For example, an increase in bulk density of 20-30 kg/m³ was confirmed during the storage of the powder in a hopper and a decrease in bulk density of up to 20 kg/m³ was obtained as the powder was conveyed through an auger. Compression, due to powder weight, is believed to be primarily

responsible for the powder breakdown happening in the storage hopper. It should be noted that the pressure on the base of the powder in the hopper is not proportional to the height of the solids provided the powder height is greater than the diameter of the storage hopper (Davies 1992). The decrease in bulk density as it went through the auger suggests a reagglomeration of the fine powder particles (Finer 1993). Figure 2.10 shows how the bulk density of a powder with the same specification but produced in two different plants is changing on the way through the plant, whereas figure 2.11 shows the correlation between bulk density and particle size distribution. It is clear to see that the bulk density increases with the amount of fines smaller than 125 μm .

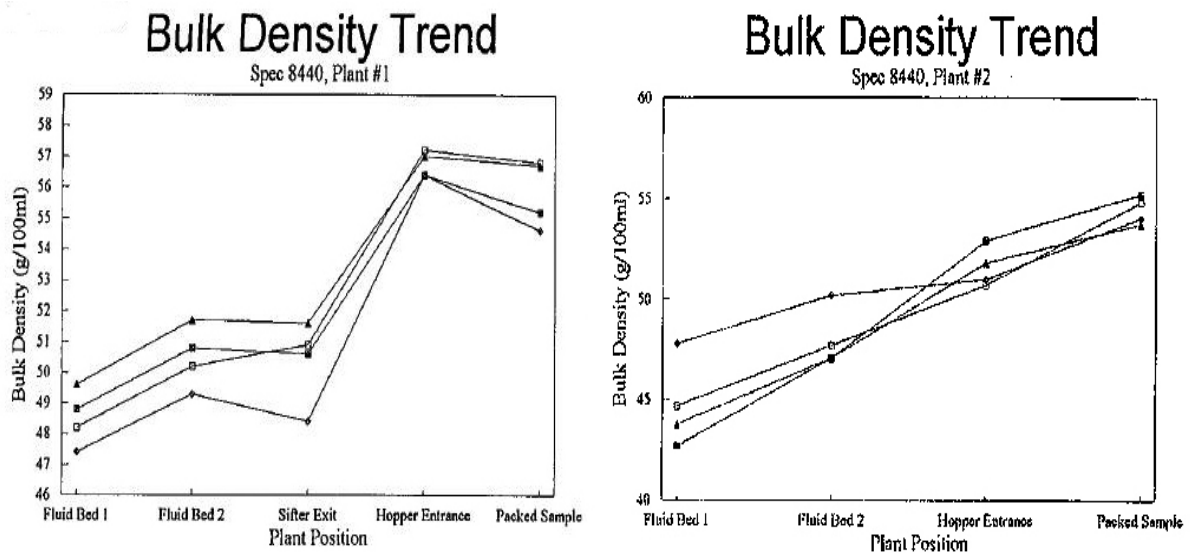


Figure 2.10 Bulk density change of powder with the same specification through two different plants

(Finer 1993)

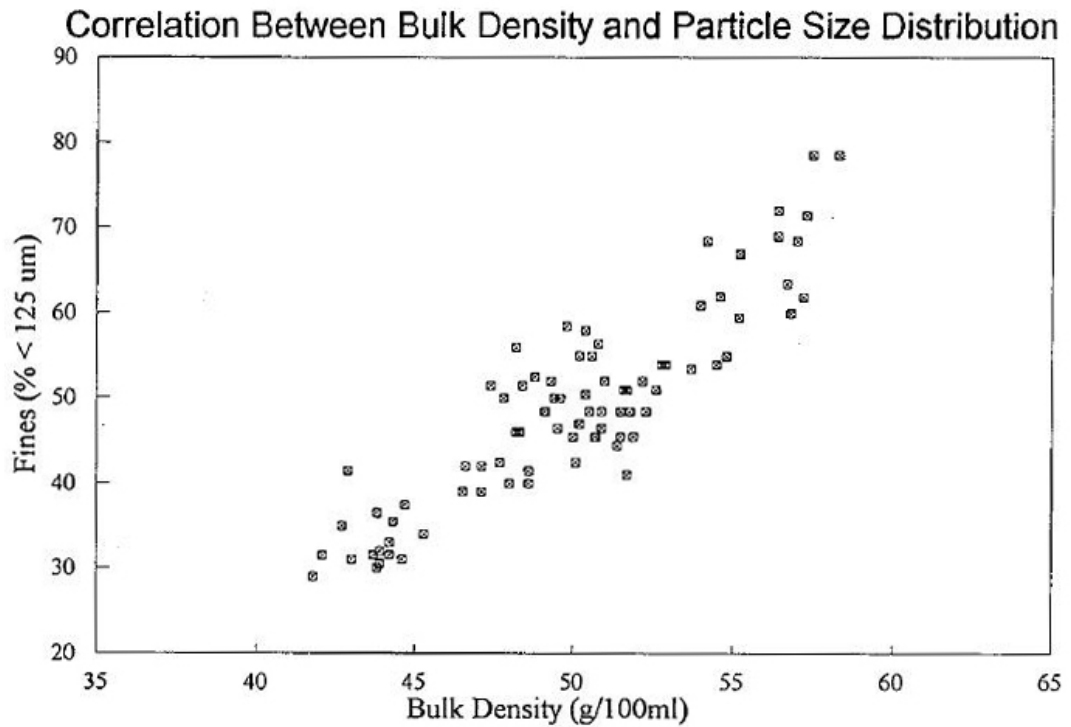


Figure 2.11 Correlation between bulk density and particle size distribution

(Finer 1993)

2.1.1.4 Bulk density change after the packaging process

The bulk density of packed powder is subjected to change, which depends strongly on the powder type. Powder with a low bulk density is stronger affected than powder with a higher bulk density because the mean particle size is bigger compared to powder with a higher density and therefore subjected to breakdowns which increases the bulk density.

It was observed that the bulk density increases after every step (Figure 2.10), starting with filling the package, sealing, conveying, palletising, stacking, loading on truck, loading in container, and finally shipping (Finer 1993). This is related to the pressure (stacking, palletising) and vibration (conveying, loading, shipping) the package experiences. This can have a negative impact, depending on the degree of the bulk density change, on the package and the stability of the pallet/container (Hartwell 2009).

2.1.1.5 Area/cube efficiency

The multiwall paper bag is construction-related not the best choice for a package. It is not possible to fill the bag completely which is expressing itself, in some cases, in good area efficiency on a pallet, but not in good cube efficiency. Most filled bags are more “wedge” shaped than the favoured rectangular shape which lead to holes inside the stacked pallet. This has negative impacts on the stability of the pallet and also important, on the economics of the package. The holes are wasted space that could be used to load more product on the pallet. The occurring negative effect through insufficient filling of the bags for the area/cube efficiency is shown in figure 2.12.



Figure 2.12 Wedge shaped bags

(Dagleish 2004)

The Amcor (Dagleish 2004) company identified the problem and developed the “Maxipack” sack which improved the stability of the pallet and reduced the warehouse and shipping costs. The new sack allowed a container load of 20 t instead of the formally 18 t.

2.2 Packaging optimisation software

Companies were always striving to optimise their packaging, mainly to reduce cost but also to improve the handling of the package. To reduce costs for corrugated fibreboard boxes, they developed charts that allowed them to assess the amount of packaging necessary to pack the product. These charts were not very exact and sometimes difficult to use, but they allowed the companies to see the relative board areas as a percentage above minimum board area required. For example, the regular slotted container (RSC) with the ratio 2:1:2 (length, width, depth) uses a minimum quantity of board. A change to another ratio results in an increased consumption of board, stated in percent. For the RSC a ratio of 2.6:1:2 would result in an increase of 1%. For each other style of box there is a particular shape which uses a minimum quantity of board (Wright, McKinlay et al. 1992).

There are four options a company has to change the shape and the size of their packaging.

- Alter the amount/number of the contents.
- Alter the arrangements and orientation of items grouped as the contents.
- Alter the shape of the individual items themselves.
- Alter all three of the above simultaneously.

The possibilities, depending on product and packaging could be endless and the calculations to find the optimum package are extensive. For example, in considering the design of a carton to contain 12 cigarette packets there are 12 arrangements (12 x 1 x 1, 6 x 2 x 1, 3 x 4 x 1 etc.) and six orientations (p, q, r, s, t, u) specifying how the inner pack can be placed within the shipper, thus giving a total of 60 possible shipper shapes. With increasing numbers of packets these possibilities increase too (Wright, McKinlay et al. 1992).

The charts mentioned earlier were a great help to optimise their package, but there was still the uncertainty that there is a better packaging solution. With the rise of the computer era companies like the Correx Company, already working in the packaging optimisation area, updated their computer program able to plot board area curves. The new software, Easi-Pack, was able to automatically

calculate different packaging solutions after keying in the necessary starting dimensions. A few results a typical presentation report included the size of the box, the area above minimum in percent, the instruction how to pack the boxes on a pallet, the costs and the box style (Wright, McKinlay et al. 1992).

With proceeding progress of the computer industry the packaging optimisation software got more and more advanced. Today there are two market leaders for packaging optimisation software and a few smaller companies selling their products. The two market leaders are Cape Systems and TOPS Engineering, both offer a software with various possibilities, from arranging the packaging to design a new package (CapeSystem 2009; TOPS-Engineering 2009).

A few important functions of the software are that they allow seeing the impact of changes to the packaging, for example the amount of packaging per pallet or the new area or cube efficiency of the changed package. Next to the pallet and container weight that should be as high as possible in most cases, it is always desirable to have an area and cube efficiency as high as possible. Consider a product palletised in such a manner that 50 mm of space exists on all sides what would give a pallet utilisation of 82.5%. When compared on a large scale to a fully utilised pallet,

- 1,175 pallets are needed instead of 1000
- Stretch-wrapping is needed for 175 extra pallets
- Forklift trucks operate 17,5% longer
- 175 more places are needed in the warehouse

The additional pallets may make up to 8 additional vehicle loads (Soroka 2002).

2.2.1 Package optimisation algorithm

Papers, published in this scientific area, widely use the term Cutting and Packing (C&P) to describe the field they are working in. This is related to the affinity of both areas, first noticed in the seventies from Brown (1971) and Golden (1976) and later further explained from Dyckhoff (1990). There is a

strong relationship between cutting and packing resulting from the duality of material and space. Packaging and loading problems are characterized by packing small objects into larger objects, for example carton in a container, which can be seen as cutting the empty space of the larger object into parts of empty spaces some of which are occupied by the smaller items, the other being trim loss. On the opposite, cutting stock problems may be looked at as packing the space occupied by large objects (Dyckhoff 1990).

Brooks et al. (1940) published one of the first papers that dealt with the C&P problem where he described a mathematical model that allows the dissection of rectangles into squares. Since then, papers related to this topic were sporadically published till around 1966. From this date on a rapid increase of published papers is to observe as shown in figure 2.13.

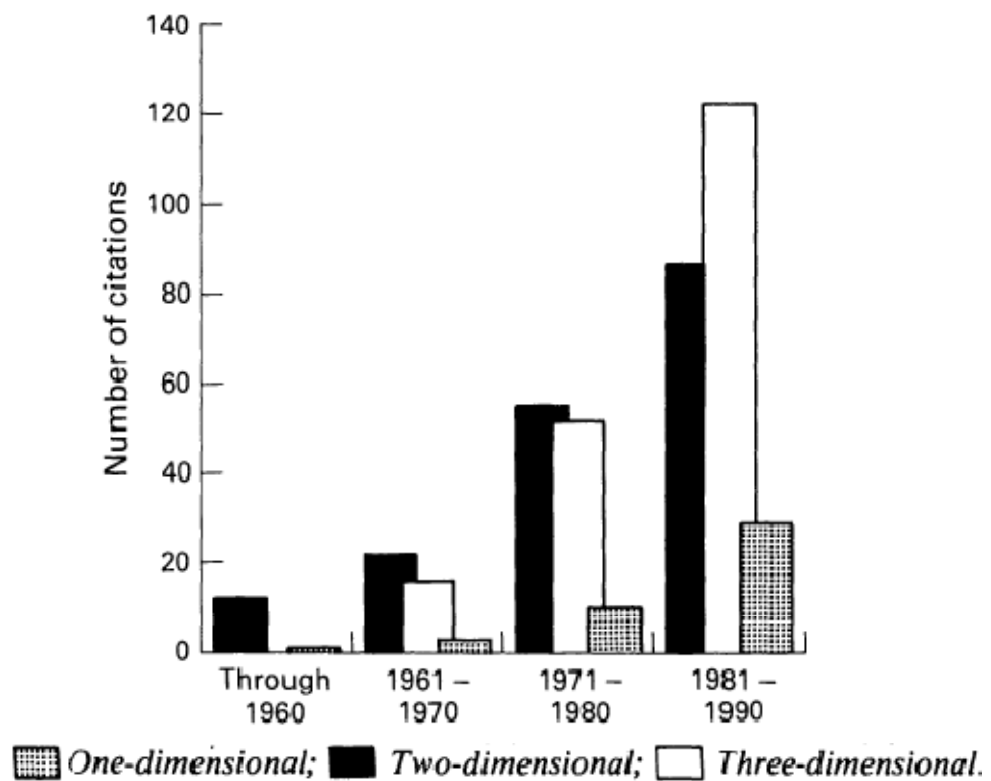


Figure 2.13 Number of publications by year and by dimension of a problem where publications that cover more than one problem are double counted

(Sweeney and Paternoster 1992)

These papers, published in different journals and in different languages, are dealing with various aspects and are based in different disciplines, such as

mathematics, operational research, management science, engineering science and information and computer science.

Even though most of this papers were dealing with the same sort of problems there was no uniform typology. This changed when Dyckhoff (1990) introduced his typology of cutting and packing problems. He categorised the existing papers related to their C&P problems into four criteria. The first criterion was dimensionality which captures the minimal number (1, 2, 3, $n > 3$) of geometric dimensions necessary to describe the required layout patterns completely. The second criterion describes the assignment of small items into large objects, like cartons in a container. He differentiates between B and V, whereas the B is coming from the German word "Beladeprobleme" and V is coming from the German word "Verladeprobleme". B means that all large objects have to be used and a selection of small items has to be assigned to the large objects. V describes a situation in which all small items have to be assigned to a selection of large objects. Criterion 3 is divided in three subsections, O, I, and D which represent the assortment of the large objects. O stands for one large object, I for several but identical large objects, and D for several different large objects. The final criterion 4 characterises the assortment of the small items. Dyckhoff divides them into four subsections, F, M, R, and C. They stand for a few items of different figures (F), many items of different figures (M), many items of relatively few different (non-congruent) figures (R) and congruent figures (C) (Dyckhoff 1990). The different criteria with their subsections are summarized in figure 2.14.

- | |
|---|
| <p>1. Dimensionality</p> <p>(1) one-dimensional</p> <p>(2) two-dimensional</p> <p>(3) three-dimensional</p> <p>(N) N-dimensional with $N > 3$</p> <p>2. Kind of assignment</p> <p>(B) all objects and a selection of items</p> <p>(V) a selection of objects and all items</p> <p>3. Assortment of large objects</p> <p>(O) one object</p> <p>(I) identical figures</p> <p>(D) different figures</p> <p>4. Assortment of small items</p> <p>(F) few items (of different figures)</p> <p>(M) many items of many different figures</p> <p>(R) many items of relatively few different (non-congruent) figures</p> <p>(C) congruent figures</p> |
|---|

Figure 2.14 Categorisation criteria, main types and coding scheme of Dyckhoff's typology

(Wäscher, Haußner et al. 2007)

The typology allowed for the first time to see the common underlying structure of C&P problems. This allowed the integration and cross fertilisation of the two research areas which were largely separated before. Although Dyckhoff's typology was a milestone for the C&P area his typology has not always been accepted as widely as desirable, most probably due to the fact that the provided coding scheme was not self-explanatory from the view point of an international (English-speaking) community of researchers (see B and V for example). However, recent developments in the C&P field have shown some drawbacks in Dyckhoff's typology that were taken seriously enough to publish an improved typology of cutting and packing problems (Wäscher, Haußner et al. 2007).

One drawback that led to a new typology was that it is not possible to assign all C&P problems uniquely to problem types. One example is the Vehicle Loading Problem that was classified by Dyckhoff as a 1/V//I/F and a 1/V//I/M problem. As a standard problem in the C&P area it is desirable to have only one option available. Furthermore, it does not become clear how Dyckhoff's differentiation will provide a set of problem categories which is more homogeneous than a single type, which includes both categories. Another problem with Dyckhoff's

typology is that it is partially inconsistent; its application might have confusing results, for example the Strip Packaging Problem, a two-dimensional packaging problem, namely the packing of a set of small items (often rectangles) of different sizes into a single rectangle with fixed width and minimal (variable) length (Martello, Monaci et al. 2003). Using Dyckhoff's typology this problem would be most probably coded 2/V/O/M whereas Dyckhoff assigned the notation 2/V/D/M. Dyckhoff says that this problem "... is equivalent to an assortment selection problem where the stock is given by an infinite number of objects of this width and of all possible lengths and where only one object has to be chosen from stock, namely that of minimal length" and he calls it a two-dimensional Bin-Packaging Problem (1990). According to Lodi (2002) and Miyazawa (2003) it would have been more obvious to reserve this name for the natural extension of the Classic (One-Dimensional) Bin Packing Problem, i.e. the packing of a set of small items of different sizes into a minimum number of rectangles (large objects) of identical size. The notation becomes even more questionable for two-dimensional problems where both width and length are variables, and, likewise, for three-dimensional problems, where width, length and/or height are variables (Lodi, Martello et al. 2002; Miyazawa and Wakabayashi 2003; Wäscher, Haußner et al. 2007).

A third problem with Dyckhoff's typology is that its application does not necessarily result in homogenous problem categories. It can be observed that using the same notation for problems that require different solution approaches, for example, a pattern-orientated approach for cutting problems with few groups of identical large objects and an item-oriented approach for such problems with entirely different large objects, leads to confusion as mentioned by Gradišar (2002).

The improved typology by Wäscher (2007) consists of five criteria with several subcriteria for the definition of combined problem types of C&P problems.

These are

- dimensionality
 - 1, 2, 3, $n > 3$
- kind of assignment

- output (value) maximisation
 - input (value) minimisation
- assortment of large objects
 - one large object
 - several large objects
- assortment of small items
 - identical small items
 - weakly heterogeneous assortment
 - strongly heterogeneous assortment
- shape of the small items
 - regular small items
 - irregular

Since the new typology is relatively new it is not to foresee how successful the typology will be. An overview of problem types related to C&P problems is shown in figure 2.15.

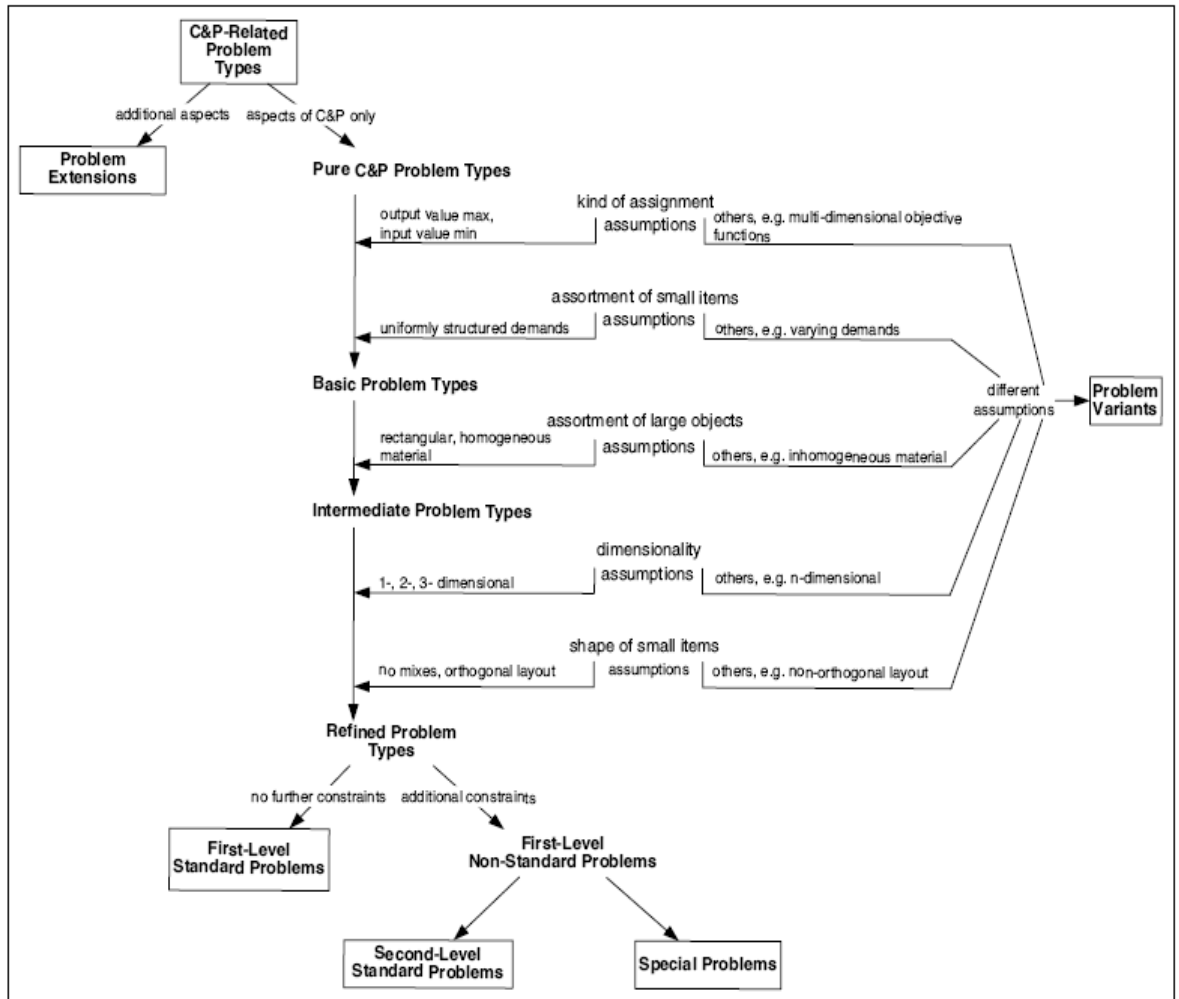


Figure 2.15 Overview of problem types related to C&P problems

(Wäscher, Haußner et al. 2007)

In summary, almost every problem the published papers are covering belongs to one of the six C&P problems shown in figure 2.16. These problems are the

- Identical Item Packing Problem
- Placement problem
- Knapsack Problem
- Open Dimension Problem
- Cutting Stock Problem
- Bin Packing Problem (Böltink 2004; Wäscher, Haußner et al. 2007).

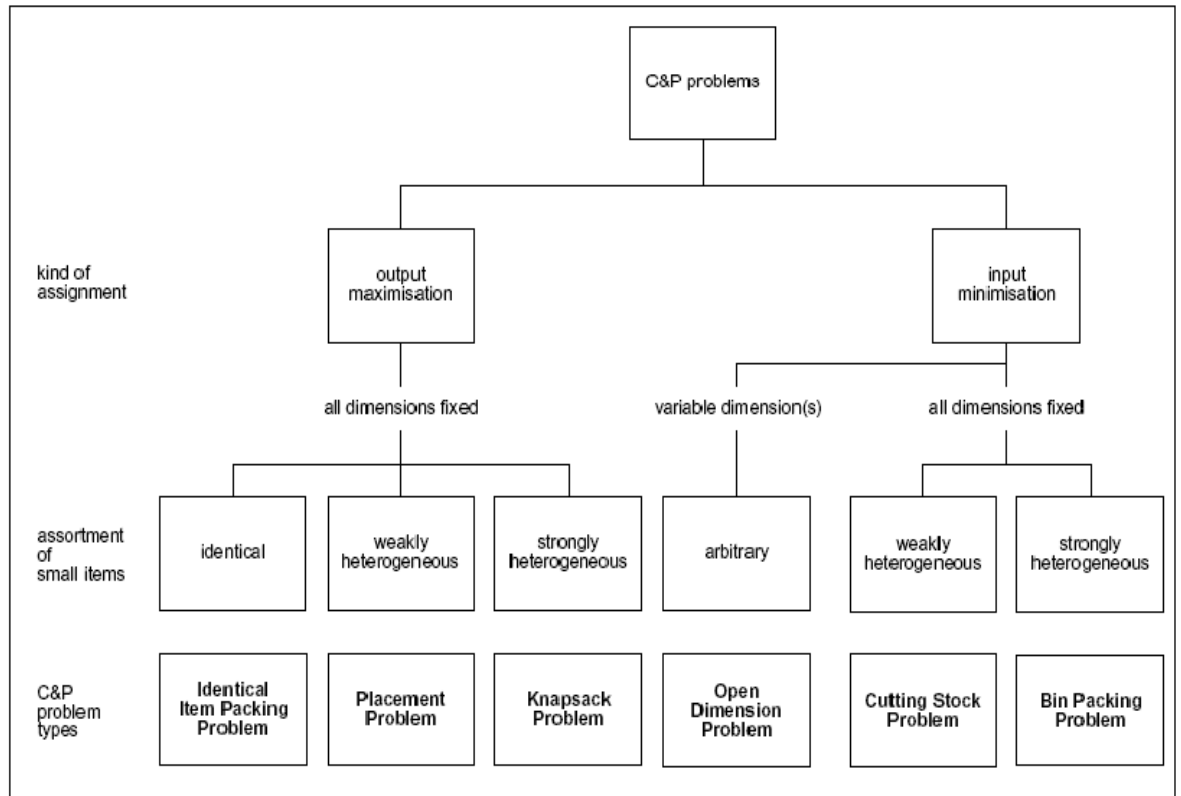


Figure 2.16 Basic problem types

(Wäscher, Haußner et al. 2007)

2.2.1.1 Basic problem types

The basic problem types shown in figure 2.16 will be described in the following sections. The first three problems are classified as output maximisation types and the second three problems are classified as input minimisation types. A landscape of intermediate problem types for both, output maximisation and input minimisation is shown in the figures 2.17 and 2.18.

2.2.1.1.1 Identical item packing problem

The Identical Item Packing Problem consist of the assignment of the largest possible number of identical small items to a given, limited set of large objects (Wäscher, Haußner et al. 2007).

2.2.1.1.2 Placement problem

The Placement Problem is a generic term for a problem known under many different names in the literature. It is dealing with weakly heterogeneous assortments of small items that have to be assigned to a given limited set of large objects (Wäscher, Haußner et al. 2007).

2.2.1.1.3 Knapsack problem

Here strongly heterogeneous assortments of small items have to be allocated to a given set of large objects, where the availability of the large objects is limited such that not all of the small items can be accommodated (Wäscher, Haußner et al. 2007).

| characteristics of the large objects | | assortment of the small items | | |
|--------------------------------------|------------------|--|---|---|
| | | identical | weakly heterogeneous | strongly heterogeneous |
| all dimensions fixed | one large object | Identical Item Packing Problem IIPP | Single Large Object Placement Problem SLOPP | Single Knapsack Problem SKP |
| | identical | X | Multiple Identical Large Object Placement Problem MILOPP | Multiple Identical Knapsack Problem MIKP |
| | heterogeneous | | Multiple Heterogeneous Large Object Placement Problem MHLOPP | Multiple Heterogeneous Knapsack Problem MHKP |

Figure 2.17 Landscape of intermediate problem types: output maximisation

(Wäscher, Haußner et al. 2007)

2.2.1.1.4 Open dimension problem

This problem category consists of the assignment of small items that have to be accommodated completely by one large object or several large objects. The extension of at least one dimension of the large object is considered as a variable (Wäscher, Haußner et al. 2007).

2.2.1.1.5 Cutting stock problem

A weakly heterogeneous assortment of small items is completely allocated to a selection of large objects of minimal value, number, or total size. In contrast to

the Open Dimension Problem are the extensions of the large objects fixed in all dimensions (Wäscher, Haußner et al. 2007).

2.2.1.1.6 Bin packing problem

The Bin Packing Problem is characterised by a strongly heterogeneous assortment of small items. Like the problems before these items have to be assigned to a set of identical large objects, but this time, the large objects are weakly heterogeneous or strongly heterogeneous. The value, number, or total size of the necessary large objects has to be minimised (Wäscher, Haußner et al. 2007).

| characteristics of large objects | | assortment of small items | |
|---|------------------------|---|---|
| | | weakly heterogeneous | strongly heterogeneous |
| all dimensions fixed | identical | Single Stock Size Cutting Stock Problem SSSCSP | Single Bin Size Bin Packing Problem SBSBPP |
| | weakly heterogeneous | Multiple Stock Size Cutting Stock Problem MSSCSP | Multiple Bin Size Bin Packing Problem MBSBPP |
| | strongly heterogeneous | Residual Cutting Stock Problem RCSP | Residual Bin Packing Problem RBPP |
| one large object variable dimension(s) | | Open Dimension Problem ODP | |

Figure 2.18 Landscape of intermediate problem types: input minimisation

(Wäscher, Haußner et al. 2007)

Continuative to figure 2.13 that shows the number of C&P publications by dimension till the 90s, table 2 shows the number of C&P publications by

dimensions from 1995 to 2004. The new improved typology is used for the problem types (figure 2.17 and 2.18).

Table 3 Number of publications by year and by dimension of a problem where publications that cover more than one problem are double counted

(Wäscher, Haußner et al. 2007)

| Problem types | 1D | 2D regular | 2D irregular | 3D | Total |
|---------------|-----|---------------|-----------------|----|-------|
| ODP | – | 46 | 49 | 7 | 102 |
| SBSBPP | 61 | 17 | 2 | 9 | 89 |
| SKP | 49 | 18 | 7 | 12 | 86 |
| SLOPP | 4 | 32 | 1 | 19 | 56 |
| SSSCSP | 29 | 2 | 1 | 6 | 38 |
| Other | 29 | 35 | 4 | 6 | 74 |
| Total | 172 | 150 | 64 | 59 | 445 |

The Identical Item Packing Problem which is of particular interest for this thesis has been extensively studied in the 1980s. However, in the years between 1995 and 2004 this specific problem is only represented in 23 papers. This seems to indicate that the central standard problem of this type, the classic Manufacturer’s Pallet Loading Problem, has been solved satisfactorily (Wäscher, Haußner et al. 2007).

The possible structure of a container packing algorithm for a single box-type is described by George (1992) as followed:

- Step 1. Consider first a packing arrangement against the end of the container.
 - (a) Choose each dimension of the box, in order, to be considered as the depth dimension and thus the depth of the layer.
 - (b) Use a suitable two-dimensional cutting/packing algorithm to find the best fit of the height and width dimensions. This gives the best fit for that depth dimension.
 - (c) Choose, between the depth dimensions, the one that gives the best percentage coverage.
- Step 2. Pack as many layers as feasible using the fit found in step 1(c).

- Step 3. Modify the number of layers by unpacking them layer by layer and replacing with combinations of the best fit for the other depth dimensions until a best fit is found.
- Step 4. Amalgamate any feasible spaces to fit boxes across layers.
- Step 5. Reorientate the container to pack against first the side and then the floor.
- Step 6. Choose the best fit from the three orientations of the container.
- Step 7. Display the resulting fit as viewed from the end of the container.

This is a general structure which allows a variety of two-dimensional algorithms but it is possible to translate this structure to a three-dimensional structure by changing step 1(b) to:

- (i) For a given depth dimension of the box find the two packing arrangements of the boxes all orientated in the same direction.
- (ii) For each fit in (b)(i) modify the fit by unpacking it stack by stack and reorientating the width and height dimensions until a best fit is found.
- (iii) Modify the stacks that remain in their original orientation by repacking row by row from the top, reorientating the width and height until a best fit is found.
- (iv) Choose the better fit of the two packing arrangements (George 1992).

2.2.2 Exact algorithms vs. heuristic

Fowler (1981) found out that the rectangular packing problem is NP-complete (NP standing for Nondeterministic Polynomial time). NP- complete means that the problem cannot be computed in polynomial time whereas polynomial time is the computation time of a problem where the run time is no greater than a polynomial function of the problem size n (Cook 1971; Braatz, Young et al. 1994; Hopper and Turton 2001). According to this definition the NP-complete class has the important characteristic that all algorithms currently known for finding optimal solutions require a number of computational steps that grows exponentially with the problem size rather than according to a polynomial function. This is the reason why it is not worthwhile to search for an exact (optimal) algorithm, since it does not appear that any efficient optimal solution is

possible. This led to the development of approximation algorithms, for example, heuristics. By using these alternative approaches it is not guaranteed to find an optimal solution and furthermore, the solution quality suffers, but on contrary, computational efficiency can be gained (Hopper and Turton 2001).

For less constrained, simpler packing tasks, exact algorithms were developed along with problem specific heuristic procedures (Chen, Lee et al. 1995; Hadjiconstantinou and Christofides 1995). For more complex packing tasks, heuristic search methods have been applied successfully for their solution (Albano and Sapuppo 1980; Oliveira, Gomes et al. 2000).

It is to mention that there is no test suite available which could enable comparisons between algorithms intended for packing problems. Due to the lack of benchmarking, it is difficult to decide which method is better suited to approach packing problems. To-date only a few attempts have been made to compare meta-heuristic techniques (Hopper and Turton 2001).

3. Package optimisation software

This chapter is about the newly developed software called SADIE. SADIE is an acronym for “**S**oftware to **A**utomate **D**ata **I**mport and **E**xport” which explains exactly what the software is able to do. SADIE uses the packaging optimisation software Cape Pack (Cape Systems, Version 2.09) to find the best packaging solutions out of a multiplicity of possible product weight/bulk density combinations.

SADIE has its origin in an example macro that allows exporting data out of an Excel (Microsoft Corporation, Version 2007) spreadsheet and importing it into Cape Pack. The macro is provided from the Cape Pack company to automate data input using a so called CIF (Cape interface file). In Cape Pack, CIFs are the main mechanism for users to import any or all data input information required to automatically fill out the input fields for an individual Cape Pack program module. The CIFs are the only way to interact with Cape Pack from the outside. Originally, the option of using CIFs was provided to allow the user to import data already stored in a database, a spreadsheet or other applications to speed up the process and reduce the potential for data entry errors.

Every query needs its own CIF file which is then transferred into Cape Pack. The CIF file is generate by a macro and this macro has to be written specifically for the task the user has in mind. It is not possible to use any computer language to write the macro; in this case it has to be Visual Basic since this is the only computer language Cape Pack allows to be used. However, Cape Pack does not give access to their source code which limits the options of a coder wishing to develop a custom solution for inputting CIFs.

The whole process of a query using a macro is shown in figure 3.1.

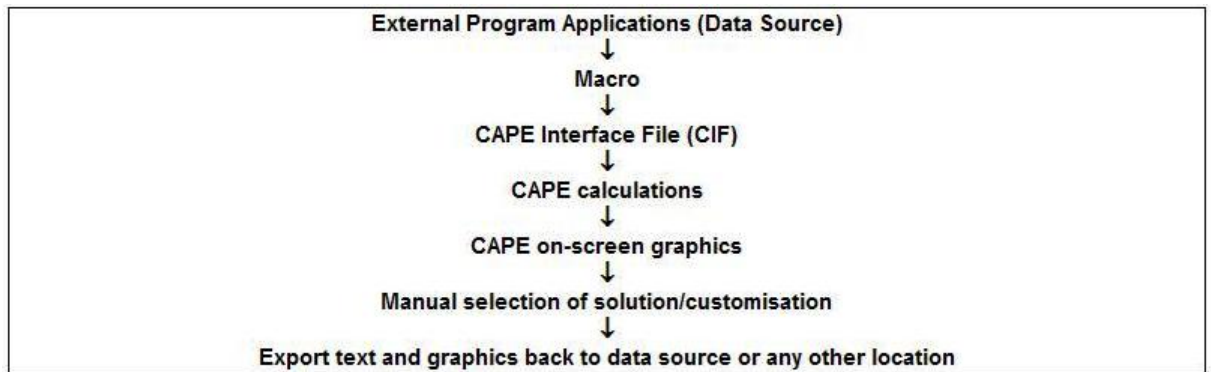


Figure 3.1 Flow diagram showing how to bring existing data into the Cape Pack software package
(System 2009)

As can be seen in figure 3.1 the process of using the automate data input function provided from Cape Pack requires certain steps that do not allow its use for this project.

For instance, SADIE is not intended to use an external program application as a data source. Having to use a pre-established data source would not be feasible because of the sheer amount of possible combinations for every query for this project. A basic query requires at least four different parameter, weight, bulk density, pallet type and container type. If one of these parameters is changed, a whole new set of data is required to be input into Cape Pack. In reality, depending on the query, up to 40 different parameters are necessary for what SADIE should be able to do.

Another shortcoming of the Cape Pack macro is that manual steps are required for every single query. After Cape Pack shows the calculated solutions the user has to choose one of them manually and if the container load is required, then Cape Pack “truck” option has to be selected manually. After these steps the user has to manually export the data before he can start another query.

3.1 Requirements of SADIE

This section lists the necessary requirements of SADIE so that SADIE in combination with Cape Pack will be able to provide results that allow investigation of the advantages and disadvantages of different weight\bulk density packaging combinations.

SADIE should be able to

- run independently without the necessity of using external data sources
- run query without human interference
- let Cape Pack calculate weights as well as bulk density on a “from – to” basis” -
- provide the same input parameters as Cape Pack offers
- allow the easy changing of all the input parameters
- export the results into a database
- use the results to calculate corrugated paperboard area used
- add new corrugated paperboard thicknesses, pallets types, and container types to the input parameters
- do this with cases and cylinders.

The development of SADIE to meet these requirements is explained in the next section.

3.2 Operation breakdown

The first thing a user sees after starting the SADIE software is the graphical user interface (GUI). The GUI displays the different parameters and allows the requires values for the Query to be added. The weight and the bulk density minimum and maximum values of the Query are set, and additionally the size of the steps between each set of calculations, as to see in figure 3.2. For this example it means that SADIE would first start to calculate the optimum (minimum board area utilised) start dimensions for a carton (pack) for a weight of 20 kg and a bulk density of 500 kg/m³. This would then be generated as a CIF for Cape Pack program. The next cycle SADIE would calculate the optimum start dimensions for 20 kg with a bulk density of 501 kg/m³. This would go on till SADIE would reach a bulk density of 510 kg/m³ and then it would start with a weight of 22 kg and a bulk density of 500 kg/m³. The last calculations would be 30 kg with a bulk density of 510 kg/m³. Thus SADIE in this example provides a total of 80 CIFs for input into Cape Pack.

| | | | |
|-----------------------------------|----------------------------------|----------------------------|----------------------------------|
| Weight [kg] | | Steps [kg] | |
| from | <input type="text" value="20"/> | to | <input type="text" value="30"/> |
| | | | <input type="text" value="2"/> |
| Bulk Density [kg/m ³] | | Steps [kg/m ³] | |
| from | <input type="text" value="500"/> | to | <input type="text" value="510"/> |
| | | | <input type="text" value="1"/> |

Figure 3.2 Part of the GUI that allows the setting of the weight/bulk density constraints

After setting all necessary parameter for the query, an entry must be made into the time frame. This sets the time that Cape Pack will be calculating packaging solutions. After this time is up Cape Pack is then instructed to calculate the best “Truck or Container” stacking pattern for the best solution (first solution calculated) then exporting this solution to an Access database (Microsoft Access 2003 or 2007). This is an important step because it allows SADIE to run automatically without additional inputs. As the Cape Pack macro is not designed to run without manual input selections it does not allow accessing its source code so it is not possible to bypass this constraint. Thus SADIE has to simulate a user inputting the required data and pushing the required buttons at the right time. This time is always different and depends on the particular calculation Cape Pack has to do. A calculation for a small package size on a big pallet needs longer than a calculation for a big package on a small pallet. A similar constraint is the time to calculate the packaging patterns for the Truck/Container, these constraints are solved by ensuring the pallet and container stays the same for the whole query. This does mean that a first test run is required to determine how long Cape Pack needs to calculate a solution and this time can be used in the “runtime” box of GUI for that Query.

After all required inputs and preparations are complete SADIE is ready to start with a click on the “Calculation” button.

SADIE then checks the GUI for all the parameter chosen and writes them into the CIF file. The CIF file consists mainly of field numbers that has its

counterpart in Cape Pack. For example, field 12 in the general section of Cape Pack is the field for the net weight as shown in figure 3. 3.

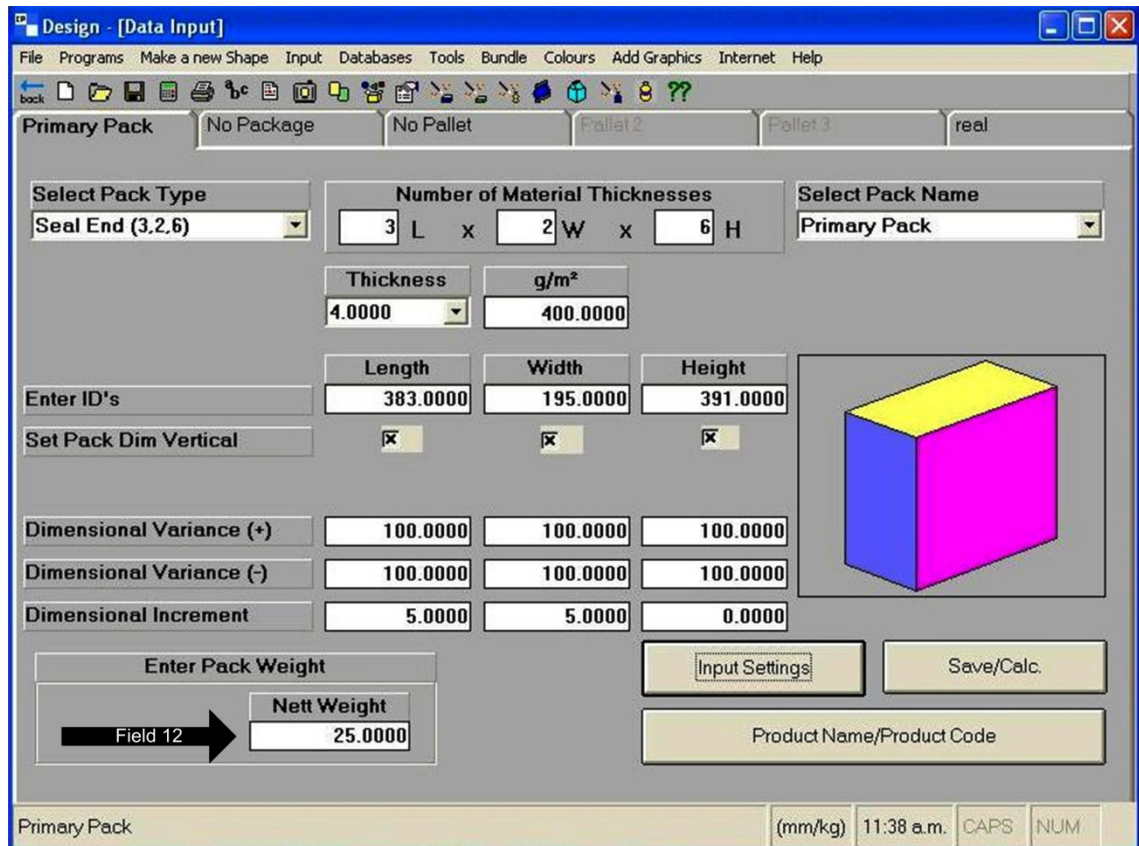


Figure 3.3 Field number 12 in Cape Pack

(System 2009)

SADIE takes the net weight written down in the GUI and writes it into the CIF file, in this case to field number 12. This is done for all the parameter chosen in SADIEs GUI. The CIF file itself is then transferred into Cape Pack to the module specified by the macro, here into the carton or cylinder module in the Design group. All numbers and information written in the CIF file are now uploaded to the right places in Cape Pack and Cape Pack starts the calculation. After Cape Pack has finished the calculation it provides up to 80 possible solutions to optimise the pallet load, however the first solution is usually the best. Depending on the parameters given in the GUI before there are now two options. The first is to export the first pallet load solution and to go on with the next set of calculations specified in the Query. The second is to use the “Show my truck” option shown clicked in figure 3.4. This option takes the first pallet load solution and calculates how much product can be loaded into specified

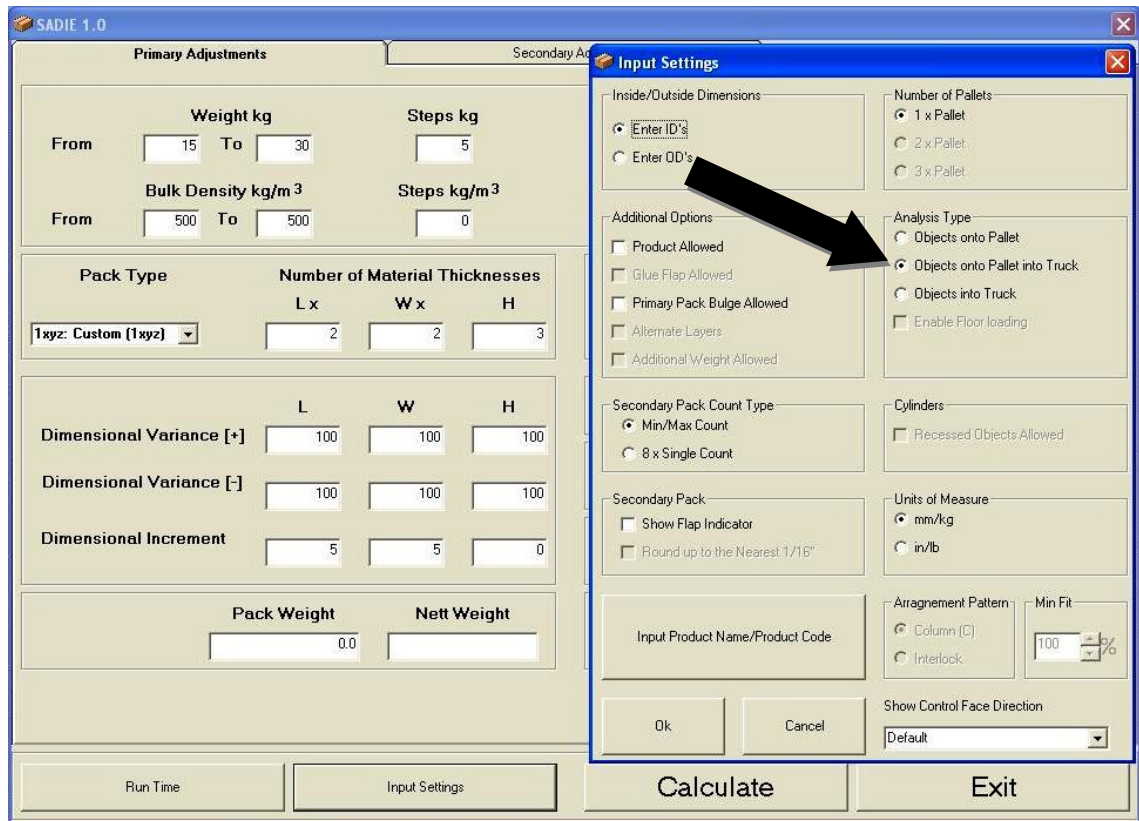


Figure 3.4 SADIEs GUI with open "Input settings" window with chosen truck option container. Cape Pack provides 40 different container load solutions however again the first given solution is the best. SADIE then saves the result of the first given container load solution and exports it with the pallet load solution into a database and the process starts again with the next set of calculations.

A loop programmed into SADIE allows it to repeat the process over and over till the end of the Query. The loop contains equations that calculate new start case or cylinder dimensions from the weight and bulk density given for the query.

A manual of SADIE is written in Appendix 19.

3.2.1 Loop equations

The software automatically calculates the package size with the optimal used corrugated paperboard area for cartons and the best material usage for cylinders if required. For a regular slotted container (RSC) the ratio is 2:1:2 (length: width: height) and for a cylinder the ratio is 1:1 (diameter : height), with a overhead of 10% in height will be given to cylinders for filling reasons. The equations to calculate the start dimensions for cartons are

$$l \text{ and } h = \sqrt[3]{\left(\frac{m}{\rho}\right)/4} * 2000 \quad (\text{Equation 1})$$

$$w = \sqrt[3]{\left(\frac{m}{\rho}\right)/4} * 1000 \quad (\text{Equation 2})$$

where l = length [mm]

w = width [mm]

h = height [mm]

m = weight [kg]

ρ = bulk density [kg/m³].

The equations for the cylinder start dimensions are

$$d = \sqrt[3]{\left(\left(\frac{m}{\rho}\right) 4\right) / \pi} * 1000 \quad (\text{Equation 3})$$

$$h = d + \left(d \frac{10}{100}\right) \quad (\text{Equation 4})$$

where d = diameter [mm]

3.3 Results

SADIE does not give the user all the details Cape Pack can provide, for example a large number of calculated solutions. SADIE gives the big picture, an overview that allows the user to select the best solution of the multiplicity of solutions Cape Pack produces, including the resulting change in pallet and container weight after changing the weight or bulk density. This allows the user to concentrate on the best results and furthermore, to know the product bulk density range in which production is possible without too much loss in pallet and container load.

For the overall results, it means that only the results necessary to give the big picture are exported and saved in a database. However, it is possible to include

export other results if necessary. The initial settings of SADIE have the following results exported from Cape Pack and transferred into the database:

- Net weight – The Net weight Cape Pack is using
- Bulk density – The bulk density used to calculate the start dimensions
- Optimal dimensions – These dimensions are the calculated start dimensions calculated with the equations in section 3.2.1 (Equation
- Optimised dimensions – The dimensions given as a result of the calculation done by Cape Pack
- Flute type – When using the case module the used flute type is shown
- Optimal and optimised base area – The base area necessary to build the package, calculated out of the optimal and the optimised dimensions in square meter. Depending on the package different equations are necessary.

- For cases it depends on the used flute type. There is one equation per flute type for the four flute types (B, C, BC, and E) used by Fonterra. These equations (Equations 5 to 8) are:

- for B (Equation 5):

$$\frac{(w + 3 + h + 12)((l + 3) * 2 + (w + 2)^2 + \text{glue flap size} + 6)}{1000000}$$

- for C (Equation 6):

$$\frac{(w + 4 + h + 16)((l + 4)^2 + (w + 3)^2 + \text{glue flap size} + 6)}{1000000}$$

- for BC (Equation 7):

$$\frac{(w + 7 + h + 28)((l + 7)^2 + (w + 5)^2 + \text{glue flap size} + 6)}{1000000}$$

- for E (Equation 8):

$$\frac{(w + 3 + h + 12)((l + 3)^2 + (w + 2)^2 + \text{glue flap size} + 6)}{1000000}$$

- For cylinders, the equation to calculate the package base area is:

- $A = 2\pi r^2 + 2r\pi h$ (Equation 9)

where $A =$ used area [m^2]

$r =$ radius [m]

$h =$ height [m]

- Board difference – It shows the difference between the optimised and the optimal packaging base area projected for 1000 m². It is done for 1000 m² to have a bigger numbers for comparing the different solutions.
- Pallet name – Since hundreds of different pallets are in use worldwide the used pallets name is exported with the results
- Pallet net weight – The product net weight on the pallet
- Pallet area efficiency – How much of the area provided by the pallet is used
- Pallet cube efficiency – How much of the given volume of a pallet is used
- Truck name – Name of the truck or container that is used
- Product net weight container – The product net weight of the container
- Container area efficiency – How much of the area provided by the container is used
- Container cube efficiency – How much of the given volume of a container is used

All of these results are saved in an Access database which makes it easy to export the data into an Excel file for further use.

3.4 Data flow chart

The following two charts show the data flow during the whole process, the first chart as an overview and the second in detail.

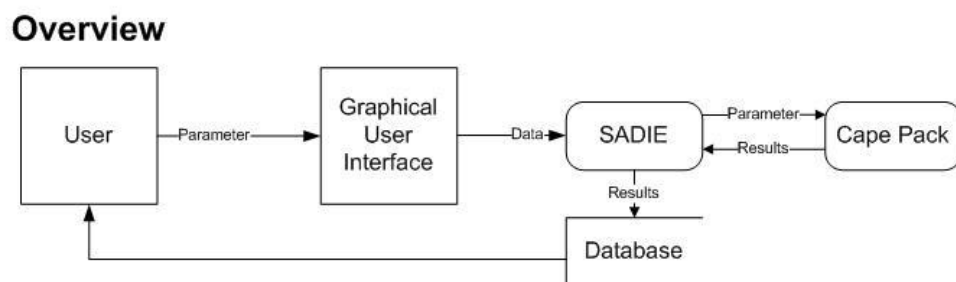


Figure 3.5 Data flowchart overview



Legend data flowchart

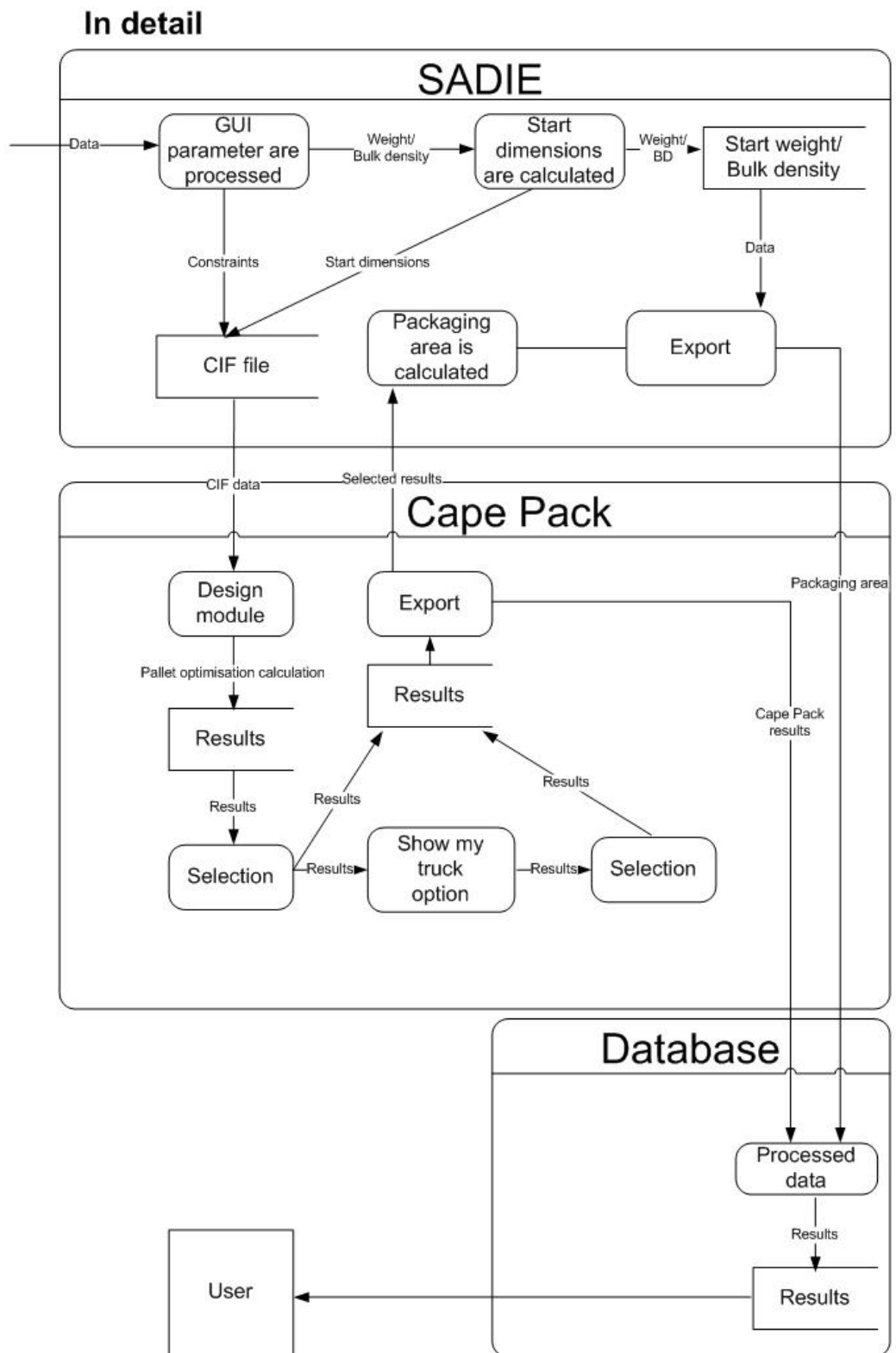


Figure 3.6 Data flow chart in detail

4. Methodology

Verification and Validation is the process of checking that a software meets specifications and that it fulfils its intended purpose. According to the Capability Maturity Model verification is “the process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of the phase” (Society 1990). Validation, on the other hand, is “the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements” (Society 1990). In short, verification ensures that ‘you built it right’ and validation ensures that ‘you built the right thing’ and confirms that the product will fulfil its intended use.

Since the verification of SADIE was done during the programming process this chapter concentrates on the necessary validating process.

There are two ways to validate SADIE. The first way includes test methods to check and verify the data whereas the second way is about actual using the data to prove their validity in real life.

4.1 Software validation of the results

SADIE software produces results, so it is now necessary to see if the results are

- right,
- always the same and
- the best possible solution.

This is done by three different methods described in the next sections, all with the help of established software like Excel and Cape Pack.

4.1.1 The right results

SADIE uses different equations to calculate the start dimensions, the optimal and optimised used material area, and the difference between them projected on 1000 m². These numbers have to be checked for their validity. This is done with an excel spreadsheet that includes the equations necessary to calculate these values (figure 4.1). The equations are the same used in SADIE Equations 5 – 8 as written in chapter 3.

| | A | B | C | D | E | F | G | H |
|----|------------------------------------|-------------------------|-------------------------------|---------------------|--------------------------------------|--|---------------------|------------------------------|
| 1 | Corrugated cases | | | | Thickness | Number of material thicknesses | | |
| 2 | | | | | 4 | 2 | 2 | 3 |
| 3 | Case Size 2:1:2 (Inner Dimensions) | | | | Optimised dimensions Cape Pack (OD) | | | |
| 4 | | BD [kg/m ³] | Length [mm] | Width [mm] | Height [mm] | Length [mm] | Width [mm] | Height [mm] |
| 5 | 5 | 500 | 271 | 136 | 271 | 199 | 169 | 327 |
| 6 | Flute Type | Glue flap size | Sheet Length [mm] | Sheet Width [mm] | Optimum Board area [m ²] | Recalculated optimised dimensions Cape Pack (OD) | | |
| 7 | C | 25 | 859 | 427 | 0.3671 | 191 | 161 | 315 |
| 8 | | | | | | Sheet Length [m] | Sheet Width [mm] | Board area [m ²] |
| 9 | | | | | | 781 | 516 | 0.4030 |
| 10 | | | | | | Difference in board area for 1000 m ² | | |
| 11 | | | | | | 35.92 | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | Volume Case [m ³] | Product weight [kg] | | Volume Case [m ³] | Product weight [kg] | |
| 15 | | | 0.0100 | 5.00 | | 0.0097 | 4.84 | |
| 16 | | | | | | | | |

Figure 4.1 Excel interface used to verify the results coming from SADIE

The spreadsheet is flexible enough to allow it to be used for all the different calculation variables SADIE offers. The user can change the green fields to get the calculated results in the pink fields. An example is shown in figure 4.1 where a weight of 5 kg and a bulk density of 500 kg/m³ is used. The spreadsheet comes up with the start dimensions of 271 x 136 x 271 mm and the calculated product weight of 5 kg. It also calculates the optimum board area. The optimised dimensions (199 x 169 x 327 mm) coming from SADIE plus the number of thicknesses (2;2;3) and the thickness (4 mm) are used to calculate the outer dimensions which are used to calculate the optimised board area (0.4030 m²) and the product weight (4.84 kg). The difference in board area for 1000 m² is also calculated by subtracting the optimal board area from the optimised board area times 1000 (35.92 m²).

The calculated results are then to compare with 20 different results coming from SADIE. Additionally to the variables calculated from SADIE the calculated product weight was rechecked. This was done for the optimal start dimensions as well as for the optimised dimensions coming from SADIE. The input data used for the test is shown in table 4. Every density is used for every weight with the constraints not changing for every calculation.

Table 4 Parameter used to check the right results

| Bulk Density [kg/m³] | Weight [kg] | Flute Type | Glue flap size [mm] | Thick-ness [mm] | Number of material thicknesses | Pallet |
|--|--------------------|-------------------|----------------------------|------------------------|---------------------------------------|---------------------|
| 500 | 5 | C | 25 | 4 | 2;2;3 | no pallet, 1200x800 |
| 600 | 10 | | | | | |
| 750 | 15 | | | | | |
| 1000 | 20 | | | | | |
| | 35 | | | | | |

4.1.2 The same results

The next step is to check if the results for a query are always the same. For this 10 different queries are processed with SADIE, whereas every single query has to run five times to get a total of 50 runs. The used Queries are shown in table 5.

Table 5 Table of Queries used to check for the same result

| Weight [kg] | | in steps of [kg] | Bulk density [kg/m³] | | in steps of [kg] |
|--------------------|-----------|-------------------------|--|-----------|-------------------------|
| from | to | | from | to | |
| 9 | 11 | 0.05 | 950 | 950 | 0 |
| 14 | 16 | 0.1 | 650 | 650 | 0 |
| 19 | 21 | 0.01 | 884 | 884 | 0 |
| 24 | 26 | 0.25 | 633 | 633 | 0 |
| 180 | 220 | 1 | 687 | 687 | 0 |
| 950 | 1000 | 1 | 996 | 996 | 0 |
| 4.5 | 5 | 0.05 | 500 | 500 | 0 |
| 25 | 25 | 0 | 550 | 750 | 4 |
| 25 | 25 | 0 | 900 | 1000 | 4 |
| 20 | 20 | 0 | 1000 | 1100 | 4 |

Since one query runs five times there are always five data packages per query. These packages are copied out of the Access database where SADIE saves them into an Excel spreadsheet, one data package per worksheet. The five worksheets are then compared with each other for differences between them. This is done with the software Synkronizer (XL Consulting, Version 9.5) which is a tool made to compare two Excel tables.

4.1.3 The best possible solution

SADIEs default value for the dimensional variance in length, width and height (+/-) is set at 100 mm whereas it is set to 5 mm for dimensional increment in length and width and 0 mm in height. These values are necessary to allow a bigger window for Cape Pack to operate in to find the best result. Experience with Cape Pack showed that the initial result coming from a calculation run does not mandatory have to be the best result. Sometimes it is possible to fine-tune a result to get a better pallet/container load result. For example, the dimensions 393 x 239 x 292.2 mm were the result coming from Cape Pack. Those dimensions fine-tuned change to 388 x 240 x 294.7 mm and allow a further increase of 1.751 tonnes in container load. To check the best solution is being calculated, 20 different solutions coming from SADIE are fine-tuned. For this, the same parameter used before are used except the dimensional variance and increment. The dimensional variance is changed to 50 mm instead of 100 mm and the dimensional increment is set to 3 mm in length and width and stays 0 mm for height.

4.2 Physical validation of the results

The physical validation of SADIEs results should cover a wide range of different bulk densities to ensure consistency of results. Therefore, two skim milk powder samples of different bulk densities, one whole milk powder sample and a butter sample to cover the higher bulk densities, were obtained. A value of 960 kg/m³ was chosen for the butter based on Philpotts (2008) experiments. The bulk density of the three powder products is measured according to the test method used by Fonterra (Appendix 2).

Based on the bulk densities of the products, SADIE is used to find the case size that allows the highest container load. The key constraints input are:

- a range of 20 – 30 kg in steps of 0.5 kg
- a pallet size of 1060 x 790 x 150 mm
- a container size of 5918 x 1336 x 2374 mm
- C- flute, glued out (25 mm)
- a RSC case with thicknesses in length, width and height of 2, 2, 3
- a thickness of 4.0 mm, 400 g/m²
- no secondary pack

Based on the results of the optimisation using SADIE and Cape Pack, the case size that allows the highest container load for every of the four products was chosen and ordered in a quantity that allows to fill one layer on the pallet mentioned above. The same is done in practice to see the pallet efficiency in real.

4.2.1 Slipsheet problem

To improve the cube container efficiency it is common to use slipsheets instead of pallets in a container. That means for SADIE that only the length and width of the pallet are used as a constraint, with the height is 0 mm instead of 150 mm. Therefore, using the design mode, it can happen that the pallet area is not completely used which can manifest itself in an underhang. Figure 4.2 shows that the only an area of 1193 x 980 mm from an available 1200 x 1000 mm is used.

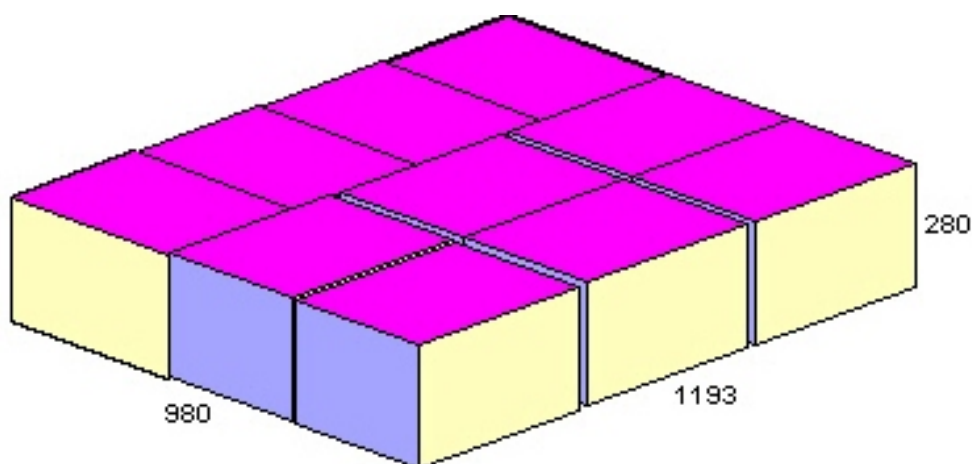


Figure 4.2 Underhang on a 1200 x 1000 mm pallet

(System 2009)

4.2.2 Case and sample handling

After the cases arrive they are measured to see if the dimensions concur with the ordered one. The cases are then erected and taped together. The powder is filled into plastic bags according to the weight given in the solution coming from SADIE. These bags are filled inside the case. The cases are then judged / evaluated in terms of

- powder fitting,
- ability to close the cases,
- bulging, and
- headspace.

The frozen butter is stored for approximately one week at a temperature of 2°C. The butter blocks are then cut according to the new case size. It is difficult to fill the cases with the exact butter weight without getting voids. So one case was filled with the right amount of butter and stored at a temperature of 40°C for two days to melt the butter. The melted butter closes all the voids and allows a better judgement if the case has the right size for the butter. The cases are judged after the same criteria used for the powder above.

4.3 Cost benefit analyse

A Fonterra report (Excel spreadsheet) that lists internal movements (excluding FNZ sales) from June 2005 to May 2006 (Fonterra 2006) is used to find out how many tonnes of WMP and SMP were shipped in 20 foot containers (5918 x 2337 x 2375 mm). This is done for every Fonterra plant where bulk density data is available for. The data is filtered out of the spreadsheet by using the following filter:

- Product
- Plant name
- Container size
- Product weight in container

For example, a search would be for WMP, Edgecumb, 20 foot container, all container over a specific weight. The specific weight is used to consider only full container in the cost benefit analyse. It depends on the plant of origin and the product and is the weight usually packed into a 20 foot container for the specific product (Meijer 2009).

The amount of powder per year is divided by the container load solution coming from SADIE which gives the number of container necessary if the SADIE solution would be used. The result is then subtracted from the old number of containers used.

An example calculation is:

Powder product per year: 10000 tonnes

Used container per year: 950 container

New SADIE solution for 25 kg and a bulk density of 500 kg/m³: 15.5 tonnes

- $10000 / 15.5 = 645$ container
- 950 container – 645 container = 305 container

By using SADIEs solution 305 container could be saved per year.

4.3.1 Butter cost benefit analyse

The bulk density of butter is almost the same in every plant so it is always the same amount of butter packed into a container. For salted butter this is 19.8 tonnes. Here aim is to find a solution that allows an increase in product weight per container by changing the product weight per case. The best new solution is compared with the number of filled containers used during the 2005/2006 season to see if savings are possible.

5. Results

The following chapter describes the results gained through the validation process and the cost benefit analysis. It is divided in three parts, the validation of the software results, the physical validation of the software results and the cost benefit analyses.

5.1 Software validation results

As written in section 4.1 three different methods were used to validate the results coming from SADIE. Their results are discussed in this section.

5.1.1 The right results

The results of this test are to find in the file “Appendix 3 - The right results test.xlsx”. Twenty different solutions coming from SADIE were compared with the Excel spreadsheet shown in chapter 4.1.1 for differences in

- the start dimensions
- the optimal board area
- the optimised board area
- the difference between optimal and optimised board area projected on 1000 m²
- the product weight.

There was no difference between the start dimension calculated by SADIE and the start dimensions calculated by the Excel spreadsheet. The dimensions are correctly transferred into Cape Pack.

The same applies for the optimal and optimised board area. Both are always the same except for one case at a weight of 15 kg and a bulk density of 1000 kg/m³. SADIE shows here a 0.01 m² higher optimal board area than Excel.

There are no differences between the optimal and optimised board area calculated by SADIE and Excel but the results for the difference between optimal and optimised board area projected on 1000 m² differ. The variations show no consistency, they are fluctuating between 0.02 m² as the lowest and 4.91 m² as the highest number. Sometimes the board area calculated by SADIE is higher, sometimes the one calculated by Excel. The differences can be

explained by the way the optimal and optimised results are handled. They are both rounded to two digits after the decimal point. The other digits are not able to be seen but still there and used by both, SADIE and Excel to calculate the board area projecting on 1000 m². That means that small differences beginning at the third digit after the decimal point are multiplied a thousand times which then leads to the different results. Table 6 is an extract out of Appendix 3 that shows the occurring differences between the results for board area projected on 1000 m² coming from SADIE and Excel.

Table 6 Differences between SADIE and Excel for calculated board area

| | Difference in board area for 1000 m² [m²] | | | | | |
|-------------------|--|-------|-------|-------|-------|-------|
| SADIE | 64.29 | 91.96 | 30.00 | 46.80 | 80.66 | 70.63 |
| Excel | 62.64 | 92.09 | 34.91 | 46.73 | 79.32 | 70.81 |
| Difference | 1.65 | -0.13 | -4.91 | 0.07 | 1.34 | -0.18 |

The results from SADIE and Excel for the optimal and optimised board area are identical for the first two digits after the comma. The variations for the projected board area for 1000 m² coming from differences beginning with the third digit after the comma are small enough to be insignificant as to see in table 6.

It was found out that the new dimensions coming from Cape Pack sometimes alter the product weight (see table 7). For example, if the Query started with a product weight of 20 kg the dimensions coming from Cape Pack allow 20.05 kg. This can go in both directions; the highest difference between start and end product weight was minus 90 g for the new packaging dimensions. This is happening even with the option “Vary volume/Weight” switched off and that should not be the case. The Cape System company was asked why that is happening but there was no answer till now.

There is, however, an answer to that question that might explain why this is happening. Sometimes Cape Pack comes up with a dimension like 327.7 mm. If this number is rounded the dimension of the case is changing. Tests showed that even a small change can lead to relatively great volume changes of the case. The change is even bigger when the smallest dimension is changed as to see in table 7. In this table the first row shows the original dimensions coming

from Cape Pack, the next four lines the green marked dimensions were changed +/-1 mm. The change of the end product weight was higher when the smallest of the three dimensions was changed.

Table 7 Change of product weight by altering the dimensions

| Start product weight [kg] | Length (OD) [mm] | Width (OD) [mm] | Height (OD) [mm] | End product weight [kg] |
|----------------------------------|-------------------------|------------------------|-------------------------|--------------------------------|
| 20 | 378 | 168 | 371 | 20.03 |
| 20 | 378 | 169 | 371 | 20.15 |
| 20 | 378 | 167 | 371 | 19.91 |
| 20 | 379 | 168 | 371 | 20.08 |
| 20 | 377 | 168 | 371 | 19.97 |

An example calculation for a start weight of 22.5 kg and a bulk density of 850 kg/m³ is:

Based on the start dimensions (375 x 188 x 375 mm) SADIE came up with new outer dimensions of 282 x 255 x 367.6 mm. Those dimensions were used to calculate the volume of the case:

$$(282 \times 255 \times 367.6 \text{ mm}) / 1000000000 = 0.03 \text{ m}^3$$

To calculate the product weight the bulk density is multiplied with the volume of the case:

$$850 \text{ kg/m}^3 \times 0.03 \text{ m}^3 = 24.96 \text{ kg}$$

It should be noted that there are variations in the overall dimension for the panels of an RSC of +/-3 mm during the production process of the corrugated paperboard cases (Association 2002).

5.1.2 The same results

The following Queries were processed by SADIE, with every Query being run five times. The results are to find in the Appendixes 4 – 13.

The results for every run were copied from the AccessSteps database into five Excel spreadsheets. The Synkronizer software (XL Consulting GmbH) compared the five sheets of the particular Query which determined that there are no differences between them. Figure 5.1 shows a Synkronizer result table after comparing two excel sheets. The meanderings for the point “Different values” relate only to the solution ID and date which are different from each other. All the other values are unchanged.

The screenshot shows two Excel worksheets side-by-side. The left worksheet is titled 'Master: Appendix 4 - 9-11kg - Steps 0.05.xls' and the right is 'Update: Appendix 4 - 9-11kg - Steps 0.05.xls'. Both contain a table with the following columns: ID, date, weight_kg, ty_kg_m3, bulkDensi, length_id, width_id, height_id, length_od, width_od, height_od, flute. A dialog box from Synkronizer 9.5 (Developer Version) is overlaid on the tables, stating: 'The two worksheets have been compared. The following differences have been found: Deleted columns: 0, Added columns: 0, Deleted rows: 0, Added rows: 0, Different values: 82'. The 'Different values' row is highlighted in yellow. The dialog box also features the Synkronizer logo and the text 'excel compare tool'.

Figure 5.1 Result screen Synkronizer

That means the results coming from SADIE are, if the same parameters are used, always the same. This is true for the examples used for this trial (see table 5) in both cases, a changing weight and a changing bulk density.

5.1.3 The best possible solution

The results of this test are to find in Appendix 14. Twenty different solutions were tested. An improvement of the results was achievable in eight cases, four times for the pallet load and four times for the container load. One improvement in pallet load only led to a higher container load, for the rest the improvement in pallet load led to a lesser container load than before. For this reason and because the container load is much more important for Fonterra the improvements of pallet loads were not considered important.

20% of the tested solutions could be improved, some of them significantly with up to 2 tonnes per container as shown in table 8.

Table 8 Summary of Container load difference between SADIE and Cape Pack

| Bulk density [kg/m³] | 500 | | | | |
|--|------------|-----------|-----------|-----------|-----------|
| Product weight [kg] | 5 | 10 | 15 | 20 | 25 |
| SADIE Container load [kg] | 11839 | 13735 | 12723 | 12694 | 12800 |
| Cape Pack Container load [kg] | 11521 | 13441 | 12481 | 14401 | 13001 |

| Bulk density [kg/m³] | 600 | | | | |
|--|------------|-----------|-----------|-----------|-----------|
| Product weight [kg] | 5 | 10 | 15 | 20 | 25 |
| SADIE Container load [kg] | 12971 | 13460 | 14650 | 14622 | 15820 |
| Cape Pack Container load [kg] | 12761 | 13201 | 15601 | 14401 | 14401 |

| Bulk density [kg/m³] | 750 | | | | |
|--|------------|-----------|-----------|-----------|-----------|
| Product weight [kg] | 5 | 10 | 15 | 20 | 25 |
| SADIE Container load [kg] | 16183 | 19034 | 20455 | 20422 | 18222 |
| Cape Pack Container load [kg] | 15841 | 16501 | 20161 | 15841 | 18001 |

| Bulk density [kg/m³] | 1000 | | | | |
|--|-------------|-----------|-----------|-----------|-----------|
| Product weight [kg] | 5 | 10 | 15 | 20 | 25 |
| SADIE Container load [kg] | 20536 | 23359 | 27207 | 27175 | 24250 |
| Cape Pack Container load [kg] | 16522 | 23041 | 25351 | 26881 | 26001 |

Unfortunately there is no way to see which of the results can be improved without actually doing the calculations. SADIE is designed only to give the overall picture. Should a more accurate output be required then the user is able to choose the best solution coming from the 2:1:2 start dimensions and can then try to improve it by fine-tuning. In most cases this will not result in an

improved solution, but as possible improvements of up to a few tonnes per container are possible it is definitely worth fine-tuning the optimum result provided.

5.2 Physical validation results

This section contains the results gained from the physical case size validation. It is divided into three parts, the preparation of the validation tests, the butter and the powder case size validation.

5.2.1 Test preparation

The bulk density of the butter was given by the work of Philpott (2008) whereas the bulk densities of the power samples were measured by the Fonterra test method (Appendix 2). The measured bulk densities were

- 480 kg/m³ – SMP FT09
- 570 kg/m³ – WMP AT12
- 680 kg/m³ – SMP IT05
- 960 kg/m³ – Butter.

These bulk densities were entered into SADIE with the parameters given in section 4.2 to find the best solutions. The calculated case sizes from SADIE are in table 9.

Table 9 Case solutions

| Name | Weight [kg] | Length [mm] | Width [mm] | Height [mm] |
|-----------------|--------------------|--------------------|-------------------|--------------------|
| SMP FT09 | 26 | 387 | 263 | 572 |
| WMP AT12 | 20 | 382 | 261 | 381.5 |
| SMP IT05 | 21.5 | 348 | 259 | 381.4 |
| Butter | 28 | 323 | 259 | 381.4 |

For every product, ten corrugated paperboard cases were ordered from a corrugated box manufacturer (Carter Holt Harvey Packaging, Levin) according to the dimensions in table 9. The corrugated paperboard cases were made on a

Kongsberg CAD cutting table. This affects the outcome of the test in so far that cases made on a sample table are normally not crushed by feeder rolls and printing plates. That means they are thicker than cases produced commercially. Furthermore, the inside dimensions can be slightly bigger than they are if the case would be from commercial quality due to the different creasing techniques used to produce the cases.

The supplied cases were measured to confirm and compare their dimensions with the dimensions in table 9. Table 10 shows an extract of the different measured case sizes out of Appendix 15.

Table 10 Extract of measured case sizes from Appendix 15

| | Case size | | |
|-------------------------|------------------------|-----------------------|------------------------|
| | Length [mm] | Width [mm] | Height [mm] |
| Butter 960 kg\m3 | 323 | 259 | 381.4 |
| | 320 | 255 | 381 |
| | 321 | 258 | 380 |
| | 320 | 257 | 382 |
| | | | |
| SMP 480 kg\m3 | 387 | 263 | 572 |
| | 383 | 259 | 570 |
| | 385 | 258 | 571 |
| | 385 | 259 | 570 |
| | | | |
| SMP 680 kg\m3 | 348 | 259 | 381.4 |
| | 345 | 257 | 379 |
| | 345 | 259 | 381 |
| | 347 | 253 | 380 |
| | | | |
| WMP 570 kg\m3 | 382 | 261 | 381.5 |
| | 379 | 256 | 383 |
| | 379 | 257 | 382 |
| | 382 | 256 | 382 |

As can be seen from table 10 there are differences between requested specifications and those supplied as a result of the manufacturing process. It was found out that the cases were almost every time smaller than the requested dimensions in a range of plus 2 mm to minus 6 mm. This is caused by the production equipment manufacturing tolerances.

5.2.2 Butter case validation

Butter is not free flowing like powder and has to be chilled to make it workable. The almost frozen state of the butter does not allow filling the case without getting voids. This is the reason why only an average packaging weight of 27.85 kg instead of 28 kg was reached (Appendix 15). The case itself showed enough free space on the sides of the butter block to fill it with 28 kg of butter. The pictures of this test are to see in Appendix 16. Some of the filled cases were not easily or completely closable which is again related to the difficulties filling the cases with the butter. To see if the butter really fits into the case exactly 28 kg of butter was stored at 40°C for two days. The butter melted and therefore all voids were closed. After cooling down the butter to a solid block it is clearly to see that the dimensions coming from SADIE are valid for butter. The figure 5.1 shows that the butter fits into the case with a small headspace of approximately 10mm.



Figure 5.2 Solidified butter in case after melting

All cases developed a bulge which was mainly caused by the difficulties of packing the butter into the cases. The melted butter, however, fitted into the case with only a very small bulge not even to see on figure 5.2. This had something to do with the temperature of the butter, which was still warm when evaluated. Furthermore, Middleton (1996) reported that butter shrinks by 3% when it is frozen from ambient temperatures to -15°C . That means that the bulge will disappear with further cooling of the butter.

The butter cases would have been packed on a pallet to see how they fit. It was intended to use a pallet with a size of 1060 x 790 mm but there was no pallet this size on site. Figure 5.3 shows how it would have looked if the right pallet would have been on site.

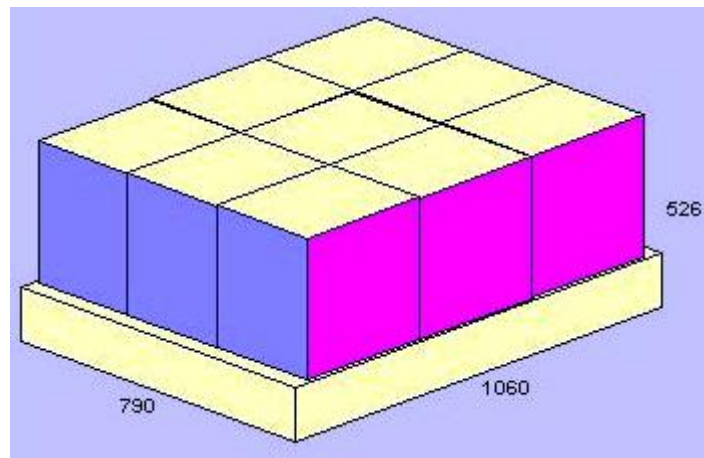


Figure 5.3 Butter cases on 1060 x 790 mm pallet

(System 2009)

5.2.3 Powder case validation

After the cases were taped together they were put one at a time onto a scale, a plastic bag inside them. They were then filled with the, for the corresponding case, right amount of powder by pouring it out of the powder bag into the plastic bag inside the case. A small powder hill due to the pouring prevented the cases from being closed. To be able to close the cases they had to be shaken. This allowed the case to be closed but at the same time resulted in a bulged case. The bulge was bigger the higher the height of the case was, hence the case for the SMP FT09 with a height of 572 mm had the biggest bulge.

Additional to figure 5.4 that shows a case after filling more pictures of the powder case validation are shown in Appendix 17.



Figure 5.4 Case after filling

Figure 5.5 shows the bulge that appeared after shaking the case to flatten the powder hill and close the case. The bulge was big enough to make problems closing the case (see Appendix 17).



Figure 5.5 Bulging after flatten the powder hill

After flatten the powder hill by shaking the case the powder fitted into the case. There was no measurable headspace which shows that the dimensions coming from SADIE are valid.

The closed cases would have then stored on a pallet like the butter cases. The same problem of the missing pallet there applied to the powder cases. Figure 5.6 shows how the pallet pattern would have looked if the right sized pallet would have been available.

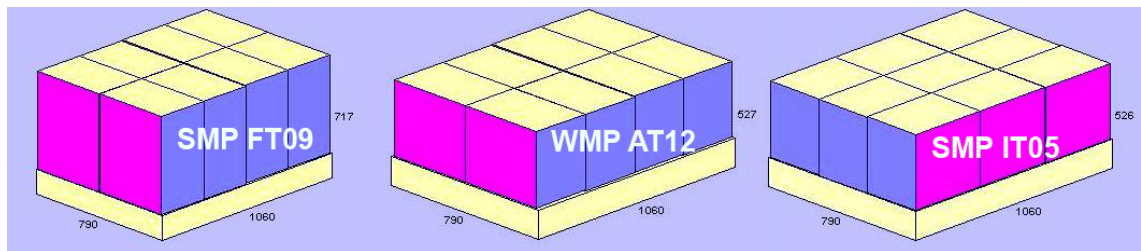


Figure 5.6 Theoretical pallet pattern for powder validation

A headspace developed after one day of storage. During this time the powder was not moved and had time to settle which resulted in a headspace of 10 to 20 mm (exact results in Appendix 15).

5.3 Results cost benefit analyses

Getting valid data for a cost benefit analyses (CBA) proved to be difficult. The average container load for a twenty foot container (5918 x 2337 x 2375 mm) for all the different Fonterra plants bulk density data was available was used. The data was gained by personal communication with Mr Meijer (2009). This was done for WMP and SMP.

SADIE was then used to calculate new packaging solutions with a bulk density that fits in the bulk densities range for the different Fonterra plants of table 2 in chapter 2. The shipped product per year was then divided through the container load for the respective solution. The result was the number of containers necessary to ship the same amount of powder using the new packaging solution. The results for both, WMP and SMP, are shown in table 11. The column “differences old/new” shows if savings through the new packaging solution are possible. Red numbers are an additional consumption of containers compared to the old number of containers used and therefore an aggravation.

Table 11 Results CBA WMP/SMP

| WMP | | | | | | | |
|------------------------------------|------------------------|-----------------------|-----------------------------------|--------------------------------------|--|-----------------------|---------------------------|
| Sales June 2005 to May 2006 | | | | | Results SADIE for 1120*982*1146 | | |
| Plant | tonnes year [t] | container year | average container load [t] | average BD [kg/m³] | container load [t] | container year | difference old/new |
| Plant 5 | 29449 | 1857 | 16.00 | 590 | 14.82 | 1987 | 130 |
| Plant 4 | 51324 | 3316 | 16.00 | 570 | 14.83 | 3461 | 145 |
| Plant 1 | 12573 | 829 | 14.00 | 480 | 13.03 | 965 | 136 |
| Plant 7 | 2795 | 178 | 16.00 | 600 | 16.68 | 168 | 10 |
| Plant 8 | 1327 | 83 | 16.00 | 610 | 16.62 | 80 | 3 |
| Plant 2 | 6283 | 452 | 14.00 | 480 | 13.03 | 482 | 30 |
| Plant 6 | 13626 | 934 | 16.00 | 580 | 14.82 | 919 | 15 |
| Plant 3 | 21614 | 1559 | 16.00 | 490 | 13.02 | 1660 | 101 |

| SMP | | | | | | | |
|------------------------------------|------------------------|-----------------------|-----------------------------------|--------------------------------------|--|-----------------------|---------------------------|
| Sales June 2005 to May 2006 | | | | | Results SADIE for 1120*982*1146 | | |
| Plant | tonnes year [t] | container year | average container load [t] | average BD [kg/m³] | container load [t] | container year | difference old/new |
| Plant 4 | 35815 | 1985 | 18.00 | 680 | 18.48 | 1938 | 47 |
| Plant 5 | 52714 | 2926 | 18.00 | 740 | 20.3 | 2597 | 329 |
| Plant 1 | 1079 | 60 | 18.00 | 740 | 20.3 | 53 | 7 |
| Plant 2 | 449 | 25 | 18.00 | 740 | 20.3 | 22 | 3 |

Table 11 shows that there is, except for three solutions, no improvement in container loadout for WMP. It looks different for SMP where all solutions are better than the one used before. Those differences are related to the sort of product and therefore the bulk density.

The results show that it is possible to get an improvement in container packing when the powder has a bulk density higher or equal to 580 kg/m³. This has to do with the compressibility of powder with a lower bulk density, in this case WMP. Low bulk density WMP compresses more when weight is applied than SMP. An experiment with the powder used for the physical packaging validation shows the bulk density change of SMP and WMP in the undermost layer of a pallet when the weight of six other pallets rest on it. The results are shown in table 12.

With a bulk density change of 66 kg/m^3 WMP can be compressed up to three times more than SMP. The bulk densities after compression are still lower than the measured tabbed bulk densities for the samples. If therefore the powder would be compressed over a longer period of time than done in the experiment a further increase in bulk density is expected.

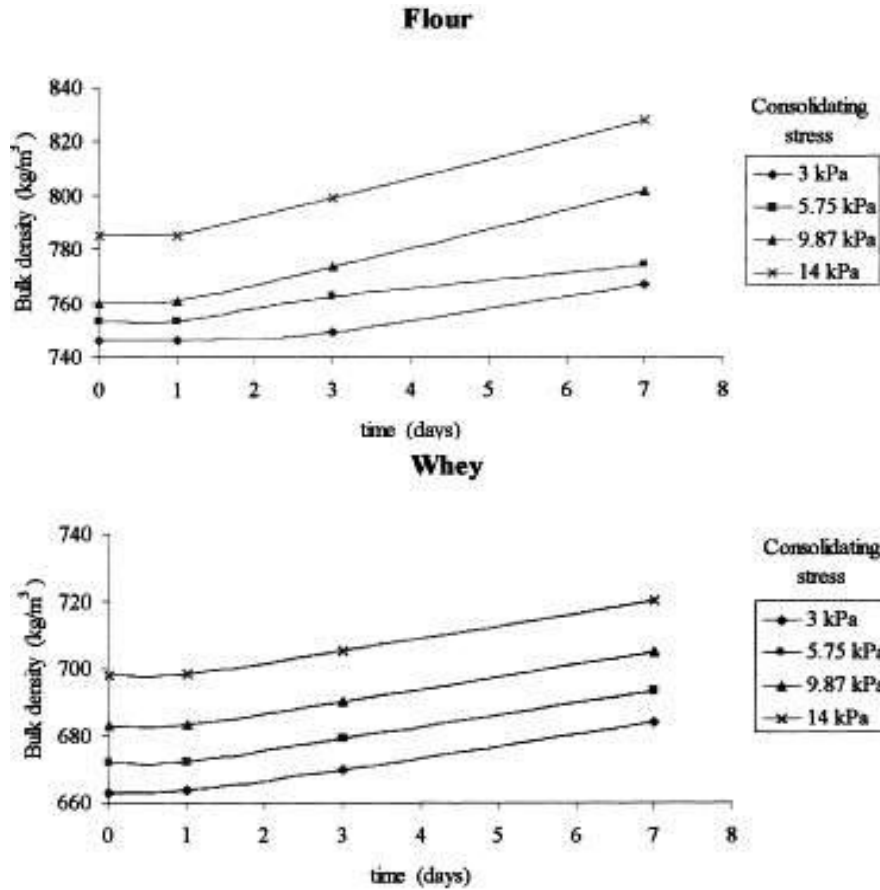


Figure 5.7 Variation in powder bulk density as a function of consolidating stress and time

(Fitzpatrick and Teunou 1999)

This is proven by Fitzpatrick and Teunou (1999) for whey and flour, two comparable products to WMP and SMP. Their results for flour and whey are shown above in figure 5.7.

Table 12 Bulk density change after compression equal to the weight of six filled pallets

| | SMP IT05 | | | SMP FT09 | | | WMP AT12 | | |
|--|----------|-----------|-----|----------|-----------|-----|----------|-----------|-----|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Density before [kg/m³] | 606 | 598 | 608 | 442 | 439 | 431 | 488 | 476 | 464 |
| Density after [kg/m³] | 635 | 631 | 635 | 470 | 462 | 456 | 532 | 539 | 532 |
| Difference [kg/m³] | 29 | 33 | 27 | 29 | 23 | 24 | 44 | 63 | 69 |
| Mean [kg/m³] | | 30 | | | 26 | | | 59 | |
| Mean without outlier [kg/m³] | | 28 | | | 24 | | | 66 | |

The results of the experiment explain why SADIE cannot come up with a better solution for lower bulk densities. Current practice has powder packed into multiwall bags. Those powder bags are not rigid like the corrugated paperboard cases used by SADIE; they are flexible and therefore able to change size if pressure is applied to them, especially those bags that have perforations in the liner. That shows itself in the pallet height, for example, if a pallet is filled with bags to a height of one meter and no other pressure is applied than the bags on the pallet, then the pallet height shrinks due to powder settling and the weight of the other bags resting on them. If, however, more weight in form of other filled pallets is applied then the pallet height shrinks even more. The problem is that it is not foreseeable how much the pallet height will shrink. The shrinkage depends on many factors like the plant that has produced the powder, the pressure applied to the pallets, the pallet pattern, the product, the de-aeration, the quality of the packaging material and most important the bulk density of the product. Figure 5.8 shows how the problem become manifest in real life.

The pallets contain all the same product and the same amount of bags stacked on them. In theory the pallet height should be the same for all pallets on the same level. Figure 5.8 shows that there are height differences up to 10 cm, sometimes more, between the pallets. If a pallet shrinks 10 cm in height another layer of bags would be possible. For a standard Fonterra container that means a plus of 80 bags per container.

Fitzpatrick's and Teunou's experiments and real life observations prove that the measured bulk density right after production of the powder is lower than the bulk density of the containerised products.

A rigid case, however, will always stay the same size, it does not matter how much weight is put onto it. The powder still settles and this will lead to a headspace inside the case as mentioned in section 5.2.3, but the height of the case stays the same.



Figure 5.8 Same pallet load, different pallet heights

Because of this reason are the WMP solutions coming from SADIE not as good as the solutions currently in use due to the changing bulk density from the time of measurement the data used in this analysis) and when the product is containerised.

A way to overcome these problems could be the use of Partial-Telescope Half-Slotted-Cases (PTHS) instead of RSC cases. PTHS cases (see figure 5.9) are suitable for powder products. The case can be overfilled and the style's flexibility allows it to remain intact as the settling or compression takes place. Furthermore, the style has great resistance to bulging when subjected to

overhead weight due to the two layers of corrugated board over a majority of the side and end panel.

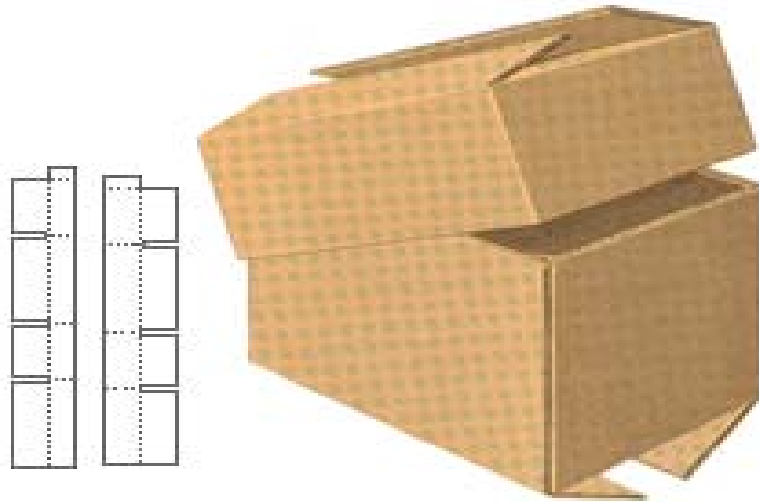


Figure 5.9 Partial-Telescope Half-Slotted-Case

(Fibre-Box-Association 2005)

Butter, however, is a different story. It is already packed in cases and shipped frozen in refrigerated containers. Based on a normal container load of 19.8 tonnes of salted butter an improvement in container load was possible for every solution coming from a SADIE Query (input weights: 15 to 50 kg in steps of 0.5 kg). Figure 5.10 shows the results of the Query.

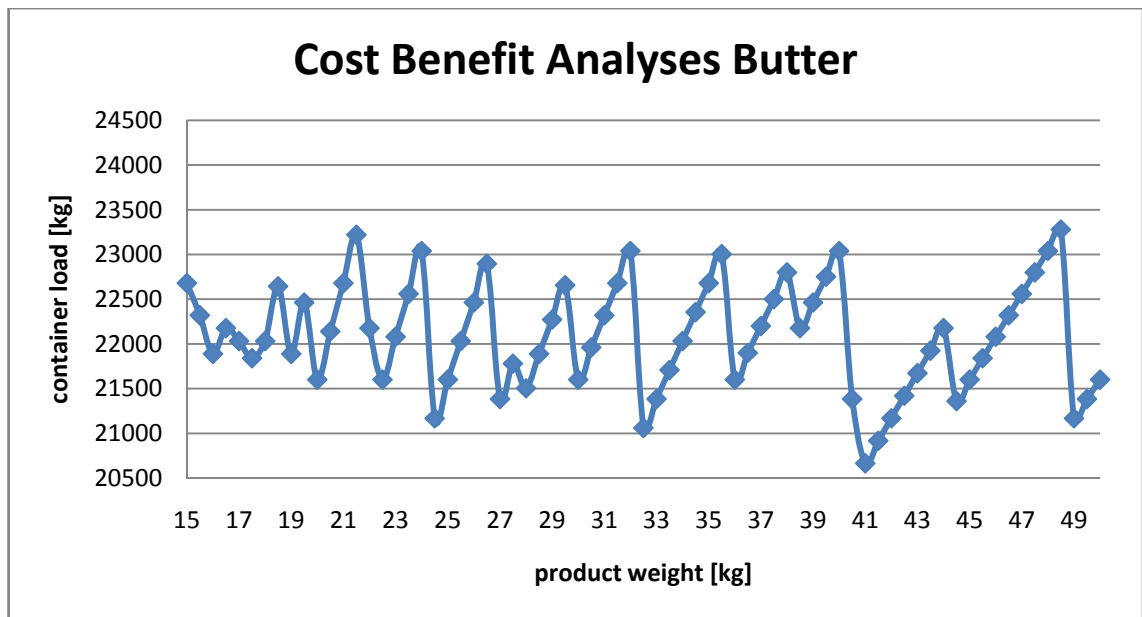


Figure 5.10 Cost Benefit Analyses Butter

Every result is higher than the normal 19.8 t per container with an optimum of 23.28 tonnes at a product weight of 48 kg. A more consumer friendly product weight of 21.5 kg still gives a container load of 23.22 tonnes, slightly less than the optimum and an improvement to the actual container load of approximately 15%. This means, for the season 2005/2006 numbers (Fonterra 2006) where 1565 container filled with 30987 tonnes of salted butter where shipped, 231 container could have been saved.

6. Conclusion

SADIE is a powerful tool that allows browsing of a huge amount of packaging solutions for different weight/bulk density combinations in a relatively short time compared to the large number of man-hours that would be required if the same Query would be handled manually on Cape Pack. For example, the relatively small Query shown in figure 5.7 contains 71 different weight/bulk density solutions and was done by SADIE in approximately 50 minutes. This Query done manually would have needed at least 120 min and somebody would have to sit next to the personal computer the whole time. SADIE, on the contrary, is fully automatic and therefore does not need supervision.

The results can easily be picked up and, for further processing, copied into Excel. The different key results from Cape Pack, like area and cube efficiency, container load and the packaging dimensions for every solution can be used for graphs that give an easy to understand overview over the whole Query. An example is shown in figure 6.1 where four different bulk densities over a weight range of 5 kg from 20 to 25 kg in steps of 0.1 kg were tested.

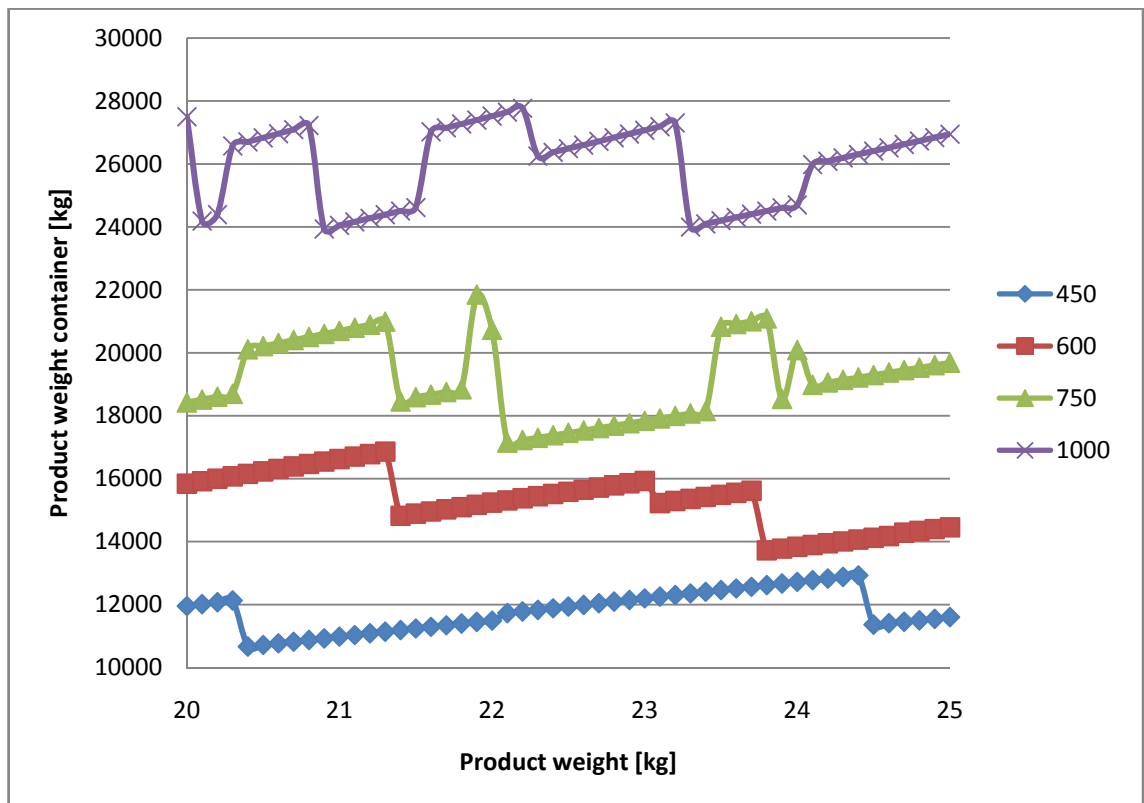


Figure 6.1 SADIE results of a Query (4 Bulk Densities, 20-25 kg in steps of 0.1 kg)

Graphs like this make it easy to see the best weight/bulk density combination the Query has to offer. Additionally, they allow seeing the differences in container load that can happen by changing the product weight by, in this example, 100 g. For a bulk density of 750 kg/m³ and a product package weight of 22 kg a container load of 20726 kg is possible. By changing the product package weight to 22.1 kg the container load shrinks to 17146 kg, 3580 kg less than possible before (Figure 6.1).

6.1 Powder packaging

An important problem with powder packaging are the different bulk densities for the same specification product from the same and from different plants. As table 2 in chapter 2 shows, the same powder products produced in different plants have totally different bulk densities. In reality that means that a good packaging solution for the powder of one plant can not necessarily used in another plant for the same product. This results in different packaging solutions for every plant which are making the whole packaging process much more difficult. Furthermore, the bulk densities are mostly measured right after the powder production. As explained in section 5.3 the bulk density increases while the powder is packed and shipped to the customer. This complicates the packaging process even more because no one can foresee how much the bulk density changes due to different factors, like product and applied pressure, that have to be considered. To overcome this problem the powder production process has to be standardised so that the same powder has the same bulk density in every plant. This, however, is a very unlikely outcome since every plant gets a different milk quality and uses different equipment and settings.

Another important step would be to actually measure the bulk density of the powders at the different parts of the production and packaging process which is not done by all the plants. This was one of the biggest obstacles that came up during the making of the project, the lack of reliable bulk density data. There is no real knowledge available about how much the bulk density is changing from production to customer delivery.

The knowledge of the bulk density for powder products is crucial for the whole packaging process.

Many problems during containerisation, like the wrong pack height or a packaging overhung on the pallet due to the wrong bulk density could be prevented by producing a specified and packaging approved bulk density. The containerisation would run smoother due to a pallet that fits into the container which results into time savings. It would also improve the health and safety on side. Health because no manual destacking would be necessary to bring the pallets into the container and safety because methods like lifting the container on one side to let the pallets slide in, a forceful entering with the forklift or pressure applied to the container doors with the forklift to close them would not be necessary anymore.

As the cost benefit analyses of WMP and SMP shows, an improvement in container load is not always possible when substituting a corrugated case for a multiwall bag due to the compressibility of the powder bags due to the changing bulk density particularly with the lower bulk density products (under 580 kg/m^3). A change to PTHS cases is approximately 30 – 50%, depending on the design of the case (Hartwell 2009), more expensive than using a RSC or the old bags but would give reliability. The footprint of the pallet would be always the same which makes containerisation easier, faster and more secure. It would also allow, as it is often the case during containerisation (Meijer 2009), to clamp a whole pallet layer at once to restack it on another pallet without having to do it manually. This, again, would result in time savings and an improved health and safety. With all these factors in mind the extra costs for the case might be worthwhile.

The cost benefit analyses shows that SADIE does not come up with better solutions for low bulk density powder (less than 580 kg/m^3) for reasons explained in chapter 5. If more accurate data on the bulk density of the packed powders was made available then SADIE would provide more usable results for the low bulk density powders.

However, SADIE is to be used for a confidential packaging project where it is able to come up with major improvements even for low bulk density powder.

6.2 Butter and cheese packaging

Changing the existing packaging size for butter and cheese is much easier than changing it for powder products. There is no big difference between the bulk densities; even when they are produced in different plants. That means in terms of packaging the motto “One size fits them all” can be used. One good packaging solution could be used in every plant, a standardisation of the production process is not necessary.

With high probability the new packaging solution has a different product weight from the traditional 25 kg for butter and 20 kg for cheese. A container load improvement of over three tonnes for salted butter and up to six tonnes for unsalted butter is possible by changing the product weight from 25 kg to 21.5 kg. Furthermore, the pallet size has to be changed to a pallet optimised for a refrigerated container (1115 x 900 mm).

Extensive economies in shipping cost would be the result of those changes. Taken the container savings for butter from section 5.3, depending on the destination of the butter, cost savings from 184,000 US\$ to 577,500 US\$ would be possible for salted butter alone per annum.

6.3 Implications

Side effects of working with SADIE can prove very useful for the production process of products with changing bulk densities. For example, the graph in figure 6.1, made with data coming from SADIE, shows that by changing the bulk densities the container load rises in steps and not continuous. This gives Fonterra a bulk density range they can produce, if stayed within, that will only slightly affect the packaging and containerisation process. On the other hand the graph shows how much the bulk density has to be changed to reach the next level to improve the container load. For example, there are two Fonterra plants that are close of being able to add another layer of milk powder bags on the pallet. Data shows that the powder they produce has a bulk density of around 700 kg/m³. If they would increase their bulk density to the next step at 720/730 kg/m³ they might be able to add the additional layer.

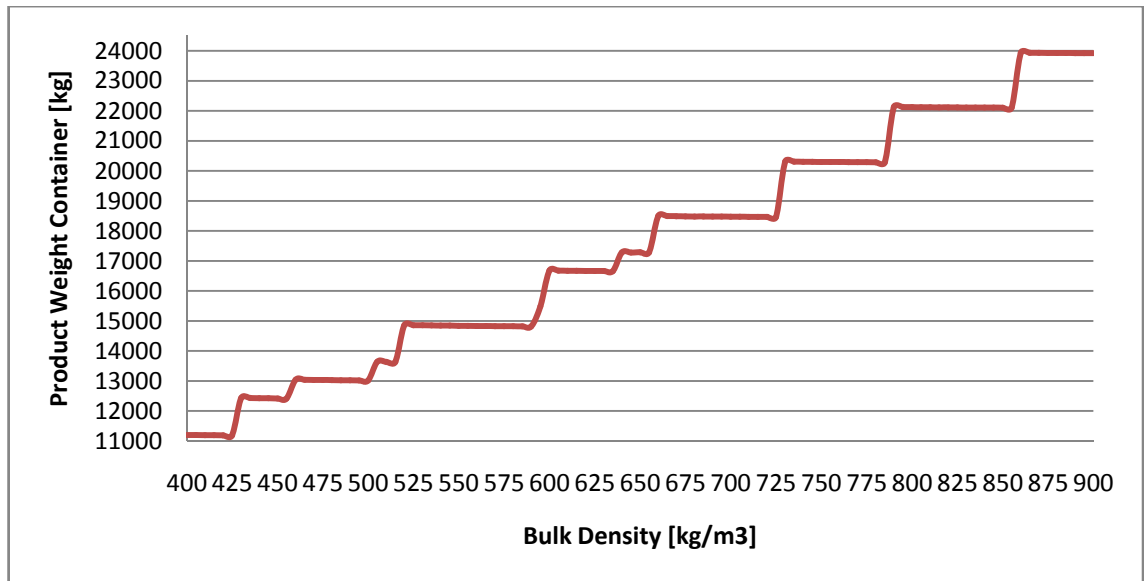


Figure 6.2 Container load change through bulk density change

The lack of powder bulk density data available does not allow a verifying of the possible improvement by increasing the bulk density as explained above. There is, however, a high probability that it is true. Nevertheless, it still has to be proven by experiments.

SADIE could also be used to optimise most of the Fonterra products to fit on the same pallet. Only two pallets would be necessary, one for dry goods and one for refrigerated goods. This would simplify the whole logistic and shipping process. It would solve storage problems in warehouses were the up to 30 different pallets Fonterra is using, have to be stored.

6.4 Recommendations

For future work this paper proposes to investigate the bulk density change of milk powder after it is packed. This involves

- the rate of powder compression over time, with and without any additional forces being applied on the packed milk powder, and also the impact of different types of vibration.
- to model the bulk density change of the packed milk powder from the time of manufacture to the customer, at each point through the distribution system.

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