DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATUREL AND APPLIED SCIENCES

AN EFFICIENT WAY OF SINGLE AND MULTIPLE CONTAINERS LOADING BY RESIZING THE BOXES

by
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İZMİR

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We have read the thesis entitled **"AN EFFICIENT WAY OF SINGLE AND MULTIPLE CONTAINERS LOADING BY RESIZING THE BOXES"** completed by **EVREN MEDİNOĞLU** under supervision of **ASSIST.PROF. ÖZCAN KILINÇCI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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AN EFFICIENT WAY OF SINGLE AND MULTIPLE CONTAINERS LOADING BY RESIZING THE BOXES

ABSTRACT

This thesis presents efficient ways of loading boxes into containers by resizing them. Two different problems are determined to apply the proposed method. First problem contains filling a single container with only one type of boxes. It is objected to pack maximum products in the container. In second one, customers give orders of different products and thus different boxes are tried to be filled efficiently in one or multiple containers in a fashion of blocks for purpose of minimizing the volume of the block areas and increasing the remained space for the next orders. Also a procedure and its sub-procedures and policies are defined to create more customer satisfaction. Two mathematical models are formed to solve the problems and three stages are defined in appliance of each. At first stage, the model is modified to the reduced form which has integer linear properties and applied to the current box sizes. Second stage uses the original model which has integer nonlinear properties and may not get global optimal solutions although operates in less time for the solution. Third stage contains reduced form of the model as the first stage. This time all candidates for box sizes are applied and global optimal solutions are found. At the end, a comparison for all stages and 2D visualizing of the solutions are given in order.

Keywords: Container loading problem (CLP); Single CLP; Multiple CLP; Mathematical modeling

KUTULARI TEKRAR BOYUTLANDIRARAK TEK VE BİRDEN FAZLA KONTEYNIRA YÜKLEMENİN ETKİN YOLU

ÖZ

Bu çalışma çeşitli ebatlardaki konteynırlara yüklenecek olan kutuların yeniden boyutlandırılarak en etkin şekilde yerleştirilmesi için belirlenen yaklaşımları, bunların sonuçlarını ve mevcut durumla karşılaştırılmalarını içermektedir. Bu yaklaşımların uygulandığı iki çeşit problem tanımlanmıştır. Birinci problemde bir (tek) konteynırın bir çeşit ürün için tasarlanan kutu tipiyle nasıl doldurulacağı ele alınmıştır. Buradaki amaç konteynır içerisine en fazla miktarda ürün yerleştirebilmektir. İkinci problemde, müşteriler farklı ürünler için sipariş verirler. Her ürün için ayrı kutu tipi tasarlanacak olup, her bir siparişe ait kutular bloklar halinde bir veya birden fazla konteynıra en etkin şekilde yerleştirilir. Burada etkin yerleştirme, blokların kapladığı alanların minimize edilmesi ve her bir siparişin yerleştirilmesi sonucu kalan boşluğun arttırılmasıyla sağlanır. Bununla beraber ikinci problem için daha yüksek bir müşteri memnuniyetinin sağlanması amacıyla bir prosedür ve bu prosedürün alt prosedürleri ve politikaları oluşturulmuştur. Bu problemlerin çözümü için iki matematiksel model oluşturulmuş ve her bir modelin uygulamasının sonuçlarının karşılaştırılması için üç aşama belirlenmiştir. Birinci aşama, modellerin "tamsayı ve doğrusal" özelliklerindeki indirgenmiş modeli kullanarak mevcut durumun performansını belirler. İkinci aşama, "tamsayı ve doğrusal olmayan" orijinal modeli kullanarak global optimum olmayan (lokal optimum) sonuçları verir. Bu modellerin bilgisayar programındaki işlem süreleri indirgenmiş modellere göre daha azdır. Üçüncü aşamada da indirgenmiş modeller kullanılır ve her bir olası kutu boyutuna uygulanarak global optimum sonuçlar elde edilir. Çalışmanın sonunda bu üç aşamadaki sonuçlar değerlendirilmiş ve etkin olarak yüklenmiş konteynırların 2B çizimleri verilmiştir.

Anahtar Kelimeler: Konteynır yükleme problemi, tek konteynırı yükleme problemi, birden fazla konteynırı yükleme problemi, matematiksel modelleme.

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CHAPTER ONE
INTRODUCTION

1.1 General Information about the Transportation

Transportation of items is the biggest component of the field of logistic. In developing countries it is assumed that the logistic costs are generally 20% of the total income of companies but in developed countries because volume of their sales are higher, this ratio is reduced to 10%. Also petroleum prices have a big effect on the logistic costs. Because the fuel of all the ways of transportation is still oil and the cost of it is rising continuously, transportation costs are getting more expensive day by day. Hence this forces companies giving more engineering effort to other logistic problems to gain cost advantage in the market.

Logistic costs are composed of four important components. Percentages of these components are given as below (http://www.muhasebedergisi.com/maliyet-muhasebesi/lojistik-maliyetler.html).

- 26 percent is warehousing,
- 9 percent is management costs,
- 20 percent is holding cost of inventory and
- 45 percent is transportation costs.

Transportation of items is mostly performing by standard sized containers as land or sea cargo. This provides many advantages to transportation planning and improves the safety conditions. To reduce the transportation costs per item, using the containers in an efficient way is very important. Some improvable points can be expressed as follows: an exact type of container for the items should be selected to fill the container safely and efficiently, a correct placement of items inside the container should be provided, an available way of transportation as sea, air, road or railroad should be selected by considering the shortest route to the customer and a correct placement of containers in the customhouses, warehouses or inside the transportation vehicles, especially, cargo boats should be determined.

1.2 Introduction to Container Loading Problems

Container Loading Problems are usually studied about packing fixed dimensional items into one or more containers which are also fixed dimensional items in an efficient way. As the forwarding offices mostly experienced, loading of containers without a plan may cause inefficient loads. This means that the container will carry less than it could be. So that causes the cargo is transported more costly. Although there are several approaches about the container loading pattern of fixed dimensional boxes, determining the pattern and the box dimensions at the same time is not considered too much. The current study contains packing boxes which their dimensions can vary according to the quantity of small sized plastic products put inside. By this way it is aimed to use the container space more efficiently without any dependency of box sizes although new variables are added to the problem. Also usage of the block arrangement packing pattern helps to create more stable and easy filling process.

1.3 Main Objective

The main objective of the problem in this study is to find new box dimensions for all types of products in order to maximize the total number of products being transported in a container. This objective also provides efficient usage of the container space beside. In this study, the quantity of cup maximization is more important than the utilization of the container space for us because there can be some situations which include the number of cups could get behind the desired value although the space usage is maximized.

1.4 Organization of the Thesis

This thesis is organized in five chapters. In the first chapter after giving general information about the transportation, container loading problems and the main objective of the thesis are introduced. The second chapter focuses on the literary review in two main types of problem: single and multiple containers loading problems. The third chapter gives the methodology of the proposed approaches and Filltype I and Filltype II are introduced. The fourth chapter shows the results obtained from the mathematical models for the example problems. The fifth and the last chapter gives the conclusion of the study. Finally the references and appendices which contain model formulations written in a computer program and outputs are given.

CHAPTER TWO
CONTAINER LOADING PROBLEM

The container loading problems (CLPs) are in interest of the researchers in the last couple of decades. These problems contain packing several small, three-dimensional, rectangular items (e.g. boxes) into a container (Eley, 2001). With the recent studies it is seen a rapid development in the research area, but there is still need to improve the current cases by being adapted to the real life well and decreasing the computation time of solutions. Although early studies consist of one or two dimensional (2D) approaches, as the research area has been enlarged and requirements are increased, three dimensional (3D) loadings have been put forward and researches have faced with a kind of NP-Hard problems. In two dimensional container loading problems different types of boxes which have identical heights are used to fill the container. Thus a two dimensional area is filled with the base dimensions of the boxes layer by layer aiming minimization of the remained area. This kind of problems is studied in the literature by solving them with knapsack type mathematical models (Guha, 2000). Also pallet loading problems (PLPs) are often constructed as two dimentional loading problem (Terno, Scheithauer, Sommerweiss, & Reihme, 2000). But more generalized CLPs are more complicated problems because all dimensions of the different types of boxes vary and this creates a huge number of loading pattern combinations and thus obtaining an optimal solution is getting harder.

The 3D CLPs are classified in two main subjects, which are composed due to the number of containers being filled. First subject consists of packing boxes into a single container. These problems are called as single container loading problems (SCLPs). The construction of SCLPs provides us to handle them as a well-known knapsack loading type problem. For the SCLPs, the objective is generally minimizing the wasted space of a specific container. Also the maximization of utilization of the container space could be chosen as an objective (Pisinger, 2002). But, in real world customers have other expectations behind these cost basis objectives; such as the safety of transporting, the ease of unloading, the packages availability. In recent studies, in the literature these expectations are also adapted to the problem by adding some constraints to the models. Most widely-known constraints can be signified as the orientation of boxes, the weight distribution of container and the load stability. Also, the predefined box dimensions, the predefined container or the truck type, the characteristics of boxes (e.g. durability of boxes) and the characteristics of boxed items or products (e.g. valuable products which are not demanded to be stowed) could be used as constraints in specific production systems. In second subject, more than one container is filled with boxes. These problems are called as multiple containers loading problems (MCLPs). MCLPs are also classified as bin-packing and multi-container loading problems. In bin-packing problems, all containers have fixed dimensions, and all the boxes are to be packed into a minimum number of containers. Multi-container loading problems are similar to the bin-packing problems except that the containers may have varying dimensions and the objective is to choose a subset of the containers which results in the minimum shipping costs. (Pisinger, 2002) Beside this categorization, also boxes are grouped according to their diversity in the container. If there exists only one box type to pack, it means that homogeneous box type is used to fill the container(s), but if there are more than one box type, then, heterogeneous box type is noted. Heterogeneity is studied in the literature as weakly heterogeneous box types which contain a few box types and strongly heterogeneous box types which have several box types for loading separately (Bortfeldt, Gehring, & Mack, 2002).

Because one of the six surfaces of the box can be used as a base for placement, several packing combinations can be derived. Thus, the researchers developed several heuristics to obtain an easy way to form a better loading pattern. For weakly heterogeneous boxes, the block arrangement approaches and creating walls, the layers or towers approaches are seen as efficient studies to load a cargo. But for strongly heterogeneous boxes, the cluster of the solution alternatives get bigger and the problem becomes more complicated to solve. In the literature, most of the researchers study how to decompose and then employ the residual space after loading a box is done and they have mostly used the search methods like the tree search, the tabu search or the genetic algorithm to find a loading pattern combination in a reasonable time. The literary reviews are given in two headlines as single and multiple containers' loading problems in the following pages and after that they are summarized and categorized in Table 2.1 and Table 2.2 to understand the container loading problems more easily.

2.1 Single Container Loading Problems

Pisinger (2002) defines the knapsack container loading problem (KCLP) as an extension of the wall building approach; but before explaining the approach some other approaches for container loading problem are put forward and classified as wall building algorithms, stack building algorithms, guillotine cutting algorithms, and cuboid arrangement algorithms. The proposed procedure is defined as four steps: determining the layers, determining the strips, determining how to fill the strips and pairing boxes.

Box dimensions always determine the layer depths or strip widths. A tree-search algorithm is used to find the set of layer depths and strip widths which results in the best overall filling. To decrease the complexity, an m-cut approach is used for the enumeration where only a fixed number (M) of sub-nodes are considered for every branching node. Thus nine ranking rules are given for determining M best layers or strips among all. These rules are based on choosing the M largest dimensions in order to get rid of difficulties in packing boxes or the M most frequent dimensions to obtain a homogeneous layer or strip with a good filling or the hybrid of them. Determining of filling the strips has formulated as well-known knapsack problem. If the strip is vertical then the total heights of boxes in the strip are tried to fit the height of the container efficiently. Else, if the strip is horizontal then the total length of the boxes in the strip are tried to fit the width of the container efficiently. The solution found by the Knapsack Problem may be improved by pairing boxes two by two whenever possible.

The example data has been created for weakly heterogeneous, strong heterogeneous and homogeneous types of boxes by author himself. Although random data has been used, a 95% (which is 5% more than others) of efficiency is achieved for large-sized instances.

In the paper of **Bortfeldt, Gehring and Mack (2002)** suggested a Parallel Tabu Search Algorithm (Parallel TSA) for loading the single container with a weakly heterogeneous set of boxes. They consider two constraints out of several for formulation of the problem. These constraints are orientation constraint and stability constraint. The proposed algorithm is structured into three modules: the lowest module, the middle module and the uppermost module. The lowest module consists of a simple heuristic, called basic heuristic, which serves the complete loading of a container. The middle module contains a sequential TSA (Parallel TSA is improved method of sequential TSA). For each solution generated by the TSA the basic heuristic is applied once. For the purpose of diversification, the search process is subdivided into several phases each carried out by the same but differently configured TSA. The uppermost module several differently configured instances of the TSA evolve independent search paths. The instances cooperate through the exchange of best solutions. The exchange always takes place at the end of defined search phases and exerts an influence on the further search of the individual instances. In parallel TSA, an instance of a container loading problem is treated by several processes. Each process is an instance of the sequential TSA and solves the complete problem at the same time. However, the individual instances are configured differently. The processes cooperate through the exchange of calculated solutions. In exchanging, the process reads a solution that was provided by another process. A transmitted solution is possibly used by the receiving process as a starting point for further search. The next neighborhood examined by the process is therefore the neighborhood of the foreign solution. While the varying configuration of the processes causes a diversification of the search, the exchange of solutions serves the intensification of the search within the regions of best solutions.

Although high utilizations of the container volume are already obtained with the sequential TSA, the parallelization of the TSA leads to a mean enhancement of the volume utilization of 0.66% of the container volume. It is clearly seen that the utilization values gathered from TSA algorithms (sequential and parallel) are over the 90% deadline while others are behind it.

The container loading problem studied by **Chien and Deng (2002)** is about filling a standard container with heterogeneous set of boxes.

A computer-based procedure and the matlab programming language is used to implement the proposed algorithm and a graphic user interface (GUI) is created for the user to input the data and visualize the packing pattern. The proposed computational procedure uses the wall-building concept that mirrors the actual container packing process and requires solving a series of knapsack-type sub problems that involve complex combinatorial optimizations. First, vertical strips are created by placing the boxes over and over and then these strips are combined into various lateral walls and the walls are combined into the container. The computational procedure is given in six steps. First step is initialization. The algorithm ranks the boxes in the order based on the five ranking criteria according to their base dimensions. Second step is selecting a box in the ranking order. The initially packed box determines the length and width of the corresponding strip. Third step is summarizing the empty spaces. Spaces are collected upward and merged then belong to the same lateral (or longitudinal) wall are collected and merged again. If there is no suitable space for the selected box then second step is applied. Fourth step is matching the box with the suitable empty spaces. The algorithm ranks the suitable spaces, by checking their referencing points, that the inner and lower spaces have higher priorities and select a space in the ranking order. Fifth step is packing the box, updating the data, and updating the spatial representations. After updating the data if there is any unselected box then second step is applied. Sixth step is cutting the packing process and generating the output. The packing processes stop when all the empty spaces are smaller than the unpacked boxes or all the boxes are packed.

In example A 20-ft dry containers are considered and 49 non-identical boxes are used. In total 11 containers are filled with these boxes and the utilization rates and computing times are collected. The proposed algorithm is compared with the greedy algorithm and the container space utilization rate is increased to 92.02% and the elapsed computing time is reduced to 370.483 second.

The procedure introduced by **Birgin, Martinez and Ronconi (2003)** tries to find the maximum number of cylinder centers that satisfy the restrictions of a rectangular container. A model based on a nonlinear decision problem is presented to solve the cylinder packing problem with identical diameters. Also all cylinders are assumed as they have the same height and the problem is taken into consideration as two dimensional problem.

The decision problem is about locating all the circles into a box or not. To find the answer for the decision problem an objective function (minimization) with the overlapping constraints is composed. To find the global minimizer(s), N different initial guesses are proposed as local minimizers and the problem is solved with each of these until finding a zero optimal cost. If a solution with optimal cost equal to zero is found, the answer for the decision problem is yes. Else if the answer is we do not know, this is assumed as no. These local minimizers are created by their new formulation using regularized hessians which are helpful to solve the integer nonlinear problem. By this way the probability of finding global minimizers is enhanced. Also, the scope of the decision problem is extended and the following questions are tried to be answered: how to pack as many circles as possible, how to pack identical circles into circles and how to pack nonidentical circles into rectangles and circles.

The proposed procedure is compared with some examples given by other papers. As a result this procedure gives better solutions at difficult problems which have big size of rectangle containers and several circles to be packed in.

Y. T. Wu, Y. L. Wu and Kong (2004) describe the Less Flexibility First (LFF) based algorithm for solving container loading problems in which boxes of given sizes are to be packed into a single container. The objective is to maximize volume utilization.

The order of packing is determined by the flexibility concept of two parameters. First one is the flexibility of empty space which corners are considered to have the least flexibility than other spaces. Second one is the flexibility of boxes which are depending on size and shape. That causes large boxes to be considered to have least flexibility than other boxes. The main idea of the Less Flexibility First Rule in packing order is that; less flexible objects are packed into less flexible positions of the container. Thus, it means that large boxes are packed first to the empty corners. In application of this rule, the representation of a packing relationship between a box and a corner is defined as a corner occupying packing move (COPM) and they are sorted in a list in ascending order of flexibility and packing moves are applied in this order. After a COPM is applied for a box, remained boxes are packed greedily and a Fitness Cost Function Value (FFV) of this move is calculated by dividing the volume of occupied space to the total volume of the container. After all FFVs of related box's COPMs are calculated, the COPM with highest FFV is picked from the list and really packed into the container. The corner list is then updated for later loadings. The authors used the Bischoff and Ratcliff test cases for comparing the performance of the LFF algorithm with the heterogeneous boxes and saw that as the heterogeneity increased, the volume utilization did not change so much and stood stable. Also they used Loh and Nee examples for comparison of LFF algorithm with other heuristics and they achieved the average volume utilization which was 70.1% and better than four other methods of Ngoi (1994), Bischoff (1995), Bischoff and Ratcliff (1995), Gehring and Bordfeldt (1997).

Lim, Rodrigues and Yang (2005) study the single container loading problem with homogeneous, weakly and strongly heterogeneous types of boxes. After applying the basic heuristic they have noticed the weakness of their heuristic and improved it using wasted space filling methods.

A Packing Tree Generating Heuristic is used to fill the container. This is a basic heuristic which packs the boxes greedily. The main idea is to partition the space after packing a box (or pair of boxes) into the container. This partition is composed of generating three sub-spaces. After generating the spaces, they are filled with boxes by the same partitioning strategy until no more boxes is packed. Thus, a tertiary tree could be composed to find the best branch to the solution. Because the considered algorithm uses the greedy algorithm which is based on ordering(or ranking) boxes and/or spaces to be packed in order to their volume or dimension, results were not desirable and remained behind the other algorithms in the literature according to the volume utilization criteria. Thus, the authors try to improve the heuristic for homogeneous and heterogeneous problems separately; because, the weak points of their heuristic for the homogeneous and heterogeneous problems were distinct. For homogeneous problems they have experienced that most unused or wasted space has been found to be at the boundaries of the container, so they have developed an algorithm which finds empty spaces and fills these spaces using 2D recycling method and their packing tree generating heuristic. For heterogeneous problems they have enhanced their greedy algorithm and used a more complicated method which is based on finding other packing combinations of boxes which may increase in volume utilization. The developments in algorithms were successful and as compared to others, it gives 0.25% better space utilization results than Han, Knott and Egbelu (1989) in homogeneous problems and 4.5% better than Bischoff and Ratcliff (1995) in heterogeneous problems. And, note that this algorithm is very like a tertiary-tree-based algorithm given in the paper of Wang, Li and Levy (2007).

The heuristic algorithm is presented by **Wang, Li and Levy (2007)** to solve the single container loading problem with weakly heterogeneous items. The objective of the algorithm is to determine a loading scheme that will maximize the space usage of the container. The approach employs a tertiary tree structure to represent the container space and develops a dynamic decomposition method to partition the space after a block of identical items is loaded. This dynamic decomposition, assisted by an optimal-fitting sequencing rule and an inner-right-corner-occupying rule, is designed to search for an optimal partition of the remaining space for next-step packing. A tertiary tree consists of a node that has either none or three nodes below it. So the different space decomposition scenarios and distinct searching paths which directly affect the efficiency and the quality of the solution can be formed in an easy way.

The heuristic algorithm is expressed by three concepts. The dynamic space decomposition, the optimal-fitting sequencing and the holistic loading. The dynamic space decomposition is the most important issue. After a block of boxes is loaded, the remaining empty volume in the current space can be divided into three mutually exclusive sub-spaces, corresponding to the left, middle, and right child nodes of the root in the tertiary tree. Each of the three subspaces (child nodes) is then set to be the current space sequentially from the left to the middle and then to the right node, and after a packing is done the same decomposition procedure is repeated for each new current space until no unused space is available in the container. Sub-spaces can be formed in different combinations. To determine the most available combination, authors give a dynamic space decomposition procedure that consists of four steps. After the dynamic space decomposition is finished, the optimal-fitting sequencing stage starts, and a box or group of boxes (includes identical boxes) and their orientations which maximize the efficiency of the space are chosen from several candidates for the current space (one of three subspaces). The choice is made by calculating and ranking every candidate efficiency value. It is possible that the chosen boxes can not form a cuboid block. So, the exact number of boxes is finalized at the holistic loading stage to form a cuboid block of boxes.

As a result, comparative studies indicate that only two out of the fifteen sets of test data can not be completely loaded in a container for this algorithm while the other four algorithms leave more boxes behind. Also it has been proved that the dynamic space decomposition is more effective behind other space usage strategies.

Nepomuceno, Pinheiro and Coelho (2007) present a novel hybrid approach for solving the Single Container Loading problem based on the combination (or hybridizing) of Integer Linear Programming and Genetic Algorithms. By this way, it is aimed at taking the advantages of two techniques and achieving acceptable optimal solutions with shorter execution time.

First Component of the described hybrid framework is the Generator of Reduced Instances (GRI) which is the master algorithm and uses the Genetic Algoritm. Second component is the Decoder of Reduced Instances (DRI) which aims to interpret and solve any of the generated problem instances coming out of the GRI. This is the slave algorithm and uses the exact method which is given as Integer Linear Programming. The application of the method is given as three steps. Mathematical formulation of the problem, identification of the reducible structures and specification of the metaheuristic sub-problem generator. The authors also adopted this method to the layer constructive packing. And they have studied as each generated layer can be treated as a distinct container loading problem, which must be solved by the hybrid algorithm. They have used the layer constructive packing in the comparison of heuristic of Bischoff and Ratcliff (1995). The results show that, their methodology has reached the mark of 86.53% of effective volume utilization of the container on average, and the 83.53% score achieved by the other heuristic- B/R.

Huang and He (2008) consider a single container loading problem which requires loading a subset of cuboid items into a single cuboid container so that the volume of the packed items is maximized. Weakly heterogeneous and strongly heterogeneous items are tried to be packed. The key issue is that the packing item always occupies a corner or even a cave if possible, such that the items are packed as compactly as possible.

Two definitions are introduced: Corner occupying action and Caving degree. A Corner Occupying Action (COA) is a packing action that places an item so that one of its vertices coincides with a corner. A COA includes three aspects: which item to be packed, which corner to be selected, and which item orientation to be set. Caving degree determines the availability of an item for the pointed cave and helps us to select an item that decreases the probability of creating more caves in further iterations. In other words, the higher the value of caving degree, the more desirable a cave is for the action item, because more surfaces of the item are pasted, more close it is to other packed items, and more area of its surface is pasted. (The surface of an item is 'pasted' when the surface contacts at least one surface of other items.) Caving degree consists of paste number, paste ratio and adjacent degree in its formulation.

At each step of placing an item to the container, the basic Algorithm A_0 always selects a COA with the largest Caving Degree and finds a near optimal solution. The strengthened Algorithm A_1 always selects a COA with the largest Pseudo Utilization at each step. When a COA is done to get a new step, pseudo execute the basic Algorithm A_0, then the final container volume utilization obtained by A_0 is called the pseudo utilization of this action. The strengthened top-N Algorithm A_2 is similar to Algorithm A_1. The only difference is that at each step, instead of considering all COAs, A_2 orders these COAs by A_0 ranking rules and just considers the best N actions. This is sometimes required to decrease the computation time and for this reason A_2 is maybe classified as a kind of tree search method. In summary, A_0 finds a way to near optimal solution. But a better way can be found by evaluating other item-cave pairs. So A_1 or A_2 are used to find a better solution or the best solution by searching all possible combinations of item-cave pairs and computing utilization of the container at each step.

In comparisons with other related studies, the without-orientation-constraint benchmarks are studied with the Multi-Faced Buildup Look-ahead strategy (which is called MFB_L) because its average packing utilization of 91% is the best result reported in the literature. As a result, A_1 achieves 3.9% (94.9%) better solution on average than MFB_L (91.0%). The strongly heterogeneous benchmarks are also analyzed. Because, A_1 takes a long time(over 10 hours), A_2 is used in comparisons. As a result, A_2 achieves 0.28% (87.97%) better solution on avarage than second better solution (PGA_GB) (87.69%).

Parreño, Valdez, Oliveira and Tamarit (2008) introduce a constructive algorithm and then a neighborhood search algorithm (like in the tabu search) for all kinds of container loading problems (homogenous, weakly and strong heterogeneous problems) to improve and compare the current studies. Only the stability constraint is adapted to the problem after the search algorithm is given. Other constraints do not take into account.

Firstly an initial solution is obtained by using the constructive algorithm. It is a basis for the search algorithm and has four steps: initialization, choosing the maximal space, choosing the boxes to pack and updating the list S. Variable neighborhood search (VNS) is a metaheuristic procedure and explores the solution space through a systematic change of neighborhoods. The aim is to avoid being trapped in current local solution and achieve a better solution near global optimal in the large cluster of packing combinations. The variation of the packing is reached by using different movements of the boxes from the initial slolution. And after defining the movements five different neighborhood structures are build from them. The movements are defined as layer reduction, column insertion, box insertion, emptying a region with best-volume filling strategy and emptying a region with best-fit filling strategy. The search of a better local optimal solution has done in two ways. First one is variable neighborhood descent (VND), and second one is VNS which includes shaking strategy. In VND, the best result of movements is used at each iteration. In VNS, random neighbors are created and a strategy known as shaking is used to escape from local optimal and more different combinations of packing are used. Thus, the computation of VNS takes more time than VND. Also, the effect of order of the neighborhoods and the cargo stability analysis are given in the paper. As a construction of the search method, a similarity is noticed between the study of Bortfeldt, Gehring and Mack (2002) about the parallelization of the tabu search.

For the comparison with other algorithms, the VNS strategy has been chosen and the complete set of 1500 instances generated by Bischoff and Ratcliff is used. And the proposed approach found 1% better results than other studies which are a parallel simulated annealing algorithm, a parallel hybrid algorithm, a massive parallel hybrid algorithm, and their older study, GRASP algorithm (Parreño, 2008).

2.2 Multiple Container Loading Problems

Raidl (1999) studies to pack a subset of the homogeneous and heterogeneous types of items in such a way that the total value of the packed items is maximized.

It has been denoted that multiple container loading problems have two strongly dependent parts which must be solved simultaneously: (a) select items for packing and (b) distribute chosen items over available containers.

The paper presents a GA that encodes candidate solutions by using a technique called weight-coding. After processing the GA, decoding heuristic is applied to get the actual solution. Encoding of the items is given in two classes: Direct encoding (DE) and Order-based encoding (OBE). Direct encoding (DE) means that a chromosome of the GA contains a gene for each item indicating directly if the item is supposed to be packed into the container. On the other hand, in order-based encoding (OBE), a chromosome contains a permutation of all items.

Two heuristics are given for decoding process. In Decoding Heuristic *A*, one container after the other is filled by going through all unpacked items and packing all items not violating the size constraint into the current container. Since the objective is to maximize the total value of all packed items, valuable items should be favored and ranked at the beginning. Thus, the processing order is obtained by sorting the items according to decreasing absolute or relative values. Absolute value of an item is gathered by multiplying item size and the relative value of it. Equally valuable items are ranked in random order. In Decoding Heuristic *B*, the containers are filled in parallel. For one item after the other, the container where the item fits best is identified. The GA uses random weights from a specific interval for the items initially. Then, by applying the mutation and crossover operators, variation is created in the population.

Experimental comparison shows that the GAs with the heuristics based on relative value item ordering which fills containers in parallel (Decoding Heuristic *B*) outperformed the heuristics that used absolute value item ordering.

Soak, Lee, Yeo and Jeon (2008) proposes a new evolutionary approach for multiple container loading problems. The proposed evolutionary approach uses Adaptive Link Adjustment Evolutionary Algorithm (ALA-EA) as a basic framework and it incorporates a heuristic local improvement approach into ALA-EA. The main goal is to propose a new evolutionary algorithm to encode and decode the items used for genetic algorithm. For the selection strategy, real world tournament (RWTS) selection and crossover-mutation operators are used. After these processes, two local search methods and a combination of them are presented. First method is empty space raising heuristic (ESRH). The main idea of ESRH is to raise the empty space of a specific container through the movement of packed items and to pack the current unpacked items into the raised empty space. Second one is exchange heuristic (EH). The main idea of EH is to check whether the packed items and the unpacked items are exchanged with improving of the fitness value. Then, as a combination of them a 2-step heuristic local search algorithm is given. This heuristic algorithm combines the previous two local search methods: ESRH and EH.

The results are gathered for the same and different container capacities and the comparison is made against other evolutionary approaches: WEBr which have been known to give very good performance at MCPP and made by Raidl. The authors report that the proposed algorithm is better at 20 test cases given in the paper of Raidl.

Terno, Scheithauer, Sommerweiss and Reihme (2000) study the multi-pallet loading problem which deals with efficient loading patterns of different types of boxes on pallets.

The constraints are given as the special conditions of the problem. These are weight condition, placement condition, splitting condition, connectivity condition and stability condition. As a different concept of the literature, the connectivity condition is about loading a single pallet only a type of boxes to satisfy the uniformity if the order demand of this box type is large enough. The solution approach is based on a complex branch-and-bound concept. After finding the upper and the lower bound for pallets needed to load the whole consignment, two main procedures are applied. The splitting procedure is an algorithm to find a partition of the whole consignment into k sub-consignments. It adapts the splitting, weight and placement condition. The loading procedure consists of loading the sub-consignments which are determined with splitting procedure efficiently. It adapts connectivity and stability conditions. Four types of loading strategies are given as the layer-wise loading of identical pieces (G4-heuristic), the layer-wise loading of pieces with same heights or height combination (at most 4 piece types, M4-heuristic), the generalized layer-wise loading of pieces of at most 4 types (M4-heuristic) and the generalized layer-wise loading of pieces of at most 8 types (M8-heuristic).

The comparison is done by using two groups of examples (1-Loh and Nee and 2-Bischoff and Ratcliff examples). For both groups the proposed approach generally provides similar results or approximately 1% better than the genetic algorithm and the tabu search algorithm.

The paper of **Eley (2001)** deals with a single and a multiple container problem at the same time with several type of heterogeneous items. It suggests building homogeneous blocks that are made up identical items and using same orientation within the block rather than building layers or towers in the container. First, a greedy heuristic is applied to solve a single container problem. Then, an improved heuristic (tree search) is introduced. Also, some objectives are added behind volume utilization objective; load stability and weight distribution. And third, the multiple container loading problem (bin-packing) which has an objective of minimizing number of containers needed is introduced.

Tree search is implemented for different item loading sequence alongside volume determined sequence (greedy heuristic) to find more utilized arrangements. In the tree each partial solution can be branched into 6 x m partial solutions where m is the number of different types of items and number 6 is the number of orientation options.

To evaluate each partial solution and realize the bounding, an evaluation function is developed. Evaluation function should include obtained volume utilization and potential for filling remaining spaces with remaining items. This function is determined by applying greedy heuristic. So the greedy heuristic becomes the lower bound of the partial solutions by the way that filling the remaining space of each partial solution. Breadth of the tree is determined by number of types and number of item orientations and depth of the tree is determined by number of items. Because a breadth or a depth searches seem to be inappropriate (#of partial solutions are too much-1.7 million only after third iteration) a search strategy is obtained by expanding only specified number of nodes to simplfy the search and avoid unnecessary calculations. These nodes have the highest evaluation function values and the number of them is determined by the breadth parameter. Because, an arrangement for an item can be found by applying different loading sequences, identical solutions may be created along tree. Thus, if two nodes have same depth and same number of items for all types, one of the two nodes is removed. This also simplifies the tree structure. With given test cases following objective parameters are examined along 8 different approaches. Volume utilization, stability, weight distribution and running times. For the modification of solving multiple container problems, two strategies are given. Sequential strategy considers single containers are filled one after other. But in simultaneous strategy, a given number of containers are filled at the same time.

As a result, introduced algorithm for single container problem with heterogeneous item types obtained better result among most of algorithms (except tabu search approach introduced by Bortfeldt and Gehring (1997)) although weight distribution and stability objectives are also added to volume utilization objective. Multiple containers problem is solved also by using improved algorithm among two strategies.

Takahara (2005) considers multiple containers and pallets packaging with weak heterogeneous types of boxes. The objective function is given as minimization of useless volume of containers or pallets.

Two kinds of loading procedure in multiple containers and pallets are considered: package priority procedure and container and pallet priority procedure. In package priority procedure loading sequence of packages (boxes) is determined. As a search strategy, in order to decide a package loading sequence, the meta-heuristics method which is based on a neighborhood search, such as local search (LS) and simulated annealing (SA), is given. In container and pallet priority procedure the priority of filling of containers and pallets are determined. Also note that containers are filled one by one. Three strategies are given to satisfy variation of solutions and find better results than regular local solutions. After this separation, a main logic of loading in multiple containers and pallets is given. This selects a sequence of boxes to be loaded first according to the package priority procedure. Then a container is selected according to the container and pallet priority procedure and the selected container is started to be filled until no boxes are available to be filled. At last a useless space of the containers and pallets value is calculated. After applying the search strategies the utilization values are calculated again to get a better value. Comparison of other filling methods of multiple containers such as local search (LS), simulated annealing (SA) methods proves that the proposed procedures gives 2% less useless space value than others.

The contents of the studies about single and multiple containers loading problems given above are summarized and catogorized in the titles of year, problem type, loading heuristics, solution approaches and the objective in Table 2.1 and Table 2.2. Also for multiple containers, loading methods and multiple container types are added to the tables. As it is seen, most of the studies are objected to fill a single container with fixed dimensional boxes in a more efficient way, thus it is possible to encounter more articles about single container loading than multiple containers in the literature.

Table 2.1 Classification of the SCLP (Single Container Loading Problem) Article

Authors	Year	Problem Type	Container Loading Heuristic(s)	Combinatorial Solution Approach(es)	Objective
Eley	2001	SCLP (Single Container Loading Problem)	Block arrangement	Tree Search	Maximization of the volume utilization
Pisinger	2002	SCLP	Wall-building	Tree Search, Mathematical model / Linear Integer Programming	Maximization of the packed item volume
Bortfeldt, Gehring and Mack	2002	SCLP	Block arrangement / Layer-building	Parallel Tabu Search Algorithm	Maximization of the packed item volume
Chien and Deng	2002	SCLP	Wall-building	Mathematical Model / Matrix computation	Maximization of the volume utilization
Birgin, Martinez and Ronconi	2003	SCLP	Cylinders Packing	Nonlinear Programming	Number of cylinders maximization
Y. T. Wu, Y. L. Wu	2004	SCLP	Remained space evaluation	Greedy Approach	Maximization of the volume utilization
Lim, Rodrigues and Yang	2005	SCLP	Remained space evaluation	Tree Search	Maximization of the volume utilization
Wang, Li and Levy	2007	SCLP	Remained space evaluation	Tree Search	Maximization of the volume utilization
Nepomuceno, Pinheiro and Coelho	2007	SCLP	Layer-building	Combination of Integer Linear Programming and Genetic Algorithms	Maximization of the volume utilization
Huang and He	2008	SCLP	Remained space evaluation	Tree Search	Maximization of the packed item volume
Parreño, Valdez, Oliveira and Tamarit	2008	SCLP	Layer-building / Space evaluation	Variable Neighborhood Search (VNS)	Maximization of the packed item volume

Table 2.2 Classification of the MCLP (Multiple Containers Loading Problem) Articles

Authors	**Year**	**Problem Type**	**Loading Method of several Containers or Pallets**	**Multiple Container Types**	**Container Loading Heuristic(s)**	**Combinatorial Solution Approach(es)**	**Objective**
G. R. Raidl	1999	MCLP (Multiple Containers Loading Problem)	Sequential / Simultaneous	Identical containers	Remained space evaluation	Genetic Algorithm	Maximization of the total value of all packed items
Soak, Lee, Yeo and Jeon	2008	MCLP	Sequential / Simultaneous	Identical / Different containers	Remained space evaluation	Genetic Algorithm	Maximization of the total value of all packed items
Terno, Scheithauer, Sommerweiss and Reihme	2000	MCLP	Sequential	Identical containers	Layer-building	Branch-and-Bound Approach	Minimization of the number of pallets needed
Eley	2001	MCLP	Sequential / Simultaneous	Identical containers	Block arrangement	Tree Search	Minimization of the number of containers needed
Takahara	2005	MCLP	Sequential	Different containers	Wall-building	Neighborhood Search	Minimization of the useless space of the containers and pallets

CHAPTER THREE
METHODOLOGY OF THE PROPOSED APPROACH

3.1 Problem Description

Liquids are packaged in cylindrical objects in order to ease filling and emptying process and these objects are generally produced from light materials such as plastics or glass which have also fragile properties. Thus, transporting these objects is usually carried out inside carton or plastic boxes which have reasonable sizes to be carried by a person in order to prevent them to be broken while forwarding. Boxes are produced in rectangular shaped geometry with a needful thickness to provide the stability when they are put over and over and alongside into a carriage. So the design of a box is determined by the properties of these cylindrical objects. Such properties are the physical attributes of objects: diameter, height, thickness and weight. There are several placement patterns of the cylindrical objects into a rectangular space. Figure 3.1 shows the most employed patterns in industries. Also there are several detailed studies in the literature about this subject. As an efficient approach, Birgin, Martinez and Ronconi (2003) presents a procedure based on a nonlinear decision problem to solve the cylinder packing problem which has an objective of maximizing the number of cylinder centers of objects with identical diameters. Figure 3.1 (c) shows an example of the result of their study.

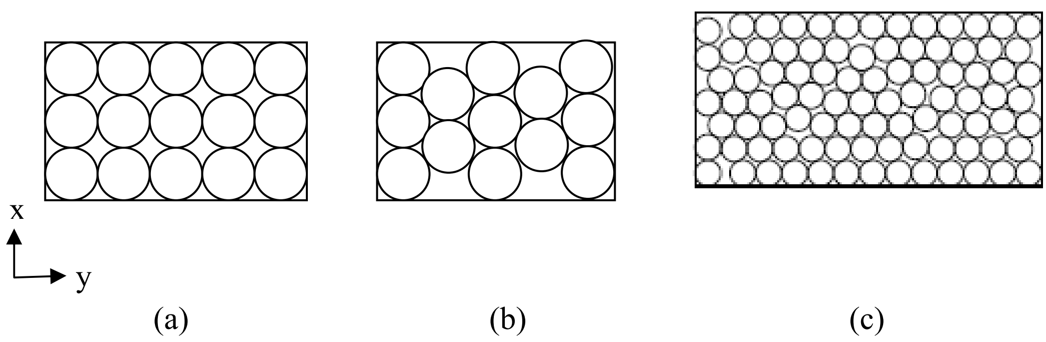

Figure 3.1 Examples of the placement patterns of the cylindrical objects in 2D.

As industries generally use the Figure 3.1 (a) because of the easiness of object placement process, box length and width is determined by diameter multiple of the identical cylindrical objects. (Thickness of the box is not considered) Otherwise, when the objects are not identical, different diameters are added up. In Figure 3.1 (b), to find the side dimensions, more complexive calculations are needed. This information was about two dimensions of the box. Third dimension is formed by stowing the objects. The stowage could be in two different forms: crowded form and overlapping form. If the object has a cavity like cups, then several objects can be put in another one in crowded form. As it is seen in Figure 3.2 (a) every added object increases the total height by its step height. This means that the base dimensions and the height of the box vary discontinuously according to the object's properties. Otherwise, because the object has a rigid structure, they are put on another one by overlapping inside a box. (Figure 3.2 (b)). In this manner total height is sum of the heights of stowed objects.

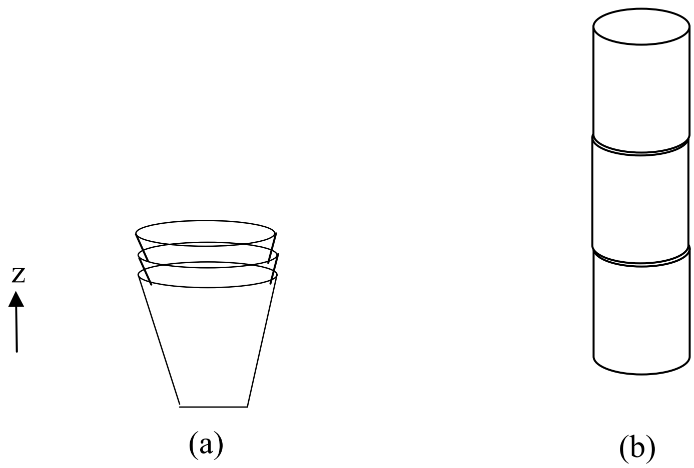

Figure 3.2 Examples of stowage forms. (Third dimension)

The boxes are then arranged in an order inside the container. This arrangement can be called as a different form of a cylindrical objects placement process in a rectangular space. This time rectangular objects are tried to be packed into a bigger rectangular space (e.g. container). At this point our problem contains arrangement of these boxes which are filled by 3D cylindrical cups with a given diameter, height and step height into a specific container.

Customers may desire the orders in two different sorts. First, they ask how many cups of a specific type can be transported in a container and if the quantity is reasonable, they order a container full of with these cups. So, the supplier should fill a container in an efficient way to send more cups at once. Second they demand different orders of cups. These orders may fill a container or need more than one container. Again a successive filling pattern is needed to fill containers in order to reduce the used space and the number of containers. But this time more than one type creates a handicap while operating filling process. Thus, this study considers these two facts and tries to determine better applications in the filling process. Therefore, we proposed two container loading procedures for these two conditions. The proposed Filltype I procedure determines the best container loading pattern for the first condition. And developed Filltype II procedure provides the orders to be located into the container by minimizing the unused space. Both of the procedures operate the loading pattern and resizing the box dimensions simultaneously. To the best our of knowledge, this is the first study searching them at the same time. Hence, the difference between most of the related studies in the literature and the proposed approach is performing the box resizing while obtaining minimum space usage.

3.2 Filltype I

3.2.1 Objective

The first condition mentioned above includes customers who order a single container loaded fully with one type of cups. So, loading more cups means selling more at once and needs less number of containers in sum. The study is objected to load much more cups in a container rather than obtain a better utilization of the space. Thus, to succeed in this objective the box dimensions should be determined again according to container and cup sizes. A mathematical model is constructed with integers to find an optimal (or near optimal) solution. The model assumptions, inputs, variables, notations and the formulation are given in the following pages.

3.2.2 Model Assumptions

Some assumptions should be highlighted to understand the problem and discuss about the study in terms of the subject matter. These are given as following for the problem model: Filltype I.

Fragile Properties: Only two box orientations are applied. Other four are not possible because of the fragile materials inside the box. An illustrative example is given in Figure 3.3.

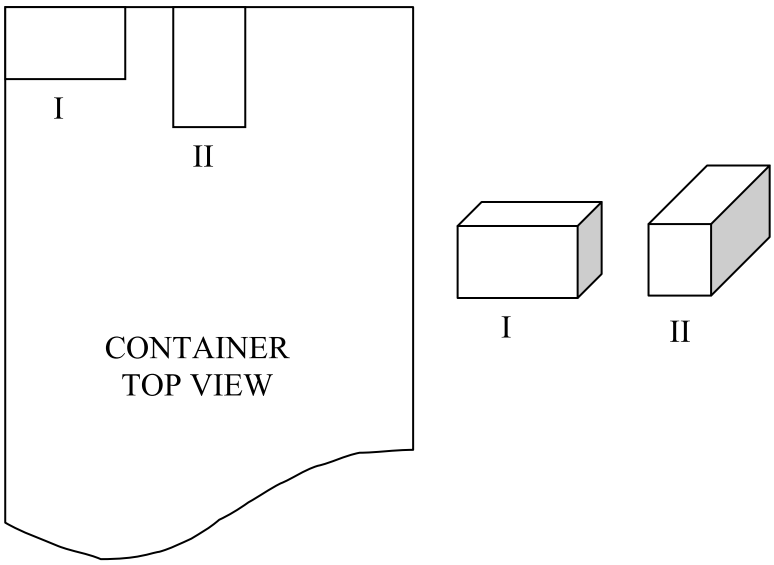

Figure 3.3 Available box orientations

Ergonomics: Boxes must be in appropriate dimensions and weight to be hold and carried by a person.

Cup Quantities: Number of cups in a box may not be at exact numbers and predetermined.

Pallets: Loading is done without any pallets. Boxes are placed on to the floor of the container.

Costs: Any cost which appears during the transportation transactions is not considered. Especially the supplier of the carton boxes is assumed not to be affected by producing different box orders. In other words, order quantity has not an impact on box costs.

The Container Loading Policy: Container loading pattern is based on building layer structures. The layers are then merged to fill the container. The width of the layers can be determined along the width (W) or the length (L) of the container. Because the selection does not affect the solution, the Filltype I approach assumes that the layers' width will be structured along the dimension of container W. An illustrative example about the layers is given in Figure 3.4.

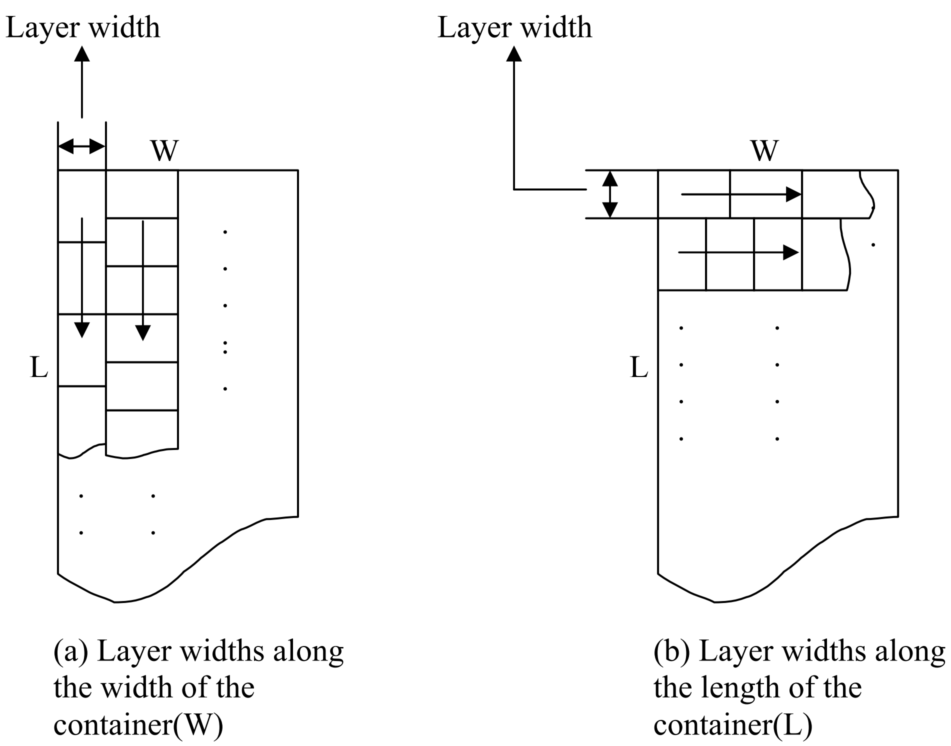

Figure 3.4 The Container Loading Policy representation

3.2.3 Model Inputs

Inputs of the model for Filltype I problem are given below. This data is used in the model as it is given by the company. Three categories are defined to explain the inputs. As first, container attributes, then box and cup attributes are determined.

Container Attributes: The width (W), the lenght (L), the height (H), the maximum weight of cargo (Cmax). The relevant example about container attributes is given in Figure 3.5 below.

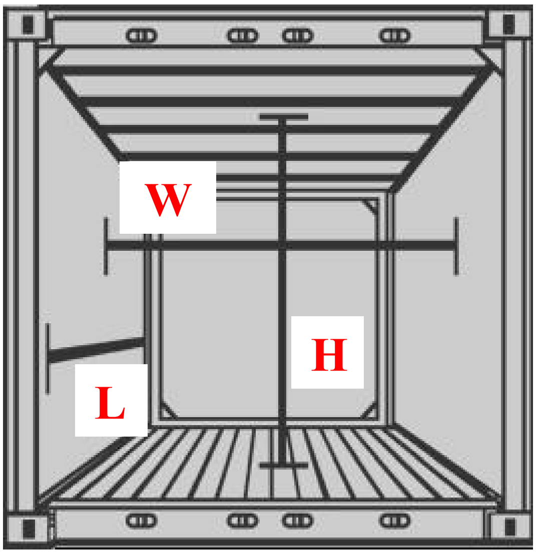

Figure 3.5 Container attributes

Box Attributes: The minimum and maximum width of the box for carrying-for ergonomics (xmin, xmax), the minimum and maximum length of the box for carrying -for ergonomics (ymin, ymax), the minimum and maximum height of the box for carrying -for ergonomics (zmin, zmax), the thickness of the carton (t), the weight of the carton (Bckg), the maximum weight of the box (Bmax). The relevant illustrative example about minimum and maximum box sizes is given in Figure 3.6 below.

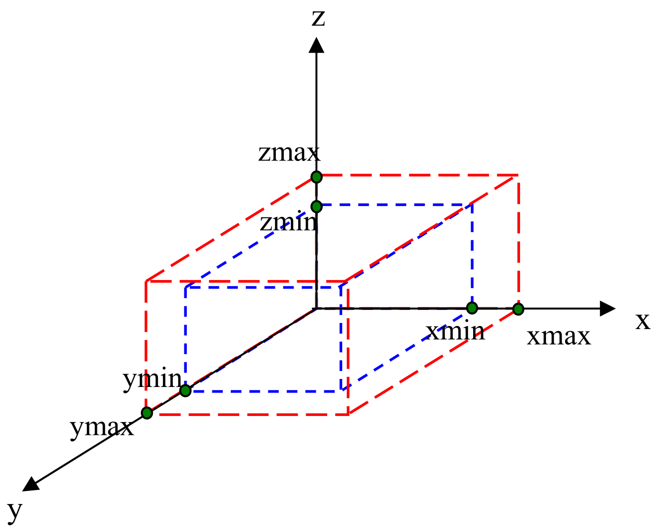

Figure 3.6 Box attributes

Cup Attributes: The diameter (DI), the height (hb), the step height (ha) and the weight (cgr). The relevant example photos about cup attributes are given in Figure 3.7 below.

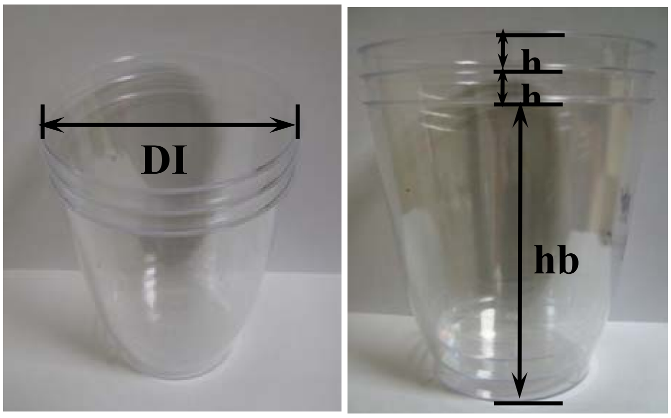

Figure 3.7 Cup attributes

3.2.4 Variables

The model variables are derived from the equations and used in the constraints.

Container Attributes: Utilization value of the container (U). It is also one of the decision variable of our problem.

Box Attributes: Width of the box (x), lenght of the box (y), height of the box (z), number of used width of the box along the width of the container (a), number of used length of the box along the width of the container (b), number of used width of the box along the length of the container (c), number of used length of the box along the length of the container (d), number of used height of the box along the height of the container (e), number of boxes in the container (BN), weight of the cups inside the box (Bikg). Illustrative examples of box dimensions (x, y, z) and other variables (a, b, c, d, e) are given in Figure 3.8, Figure 3.9 and Figure 3.10.

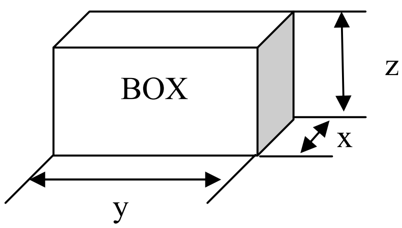

Figure 3.8 Box dimensions

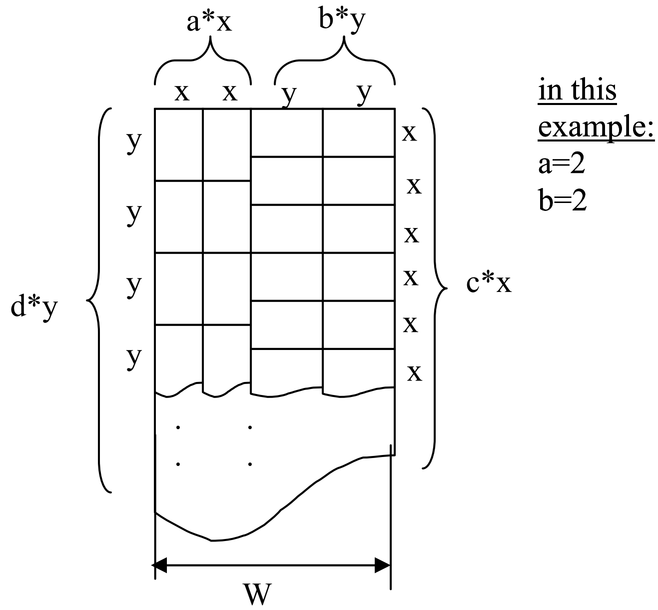

Figure 3.9 An illustrative example (upper view of the container)

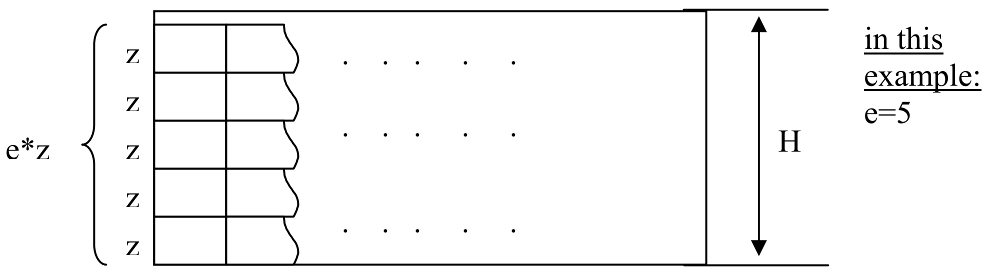

Figure 3.10 An illustrative example (side view of the container)

Cup Attributes: Number of cups in the box (CN), number of cups along the width of the box (m), number of cups along the lenght of the box (n), number of cups which increase the height of the box by its step height (p), number of cups along the height of the box (pe), total cup number in the container (TCN). “TCN” is also one of the decision variables of our problem. Illustrative examples of the variables (m, n, p) and the open forms of the box dimensions (x, y, z) are given in Figure 3.11 and Figure 3.12.

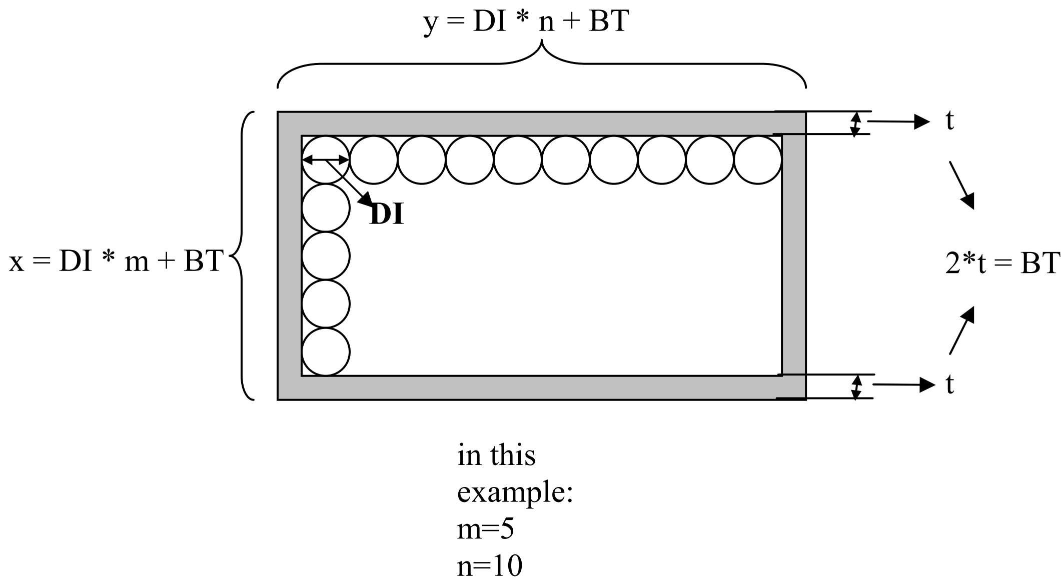

Figure 3.11 An illustrative example (upper view of the box)

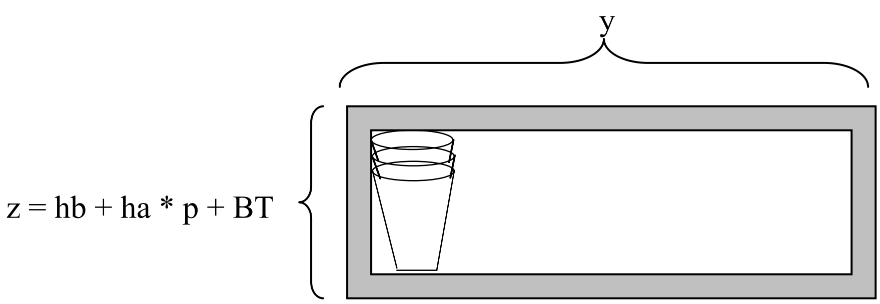

Figure 3.12 An illustrative example (side view of the box)

3.2.5 Notations

The decision variables and the model inputs are classified as container, box and cup data and given in Table 3.1, Table 3.2 and Table 3.3 below. The variables are denoted as “V” and the model inputs are denoted as “I” in the tables. Also note that the utilization value of the container “U” and the total cup number in the container “TCN” are the decision variables of our problem.

Table 3.1 Container Data

Term	Explanation	V/I	Unit
W	The width of the container	I	mm
L	The lenght of the container	I	mm
H	The height of the container	I	mm
U	Utilization value of the container	V	%
Cmax	The maximum weight of cargo in the container	I	kg

Table 3.2 Box Data

Term	Explanation	V/I	Unit
x	Width of the box	V	mm
y	Lenght of the box	V	mm
z	Height of the box	V	mm
xmin	The minimum x value (lower limit)	I	mm
xmax	The maximum x value (upper limit)	I	mm
ymin	The minimum y value	I	Mm
ymax	The maximum y value	I	Mm
zmin	The minimum z value	I	Mm
zmax	The maximum z value	I	Mm
a	Number of usage of the width of the box along the width of the container W	V	#
b	Number of usage of the length of the box along the width of the container W	V	#
c	Number of usage of the width of the box along the length of the container L	V	#
d	Number of usage of the length of the box along the length of the container L	V	#
e	Number of usage of the height of the box along the height of the container	V	#
t	The thickness of the carton	I	Mm
BT	The total thickness of the carton on both sides of the box	I	Mm

BN	Number of boxes in the container	V	#
Bckg	The total weight of the carton for boxes and the pochette for cups	I	Kg
Bikg	Weight of the cups inside the box	V	Kg
Bmax	The maximum weight of the box	I	Kg

Table 3.3 Cup Data

Term	**Explanation**	**V/I**	**Unit**
DI	The diameter of the cup	I	Mm
hb	The height of the cup	I	Mm
ha	The step height of the cup	I	Mm
CN	Number of cups in the box	V	#
cgr	The weight of the cup	I	gr
m	Number of cups along the width of the box	V	#
n	Number of cups along the lenght of the box	V	#
p	Number of cups which increase the height of the box by its step height	V	#
pe	Number of cups along the height of the box	V	#
TCN	Total cup number in the container	V	#

Explanation of the equations which are used in the model should be given to understand how to find the variables. The equations are as following:

1- U = (BN * x * y * z) / (W * L * H)

Utilization measures the efficiency of the usage of the container space which is filled by boxes. This is an important decision variable for us to evaluate the solutions. It is calculated by dividing the total volume of the boxes to the volume of the container space. The total volume of the boxes is calculated by multiplying the dimensions of the boxes (x, y, z) and the number of the boxes in the container (BN). And the container space is found by multiplying its dimensions (W, L, H).

2- x = DI * m + BT

"x" variable is one of the dimensions of a box and gives the width of it. Because, our problem contains resizing the box dimension, "x" value becomes a variable and is determined by adding box thickness (BT) to the multiplication of diameter of the cup (DI) and number of cups along the width of the box (m) (See Figure 3.11).

3- y = DI * n + BT

"y" variable is one of the dimensions of a box and gives the length of it. Because, our problem contains resizing the box dimension, "y" value becomes a variable and is determined by adding box thickness (BT) to the multiplication of diameter of the cup (DI) and number of cups along the length of the box (n) (See Figure 3.11).

4- z = hb + ha * p + BT

"z" variable is one of the dimensions of a box and gives the height of it. Because, our problem contains resizing the box dimension, "z" value becomes a variable and is determined by adding box thickness (BT) and height of the cup (hb) to the multiplication of the step height of the cup (ha) and the number of cups which increase the height of the box by its step height (p) (See Figure 3.12).

5- pe = p + 1

"pe" gives the number of cups along the height of the box. It is found by adding the variable "p" only one which represents the last cup in the stack (See Figure 3.13).

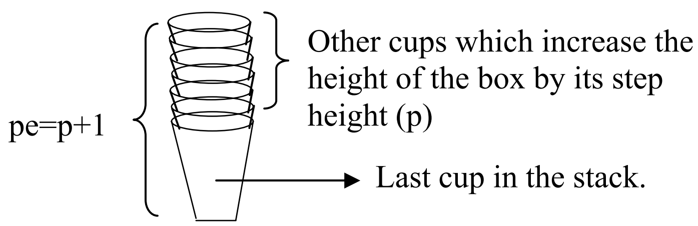

Figure 3.13 An illustrative example

6- BT = 2 * t

"BT" gives the carton thickness in a dimension (See Figure 3.11).

7- CN = m * n * pe

"CN" is gives the number of cups in the box. It is calculated by multiplying the number of cups placed on the floor and the number of cups along height of the box.

8- BN= (a * d + b * c) * e

"BN" gives the number of boxes in the container. It is found by multiplying the number of boxes placed on the floor and the number of boxes along height of the container (See figure 3.14).

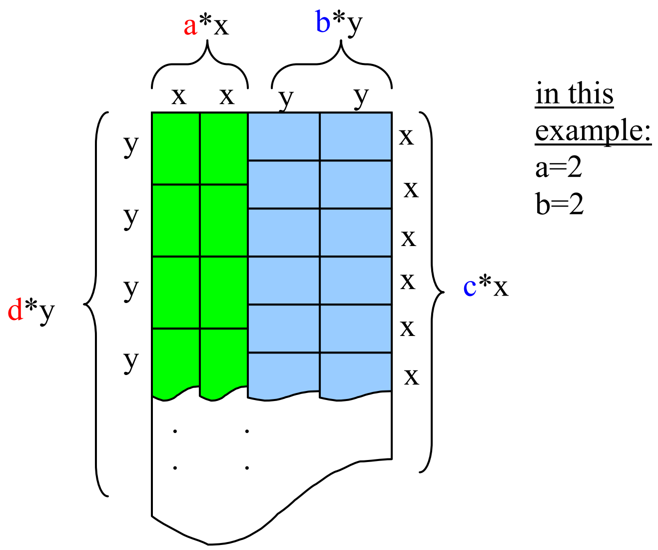

Figure 3.14 An illustrative example

9- Bikg = cgr * CN / 1000

"Bikg" is the weight of the cups inside the box. It is found by multiplying the number of cups in the box (CN) and the weight of the cup. And the unit of kg is found by dividing it to 1000.

10- TCN = BN * CN

"TCN" is the total cup number in the container and found by the number of boxes in the container and the number of cups in the box.

3.2.6 Formulation

The mathematical model can be given as following with the assistance of the definitions and the equations above. This model is also called as the main form of Filltype I in the following sections.

THE MAIN MODEL:

Objective function (Maximization of cup quantity)	Maximize TCN (11)
Box availability constraints (Ergonomics)	$x \leq xmax$ (12)
	$x \geq xmin$ (13)
	$y \leq ymax$ (14)
	$y \geq ymin$ (15)
	$z \leq zmax$ (16)
	$z \geq zmin$ (17)
Rotation constraints (Placement)	$a * x + b * y \leq W$ (18)
	$c * x \leq L$ (19)
	$d * y \leq L$ (20)
	$e * z \leq H$ (21)
Box weight constraint	$(Bikg + Bckg) \leq Bmax$ (22)
Container cargo weight constraint	$(Bikg + Bckg) * BN \leq Cmax$ (23)
Integer constraints	a, b, c, d, e, m, n, p are integers (24)

The objective function (11) expresses the maximization of quantity of cups in identical boxes loaded in a container (See the equation 10). The box availability constraints (12-17) and the box weight constraint keep the boxes in acceptable sizes and weight which can be hold and carried by a person and provide ergonomics (See the equations (2, 3, 4)). While three of six constraints of box availability give the minimum other three give maximum limits in three dimensions. The rotation constraints (18-21) are the key constraints of the model and assure the placement of boxes inside the container. First constraint supplies sum of the dimensions of x and y located along the width of the container not to exceed W. Because, we create a combination of x and y dimensions in the width, two terms must be in the same expression (See Figure 3.9). Other three constraints supply the layer lengths and heights not to exceed container dimensions L and H. The box weight constraint (22) provides not to exceed the box weight limits. Total weight of a box can be found by adding the weight of the cups inside the box (Bikg) and the total weight of the carton for boxes and the pochette for cups (Bckg) (See also the equation 9). And the container cargo weight constraint (23) provides the weight limits of the container and the transportation vehicle. Total weight of a container can be found by multiplying the total weight of a box and the number of boxes in the container (BN). At last, eight variables are used as integer numbers (24).

3.2.7 Solution Process to Filltype I

Because the structure of the formulation contains variables as multiplication or division of other variables in objective function and in the constraints, the problem can be called as an integer nonlinear problem. As we have experinced the solutions of the integer nonlinear program could not be global optimals, we assume that this creates a trouble about the positiveness of the study. Thus because we have to make sure about solutions given as global optimal(s) and how much the program is close to the real global optimal(s), the formulation given above should be modified to a structure which has integer linear properties and solved again. The modification process includes transforming some variables into the model inputs. When the objective function and the constraints are examined in order to eliminate the nonlinear expressions from the formulation, it is seen that one of “a” and “d” and one of “b” and “c” variables also all of “e”, “m”, “n”, “pe” variables must be transformed into the model inputs. Below open form of the objective function is given and note that its terms are all variable.

Objective function open form: TCN = (BN * CN) = (a * d + b * c) * e * m * n * pe

Thus, when we transform the “m”, “n”, “pe” variables into the model inputs, we can calculate the box dimensions (x, y, z) by using the equations (2, 3, 4). Also, by this way the number of boxes along the length of the container becomes clear and “c” and “d” variables are also calculated easily by rounding the results of the equations given below down to the nearest integer value.

c = (L / x)
d = (L / y)
e = (H / z)

Then only “a” and “b” variables of the formulation are left. This means that only “a” and “b” will be obtained from results and this time the first rotation constraint and the weight constraints will be left behind and the formulation gets an integer linear structure (See Figure 3.9). When this reduced form of the formulation is used, the problem will be solved for all alternatives of the box dimensions inside the box availability or ergonomics limitations. In derivation of these alternatives, “x”, “y” and “z” variables are found from the equations (2, 3, 4). While “x” and “y” variables increase as only “DI” value inside the intervals of [xmin, xmax] and [ymin, ymax], “z” variable increases as “ha” value inside the interval of [zmin, zmax] for each alternative. For example, in Figure 3.15 the upper view of the box is given and it is clearly seen that “x” and “y” dimensions of the box can be changed by “DI” value inside the limits. Also two examples of the box alternatives in upper view inside these intervals are given afterwards. Similarly, in Figure 3.16 the side view of the box is given, “z” dimension of the box can be changed by “ha” value inside the limits. Again two examples of the box alternatives in the side view inside this interval are given afterwards. Then, the box dimensions give the best objective value chosen from the solution cluster which is developed from these alternatives. The reduced form of Filltype I is given in next section with new model inputs and calculations.

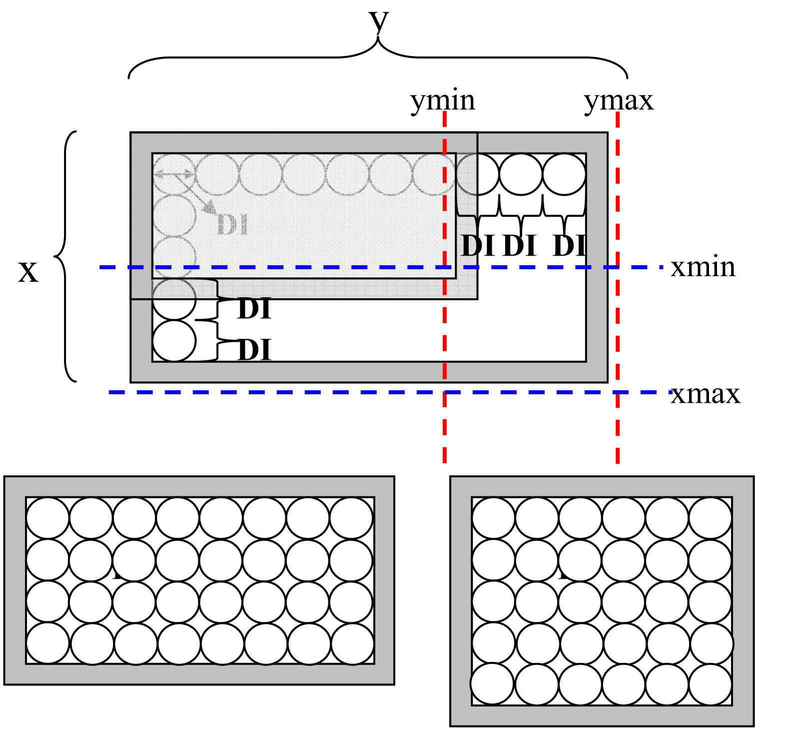

Figure 3.15 An illustrative example (upper view of the box)

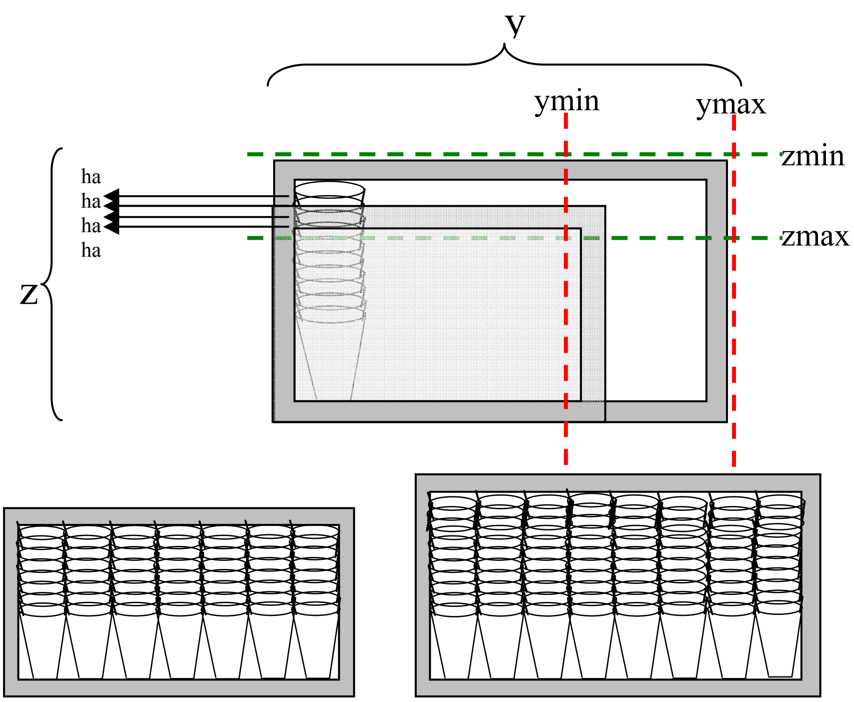

Figure 3.16 An illustrative example (side view of the box)

3.2.8 Reduced Form of Filltype I

3.2.8.1 Model Inputs

Because all alternatives of the box dimensions are developed and operated for the reduced model, the box dimension limits (xmin, xmax, ymin, ymax, zmin, zmax) are not needed and removed from the inputs. Additional inputs: m, n and pe values.

3.2.8.2 Reduced Formulation

The mathematical model can be given below with the assistance of the definitions and the equations above. This model is also called as the reduced form of Filltype I in the following sections.

THE REDUCED MODEL:

Objective function (Maximization of cup quantity)	Maximize TCN (25)
Rotation constraints (Placement)	$a * x + b * y \leq W$ (26)
Box weight constraint	$(Bikg + Bckg) \leq Bmax$ (27)
Container cargo weight constraint	$(Bikg + Bckg) * BN \leq Cmax$ (28)
Integer coonstraints	a, b are integers (29)

Because the main model of Filltype I contains nonlinear expressions, some constraints should be removed to transform the model to a linear structure which provides exact solutions. By this way the box availability constraints (12-17), the rotation constraints except first one (19-21) and the integer constraints (24) except “a” and “b” are omitted from the main model. But as a difference in the operation of the main model, the reduced model will be run for each alternative of the box dimensions (x, y, z) and the objective value for each (x, y, z) combination will be compared and the best one will be chosen.

3.3 Filltype II

3.3.1 Objective

The Filltype II is about the second condition of the study. In this condition, the customer may desire more than one type of product and these distinct orders may fill a container or need more than one container. Thus the dimensions of more than one type of boxes which fulfills the container efficiently are tried to be find. The solution process for Filltype II is developed as like the solution process for Filltype I. In Filtype II procedure behind the determination of the box sizes, the objective is to minimize the volume of the block areas which contains a particular order quantity of cups. This structure will also provide cup maximization in this space. Obtaining this objective differs from Filltype I; because, there is not an exact size of the space like a container to fill. Just blocks are created inside the container space for a specific order.

After the filling process is finished, some orders could be remained unpacked. Thus, more than one container may have to be filled. Filltype II process again can be used to fill other containers. By this way multiple containers are filled efficiently by designing the box dimensions simultaneously.

3.3.2 Model Assumptions

The Filltype II includes the assumptions below as an addition to the Filltype I assumptions. (See section 3.2.2)

Cup Types: A customer demands only a few types of cups. This means that weakly heterogeneous box types are considered in loading process.

Order Quantity: Order quantity of a cup should not be too much to fill the container fully; but, also should be large enough to fill a layer. Otherwise Filltype I is more available for filling process. Because of the layer-based structure of the blocks, the orders may not be created at an exact number of the quantity given by the customer. Thus, it is assumed that customers give a tolerance of only one box of cups to exceed the order quantity.

The Order Cutting Policy: When the orders cannot fit into the container, we assume that an available order may have to be cut to fill the container more efficiently. It is applied in order to satisfy the customer priorities while maximizing the container space usage and prevent to spend unnecessary time in processing. The explanation of the policy are given in the title of *The Order Cutting Policy* in section 3.3.8.

Mixing the orders: It is not allowed the boxes of different orders to be mixed. Because of the block arrangement structure, an area of a block should be filled only a specific type of boxes.

Fixity Rule of Cut Orders: When an order is cut, box dimensions determined for the first container will be used in second container as well.

3.3.3 Model Inputs

The Filltype II includes the inputs below as an addition to the Filltype I inputs. (See section 3.2.3)

Cup Attributes: Order quantity of the cup types (O).

3.3.4 Variables

We have used the total cup number in the container (TCN) and the utilization value of the container (U) as the decision variables of Filltype I. But, because

Filltype II needs a different solution approach, the decision variables are changed and given as below. Other variables of the model are remained as given in section 3.2.4.

Container Attributes: Width of the block area (Ls), cumulative utilization of the container (U_{cum}). Two of them are also determined as the new decision variables of the problem.

3.3.5 Notations

Filltype II uses the variables and inputs given in section 3.2.5 and in Table 3.4 and Table 3.5 additionally below.

Table 3.4 Additional container data

Term	**Explanation**	**V/I**	**Unit**
Ls	Width of the block area	V	mm
U_{cum}	Cumulative utilization of the container (replacing with U)	V	mm

Table 3.5 Additional cup data

Term	**Explanation**	**V/I**	**Unit**
O	Order quantity	I	#

Filltype II uses the equations (1-10) and (30, 31) additionally. The new equations 11 and 12 are given as below.

30- Ls = a * x + b * y

"Ls" is the width of the block area which is formed by the boxes of an order. When all cups of an order are placed and create a block inside the container, "Ls" determines the shortest width of this block (See Figure 3.17). In the example, red, blue, purple and green coloured Lss indicate the first, second, third and fourth order successively.

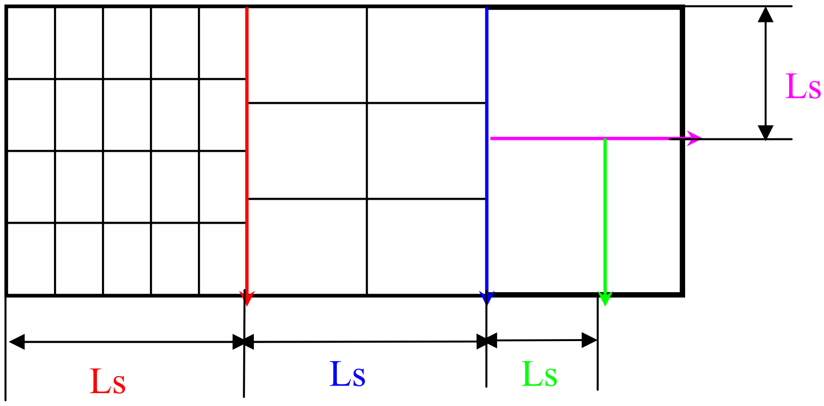

Figure 3.17 An illustrative example (upper view of the container)

31- U_{cum} = (BN * x * y * z) / (W * L * H) + (sum of U_{cum} of previously filled orders)

"U_{cum}" is the cumulative utilization of the container and similiar with the formulation of U given for Filltype I, but will be calculated cumulatively as new orders are filled. Also, because width and length values are expected to be changed for the remained space of the container during processing the *Filltype II Procedure*, the sum of U_{cum} of previously filled orders should be written as real numbers in formulation in the computer program.

3.3.6 Formulation

The mathematical model can be given below with the assistance of the definitions and the equations above. This model is also called as the main form of Filltype II in the following sections.

THE MAIN MODEL:

Objective function (Minimization of width of the block area) Minimize Ls (32)

Box availability constraints (Ergonomics) $x \leq xmax$ (33)

$x \geq xmin$ (34)

$y \leq ymax$ (35)

$y \geq ymin$ (36)

$z \leq zmax$ (37)

	$z \geq zmin$	(38)
Rotation constraints (Placement)	$Ls \leq L$	(39)
	$c * x \leq W$	(40)
	$d * y \leq W$	(41)
	$e * z \leq H$	(42)
Order quantity constraints	$BN * CN \geq O$	(43)
	$BN * CN \leq (O + CN)$	(44)
Box weight constraint	$(Bikg + Bckg) \leq Bmax$	(45)
Container cargo weight constraint	$(Bikg + Bckg) * BN \leq Cmax$	(46)
Integer constraints	a, b, c, d, e, m, n, p are integers	(47)

Objective function (32) minimizes the width of the block area that is used to pack more cups in it. The box availability (33-38), the box weight (45), the container cargo weight (46) and the integer constraints (47) are remained as given in Filltype I model. The rotation constraints (39-42) are structured according to the *The Order Adjustment Procedure* which will be explained in section 3.3.8. This procedure provides to construct the layer widths along the length of the container(L) for each order. After an order is loaded and Ls is determined, the width and the length of the space is initiliazed. This time layer widths are created along the lenght of the container. Also, the order quantity constraints (43, 44) are added to the model to keep the cup quantities as given in order as possible while creating a block of boxes inside the container as expressed in order quantity assumption given in 3.3.2.

3.3.7 Reduced Form of Filltype II

Because the nonlinear expressions exist in Filltype II formulation either, the same issue given in 3.2.7 comes across again. Thus reduced form of Filltype II formulation is constructed and all box dimensions inside box availability or ergonomics limitations are determined and solved with this reduced formulation again. As a difference from Reduced form of Filltype I, this formulation is applied for all blocks inside the container and the best "Ls" values of the blocks are gathered as a result.

3.3.7.1 Model Inputs

The reduced form of Filltype II includes the inputs below as an addition to the inputs given in section 3.3.3.

Box Attributes: m, n and pe values

3.3.7.2 Reduced Formulation

The mathematical model can be given as follow with the assistance of the definitions and the equations above. This model is also called as the reduced form of Filltype II in the following sections.

THE REDUCED MODEL:

Objective function (Minimization of width of the block area) Minimize Ls (48)

Rotation constraints (Placement) $Ls \leq L$ (49)

Order quantity constraints $BN * CN \geq O$ (50)

$BN * CN \leq (O + CN)$ (51)

Box weight constraint $(Bikg + Bckg) \leq Bmax$ (52)

Container cargo weight constraint $(Bikg + Bckg) * BN \leq Cmax$ (53)

Integer constraints a, b are integer (54)

Because the main model of Filltype II contains nonlinear expressions, some constraints should be removed to transform the model to a linear structure which provides exact solutions. By this way, the box availability constraints (33-38), the rotation constraints except first one (40-42) and the integer constraints (47) except "a" and "b" are omitted from the main model. But as a difference in the operation of the main model, the reduced model will be run for each alternative of the box dimensions (x, y, z) and the objective value for each (x, y, z) combination will be compared and the best one will be chosen for each order.

3.3.8 Solution Process to Filltype II

Before explaining the Filltype II Procedure some sub-procedures and policies should be given in details. The sub-procedures are *The Ranking Order Procedure* and *The Order Adjustment Procedure* and policies are *The Container Loading Policy* which is known from Filltype I and *The Order Cutting Policy*.

1- *The Ranking Order Procedure*: Ranking orders is a significant process because the filling is done according to the list created after this process. The O_L list is formed by two important criterias. First one considers the customer priority. If an order has a larger priority, then it is preferred to be packed earlier; because, the order is not cut at the end of the container and the cargo is sent earlier. Second criteria ranks the same prioritized orders according to their estimated volumes in descending order. The larger orders should be loaded earlier when there is still enough space in the container and also the probability of loading the smaller orders at the end of the container is higher than the larger ones.

The estimated volumes are calculated by the properties of the cups: diameter (DI), height (hb) and step height (ha). The formulation of estimation is given as below:

$$DI^2 * [hb + (50 * ha)]$$

DI^2 is given for determination of the occupied area in –x and –y axis and the expression "[hb + (50 * ha)]" is given for –z axis. Step height is multiplied with "50" to give a weight because of the crowded (stack) form of the cups. After the result of the formulation for all types of cups are found, the volume index is calculated by dividing them to the smallest one. This is to prevent studying with plenty of numbers. The volume index is then multiplied by the order quantity to obtain the ranking score. An illustrative example is given in the next chapter.

2- *The Order Adjustment Procedure:* It considers the longer side of the residual space, which is appeared after Ls_{ij} is calculated and the order is loaded, as the length of the space and it is renamed as "L" and the shorter side is renamed as "W". This is because of two reasons. First in *The Container Loading Policy* layers are created with the same boxes along the length of the container (L) and as we know, these layers are then merged to fill the container. In Filltype II, every block expresses an order. Because, the customer gives a quantity of an order, the blocks should satisfy the quantity as possible as it can be. Thus, if the layers are formed along the length it will be harder to find a feasible solution has an exact quantity or a closer one. By forming layers along the width of the container, we are able to reduce the probability of finding no feasible solution on the program. The effect of this case is perceived especially in lower quantity of orders. As a second reason this will make the loading-unloading process easier and provide more stable blocks. The example of *The Order Adjustment Procedure* transactions are displayed in Figure 3.18. In the example the container space is illustrated as white area. As the orders (coloured areas) are placed to the container, the width and the length of the space changes. For example, when the first order (red coloured) is placed, only length is decreased and the rotation is not eventuated, after the second order (blue coloured) is placed both of the width and the length is relocated and the rotation is eventuated. For third and fourth orders again only length is decreased and the rotation is not eventuated.

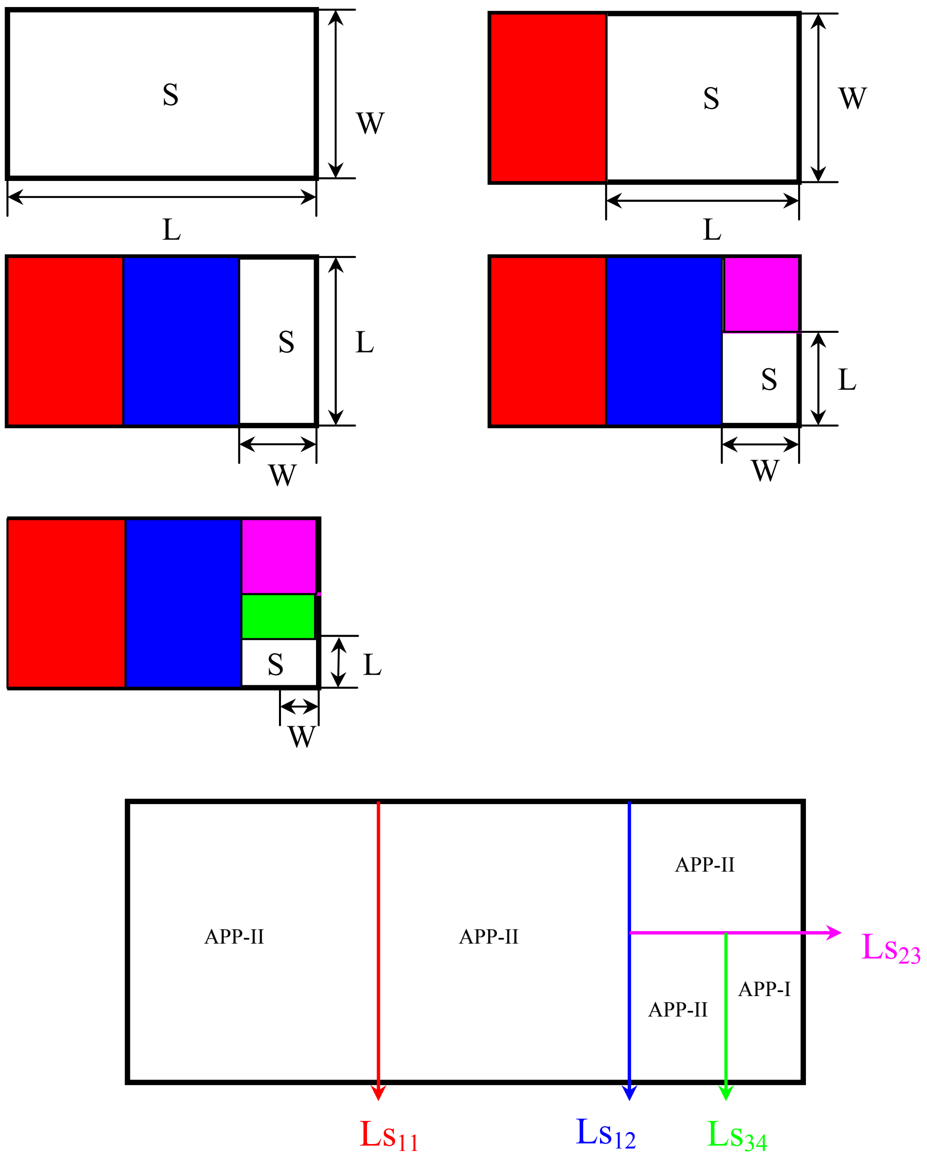

Figure 3.18 The Order Adjustment Procedure transactions.

3- *The Container Loading Policy:* As it is given in section 3.2.2; container loading pattern is based on building layer structures. The layers are then merged to fill the container. The width of the layers can be determined along the width (W) or the length (L) of the container. Because the selection does not affect the solution, the

Filltype I approach assumes the layers' width will be structured along the dimension of container W.

4- *The Order Cutting Policy:* While filling the container in an order of box types, the last packed order may have to be cut. Three criterias are determined as a policy of the company to reduce this undesired case for the customer. First, if the container utilization is achieved to a desired preset value after all orders are checked, then there is no need to cut an order. This is just to prevent the orders to be cut and reduce the cutting effort. Second, if the utilization is under this preset value, we check how much we can load into the remaining space. If more than a particular percentage of an order quantity is packed, then we can say it is worth to cutting. Third, it is preferred to cut an order which has a higher Customer Priority (CP), although there may be orders which have not been checked yet, have lower CPs and could be loaded all inside the container. In this situation, more than a particular percentage of the considered order should be packed as mentioned before in second criteria. Otherwise, the procedure continues and other orders are checked. This criteria satisfies customer priority as possible as it can. The information about applying the criterias are given in section 3.3.9 in Step 5 of the Filltype II Procedure.

3.3.9 Steps of the Filltype II Procedure

The structure of Filltype II needs a different strategy to achieve the objective. After some policies and procedures are given to explain the filling process, the steps of the Filltype II Procedure can be presented. The abbreviations of the *Filltype II Procedure* and the steps from 1 to 6 are given as following:

i = Number of packing direction changes.

j = number of orders in the O_L list (1,..P) (also number of block areas).

k = number of orders in the O_R list.

O_j = "j"th order in the O_L list.

O_k = "k"th order in the O_R list.

O_L = List of orders.

O_R = List of remained orders.

Ls_{ij} = The width of each block area in "i"th packing direction of "j"th order.

$L_{cont.}$= Control variable of Ls.

P = Number of ordered products.

CP = Customer Priority.

CTP = Cutting percentage

UD = Desired continer utilization value.

1. Rank the orders according to *The Ranking Order Procedure* and make a O_L list of orders O_j and go on.
2. Set i = 1, j = 1, k = 1 and go on;
3. a. If $j \leq P$ or CP value is not changed go on;
      1. Calculate Ls_{ij} and go to step 4.

   b. Else if $j > P$ or CP value is decreased, go to step 5.a.
4. a. If No Feasible Solution is found (the related space cannot be filled with order O_j by using Filltype II) add the order O_j as O_k in the O_R list and j=j+1, k=k+1 and go to step 3.

   b. Else if *a Feasible Solution* is found apply *The Order Adjustment Procedure* and go on;
      1. If $L - Ls_{ij} \leq W$, set $L_{cont.} = L$, $L = W$, $W = L_{cont.} - Ls_{ij}$, take O_j out of the O_L list then i=i+1, j=j+1 and go to step 3 else go on;
      2. Else if $L - Ls_{ij} > W$ set $L = L - Ls_{ij}$, take O_j out of the O_L list then j=j + 1 and go to step 3;
5. a. If $U \geq UD$ then go to step 6.

   b. Else if $U < UD$ then apply *The Order Cutting Policy* and go on.

   c. Set k = 1 and go on.

   d. If there exists an O_k in the O_R list, take out O_k from the O_R list and apply *Filltype-I* and set k=k+1 and go on. Otherwise go to step 5.e.
      1. If more than CTP of the order is located, the order will be divided and only this part of order will be loaded. Then reduce the packed quantity from O_j in the O_L list and go to step 6.
      2. If CTP of order cannot be located or no feasible solution is found, then go to step 5.d.

e. If j > P go to step 6. Otherwise set k = 1 and go to step 3.a.1.

6. If there are still orders that are not packed, update the O_L list. "j" is set to "j" value of the first element of the O_L list and pass to the other container and go to STEP 3. Set i=1. Otherwise stop and give results; Ls and U_{cum} values of the loaded container(s).

The Flow Chart of Filltype II Procedure is given in Figure 3.19. And detailed explanation of the steps are given as follows.

STEP 1- *The Ranking Order Procedure* transactions are applied and the list of O_L is developed.

STEP 2- Number of block areas, number of direction changes and the number of orders in the O_R list are counted by "i", "j" and "k" respectively. And three of them are initialized from the number "1".

STEP 3- "P" is the number of ordered products. In step 3 it is checked if "j" is achieved to the last order in the list or not. Behind that, customer priority (CP) of the current order is checked if it is decreased. If one of them is true than the procedure continues with step 5 which contains *The Order Cutting Policy*. This control point is also important to satisfy the third criteria which provides a higher customer prioritized order to be cut rather than loading full of lower customer prioritized orders as given in *The Order Cutting Policy*. Otherwise Ls_{ij} is calculated and it continues to step 4.

STEP 4- When no feasible solution is found after Ls_{ij} is calculated, the remained orders which have same customer priorities are added to a dynamic list named O_R. This list is then used in step 5 for *The Order Cutting Policy*. If a feasible solution is found, *The Order Adjustment Procedure* is applied. After all transactions are finished for an order in step 4, procedure goes on with step 3 for the next order.

STEP 5- This step is a critical step for The Filltype II Procedure because it contains the important transactions of the procedure. As it is denoted before, while the orders are being checked for loading, some orders may not be loaded all and added to the O_R list. This list is processed in step 5 which includes *The Order Cutting Policy* for cutting process. To evaluate this, Filltype I is applied to the remained space for the elements of the list (starting from the first element) and if more than the desired cutting percentage (CTP) of the order can be located, it will be cut and only this part of order will be loaded. Then the packed quantity is reduced from O_j in the O_L list to use the remained part for the next container loading process. Else if CTP of an order cannot be located, next element in the list is handled. This loop continues until all elements are processed in the O_R list. At the end of the loop, if there are still some orders to be evaluated in the O_L list (it occurs after CP changing conditions), the procedure jumps to step 3 and continues to try to fill them with Filltype II. Otherwise, the procedure is terminated and continues to step 6.

STEP 6- At the last step it is examined whether there are orders still not packed. The remained orders are processed again to fill other container(s). To realize the “j” value which is remained as “P+1” at the end of loading process of a container, it is set to “j” value of the first element of the O_L list. Also for new loading adjustments “i” is set to 1 and all container attributes are set to their default values. Else if no orders are remained the procedure is stopped. As outputs Ls and U_{cum} values of the loaded container(s) and an illustration of packed container(s) are obtained. Here “i” and “j” values help to illustrate the container loading pattern.

The application of the Filltype II Procedure is given in the next chapter by explaning all six steps in details.

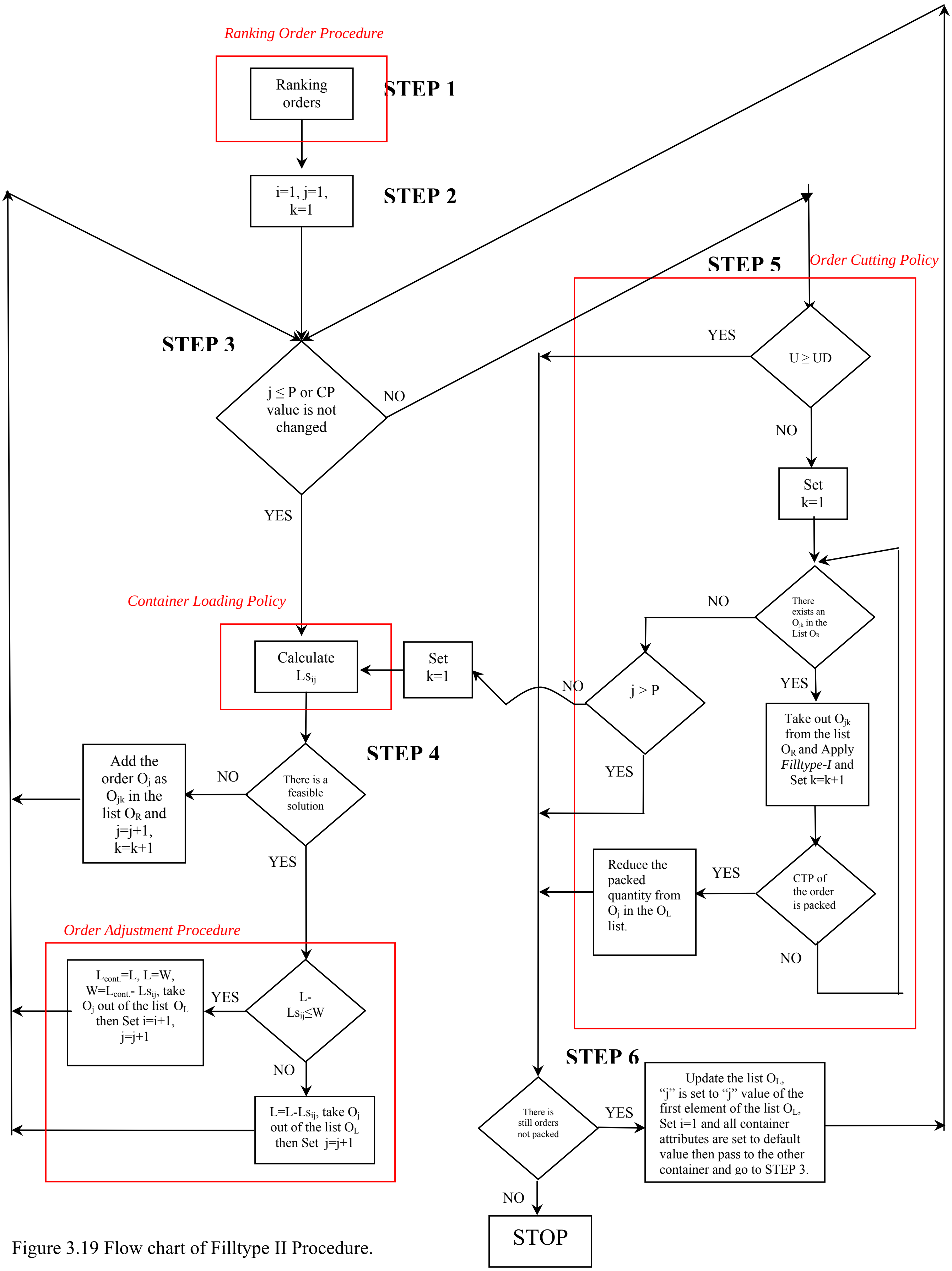

Figure 3.19 Flow chart of Filltype II Procedure.

CHAPTER FOUR
APPLICATION

4.1 A Specific Problem Definition

A study has been done in a real world company to experience the proposed Filltype I and II Procedures. As first, the company is introduced and current conditions are defined. After that, the developed procedures are applied and the recorded observations are interpreted in the rest of the study.

The plastic cup manufacturing company Teknika Plast A.Ş. is built in 2005 in Organized Industrial Zone of Manisa in Turkey. It also produces plastic food beverages especially yoghurt pails and lids, but we are only interested in plastic cups and their loading processes. There are two main types of cups which are classified according to volume capacity of liquids put inside; 180cc and 200cc cups. These two types also have different sub-types with different physical properties beside the main classification. All the types are given in the table as follow:

Table 4.1 Current cup types of the company

Main Class	Cup Type	Name
200cc CUPS	I	200cc(1)
	II	200cc(2)
	III	Straight
	IV	Star
180cc CUPS	V	180cc(1)
	VI	180cc(2)

After injection process, cups are put on a line by a robot in the crowded form and come towards employee’s front to be packaged in a nylon pochette. These crowded formed cups are then put in a carton box in a form of given in Figure 3.1 (a).

Although the placement in Figure 3.1 (b) provides more efficient usage of space than Figure 3.1 (a), cups are more likely to be broken while carrying the loaded box. By the way, the problem is structured as the form of placement in a box given in Figure 3.1 (a) and because the cavity in all types of cups provides to put them in each other, crowded form given in Figure 3.2 (a) is used. Packaging and transporting transactions of cups can be figured out in Figure 4.1.

Figure 4.1 Cup →Dust free Packaging(pochette)→Box→ Container or truck

One of the problems encountered in the plant is inefficiency in packaging the cups in boxes and loading the boxes to the containers. Because packaging and transporting are important parts of cost of the product (approximately %10 of total cost), it is worthy to study on it. Also, as the new products are introduced to the market, making an efficient packaging and transporting design at first becomes an important point. Thus, the cargo plans generated at the end of the study will help the company to load the boxes with no wasted time on calculations. As it is denoted before in Section 3.1, there are two sorts of customer orders. The examples of these two sorts are given in the next two sections.

The company uses following boxes currently given in Table 4.2 for the cups above. Also the predetermined model inputs which are cups, box and container attributes used for the proposed approach are given in Table 4.3, Table 4.4 and Table 4.5.

Table 4.2 Current Box Attributes

Cup Type	Name	x (mm)	y (mm)	z (mm)	CN (#)
I	200cc(1)	390	545	365	1,400
II	200cc(2)	380	605	410	2,000
III	180cc(1)	410	490	405	1,500
IV	180cc(2)	380	460	400	1,500
V	Straight	445	590	295	1,536
VI	Star	380	450	405	1,350

Table 4.3 Cup Attributes

Cup Type	Name	Diameter (mm)	Height (mm)	Step height of stacked cups (mm)	Cup weight(cgr) (gr)
I	200cc(1)	76	80	7.0	9.61
II	200cc(2)	74	78	6.5	11.65
III	180cc(1)	79	71	6.5	9.91
IV	180cc(2)	74	69	6.5	9.35
V	Straight	72	81	6.5	9.78
VI	Star	73	83	7.0	9.25

Table 4.4 Box Attributes

Cup Type	xmin (mm)	xmax (mm)	ymin (mm)	ymax (mm)	zmin (mm)	zmax (mm)	t (mm)	Bmax (kg)	Bckg (kg)
For all types of cups	250	450	450	650	250	450	5	20	0.5

Table 4.5 Container Attributes

Container Name	L (mm)	W (mm)	H (mm)	Cmax (kg)
20 ft Std.(Dry)	5,880	2,330	2,380	21,800
40 ft Std.(Dry)	12,024	2,330	2,380	26,680
40 ft HC	12,024	2,330	2,690	26,680

Source: www.intexturk.com/download/konteynerolculeri.pdf

4.2 An example of Single Container Loading with Homogeneous Type of Box and Cargo Plans

The homogeneous box type for an order is used to see the benefits of Filltype I for a 40ft Standard Dry container. The results are given in three stages. At first stage, the reduced form of Filltype I is processed for the current box attributes which are developed experimentally and intuitively. As the current boxes are created according to the personal experience and decision and there is not a method to fill the containers, applying the reduced form of Filltype I to the current boxes give the best solutions of the current condition. Thus, it provides a good reference for the performance comparison. Second stage, the main form of Filltype I is applied and questionable solutions (local optimal(s)) are gathered. Third stage, the absolute solutions are found by using the reduced form of Filltype I for all box dimensions in box availability (ergonomics) limits.

4.2.1 Results

The Filltype I models which are given under Section 3.2 are adapted to LINGO Release 9.0 / 2004 program and a machine is used which has AMD Athlon 4800+, 2gbRAM and Windows XP to solve them. The comparison is applied for only 180cc(1) cup to figure out the difference of efficiency by examining the TCN and the utilization values. In Table 4.6 and Table 4.7, the reduced form of Filltype I for current layout and the main form of Filltype I solutions include box sizes and box quantities (CN) for 180cc(1) cup gathered from the program are given as stage I and II. The best ten solutions obtained by the reduced form of Filltype I for all possible dimensions of the box for 180cc(1) is given in Table 4.8. The full list is given in Table A07 in appendix. Also comparison of all stages is summarized in Table 4.9.

Table 4.6 Stage I: Current layout solutions for 180cc(1) cup obtained by the the reduced form of Filltype I

Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization
III	180cc(1)	410	490	405	5	1,500	675	1,012,500	0.8237

Table 4.7 Stage II: Solutions for 180cc(1) cup obtained by the main form of Filltype I.

Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization
III	180cc(1)	405	563	393	6	1,715	696	1,193,640	0.9354

Table 4.8 Stage III: Best ten solutions for 180cc(1) cup obtained by the reduced form of Filltype I

No	Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization
1	III	180cc(1)	326	563	393	6	1,372	882	1,210,104	0.9541
2	III	180cc(1)	405	563	393	6	1,715	696	1,193,640	0.9354
3	III	180cc(1)	405	484	393	6	1,470	810	1,190,700	0.9358
4	III	180cc(1)	405	642	393	6	1,960	606	1,187,760	0.9287
5	III	180cc(1)	326	563	386.5	6	1,344	882	1,185,408	0.9383
6	III	180cc(1)	326	484	393	6	1,176	1008	1,185,408	0.9374
7	III	180cc(1)	326	672	393	6	1,568	756	1,185,408	0.9326
8	III	180cc(1)	326	563	445	5	1,596	735	1,173,060	0.9003
9	III	180cc(1)	405	563	386.5	6	1,680	696	1,169,280	0.9199
10	III	180cc(1)	405	484	386.5	6	1,440	810	1,166,400	0.9204

Table 4.9 Comparison of all stages

Stage No	Stage Explanation	Cup type	Cup Name	TCN	Utilization
I	The reduced form of Filltype I for current box dimensions	III	180cc(1)	1,012,500	0.8237
II	The main form of Filltype I	III	180cc(1)	1,193,640	0.9354
III	The reduced form of Filltype I for all box dimensions in box availability (ergonomics) limits.	III	180cc(1)	1,210,104	0.9541

The results gathered from Table 4.9 above can be given under five topics:

1- **The best result can not be found for Stage II.** Because, Stage II does not guarantee finding a global optimal solution, it can be found one of the local optimal solutions. Table 4.8 gives ten best solutions gathered by Stage III. As it is seen, the solution found by Stage II is the second best solution within others.

2- **The difference between the packed quantity of cups and the utilization as an objective.** As it is mentioned in the main objective, before packing more cups is more important than utilization; because they do not point out the same thing. As it is seen in the Table 4.8, fifth line has a more utilization value than fourth one; although its total cup number (TCN) value is less. This is because of the number of stowed boxes and detailed information is given in the fourth topic.

3- **Improvement of the packed quantity of cups and the utilization against current situation.** When the solutions of Stage I and II are compared for 180cc(1) cup in Table 4.9, it is seen that TCN is increased 181,140 cups and the utilization comes from 82.37% to 93.54%. Also, when we look at the best solution of Stage III, TCN is increased 197,604 cups and the utilization comes from 82.37% to 95.41%. Thus, it can be said that although Stage II gives local optimal solutions, there is a really great improvement in TCN and the utilization and there is not a dramatic difference between Stage II and Stage III solutions.

4- **The importance of term “e” and “BN” in the packed quantity of cups and the utilization.** The number of stowed boxes and the thickness of cartons are the critical parameters for the objective. As the number of stowed boxes which is expressed with the term “e” in the formulation is increased, it means base cups which are placed on the floor of boxes are used much more than the crowded cups along the z-axis. This causes transporting fewer cups in one time. Also as “BN” which is composed of the stowed and adjoined boxes is increased along the container dimensions, the number of cups you could load decreases. It means you put more carton than the cup inside the container. To overcome these inefficiencies, the design of the boxes should be examined again.

5- **Cargo Plan and the 2D visualizing of the best layout solution.** According to the best layout solution gathered from all three stages for 180cc(1) cup and a 40ft Standard Dry container, the box dimensions (x, y, z) should be 326, 563 and 393mm and each box should carry 1372 cups inside. By this solution, the a, b, c, d and e values which help to visualize the layout are determined as 7, 0, 36, 21 and 6. This means that the number of usage of the width of the box along the width of the container W (a) is 7. Because "b" value is 0, also "c" value has not a meaning because they are in multiplication in the objective function. As we know "a", also "d" value is meaningful and the number of usage of the length of the box along the length of the container L (d) is determined as 21. "e" value is given as 6 and gives the number of the floors which is structured by the boxes. By using 882 boxes, we can conclude that 1210104 cups can be filled in a 40ft Standard Dry container which has dimensions of 12024mm, 2330mm, and 2390mm.

The cargo plan of the best solution gathered from Stage III for 180cc(1) cup and a 40ft Standard Dry container is given in Table 4.10 and the 2D visualizing of the best layout solution is illustrated as three views of the container in Figure 4.2 on next page.

Table 4.10 The cargo plan of the best solution gathered from Stage III for 180cc(1) cup and a 40ft Standard Dry container

No	Cup Type	Name	m	n	pe	e	x	y	z	a	b	c	d	CN	BN	TCN	Utilization	Bikg	Bckg
1	III	180cc(1)	4	7	49	6	326	563	393	7	0	36	21	1,372	882	1,210,104	0.9541	13.60	0.50

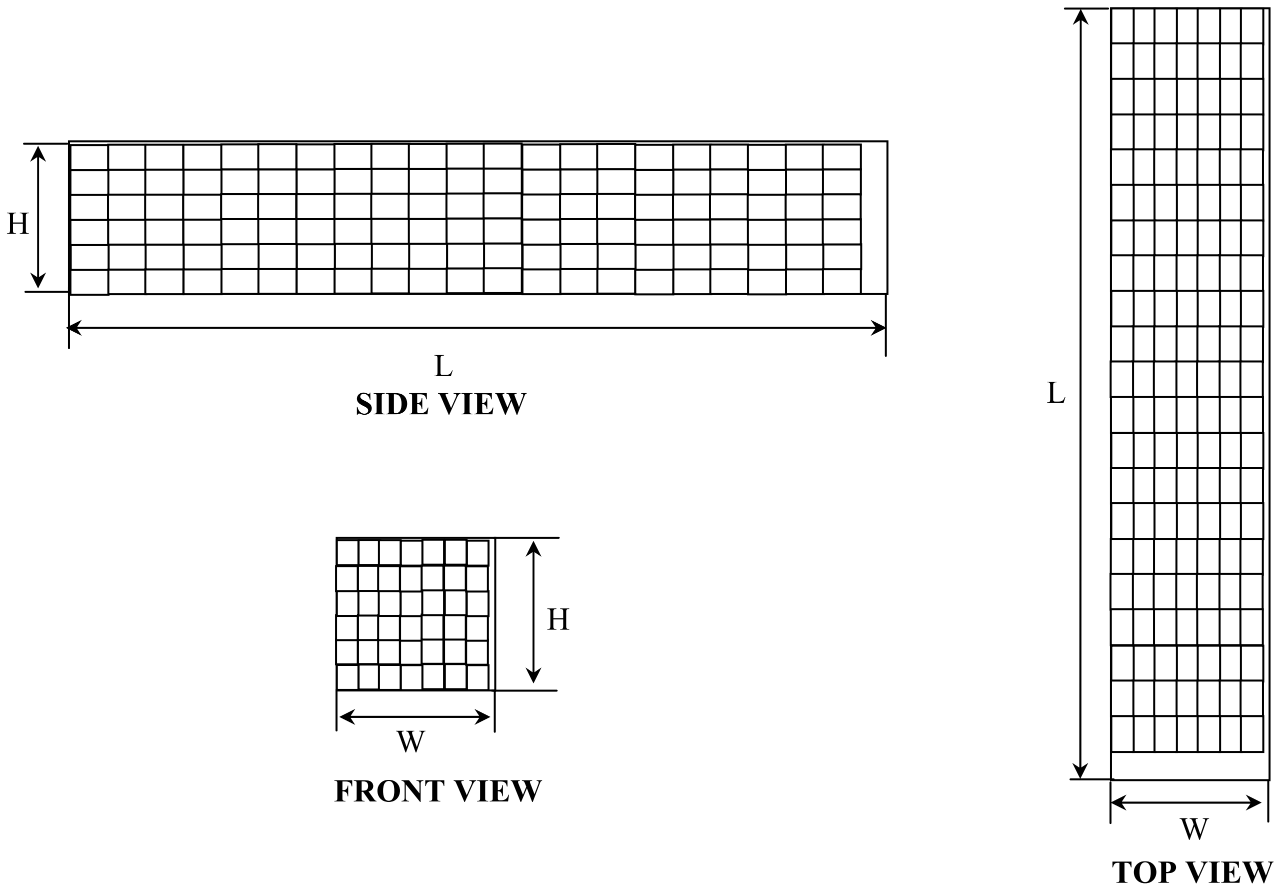

Figure 4.2 The 2D visualizing of the best layout solution

4.2.2 Solutions of Stage I and Stage II for the other cups

For the other cups, the solutions of Stage I and Stage II for the 40ft Standard Dry container gathered from the program are given in Table 4.11 and Table 4.12. Also comparison of these two stages is summarized in Table 4.13.

Table 4.11 Stage I: Current layout solutions for all types of cups obtained by the reduced form of Filltype I

Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization
I	200cc(1)	390	545	365	6	1,400	756	1,058,400	0.8796
II	200cc(2)	380	605	410	5	2,000	570	1,140,000	0.8058
III	180cc(1)	410	490	405	5	1,500	675	1,012,500	0.8237
IV	180cc(2)	380	460	400	5	1,500	780	1,170,000	0.8179
V	Straight	445	590	295	8	1,536	808	1,241,088	0.9386
VI	Star	380	450	405	5	1,350	780	1,053,000	0.8101

Table 4.12 Stage II: Solutions for all types of cups obtained by the main form of Filltype I

Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization
I	200cc(1)	314	466	391	6	1,056	1,140	1,203,840	0.9782
II	200cc(2)	380	454	393.5	6	1,440	936	1,347,840	0.9526
III	180cc(1)	405	563	393	6	1,715	696	1,193,640	0.9354
IV	180cc(2)	306	454	391	6	1,176	1,170	1,375,920	0.9531
V	Straight	298	514	396.5	6	1,344	1,068	1,435,392	0.9728
VI	Star	375	521	394	6	1,540	852	1,312,080	0.9836

Because the Stage III solutions need a huge effort, they are not given in the tables. As it is seen at Table 4.13, we can conclude that, Stage II provides better solutions of TCN and utilization values than the Stage I although we know that Stage II can not find global optimal solutions and generally gives local optimals. Thus because the Stage II gives closer solutions to Stage III, it is clear that the improvement in performance will not be undesirable. As a result, it can be said that the improvement will be at least 10% at average.

Table 4.13 The comparison of Stage I and Stage II for all types of cups obtained by Filltype I.

Cup type	Cup Name	Stage Name	Stage No	TCN	Utilization
I	200cc(1)	The reduced form of Filltype I for current box dimensions	I	1,058,400	0.8796
		The main form of Filltype I	II	1,203,840	0.9782
II	200cc(2)	The reduced form of Filltype I for current box dimensions	I	1,140,000	0.8058
		The main form of Filltype I	II	1,347,840	0.9526
III	180cc(1)	The reduced form of Filltype I for current box dimensions	I	1,012,500	0.8237
		The main form of Filltype I	II	1,193,640	0.9354
IV	180cc(2)	The reduced form of Filltype I for current box dimensions	I	1,170,000	0.8179
		The main form of Filltype I	II	1,375,920	0.9531
V	Straight	The reduced form of Filltype I for current box dimensions	I	1,241,088	0.9386
		The main form of Filltype I	II	1,435,392	0.9728
VI	Star	The reduced form of Filltype I for current box dimensions	I	1,053,000	0.8101
		The main form of Filltype I	II	1,312,080	0.9836

4.3 An example of Multiple Containers Loading with Heterogeneous Type of Boxes

The heterogeneous box types for more than one orders are used to see the benefits of Filltype II for a 20ft Standart Dry container. The results are given in three stages again like in 4.1.1.

Before the Filltype II Procedure is applied, UD and CTP should be determined as the company policy. In our problem, UD and CTP values are given as 0.95 and 0.50 consecutively as used in *The Order Cutting Policy*. These values can change according to behavior of the customers.

4.3.1 Appliance of Filltype II Procedure

This section explains step by step how to apply the Filltype II Procedure for the third stage: the reduced form of Filltype II for all box dimensions in box availability (ergonomics) limits. Note that all possible box dimensions in the limits for each cup type are given in Table A01-A06 in appendix.

STEP 1- In the first step, the customer order information is taken and the O_L list is created by operating *The Ranking Order Procedure*. The customer order information is given in Table 4.14 and the ranking transactions of the related orders are summarized as follows.

Table 4.14 Customer order information customer (Not Ranked)

Cup Type	Name	Order Quantity	Customer Priority
I	200cc(1)	150,000	0
II	200cc(2)	100,000	0
III	180cc(1)	100,000	0
IV	180cc(2)	120,000	0
V	Straight	150,000	2
VI	Star	180,000	1

The estimated volumes and volume indices are calculated by using the formulation "DI^2 * [hb + (50 * ha)]" (on page 47) as follows and given in Table 4.15.

For cup type I: Estimated volume: 76^2 x [(80 + (50 x 7)] = 2,483,680

Volume index: 2,483,680 / 2,104,704 = 1.18

For cup type II: Estimated volume: 74^2 x [(78 + (50 x 6.5)] = 2,206,828

Volume index: 2,206,828 / 2,104,704 = 1.05

For cup type III: Estimated volume: 79^2 x [(71 + (50 x 6.5)] = 2,471,436

Volume index: 2,471,436 / 2,104,704 = 1.17

For cup type IV: Estimated volume: 74^2 x [(69 + (50 x 6.5)] = 2,157,544

Volume index: 2,157,544 / 2,104,704 = 1.03

For cup type V: Estimated volume: 72^2 x [(81 + (50 x 6.5)] = 2,104,704

Volume index: 2,104,704 / 2,104,704 = 1.00

For cup type VI: Estimated volume: 73^2 x [(83 + (50 x 7)] = 2,307,457

Volume index: 2,307,457 / 2,104,704 = 1.10

Table 4.15 Volume index determination.

Cup Type	Name	Diameter (DI)	Height (hb)	Step height of the stacked cups (ha)	Estimated volumes	Volume Index
I	200cc(1)	76	80	7	2,483,680	1.18
II	200cc(2)	74	78	6.5	2,206,828	1.05
III	180cc(1)	79	71	6.5	2,471,436	1.17
IV	180cc(2)	74	69	6.5	2,157,544	1.03
V	Straight	72	81	6.5	2,104,704	1.00
VI	Star	73	83	7	2,307,457	1.10

After volume indices are found, ranking score of volume for every order is calculated by multiplying order quantities and volume indices. As it is seen in Table 4.16 below, cup type III has a customer priority 2 and IV has 1, and others have 0. This means that the customer desires cup type III urgently than others. Cup type IV has a second priority and others have same priority as 0. “0” means that order has no urgency and it does not matter if it is transported in first or last order of containers. As it is known when a tie exists in customer priority, ranking is done by descending their ranking score of volume.

Table 4.16 Ranking score of volume determination.

Cup Type	Order Quantity	Volume Index	Customer Priority	Ranking Score f Volume	*j*
III	150,000	1.00	2	150,000	1
IV	180,000	1.10	1	198,000	2
I	150,000	1.18	0	177,000	3
VI	120,000	1.03	0	123,600	4
V	100,000	1.17	0	117,000	5
II	100,000	1.05	0	105,000	6

As a result, all orders are numbered with "j" value and the members of the order O_L list are created as O_js and set in order from O_1 to O_n. The O_L list is given as below:

O_L = { O_1, .., O_6} where j= 1,.. ,6 and

O_1 = Cup type V, O_2 = Cup type VI, O_3 = Cup type I, O_4 = Cup type IV, O_5 = Cup type III, O_6 = Cup type II

STEP 2- i=1, j=1, k=1

<u>CONTAINER #1</u>

PACKING STEPS OF O_1

STEP 3- 3.a j=1 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{11} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{11}) The procedure goes to Step 4.

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 W = 2,330, L = 5,880, Ls_{11} = 1,398, L – Ls_{11} = 4,482 thus L – Ls_{11} ≤ W. The answer is NO.

4.b.2 L – Ls_{11} > W. The answer is YES. L = L – Ls_{11} = 4,482 and O_1 is taken out of the O_L list and updated.

Now O_L ={ O_2, .., O_6}and j = 1+1 =2. Go back to Step 3.

PACKING STEPS OF O_2

STEP 3- 3.b j=2 and P=6, j≤P. and CP value is not changed. The answer is NO. Because CP value is decreased. The procedure jumps to Step 5.a.

STEP 5- 5.a U = 0.2084, UD = 0.9500, U ≥ UD. The answer is NO.

5.b U < UD. The answer is YES. Then apply *The Order Cutting Policy* and go on.

5.c k=1.

5.d There is not O_1 in the O_R list so go to step 5.e.

5.e j=2 and P=6, j≤P. The answer is YES. k=1 and go to Step 3.a.1.

STEP 3- 3.a.1 Ls_{12} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{12}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 W = 2,330, L = 4,482, Ls_{12} = 1,782, L – Ls_{12} = 2,700 thus L – Ls_{13} ≤ W. The answer is NO.

4.b.2 L – Ls_{12} > W. The answer is YES. L = L – Ls_{12} = 2,700 and O_2 is taken out of the O_L list and updated.

Now O_L ={ O_3, .., O_6}and j = 2+1 =3. Go back to Step 3.

PACKING STEPS OF O_3

STEP 3- 3.b j=3 and P=6, j≤P. and CP value is not changed. The answer is NO. Because CP value is decreased. The procedure jumps to Step 5.a.

STEP 5- 5.a U = 0.4765, UD = 0.9500, U ≥ UD. The answer is NO.

5.b U < UD. The answer is YES. Then apply *The Order Cutting Policy* and go on.

5.c k=1.

5.d There is not O_1 in the O_R list so go to step 5.e.

5.e j=3 and P=6, j≤P. The answer is YES. k=1 and go to Step 3.a.1.

STEP 3- 3.a.1 Ls_{13} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{13}) The procedure goes to Step 4.

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 W = 2,330, L = 2,700, Ls_{13} = 1,560, L – Ls_{13} = 1,140 thus L – $Ls_{13} \leq$ W. The answer is YES. $L_{cont.}$ = 2,700, L = 2,330, W = $L_{cont.}$- Ls_{13} = 2,700 – 1,560 = 1,140. Then O_3 is taken out of the O_L list and updated. Now O_L ={ O_4, O_5, O_6}and i = 1+1 =2, j = 3+1 =4. Go back to Step 3.

PACKING STEPS OF O_4

STEP 3- 3.a j=4 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{24} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{24}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 W = 1140, L = 2330, Ls_{24} = 2112, L – Ls_{24} = 218 thus L – $Ls_{24} \leq$ W. The answer is YES. $L_{cont.}$ = 2330, L = 1140, W = $L_{cont.}$- Ls_{24} = 2330 – 2112 = 218. Then O_4 is taken out of the O_L list and updated. Now O_L ={O_5, O_6}and i= 2+1 =3, j = 4+1 =5. Go back to Step 3.

PACKING STEPS OF O_5

STEP 3- 3.a j=5 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{35} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{35}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is YES. The order O_5 is added as O_1 in the O_R list and j=5+1=6, k=1+1=2 and go to step 3. The O_R list = { O_1 }

PACKING STEPS OF O_6

STEP 3- 3.a j=6 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{36} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{36}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is YES. The order O_6 is added as O_2 in the O_R list and j=6+1=7, k=2+1=3 and go to step 3. The O_R list = { O_1, O_2}

ORDER CUTTING STEPS AND FINALIZING

STEP 3- 3.b j=7 and P=6, j≤P and CP value is not changed. The answer is NO. Because j > P. The procedure jumps to Step 5.a.

STEP 5- 5.a U = 0.8930, UD = 0.9500, U ≥ UD. The answer is NO.

5.b U < UD. The answer is YES. Then apply *The Order Cutting Policy* and go on.

5.c k = 1.

5.d There is O_1 in the O_R list so O_1 is taken out of the O_R list and applied Filltype I. k=1+1=2.

5.d.1 CTP = 0.50, No feasible solution is found. More than CTP of the order is located. The answer is NO.

5.d.2 No feasible solution is found. CTP of order cannot be located. The answer is YES. And go to Step 5.d.

STEP 5- 5.d There is O_2 in the O_R list so O_2 is taken out of the O_R list and applied Filltype I. k=2+1=3.

5.d.1 CTP = 0.50, No feasible solution is found. More than CTP of the order is located. The answer is NO.

5.d.2 No feasible solution is found. CTP of order cannot be located. The answer is YES. And go to Step 5.d.

STEP 5- 5.d There is not O_3 in the O_R list so go to step 5.e.

5.e j=7 and P=6, j≤P. The answer is NO. k=1 and go to Step 6.

STEP 6- There is still orders not packed. The answer is YES. The O_L list is updated and given as $O_L = \{ O_5, O_6 \}$. "j" is set to 5 which is "j" value of the first element of the O_L list. i = 1 and all container attributes are set to their default values. Then the procedure passes to another container which is same as first one (20ft Std. Dry) and continues to STEP 3.

CONTAINER #2

PACKING STEPS OF O_5

STEP 3- 3.a j=5 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{15} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{15}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 W = 2,330, L = 5,880, Ls_{15} = 1,126, L – Ls_{15} = 4,754 thus L – Ls_{15} ≤ W. The answer is NO.

4.b.2 L – Ls_{15} > W. The answer is YES. L = L – Ls_{15} = 4,754 and O_5 is taken out of the O_L list and updated. Now $O_L = \{ O_6 \}$and j = 5+1 =6. Go back to Step 3.

PACKING STEPS OF O_6

STEP 3- 3.a j=6 and P=6, j≤P and CP value is not changed. The answer is YES.

3.a.1 Ls_{16} is calculated by using the reduced form of Filltype II for all possible box sizes. (The best solution is chosen as Ls_{16}) The procedure goes to Step 4

STEP 4- 4.a There is no feasible solution. The answer is NO.

4.b There is a feasible solution. The answer is YES and *The Order Adjustment Procedure* is applied.

4.b.1 $W = 2{,}330$, $L = 4{,}754$, $Ls_{16} = 918$, $L – Ls_{16} = 3{,}836$ thus $L – Ls_{16} \leq W$. The answer is NO.

4.b.2 $L – Ls_{16} > W$. The answer is YES. $L = L – Ls_{16} = 3{,}836$ and O_6 is taken out of the O_L list and updated. Now $O_L = \{ \}$ and $j = 6+1 = 7$. Go back to Step 3.

ORDER CUTTING STEPS AND FINALIZING

STEP 3- 3.b j=7 and P=6, j≤P and CP value is not changed. The answer is NO. Because j > P. The procedure jumps to Step 5.a.

STEP 5- 5.a U = 0.3205 UD = 0.9500, U ≥ UD. The answer is NO. then go to step 6.

5.b U < UD. The answer is YES. Then apply *The Order Cutting Policy* and go on.

5.c k = 1.

5.d There is not O_1 in the O_R list so go to step 5.e.

5.e j=7 and P=6, j≤P. The answer is NO. k=1 and go to Step 6.

STEP 6- There is still orders not packed. The answer is NO. Stop the procedure and give results; Ls and U_{cum} values of the loaded container(s).

4.3.2 Results

The Filltype II models given in Section 3.3 are employed on the same system in 4.1.1.1. Performance comparison of the stages is done by examining Ls and U_{cum} utilization values.

Because the layers are filled completely, the order quantities found by the procedure may deviate from the exact customers order quantities. To make a correct performance comparison, the TCN values are drawn down to the nearest value of customer order quantities for the current solutions. For example, when we look at the Stage I Outputs on page 98 in appendix the TCN value is found as 159,744 (last row). By reducing 6 boxes from the last layer, the TCN value becomes 150,528 which is the nearest value to customer order quantity of 150,000. Other TCN values are found by the same method and given in Table 4.17. This table gives the dimensions of the current boxes (x, y, z), cup quantities in boxes (CN), Ls values of each order, total cup number loaded in the container (TCN) and the cumulative utilization of the container after each of the orders are loaded. Also they are illustrated in Figure 4.3 and Figure 4.4.

Table 4.17 Stage I: Current Layout Solutions obtained by the reduced form of Filltype II

CONTAINER	Cup Type	Name	x	y	z	CN	Ls	TCN	Utilization (cumulative) U_{cum}
#1	V	Straight	445	590	295	1,536	1,625	150,528	0.2328
	VI	Star	380	450	405	1,350	2,040	180,900	0.5174
	I	200cc(1)	390	545	365	1,400	1,870	151,200	0.7744
	IV	180cc(2)	Filltype II is applied NFS is found, Filltype I is applied but CTP of the order can not be packed.						
#2	IV	180cc(2)	380	460	400	1,500	1,220	120,000	0.1715
	III	180cc(1)	410	490	405	1,500	1,390	100,500	0.3462
	II	200cc(2)	380	605	410	2,000	1,210	100,000	0.4908

After Filltype II is applied for 180cc(2) cup for the first container, no feasible solution is found and the remained space is tried to be filled by Filltype I. When Filltype I is applied, only 37,500 (31%) of 120,000 can be packed to the first container. According to *The Order Cutting Policy*, because the CTP value is given as 50%, the order will not be cut and packed to the other container.

Table 4.18 gives the same information as in Table 4.17, but this time the solutions of Stage II obtained by the main form of Filltype II is given. The solutions in this table are not global optimals and not dependable.

Table 4.19 gives the best solution obtained by the reduced form of Filltype II for each order. At every filling process of orders, all possible box dimensions are examined and the one of the combinations which has minimum Ls value is chosen as the optimum solution. But, in some cases more than one optimum solution (means same Ls values) could be found for an order. This time the optimum solution which has the nearest value to customer order quantity is chosen to make a correct performance comparison. Table 4.19 gives the chosen optimum solutions.

Table 4.18 Stage II: Best solutions obtained by the main form of Filltype II for each order.

CONTAINER	Cup Type	Name	x	y	z	CN	Ls	TCN	Utilization (cumulative) U_{cum}
#1	V	Straight	442	514	364	1,806	1,470	151,704	0.2130
	VI	Star	375	594	436	2,000	1,782	180,000	0.4811
	I	200cc(1)	390	466	433	1,500	1,560	150,000	0.7224
	IV	180cc(2)	380	528	449.5	2,030	2,280	121,800	0.8884
#2	III	180cc(1)	405	563	386.5	1,680	1,126	100,800	0.1674
	II	200cc(2)	306	528	289.5	1,204	1,056	100,352	0.3228

Table 4.19 Stage III: Solutions obtained by the reduced form of Filltype II.

CONTAINER	Cup Type	Name	x	y	z	CN	Ls	TCN	Utilization (cumulative) U_{cum}
#1	V	Straight	442	514	383.5	1,932	1,398	150,696	0.2084
	VI	Star	375	594	436	2,000	1,782	180,000	0.4765
	I	200cc(1)	390	466	433	1,500	1,560	150,000	0.7178
	IV	180cc(2)	380	528	339	1,435	2,112	120,540	0.8930
#2	III	180cc(1)	326	563	282.5	896	1,126	100,352	0.1781
	II	200cc(2)	306	454	445.5	1,344	918	100,800	0.3205

All solutions of Stage III with possible box dimensions for each order are given in appendix (Table A08-A13). As it is seen, most of the solutions give no feasible solutions. This is because order quantity and/or weight constraints scale down the solution cluster.

The results gathered from the tables above can be given under six topics:

1- **Ls is decreased for all orders.** As our objective we want to minimize the Ls value to load the blocks deeper in the container. Thus by determining the box sizes newly, Ls is decreased between 11% and 24%. This means that more area is created to pack the blocks of orders. For example, when the second containers are examined in Figure 4.4, Figure 4.6 and Figure 4.8 for each stage, while a space has a 2,060 mm depth is remained to be filled by new orders for the current solution, after using Filltype II, this space is increased up to 3,836 mm. This means that the usable space for filling process is increased 86% for the second container.

2- **The fourth order is packed all into the first container.** As a result of decrease in Ls, cup type IV is packed to the first container fully and also prevented to be cut although it is not packed in current condition.

3- **Utilization is increased.** As we fit more cups to the container, the utilization is also increased about 11% percent. In fact, the utilization should be decreased as if the area is used more efficiently. This manner is proved by the first three orders. If we compare their utilizations in Table 4.17, Table 4.18 and Table 4.19, we see that current solutions are more than other ones by 2%-5%. But, at the end of the container when we fit the fourth order fully, the utilization becomes greater than the current situation.

4- **Some of the packed order quantities are more close to the given customer orders.** Because of the box quantities are recomputed with an assistance of the order quantity constraints, some orders found after the procedure is applied satisfy the orders given by customers very closely. For example, the computed total cup number (TCN) of the second and the third orders give the customer orders perfectly. This contributes the customer satisfaction.

5- **Stage II gives very close solutions to the exact solutions gathered by Stage III.** When the Ls values are examined, it is seen that Stage II solutions gives same solutions gathered by Stage III except the first and six orders. This is another effect of the order quantity constraints. The closeness could be increased by narrowing the order quantity tolerance as expressed in order quantity assumption given in section 3.3.2.

6- **The 2D visualizing of the best layout solutions** The best solutions for the stages are given in Table 4.17, Table 4.18 and Table 4.19. By this solutions, the cargo plans which contain the a, b, c, d and e values for a 20ft Standard Dry container are given to help to visualize the layout in Table 4.20, Table 4.21 and Table 4.22. Using this information, the 2D visualizing of the best layout solutions are illustrated in Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, and Figure 4.8.

Two containers are filled in each stage and illustrated in the following figures. The illustration includes the view of four sides and a top view of the container.
F: Front view
R: Rear view
A: A side view
B: B side view

Also boxes of the orders are colored as below:
Cup type I: Purple boxes
Cup type II: Brown boxes
Cup type III: Yellow boxes
Cup type IV: Green boxes
Cup type V: Red boxes
Cup type VI: Blue boxes

The variables (a, b, c, d and e) which help to draw the illustrations for the stages and also total weight of the cargo are given in the following tables (Table 4.20-4.22)

Table 4.20 Stage I layaout variables

	Cup Type	i	j	a	b	c	d	e	kg (cumulative)
CONTAINER #1	V	1	1	1	2	5	3	8	1,472
	VI	1	2	3	2	6	5	5	3,145
	I	2	3	2	2	5	4	6	4,598
	IV	Filltype II is applied NFS is found, Filltype I is applied but CTP of the order can not be packed.							
CONTAINER #2	IV	1	4	2	1	6	5	5	1,122
	III	1	5	1	2	5	4	5	2,118
	II	1	6	0	2	6	3	5	3,283

Table 4.21 Stage II layout variables

	Cup Type	i	j	a	b	c	d	e	kg (cumulative)
CONTAINER #1	V	1	1	1	2	5	4	6	1,484
	VI	1	2	0	3	6	3	5	3,149
	I	1	3	4	0	5	5	5	4,591
	IV	2	4	6	0	2	2	5	5,730
CONTAINER #2	III	1	5	0	2	5	4	6	999
	II	1	6	0	2	7	4	8	2,570

Table 4.22 Stage III layout variables

	Cup Type	i	j	a	b	c	d	e	kg (cumulative)
CONTAINER #1	V	1	1	2	1	5	4	6	1,474
	VI	1	2	0	3	6	3	5	3,139
	I	1	3	4	0	5	5	5	4,581
	IV	2	4	0	4	3	2	7	5,708
CONTAINER #2	III	1	5	0	2	7	4	8	995
	II	1	6	3	0	7	5	5	2,169

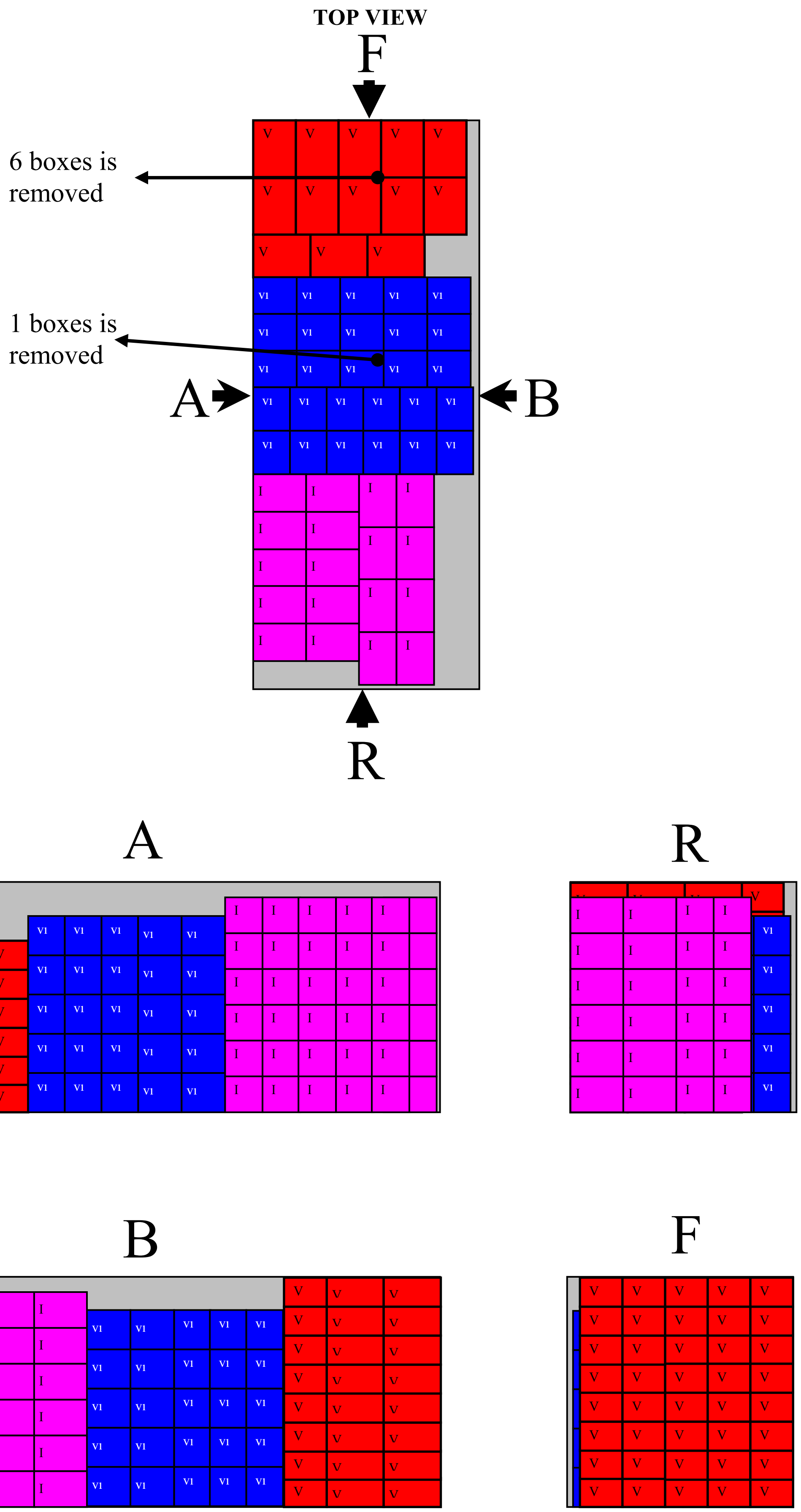

Figure 4.3 Stage I: The 2D visualization of the best current layout solution of the first container obtained by the reduced form of Filltype II.

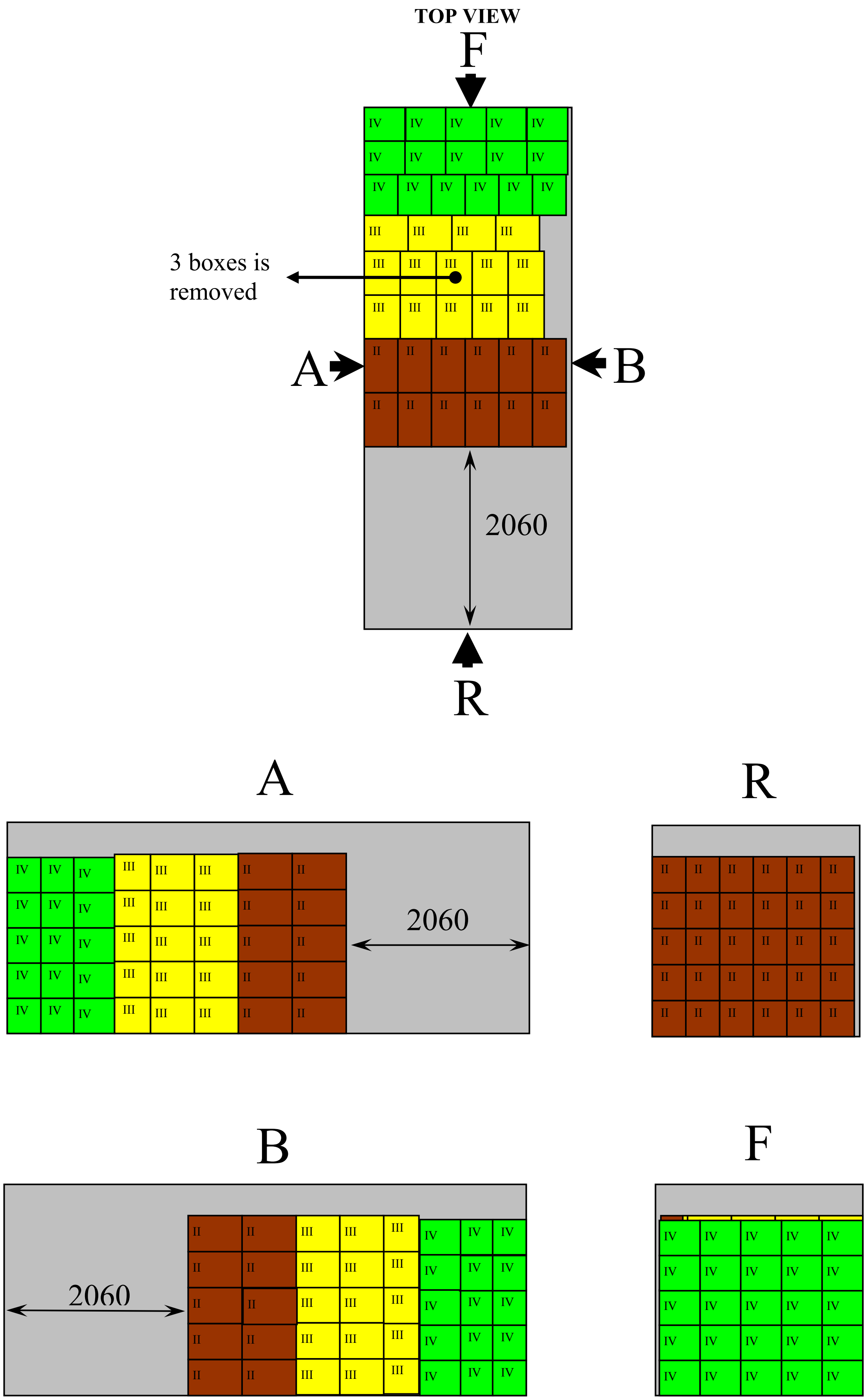

Figure 4.4 Stage I: The 2D visualization of the best current layout solution of the second container obtained by the reduced form of Filltype II.

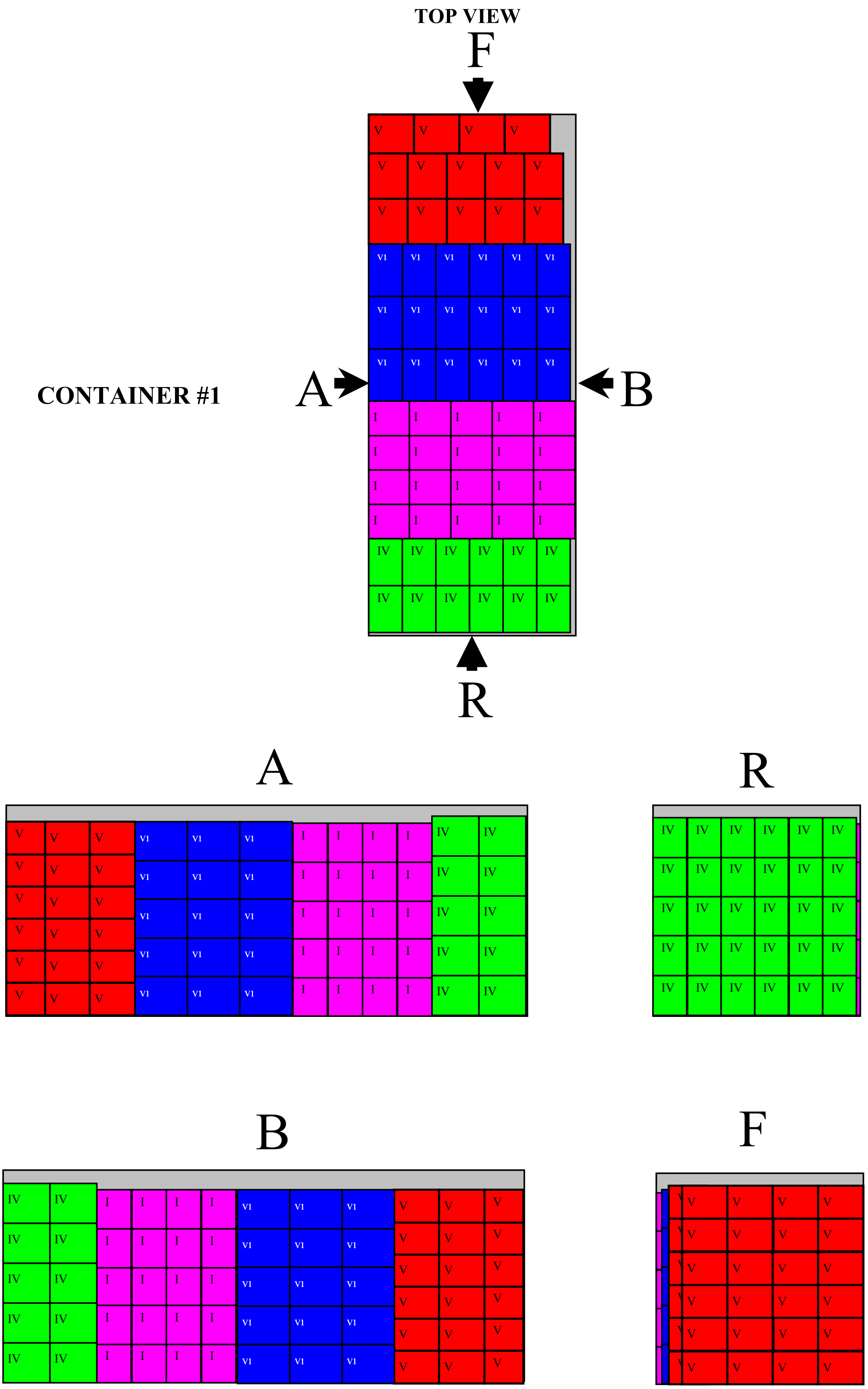

Figure 4.5 Stage II: The 2D visualization of the best solution of the first container obtained by the main form of Filltype II.

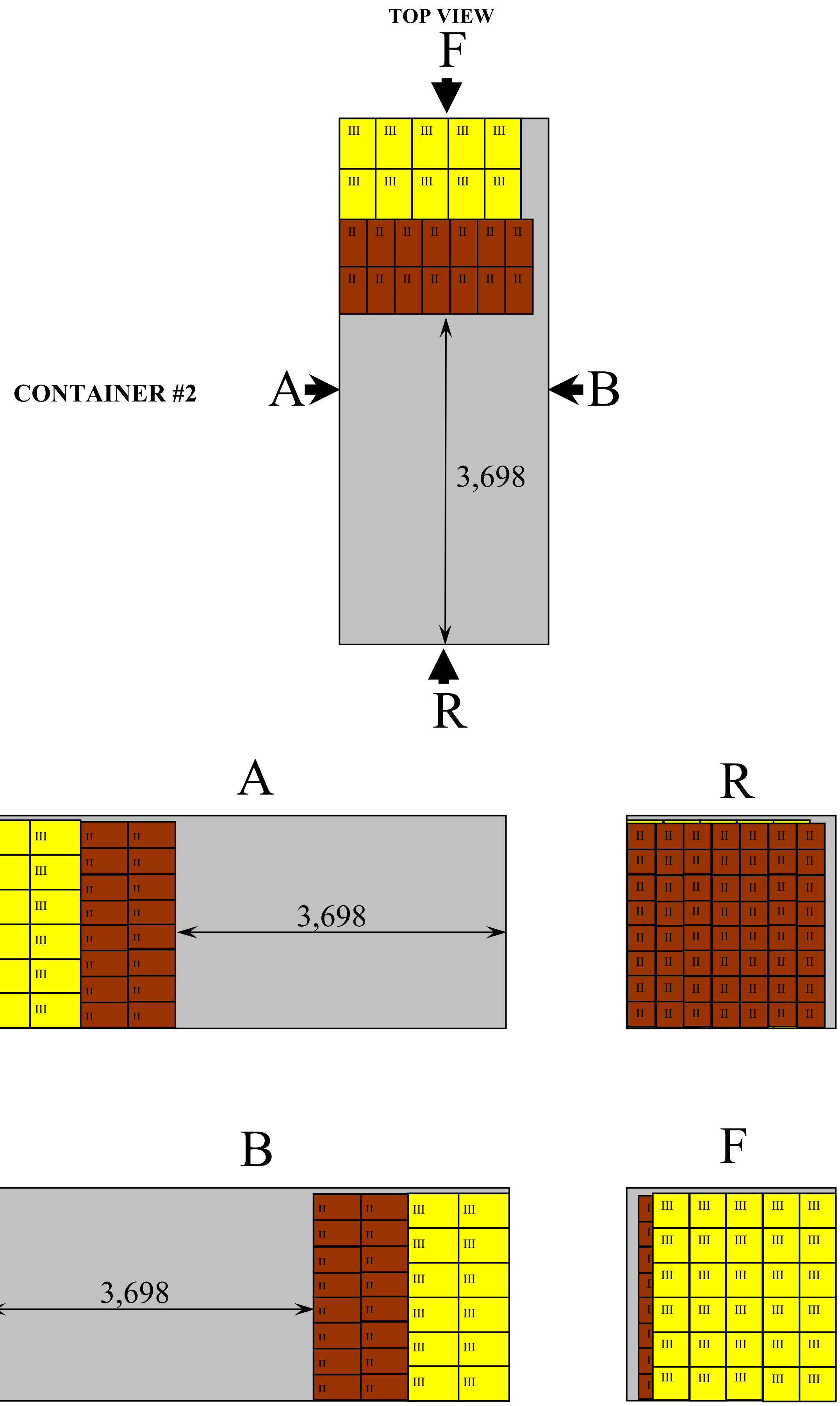

Figure 4.6 Stage II: The 2D visualization of the best solution of the second container obtained by the main form of Filltype II.

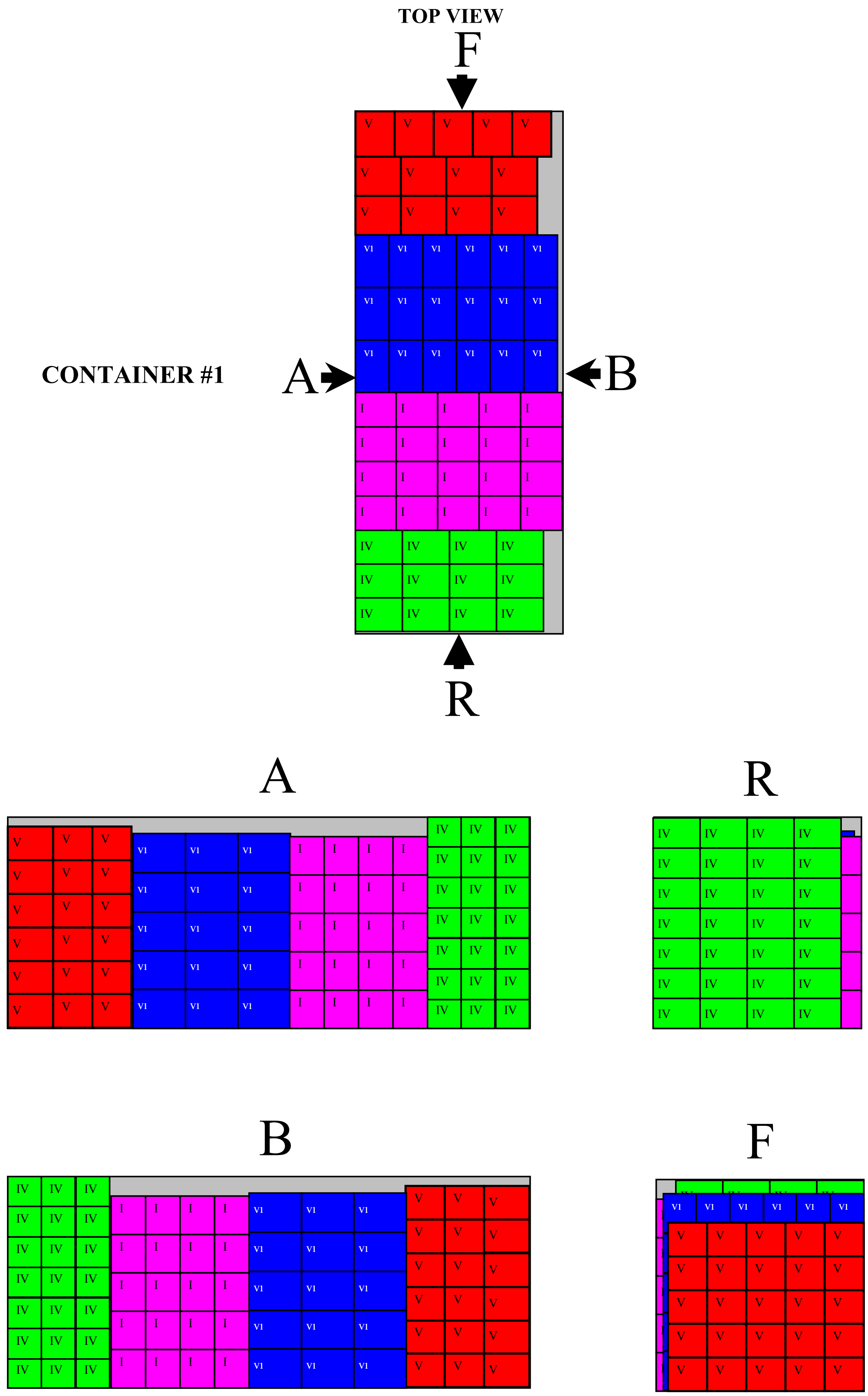

Figure 4.7 Stage III: The 2D visualization of the best solution of the first container obtained by the the reduced form of Filltype II for the box dimensions in box availability (ergonomics) limits.

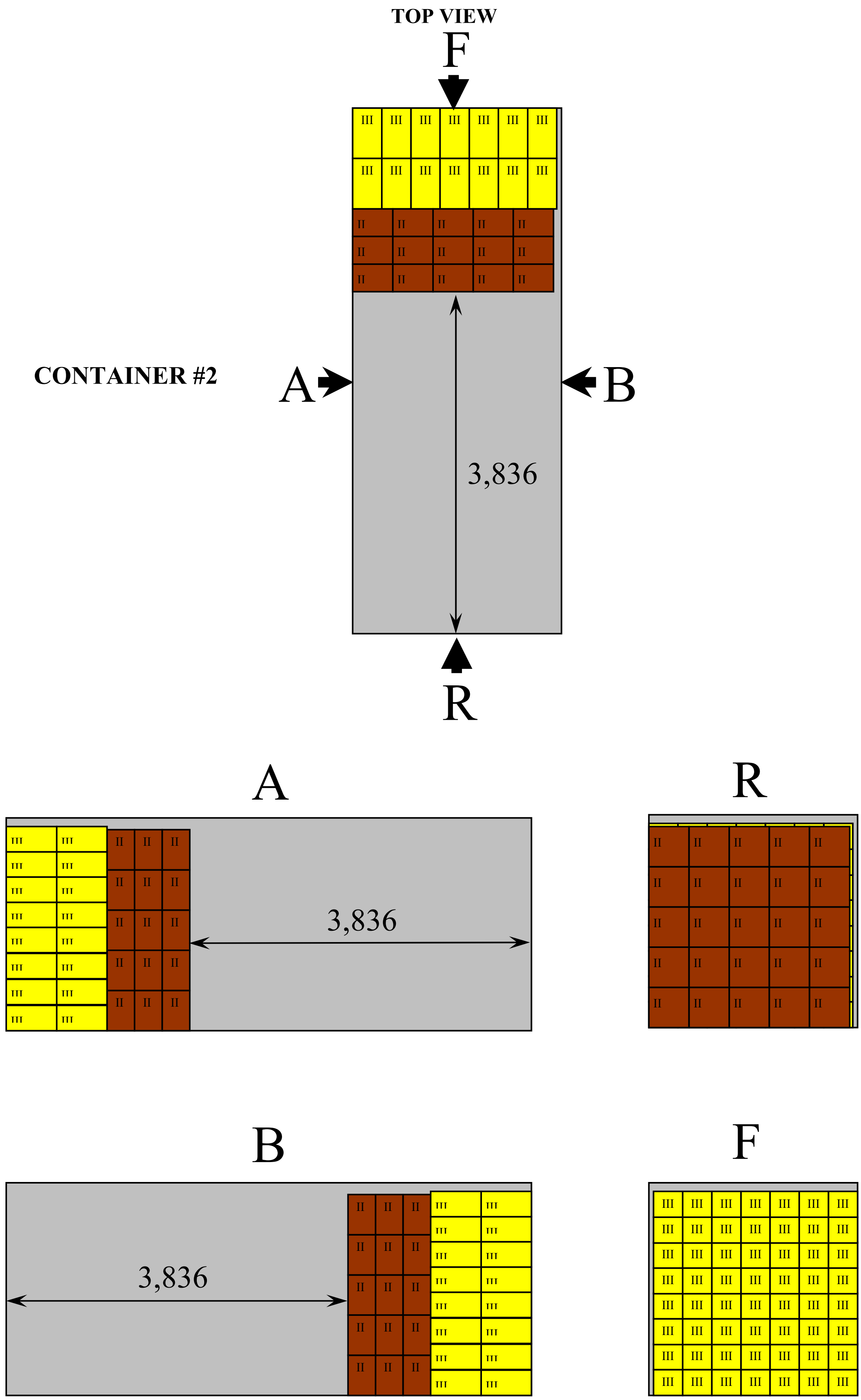

Figure 4.8 Stage III: The 2D visualization of the best solution of the second container obtained by the the reduced form of Filltype II for the box dimensions in box availability (ergonomics) limits.

CHAPTER FIVE
CONCLUSIONS

This thesis introduces two different conditions of container loading which are obtained from the customer order information. First condition includes packing only one type of cup (box) in a container. In second condition, customers demand different orders of cups (boxes). These orders may fill a container or need more than one container. Thus, the study proposes Filltype I and Filltype II approaches to solve these two conditions. The difference between most of the related studies in the literature and the proposed approach in this thesis is performing the box resizing while obtaining the objective of packing maximum items in boxes into the container. Because, the items (plastic cups) put inside the boxes are identical and have a regular allocation, the box dimensions can be easily resized by changing the number and the placement patterns of plastic cups. While Filltype I model fills a single container with only one type of boxes, for Filltype II model, customer orders of other cups are taken into account and more than a container could be filled. Thus single container loading problem (SCLP) with homogeneous boxes and multiple container loading problem (MCLP) with heterogeneous boxes have been undertaken together in the thesis.

The boxes are packed layer by layer in a container for Filltype I approach and optimum layer widths along the width of the container (W) are tried to be found as an output of the program. On the other side in Filltype II approach, the orders are filled successively as blocks. The boxes in every blocks are packed into the container by using a similiar logic of Filltype I. Also the presented two procedures and developed two policies are presented for Filltype II and these principles are combined and named as Filltype II Procedure. *The Ranking Order Procedure* is created for determining the packing sequence of the orders. The rules of the adjustment and rotation of the blocks are given as *The Order Adjustment Procedure*. Also for the layer based structure of the loading process, *The Container Loading Policy* and for the cutting the orders, *The Order Cutting Policy* are developed.

Because cutting the orders are not a desirable situation for a customer, the policy regulates the cut orders to satisfy the customer.

A mathematical model is formed to solve each of the problems. In structuring the mathematical models, the box availability, the weight and placement constraints are developed. While the box availability constraints and weight constraints keep the boxes in acceptable sizes and weight to be hold and carried by a person and provide ergonomics, placement constraints assure the placement of boxes inside the container.

Because, the structure of the main form of the Filltype approaches are integer nonlinear, the solutions are generally local optimals, and thus, they are not dependable. This condition forces to reduce the models from the integer nonlinear structure to the integer linear structure to gather global optimal solutions. In order to implement this, some variables are reconstructed as model inputs such as box dimensions. Then many box candidates are created and attempted to find a global optimal.

The solutions of the models are analyzed in three stages. In the first stage the performance of the current condition is handled. For the first condition, currently used boxes are packed to a 40ft Std Dry container by using the reduced form of Filltype I approach. For the second condition an example of a list of customer orders are created and the current boxes are packed into 20ft Std Dry containers as blocks by using the reduced form of Filltype II Procedure. Second stage contains solutions of the main form of the Filltype approaches for the same size of the containers. And in third stage the solutions of the reduced form of the Filltype approaches for all box dimensions in box availability (ergonomics) limits is studied for all dimensions of the box for a type.

When the solutions of the stages are compared for Filltype approaches great improvements have been recorded. For Stage II and III of Filltype I, the number of cups filled are increased about 200,000, and the utilization is improved about 13%

per container than Stage I. In Filltype II, the remained space is increased 86% for the second container although all customer orders are packed.

Finally, the main purpose of finding new box dimensions for a type of a cup in order to maximize quantity of cups being transported in a container is performed successfully behind the specific constraints. Also the 2D visualizings are given at the end to help in loading boxes easily. By using the proposed approaches several other loading problems encountered in the company can be solved in a reasonable time.

Some of the further studies can be expressed as following. This study could be generalized to the other industrial items such as powders or other symmetrical products in container loadings. Especially the powdered products would be much more available for box resizing approach because of their particle structure. This time the box could have any dimension in the interval of ergonomics constraint and would be give much more satisfactory results. Also the models can be modified by adding new constraints to adapt it more to the real world conditions. For example, the stability constraints help to prevent cargo from being damaged during transportation as Bortfeldt, Gehring, & Mack (2002) and Parreño, Valdez, Oliveira, & Tamarit (2008) defined in their papers. Also, because of the fragile properties of the plastic cups, boxes are available for only two of six possible orientations to be packed. Thus, for different products, more than two orientations could be applied. This situation is satisfied by additional orientation constraints. A more detailed study can be implemented by a cost based objective. The total cost in the objective may consist of personal costs, carton and pochette costs, customhouse costs, cost of vehicles used in loading, cost of transactions of transportation, and etc. Thus, trying to minimize it would give different layout solutions and needs much more time to be accomplished but gives more accurate results.

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APPENDICES

LINGO MODELS AND OUTPUTS

A- FILLTYPE I MODELS AND OUTPUTS

Stage I- Filltype I Reduced formulation for current 180cc(1) cup:

```
MODEL:
MAX = TCN;          !#;

DATA:
W = 2330;           !mm;
L = 12024;          !mm;
H = 2380;           !mm;
DI = 79;            !mm;
hb = 71;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.91;           !gr;

x=410;              !mm;
y=490;              !mm;
z=405;              !mm;

CN=1500;            !#;

Cmax = 26680;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA


!CALCULATIONS;
BT = 2*t;
Bikg = cgr*CN / 1000;
U = (BN*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
TCN = BN * CN;
c = @FLOOR(L/x);
d = @FLOOR(L/y);
e = @FLOOR(H/z);


!CONSTRAINTS;
a*x + b*y <= W;
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;


!INTEGER NUMBERS;
@GIN( a);
@GIN( b);
END
```

Stage I- Outputs:

```
Global optimal solution found.
   Objective value:                              1012500.
   Extended solver steps:                               0
   Total solver iterations:                             0
```

Variable	Value	Reduced Cost
TCN	1012500.	0.000000
W	2330.000	0.000000
L	12024.00	0.000000
H	2380.000	0.000000
DI	79.00000	0.000000
HB	71.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.910000	0.000000
X	410.0000	0.000000
Y	490.0000	0.000000
Z	405.0000	0.000000
CN	1500.000	0.000000
CMAX	26680.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
BT	10.00000	0.000000
BIKG	14.86500	0.000000
U	0.8236769	0.000000
BN	675.0000	0.000000
A	2.000000	-180000.0
D	24.00000	0.000000
B	3.000000	-217500.0
C	29.00000	0.000000
E	5.000000	0.000000

Stage II- Filltype I Main formulation for 180cc(1) cup:

```
MODEL:
MAX = TCN;          !#;

DATA:
W = 2330;           !mm;
L = 12024;          !mm;
H = 2380;           !mm;
DI = 79;            !mm;
hb = 71;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.91;           !gr;

xmin = 250;         !mm;
xmax = 450;         !mm;
ymin = 450;         !mm;
ymax = 650;         !mm;
zmin = 250;         !mm;
zmax = 450;         !mm;

Cmax = 26680;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA


!CALCULATIONS;
BT = 2*t;
x = DI*m + BT;
y = DI*n + BT;
z = hb + ha*p + BT;
pe= p+1;
Bikg = cgr*CN / 1000;
U = (BN*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
CN = m*n*pe;
TCN = BN * CN;


!CONSTRAINTS;
x <= xmax;
x >= xmin;
y <= ymax;
y >= ymin;
z <= zmax;
z >= zmin;
a*x + b*y <= W;
c*x <= L;
d*y <= L;
e*z <= H;
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;

!INTEGER NUMBERS;
@GIN( a);
@GIN( b);
@GIN( c);
```

```
@GIN( d);
@GIN( e);
@GIN( m);
@GIN( n);
@GIN( p);
END
```

Stage II - Outputs:

```
Global optimal solution found.
Objective value:                              1193640.
Extended solver steps:                            139
Total solver iterations:                        62992
```

Variable	Value	Reduced Cost
A	0.000000	-216090.1
D	21.00000	0.1029001E-01
B	4.000000	-298410.1
C	29.00000	-41160.03
E	6.000000	-198940.1
M	5.000000	-238728.2
N	7.000000	-170520.1
PE	49.00000	0.000000
W	2330.000	0.000000
L	12024.00	0.000000
H	2380.000	0.000000
DI	79.00000	0.000000
HB	71.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.910000	0.000000
XMIN	250.0000	0.000000
XMAX	450.0000	0.000000
YMIN	450.0000	0.000000
YMAX	650.0000	0.000000
ZMIN	250.0000	0.000000
ZMAX	450.0000	0.000000
CMAX	26680.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
BT	10.00000	0.000000
X	405.0000	0.000000
Y	563.0000	0.000000
Z	393.0000	0.000000
P	48.00000	-24360.02
BIKG	16.99565	0.000000
CN	1715.000	0.000000
U	0.9353698	0.000000
BN	696.0000	0.000000
TCN	1193640.	0.000000

<u>Stage III- Filltype I Reduced formulation for 180cc(1) cup: (the best one is given)</u>

```
MODEL:
MAX = TCN;          !#;

DATA:
W = 2330;           !mm;
L = 12024;          !mm;
H = 2380;           !mm;
DI = 79;            !mm;
hb = 71;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.91;           !gr;

x = 326;            !mm;
y = 563;            !mm;
z = 393;            !mm;

Cmax = 26680;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA


!CALCULATIONS;
BT = 2*t;
x = DI*m + BT;
y = DI*n + BT;
z = hb + ha*p + BT;
pe= p+1;
Bikg = cgr*CN / 1000;
U = ((a*d+b*c)*e*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
CN = m*n*pe;
TCN = BN * CN;
c = @FLOOR(L/x);
d = @FLOOR(L/y);
e = @FLOOR(H/z);


!CONSTRAINTS;
a*x + b*y <= W;
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;


!INTEGER NUMBERS;
@GIN( a);
@GIN( b);
END
```

Stage III- Outputs:

```
Global optimal solution found.
Objective value:                              1210104.
Extended solver steps:                               0
Total solver iterations:                             0
```

Variable	Value	Reduced Cost
TCN	1210104.	0.000000
W	2330.000	0.000000
L	12024.00	0.000000
H	2380.000	0.000000
DI	79.00000	0.000000
HB	71.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.910000	0.000000
X	326.0000	0.000000
Y	563.0000	0.000000
Z	393.0000	0.000000
CMAX	26680.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
BT	10.00000	0.000000
M	4.000000	0.000000
N	7.000000	0.000000
P	48.00000	0.000000
PE	49.00000	0.000000
BIKG	13.59652	0.000000
CN	1372.000	0.000000
U	0.9541250	0.000000
A	7.000000	-172872.0
D	21.00000	0.000000
B	0.000000	-296352.0
C	36.00000	0.000000
E	6.000000	0.000000
BN	882.0000	0.000000

B- FILLTYPE II MODELS AND OUTPUTS

Stage I- Filltype II Reduced formulation for current Straight cup:

```
MODEL:
MIN = Ls;           !mm;

DATA:
W = 2330;           !mm;
L = 5880;           !mm;
H = 2380;           !mm;
DI = 72;            !mm;
hb = 81;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.78;           !gr;
O=150000;           !#;

x=445;              !mm;
y=590;              !mm;
z=295;              !mm;

CN=1536;            !#;

Cmax = 21800;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA


!CALCULATIONS;
Ls = a*x + b*y;
BT = 2*t;
Bikg = cgr*CN / 1000;
Ucum = (BN*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
TCN = BN * CN;
c = @FLOOR(W/x);
d = @FLOOR(W/y);
e = @FLOOR(H/z);


!CONSTRAINTS;
Ls <= L;
TCN >= 0;
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;

!INTEGER NUMBERS;
@GIN( a);
@GIN( b);
END
```

Stage I - Outputs:

```
Global optimal solution found.
Objective value:                              1625.000
Extended solver steps:                               0
Total solver iterations:                             7
```

Variable	Value	Reduced Cost
LS	1625.000	0.000000
W	2330.000	0.000000
L	5880.000	0.000000
H	2380.000	0.000000
DI	72.00000	0.000000
HB	81.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.780000	0.000000
O	150000.0	0.000000
X	445.0000	0.000000
Y	590.0000	0.000000
Z	295.0000	0.000000
CN	1536.000	0.000000
CMAX	21800.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
A	1.000000	445.0000
B	2.000000	590.0000
BT	10.00000	0.000000
BIKG	15.02208	0.000000
UCUM	0.2470343	0.000000
BN	104.0000	0.000000
D	3.000000	0.000000
C	5.000000	0.000000
E	8.000000	0.000000
TCN	159744.0	0.000000

Stage II- Filltype II Main formulation for Straight cup:

```
MODEL:
MIN = Ls;           !mm;

DATA:
W = 2330;           !mm;
L = 5880;           !mm;
H = 2380;           !mm;
DI = 72;            !mm;
hb = 81;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.78;           !gr;
O=150000;           !#;

xmin = 250;         !mm;
xmax = 450;         !mm;
ymin = 450;         !mm;
ymax = 650;         !mm;
zmin = 250;         !mm;
zmax = 450;         !mm;

Cmax = 21800;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA

!CALCULATIONS;
Ls = a*x + b*y;
BT = 2*t;
x = DI*m + BT;
y = DI*n + BT;
z = hb + ha*p + BT;
pe= p+1;
Bikg = cgr*CN / 1000;
Ucum = (BN*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
CN = m*n*pe;
TCN = BN * CN;
c = @FLOOR(W/x);
d = @FLOOR(W/y);
e = @FLOOR(H/z);

!CONSTRAINTS;
x <= xmax;
x >= xmin;
y <= ymax;
y >= ymin;
z <= zmax;
z >= zmin;
Ls <= L;
TCN >= O;
TCN <=(O+CN);
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;

!INTEGER NUMBERS;
@GIN( a);
```

```
@GIN( b);
@GIN( c);
@GIN( d);
@GIN( e);
@GIN( m);
@GIN( n);
@GIN( p);
END
```

Stage II - Outputs:

```
Global optimal solution found.
   Objective value:                              1470.000
   Extended solver steps:                               1
   Total solver iterations:                        219902
```

Variable	Value	Reduced Cost
LS	1470.000	0.000000
W	2330.000	0.000000
L	5880.000	0.000000
H	2380.000	0.000000
DI	72.00000	0.000000
HB	81.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.780000	0.000000
O	150000.0	0.000000
XMIN	250.0000	0.000000
XMAX	450.0000	0.000000
YMIN	450.0000	0.000000
YMAX	650.0000	0.000000
ZMIN	250.0000	0.000000
ZMAX	450.0000	0.000000
CMAX	21800.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
A	1.000000	441.9999
X	442.0000	0.000000
B	2.000000	513.9997
Y	514.0000	0.000000
BT	10.00000	0.000000
M	6.000000	71.99993
N	7.000000	0.000000
Z	364.0000	0.000000
P	42.00000	0.000000
PE	43.00000	0.000000
BIKG	17.66268	0.000000
CN	1806.000	0.000000
UCUM	0.2130374	0.000000
D	4.000000	-226.7773
C	5.000000	0.000000
E	6.000000	0.000000
BN	84.00000	0.000000
TCN	151704.0	0.000000

Stage III - Filltype II Reduced formulation for Straight cup: (the best one is given)

```
MODEL:
MIN = Ls;           !mm;

DATA:
W = 2330;           !mm;
L = 5880;           !mm;
H = 2380;           !mm;
DI = 72;            !mm;
hb = 81;            !mm;
ha = 6.5;           !mm;
t = 5;              !mm;
cgr=9.78;           !gr;
O=150000;           !#;

x=442;              !mm;
y=514;              !mm;
z=383.5;            !mm;

Cmax = 21800;       !kg;
Bmax = 20;          !kg;
Bckg = 0.5;         !kg;
ENDDATA

!CALCULATIONS;
Ls = a*x + b*y;
BT = 2*t;
x = DI*m + BT;
y = DI*n + BT;
z = hb + ha*p + BT;
pe= p+1;
Bikg = cgr*CN / 1000;
Ucum = (BN*x*y*z) / (W*L*H);
BN = (a*d+b*c)*e;
CN = m*n*pe;
TCN = BN * CN;
c = @FLOOR(W/x);
d = @FLOOR(W/y);
e = @FLOOR(H/z);

!CONSTRAINTS;
Ls <= L;
TCN >= O;
TCN <=(O+CN);
(Bikg + Bckg) <= Bmax;
(Bikg + Bckg)*BN <= Cmax;

!INTEGER NUMBERS;
@GIN( a);
@GIN( b);
END
```

Stage III - Outputs:

```
Global optimal solution found.
   Global optimal solution found.
   Objective value:                              1398.000
   Extended solver steps:                               0
   Total solver iterations:                             0
```

Variable	Value	Reduced Cost
LS	1398.000	0.000000
W	2330.000	0.000000
L	5880.000	0.000000
H	2380.000	0.000000
DI	72.00000	0.000000
HB	81.00000	0.000000
HA	6.500000	0.000000
T	5.000000	0.000000
CGR	9.780000	0.000000
O	150000.0	0.000000
X	442.0000	0.000000
Y	514.0000	0.000000
Z	383.5000	0.000000
CMAX	21800.00	0.000000
BMAX	20.00000	0.000000
BCKG	0.5000000	0.000000
A	2.000000	442.0000
B	1.000000	514.0000
BT	10.00000	0.000000
M	6.000000	0.000000
N	7.000000	0.000000
P	45.00000	0.000000
PE	46.00000	0.000000
BIKG	18.89496	0.000000
CN	1932.000	0.000000
UCUM	0.2084180	0.000000
BN	78.00000	0.000000
D	4.000000	0.000000
C	5.000000	0.000000
E	6.000000	0.000000
TCN	150696.0	0.000000

POSSIBLE BOX DIMENSIONS FOR CUP TYPES

Table A01- 200cc(1) cups - Combinations of box dimensions in box availiability constraints

NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z
1	314	466	251	**30**	314	542	251	**59**	314	618	251	**88**	390	466	251	**117**	390	542	251	**146**	390	618	251
2	314	466	258	**31**	314	542	258	**60**	314	618	258	**89**	390	466	258	**118**	390	542	258	**147**	390	618	258
3	314	466	265	**32**	314	542	265	**61**	314	618	265	**90**	390	466	265	**119**	390	542	265	**148**	390	618	265
4	314	466	272	**33**	314	542	272	**62**	314	618	272	**91**	390	466	272	**120**	390	542	272	**149**	390	618	272
5	314	466	279	**34**	314	542	279	**63**	314	618	279	**92**	390	466	279	**121**	390	542	279	**150**	390	618	279
6	314	466	286	**35**	314	542	286	**64**	314	618	286	**93**	390	466	286	**122**	390	542	286	**151**	390	618	286
7	314	466	293	**36**	314	542	293	**65**	314	618	293	**94**	390	466	293	**123**	390	542	293	**152**	390	618	293
8	314	466	300	**37**	314	542	300	**66**	314	618	300	**95**	390	466	300	**124**	390	542	300	**153**	390	618	300
9	314	466	307	**38**	314	542	307	**67**	314	618	307	**96**	390	466	307	**125**	390	542	307	**154**	390	618	307
10	314	466	314	**39**	314	542	314	**68**	314	618	314	**97**	390	466	314	**126**	390	542	314	**155**	390	618	314
11	314	466	321	**40**	314	542	321	**69**	314	618	321	**98**	390	466	321	**127**	390	542	321	**156**	390	618	321
12	314	466	328	**41**	314	542	328	**70**	314	618	328	**99**	390	466	328	**128**	390	542	328	**157**	390	618	328
13	314	466	335	**42**	314	542	335	**71**	314	618	335	**100**	390	466	335	**129**	390	542	335	**158**	390	618	335
14	314	466	342	**43**	314	542	342	**72**	314	618	342	**101**	390	466	342	**130**	390	542	342	**159**	390	618	342
15	314	466	349	**44**	314	542	349	**73**	314	618	349	**102**	390	466	349	**131**	390	542	349	**160**	390	618	349
16	314	466	356	**45**	314	542	356	**74**	314	618	356	**103**	390	466	356	**132**	390	542	356	**161**	390	618	356
17	314	466	363	**46**	314	542	363	**75**	314	618	363	**104**	390	466	363	**133**	390	542	363	**162**	390	618	363
18	314	466	370	**47**	314	542	370	**76**	314	618	370	**105**	390	466	370	**134**	390	542	370	**163**	390	618	370
19	314	466	377	**48**	314	542	377	**77**	314	618	377	**106**	390	466	377	**135**	390	542	377	**164**	390	618	377
20	314	466	384	**49**	314	542	384	**78**	314	618	384	**107**	390	466	384	**136**	390	542	384	**165**	390	618	384
21	314	466	391	**50**	314	542	391	**79**	314	618	391	**108**	390	466	391	**137**	390	542	391	**166**	390	618	391
22	314	466	398	**51**	314	542	398	**80**	314	618	398	**109**	390	466	398	**138**	390	542	398	**167**	390	618	398
23	314	466	405	**52**	314	542	405	**81**	314	618	405	**110**	390	466	405	**139**	390	542	405	**168**	390	618	405
24	314	466	412	**53**	314	542	412	**82**	314	618	412	**111**	390	466	412	**140**	390	542	412	**169**	390	618	412
25	314	466	419	**54**	314	542	419	**83**	314	618	419	**112**	390	466	419	**141**	390	542	419	**170**	390	618	419
26	314	466	426	**55**	314	542	426	**84**	314	618	426	**113**	390	466	426	**142**	390	542	426	**171**	390	618	426
27	314	466	433	**56**	314	542	433	**85**	314	618	433	**114**	390	466	433	**143**	390	542	433	**172**	390	618	433
28	314	466	440	**57**	314	542	440	**86**	314	618	440	**115**	390	466	440	**144**	390	542	440	**173**	390	618	440
29	314	466	447	**58**	314	542	447	**87**	314	618	447	**116**	390	466	447	**145**	390	542	447	**174**	390	618	447

Table A02- 200cc(2) cups - Possible box dimensions in box availiability constraints

NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z
1	306	454	250.5	**32**	306	528	250.5	**63**	306	602	250.5	**94**	380	454	250.5	**125**	380	528	250.5	**156**	380	602	250.5
2	306	454	257	**33**	306	528	257	**64**	306	602	257	**95**	380	454	257	**126**	380	528	257	**157**	380	602	257
3	306	454	263.5	**34**	306	528	263.5	**65**	306	602	263.5	**96**	380	454	263.5	**127**	380	528	263.5	**158**	380	602	263.5
4	306	454	270	**35**	306	528	270	**66**	306	602	270	**97**	380	454	270	**128**	380	528	270	**159**	380	602	270
5	306	454	276.5	**36**	306	528	276.5	**67**	306	602	276.5	**98**	380	454	276.5	**129**	380	528	276.5	**160**	380	602	276.5
6	306	454	283	**37**	306	528	283	**68**	306	602	283	**99**	380	454	283	**130**	380	528	283	**161**	380	602	283
7	306	454	289.5	**38**	306	528	289.5	**69**	306	602	289.5	**100**	380	454	289.5	**131**	380	528	289.5	**162**	380	602	289.5
8	306	454	296	**39**	306	528	296	**70**	306	602	296	**101**	380	454	296	**132**	380	528	296	**163**	380	602	296
9	306	454	302.5	**40**	306	528	302.5	**71**	306	602	302.5	**102**	380	454	302.5	**133**	380	528	302.5	**164**	380	602	302.5
10	306	454	309	**41**	306	528	309	**72**	306	602	309	**103**	380	454	309	**134**	380	528	309	**165**	380	602	309
11	306	454	315.5	**42**	306	528	315.5	**73**	306	602	315.5	**104**	380	454	315.5	**135**	380	528	315.5	**166**	380	602	315.5
12	306	454	322	**43**	306	528	322	**74**	306	602	322	**105**	380	454	322	**136**	380	528	322	**167**	380	602	322
13	306	454	328.5	**44**	306	528	328.5	**75**	306	602	328.5	**106**	380	454	328.5	**137**	380	528	328.5	**168**	380	602	328.5
14	306	454	335	**45**	306	528	335	**76**	306	602	335	**107**	380	454	335	**138**	380	528	335	**169**	380	602	335
15	306	454	341.5	**46**	306	528	341.5	**77**	306	602	341.5	**108**	380	454	341.5	**139**	380	528	341.5	**170**	380	602	341.5
16	306	454	348	**47**	306	528	348	**78**	306	602	348	**109**	380	454	348	**140**	380	528	348	**171**	380	602	348
17	306	454	354.5	**48**	306	528	354.5	**79**	306	602	354.5	**110**	380	454	354.5	**141**	380	528	354.5	**172**	380	602	354.5
18	306	454	361	**49**	306	528	361	**80**	306	602	361	**111**	380	454	361	**142**	380	528	361	**173**	380	602	361
19	306	454	367.5	**50**	306	528	367.5	**81**	306	602	367.5	**112**	380	454	367.5	**143**	380	528	367.5	**174**	380	602	367.5
20	306	454	374	**51**	306	528	374	**82**	306	602	374	**113**	380	454	374	**144**	380	528	374	**175**	380	602	374
21	306	454	380.5	**52**	306	528	380.5	**83**	306	602	380.5	**114**	380	454	380.5	**145**	380	528	380.5	**176**	380	602	380.5
22	306	454	387	**53**	306	528	387	**84**	306	602	387	**115**	380	454	387	**146**	380	528	387	**177**	380	602	387
23	306	454	393.5	**54**	306	528	393.5	**85**	306	602	393.5	**116**	380	454	393.5	**147**	380	528	393.5	**178**	380	602	393.5
24	306	454	400	**55**	306	528	400	**86**	306	602	400	**117**	380	454	400	**148**	380	528	400	**179**	380	602	400
25	306	454	406.5	**56**	306	528	406.5	**87**	306	602	406.5	**118**	380	454	406.5	**149**	380	528	406.5	**180**	380	602	406.5
26	306	454	413	**57**	306	528	413	**88**	306	602	413	**119**	380	454	413	**150**	380	528	413	**181**	380	602	413
27	306	454	419.5	**58**	306	528	419.5	**89**	306	602	419.5	**120**	380	454	419.5	**151**	380	528	419.5	**182**	380	602	419.5
28	306	454	426	**59**	306	528	426	**90**	306	602	426	**121**	380	454	426	**152**	380	528	426	**183**	380	602	426
29	306	454	432.5	**60**	306	528	432.5	**91**	306	602	432.5	**122**	380	454	432.5	**153**	380	528	432.5	**184**	380	602	432.5
30	306	454	439	**61**	306	528	439	**92**	306	602	439	**123**	380	454	439	**154**	380	528	439	**185**	380	602	439
31	306	454	445.5	**62**	306	528	445.5	**93**	306	602	445.5	**124**	380	454	445.5	**155**	380	528	445.5	**186**	380	602	445.5

Table A03- 180cc(1) cups - Possible box dimensions in box availability constraints

NO	**x**	**y**	**z**	NO	**x**	**y**	**z**	NO	**x**	**y**	**z**	NO	**x**	**y**	**z**	NO	**x**	**y**	**z**	NO	**x**	**y**	**z**
1	326	484	250	**32**	326	563	250	**63**	326	642	250	**94**	405	484	250	**125**	405	563	250	**156**	405	642	250
2	326	484	256.5	**33**	326	563	256.5	**64**	326	642	256.5	**95**	405	484	256.5	**126**	405	563	256.5	**157**	405	642	256.5
3	326	484	263	**34**	326	563	263	**65**	326	642	263	**96**	405	484	263	**127**	405	563	263	**158**	405	642	263
4	326	484	269.5	**35**	326	563	269.5	**66**	326	642	269.5	**97**	405	484	269.5	**128**	405	563	269.5	**159**	405	642	269.5
5	326	484	276	**36**	326	563	276	**67**	326	642	276	**98**	405	484	276	**129**	405	563	276	**160**	405	642	276
6	326	484	282.5	**37**	326	563	282.5	**68**	326	642	282.5	**99**	405	484	282.5	**130**	405	563	282.5	**161**	405	642	282.5
7	326	484	289	**38**	326	563	289	**69**	326	642	289	**100**	405	484	289	**131**	405	563	289	**162**	405	642	289
8	326	484	295.5	**39**	326	563	295.5	**70**	326	642	295.5	**101**	405	484	295.5	**132**	405	563	295.5	**163**	405	642	295.5
9	326	484	302	**40**	326	563	302	**71**	326	642	302	**102**	405	484	302	**133**	405	563	302	**164**	405	642	302
10	326	484	308.5	**41**	326	563	308.5	**72**	326	642	308.5	**103**	405	484	308.5	**134**	405	563	308.5	**165**	405	642	308.5
11	326	484	315	**42**	326	563	315	**73**	326	642	315	**104**	405	484	315	**135**	405	563	315	**166**	405	642	315
12	326	484	321.5	**43**	326	563	321.5	**74**	326	642	321.5	**105**	405	484	321.5	**136**	405	563	321.5	**167**	405	642	321.5
13	326	484	328	**44**	326	563	328	**75**	326	642	328	**106**	405	484	328	**137**	405	563	328	**168**	405	642	328
14	326	484	334.5	**45**	326	563	334.5	**76**	326	642	334.5	**107**	405	484	334.5	**138**	405	563	334.5	**169**	405	642	334.5
15	326	484	341	**46**	326	563	341	**77**	326	642	341	**108**	405	484	341	**139**	405	563	341	**170**	405	642	341
16	326	484	347.5	**47**	326	563	347.5	**78**	326	642	347.5	**109**	405	484	347.5	**140**	405	563	347.5	**171**	405	642	347.5
17	326	484	354	**48**	326	563	354	**79**	326	642	354	**110**	405	484	354	**141**	405	563	354	**172**	405	642	354
18	326	484	360.5	**49**	326	563	360.5	**80**	326	642	360.5	**111**	405	484	360.5	**142**	405	563	360.5	**173**	405	642	360.5
19	326	484	367	**50**	326	563	367	**81**	326	642	367	**112**	405	484	367	**143**	405	563	367	**174**	405	642	367
20	326	484	373.5	**51**	326	563	373.5	**82**	326	642	373.5	**113**	405	484	373.5	**144**	405	563	373.5	**175**	405	642	373.5
21	326	484	380	**52**	326	563	380	**83**	326	642	380	**114**	405	484	380	**145**	405	563	380	**176**	405	642	380
22	326	484	386.5	**53**	326	563	386.5	**84**	326	642	386.5	**115**	405	484	386.5	**146**	405	563	386.5	**177**	405	642	386.5
23	326	484	393	**54**	326	563	393	**85**	326	642	393	**116**	405	484	393	**147**	405	563	393	**178**	405	642	393
24	326	484	399.5	**55**	326	563	399.5	**86**	326	642	399.5	**117**	405	484	399.5	**148**	405	563	399.5	**179**	405	642	399.5
25	326	484	406	**56**	326	563	406	**87**	326	642	406	**118**	405	484	406	**149**	405	563	406	**180**	405	642	406
26	326	484	412.5	**57**	326	563	412.5	**88**	326	642	412.5	**119**	405	484	412.5	**150**	405	563	412.5	**181**	405	642	412.5
27	326	484	419	**58**	326	563	419	**89**	326	642	419	**120**	405	484	419	**151**	405	563	419	**182**	405	642	419
28	326	484	425.5	**59**	326	563	425.5	**90**	326	642	425.5	**121**	405	484	425.5	**152**	405	563	425.5	**183**	405	642	425.5
29	326	484	432	**60**	326	563	432	**91**	326	642	432	**122**	405	484	432	**153**	405	563	432	**184**	405	642	432
30	326	484	438.5	**61**	326	563	438.5	**92**	326	642	438.5	**123**	405	484	438.5	**154**	405	563	438.5	**185**	405	642	438.5
31	326	484	445	**62**	326	563	445	**93**	326	642	445	**124**	405	484	445	**155**	405	563	445	**186**	405	642	445

Table A04- 180cc(2) cups - Possible box dimensions in box availiability constraints

NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z
1	306	454	254.5	**32**	306	528	254.5	**63**	306	602	254.5	**94**	380	454	254.5	**125**	380	528	254.5	**156**	380	602	254.5
2	306	454	261	**33**	306	528	261	**64**	306	602	261	**95**	380	454	261	**126**	380	528	261	**157**	380	602	261
3	306	454	267.5	**34**	306	528	267.5	**65**	306	602	267.5	**96**	380	454	267.5	**127**	380	528	267.5	**158**	380	602	267.5
4	306	454	274	**35**	306	528	274	**66**	306	602	274	**97**	380	454	274	**128**	380	528	274	**159**	380	602	274
5	306	454	280.5	**36**	306	528	280.5	**67**	306	602	280.5	**98**	380	454	280.5	**129**	380	528	280.5	**160**	380	602	280.5
6	306	454	287	**37**	306	528	287	**68**	306	602	287	**99**	380	454	287	**130**	380	528	287	**161**	380	602	287
7	306	454	293.5	**38**	306	528	293.5	**69**	306	602	293.5	**100**	380	454	293.5	**131**	380	528	293.5	**162**	380	602	293.5
8	306	454	300	**39**	306	528	300	**70**	306	602	300	**101**	380	454	300	**132**	380	528	300	**163**	380	602	300
9	306	454	306.5	**40**	306	528	306.5	**71**	306	602	306.5	**102**	380	454	306.5	**133**	380	528	306.5	**164**	380	602	306.5
10	306	454	313	**41**	306	528	313	**72**	306	602	313	**103**	380	454	313	**134**	380	528	313	**165**	380	602	313
11	306	454	319.5	**42**	306	528	319.5	**73**	306	602	319.5	**104**	380	454	319.5	**135**	380	528	319.5	**166**	380	602	319.5
12	306	454	326	**43**	306	528	326	**74**	306	602	326	**105**	380	454	326	**136**	380	528	326	**167**	380	602	326
13	306	454	332.5	**44**	306	528	332.5	**75**	306	602	332.5	**106**	380	454	332.5	**137**	380	528	332.5	**168**	380	602	332.5
14	306	454	339	**45**	306	528	339	**76**	306	602	339	**107**	380	454	339	**138**	380	528	339	**169**	380	602	339
15	306	454	345.5	**46**	306	528	345.5	**77**	306	602	345.5	**108**	380	454	345.5	**139**	380	528	345.5	**170**	380	602	345.5
16	306	454	352	**47**	306	528	352	**78**	306	602	352	**109**	380	454	352	**140**	380	528	352	**171**	380	602	352
17	306	454	358.5	**48**	306	528	358.5	**79**	306	602	358.5	**110**	380	454	358.5	**141**	380	528	358.5	**172**	380	602	358.5
18	306	454	365	**49**	306	528	365	**80**	306	602	365	**111**	380	454	365	**142**	380	528	365	**173**	380	602	365
19	306	454	371.5	**50**	306	528	371.5	**81**	306	602	371.5	**112**	380	454	371.5	**143**	380	528	371.5	**174**	380	602	371.5
20	306	454	378	**51**	306	528	378	**82**	306	602	378	**113**	380	454	378	**144**	380	528	378	**175**	380	602	378
21	306	454	384.5	**52**	306	528	384.5	**83**	306	602	384.5	**114**	380	454	384.5	**145**	380	528	384.5	**176**	380	602	384.5
22	306	454	391	**53**	306	528	391	**84**	306	602	391	**115**	380	454	391	**146**	380	528	391	**177**	380	602	391
23	306	454	397.5	**54**	306	528	397.5	**85**	306	602	397.5	**116**	380	454	397.5	**147**	380	528	397.5	**178**	380	602	397.5
24	306	454	404	**55**	306	528	404	**86**	306	602	404	**117**	380	454	404	**148**	380	528	404	**179**	380	602	404
25	306	454	410.5	**56**	306	528	410.5	**87**	306	602	410.5	**118**	380	454	410.5	**149**	380	528	410.5	**180**	380	602	410.5
26	306	454	417	**57**	306	528	417	**88**	306	602	417	**119**	380	454	417	**150**	380	528	417	**181**	380	602	417
27	306	454	423.5	**58**	306	528	423.5	**89**	306	602	423.5	**120**	380	454	423.5	**151**	380	528	423.5	**182**	380	602	423.5
28	306	454	430	**59**	306	528	430	**90**	306	602	430	**121**	380	454	430	**152**	380	528	430	**183**	380	602	430
29	306	454	436.5	**60**	306	528	436.5	**91**	306	602	436.5	**122**	380	454	436.5	**153**	380	528	436.5	**184**	380	602	436.5
30	306	454	443	**61**	306	528	443	**92**	306	602	443	**123**	380	454	443	**154**	380	528	443	**185**	380	602	443
31	306	454	449.5	**62**	306	528	449.5	**93**	306	602	449.5	**124**	380	454	449.5	**155**	380	528	449.5	**186**	380	602	449.5

Table A05- Straight cups - Possible box dimensions in box availiability constraints

NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z
1	298	514	253.5	32	370	514	253.5	63	442	514	253.5	94	298	586	253.5	125	370	586	253.5	156	442	586	253.5
2	298	514	260	33	370	514	260	64	442	514	260	95	298	586	260	126	370	586	260	157	442	586	260
3	298	514	266.5	34	370	514	266.5	65	442	514	266.5	96	298	586	266.5	127	370	586	266.5	158	442	586	266.5
4	298	514	273	35	370	514	273	66	442	514	273	97	298	586	273	128	370	586	273	159	442	586	273
5	298	514	279.5	36	370	514	279.5	67	442	514	279.5	98	298	586	279.5	129	370	586	279.5	160	442	586	279.5
6	298	514	286	37	370	514	286	68	442	514	286	99	298	586	286	130	370	586	286	161	442	586	286
7	298	514	292.5	38	370	514	292.5	69	442	514	292.5	100	298	586	292.5	131	370	586	292.5	162	442	586	292.5
8	298	514	299	39	370	514	299	70	442	514	299	101	298	586	299	132	370	586	299	163	442	586	299
9	298	514	305.5	40	370	514	305.5	71	442	514	305.5	102	298	586	305.5	133	370	586	305.5	164	442	586	305.5
10	298	514	312	41	370	514	312	72	442	514	312	103	298	586	312	134	370	586	312	165	442	586	312
11	298	514	318.5	42	370	514	318.5	73	442	514	318.5	104	298	586	318.5	135	370	586	318.5	166	442	586	318.5
12	298	514	325	43	370	514	325	74	442	514	325	105	298	586	325	136	370	586	325	167	442	586	325
13	298	514	331.5	44	370	514	331.5	75	442	514	331.5	106	298	586	331.5	137	370	586	331.5	168	442	586	331.5
14	298	514	338	45	370	514	338	76	442	514	338	107	298	586	338	138	370	586	338	169	442	586	338
15	298	514	344.5	46	370	514	344.5	77	442	514	344.5	108	298	586	344.5	139	370	586	344.5	170	442	586	344.5
16	298	514	351	47	370	514	351	78	442	514	351	109	298	586	351	140	370	586	351	171	442	586	351
17	298	514	357.5	48	370	514	357.5	79	442	514	357.5	110	298	586	357.5	141	370	586	357.5	172	442	586	357.5
18	298	514	364	49	370	514	364	80	442	514	364	111	298	586	364	142	370	586	364	173	442	586	364
19	298	514	370.5	50	370	514	370.5	81	442	514	370.5	112	298	586	370.5	143	370	586	370.5	174	442	586	370.5
20	298	514	377	51	370	514	377	82	442	514	377	113	298	586	377	144	370	586	377	175	442	586	377
21	298	514	383.5	52	370	514	383.5	83	442	514	383.5	114	298	586	383.5	145	370	586	383.5	176	442	586	383.5
22	298	514	390	53	370	514	390	84	442	514	390	115	298	586	390	146	370	586	390	177	442	586	390
23	298	514	396.5	54	370	514	396.5	85	442	514	396.5	116	298	586	396.5	147	370	586	396.5	178	442	586	396.5
24	298	514	403	55	370	514	403	86	442	514	403	117	298	586	403	148	370	586	403	179	442	586	403
25	298	514	409.5	56	370	514	409.5	87	442	514	409.5	118	298	586	409.5	149	370	586	409.5	180	442	586	409.5
26	298	514	416	57	370	514	416	88	442	514	416	119	298	586	416	150	370	586	416	181	442	586	416
27	298	514	422.5	58	370	514	422.5	89	442	514	422.5	120	298	586	422.5	151	370	586	422.5	182	442	586	422.5
28	298	514	429	59	370	514	429	90	442	514	429	121	298	586	429	152	370	586	429	183	442	586	429
29	298	514	435.5	60	370	514	435.5	91	442	514	435.5	122	298	586	435.5	153	370	586	435.5	184	442	586	435.5
30	298	514	442	61	370	514	442	92	442	514	442	123	298	586	442	154	370	586	442	185	442	586	442
31	298	514	448.5	62	370	514	448.5	93	442	514	448.5	124	298	586	448.5	155	370	586	448.5	186	442	586	448.5

Table A06- Star cups - Possible box dimensions in box availiability constraints

NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z	NO	x	y	z
1	302	521	254	**30**	375	521	254	**59**	448	521	254	**88**	302	594	254	**117**	375	594	254	**146**	448	594	254
2	302	521	261	**31**	375	521	261	**60**	448	521	261	**89**	302	594	261	**118**	375	594	261	**147**	448	594	261
3	302	521	268	**32**	375	521	268	**61**	448	521	268	**90**	302	594	268	**119**	375	594	268	**148**	448	594	268
4	302	521	275	**33**	375	521	275	**62**	448	521	275	**91**	302	594	275	**120**	375	594	275	**149**	448	594	275
5	302	521	282	**34**	375	521	282	**63**	448	521	282	**92**	302	594	282	**121**	375	594	282	**150**	448	594	282
6	302	521	289	**35**	375	521	289	**64**	448	521	289	**93**	302	594	289	**122**	375	594	289	**151**	448	594	289
7	302	521	296	**36**	375	521	296	**65**	448	521	296	**94**	302	594	296	**123**	375	594	296	**152**	448	594	296
8	302	521	303	**37**	375	521	303	**66**	448	521	303	**95**	302	594	303	**124**	375	594	303	**153**	448	594	303
9	302	521	310	**38**	375	521	310	**67**	448	521	310	**96**	302	594	310	**125**	375	594	310	**154**	448	594	310
10	302	521	317	**39**	375	521	317	**68**	448	521	317	**97**	302	594	317	**126**	375	594	317	**155**	448	594	317
11	302	521	324	**40**	375	521	324	**69**	448	521	324	**98**	302	594	324	**127**	375	594	324	**156**	448	594	324
12	302	521	331	**41**	375	521	331	**70**	448	521	331	**99**	302	594	331	**128**	375	594	331	**157**	448	594	331
13	302	521	338	**42**	375	521	338	**71**	448	521	338	**100**	302	594	338	**129**	375	594	338	**158**	448	594	338
14	302	521	345	**43**	375	521	345	**72**	448	521	345	**101**	302	594	345	**130**	375	594	345	**159**	448	594	345
15	302	521	352	**44**	375	521	352	**73**	448	521	352	**102**	302	594	352	**131**	375	594	352	**160**	448	594	352
16	302	521	359	**45**	375	521	359	**74**	448	521	359	**103**	302	594	359	**132**	375	594	359	**161**	448	594	359
17	302	521	366	**46**	375	521	366	**75**	448	521	366	**104**	302	594	366	**133**	375	594	366	**162**	448	594	366
18	302	521	373	**47**	375	521	373	**76**	448	521	373	**105**	302	594	373	**134**	375	594	373	**163**	448	594	373
19	302	521	380	**48**	375	521	380	**77**	448	521	380	**106**	302	594	380	**135**	375	594	380	**164**	448	594	380
20	302	521	387	**49**	375	521	387	**78**	448	521	387	**107**	302	594	387	**136**	375	594	387	**165**	448	594	387
21	302	521	394	**50**	375	521	394	**79**	448	521	394	**108**	302	594	394	**137**	375	594	394	**166**	448	594	394
22	302	521	401	**51**	375	521	401	**80**	448	521	401	**109**	302	594	401	**138**	375	594	401	**167**	448	594	401
23	302	521	408	**52**	375	521	408	**81**	448	521	408	**110**	302	594	408	**139**	375	594	408	**168**	448	594	408
24	302	521	415	**53**	375	521	415	**82**	448	521	415	**111**	302	594	415	**140**	375	594	415	**169**	448	594	415
25	302	521	422	**54**	375	521	422	**83**	448	521	422	**112**	302	594	422	**141**	375	594	422	**170**	448	594	422
26	302	521	429	**55**	375	521	429	**84**	448	521	429	**113**	302	594	429	**142**	375	594	429	**171**	448	594	429
27	302	521	436	**56**	375	521	436	**85**	448	521	436	**114**	302	594	436	**143**	375	594	436	**172**	448	594	436
28	302	521	443	**57**	375	521	443	**86**	448	521	443	**115**	302	594	443	**144**	375	594	443	**173**	448	594	443
29	302	521	450	**58**	375	521	450	**87**	448	521	450	**116**	302	594	450	**145**	375	594	450	**174**	448	594	450

SOLUTIONS

A- FILLTYPE I

Table A07- Stage III solutions for all possible dimensions of a box for 180cc (1) cup for Filltype I. (Set in order to TCN and given next six pages)

Filltype I										
	Cup Type	Name	x	y	z	e	CN	BN	TCN	Utilization U
54	III	180cc(1)	326	563	393	6	1,372	882	1,210,104	0.9541
147	III	180cc(1)	405	563	393	6	1,715	696	1,193,640	0.9354
116	III	180cc(1)	405	484	393	6	1,470	810	1,190,700	0.9358
178	III	180cc(1)	405	642	393	6	1,960	606	1,187,760	0.9287
23	III	180cc(1)	326	484	393	6	1,176	1,008	1,185,408	0.9374
53	III	180cc(1)	326	563	386.5	6	1,344	882	1,185,408	0.9383
85	III	180cc(1)	326	642	393	6	1,568	756	1,185,408	0.9326
62	III	180cc(1)	326	563	445	5	1,596	735	1,173,060	0.9003
146	III	180cc(1)	405	563	386.5	6	1,680	696	1,169,280	0.9199
115	III	180cc(1)	405	484	386.5	6	1,440	810	1,166,400	0.9204
177	III	180cc(1)	405	642	386.5	6	1,920	606	1,163,520	0.9133
22	III	180cc(1)	326	484	386.5	6	1,152	1,008	1,161,216	0.9219
84	III	180cc(1)	326	642	386.5	6	1,536	756	1,161,216	0.9172
52	III	180cc(1)	326	563	380	6	1,316	882	1,160,712	0.9226
124	III	180cc(1)	405	484	445	5	1,710	675	1,154,250	0.8830
45	III	180cc(1)	326	563	334.5	7	1,120	1,029	1,152,480	0.9474
61	III	180cc(1)	326	563	438.5	5	1,568	735	1,152,480	0.8872
31	III	180cc(1)	326	484	445	5	1,368	840	1,149,120	0.8845
93	III	180cc(1)	326	642	445	5	1,824	630	1,149,120	0.8800
145	III	180cc(1)	405	563	380	6	1,645	696	1,144,920	0.9044
114	III	180cc(1)	405	484	380	6	1,410	810	1,142,100	0.9049
176	III	180cc(1)	405	642	380	6	1,880	606	1,139,280	0.8980
21	III	180cc(1)	326	484	380	6	1,128	1,008	1,137,024	0.9064
83	III	180cc(1)	326	642	380	6	1,504	756	1,137,024	0.9017
138	III	180cc(1)	405	563	334.5	7	1,400	812	1,136,800	0.9288
154	III	180cc(1)	405	563	438.5	5	1,960	580	1,136,800	0.8697
51	III	180cc(1)	326	563	373.5	6	1,288	882	1,136,016	0.9068
107	III	180cc(1)	405	484	334.5	7	1,200	945	1,134,000	0.9293
123	III	180cc(1)	405	484	438.5	5	1,680	675	1,134,000	0.8701
60	III	180cc(1)	326	563	432	5	1,540	735	1,131,900	0.8740
169	III	180cc(1)	405	642	334.5	7	1,600	707	1,131,200	0.9222
14	III	180cc(1)	326	484	334.5	7	960	1,176	1,128,960	0.9309
30	III	180cc(1)	326	484	438.5	5	1,344	840	1,128,960	0.8716
76	III	180cc(1)	326	642	334.5	7	1,280	882	1,128,960	0.9261
92	III	180cc(1)	326	642	438.5	5	1,792	630	1,128,960	0.8671
113	III	180cc(1)	405	484	373.5	6	1,390	810	1,125,900	0.8894
44	III	180cc(1)	326	563	328	7	1,092	1,029	1,123,668	0.9290
144	III	180cc(1)	405	563	373.5	6	1,610	696	1,120,560	0.8890
39	III	180cc(1)	326	563	295.5	8	952	1,176	1,119,552	0.9566
153	III	180cc(1)	405	563	432	5	1,925	580	1,116,500	0.8568
175	III	180cc(1)	405	642	373.5	6	1,840	606	1,115,040	0.8826
122	III	180cc(1)	405	484	432	5	1,650	675	1,113,750	0.8572
20	III	180cc(1)	326	484	373.5	6	1,104	1,008	1,112,832	0.8909
82	III	180cc(1)	326	642	373.5	6	1,472	756	1,112,832	0.8863
50	III	180cc(1)	326	563	367	6	1,260	882	1,111,320	0.8910

59	III	180cc(1)	326	563	425.5	5	1,512	735	1,111,320	0.8609
29	III	180cc(1)	326	484	432	5	1,320	840	1,108,800	0.8587
91	III	180cc(1)	326	642	432	5	1,760	630	1,108,800	0.8543
137	III	180cc(1)	405	563	328	7	1,365	812	1,108,380	0.9108
106	III	180cc(1)	405	484	328	7	1,170	945	1,105,650	0.9112
132	III	180cc(1)	405	563	295.5	8	1,190	928	1,104,320	0.9377
168	III	180cc(1)	405	642	328	7	1,560	707	1,102,920	0.9043
101	III	180cc(1)	405	484	295.5	8	1,020	1,080	1,101,600	0.9382
13	III	180cc(1)	326	484	328	7	936	1,176	1,100,736	0.9128
75	III	180cc(1)	326	642	328	7	1,248	882	1,100,736	0.9081
163	III	180cc(1)	405	642	295.5	8	1,360	808	1,098,880	0.9311
8	III	180cc(1)	326	484	295.5	8	816	1,344	1,096,704	0.9398
70	III	180cc(1)	326	642	295.5	8	1,088	1,008	1,096,704	0.9350
143	III	180cc(1)	405	563	367	6	1,575	696	1,096,200	0.8735
152	III	180cc(1)	405	563	425.5	5	1,890	580	1,096,200	0.8439
43	III	180cc(1)	326	563	321.5	7	1,064	1,029	1,094,856	0.9106
112	III	180cc(1)	405	484	367	6	1,350	810	1,093,500	0.8739
121	III	180cc(1)	405	484	425.5	5	1,620	675	1,093,500	0.8443
174	III	180cc(1)	405	642	367	6	1,800	606	1,090,800	0.8673
58	III	180cc(1)	326	563	419	5	1,484	735	1,090,740	0.8477
19	III	180cc(1)	326	484	367	6	1,080	1,008	1,088,640	0.8754
28	III	180cc(1)	326	484	425.5	5	1,296	840	1,088,640	0.8458
81	III	180cc(1)	326	642	367	6	1,440	756	1,088,640	0.8709
90	III	180cc(1)	326	642	425.5	5	1,728	630	1,088,640	0.8414
38	III	180cc(1)	326	563	289	8	924	1,176	1,086,624	0.9355
49	III	180cc(1)	326	563	360.5	6	1,232	882	1,086,624	0.8752
136	III	180cc(1)	405	563	321.5	7	1,330	812	1,079,960	0.8927
105	III	180cc(1)	405	484	321.5	7	1,140	945	1,077,300	0.8932
151	III	180cc(1)	405	563	419	5	1,855	580	1,075,900	0.8310
167	III	180cc(1)	405	642	321.5	7	1,520	707	1,074,640	0.8864
34	III	180cc(1)	326	563	263	9	812	1,323	1,074,276	0.9578
120	III	180cc(1)	405	484	419	5	1,590	675	1,073,250	0.8315
12	III	180cc(1)	326	484	321.5	7	912	1,176	1,072,512	0.8947
74	III	180cc(1)	326	642	321.5	7	1,216	882	1,072,512	0.8901
131	III	180cc(1)	405	563	289	8	1,155	928	1,071,840	0.9171
142	III	180cc(1)	405	563	360.5	6	1,540	696	1,071,840	0.8580
57	III	180cc(1)	326	563	412.5	5	1,456	735	1,070,160	0.8346
100	III	180cc(1)	405	484	289	8	990	1,080	1,069,200	0.9176
111	III	180cc(1)	405	484	360.5	6	1,320	810	1,069,200	0.8584
27	III	180cc(1)	326	484	419	5	1,272	840	1,068,480	0.8329
89	III	180cc(1)	326	642	419	5	1,696	630	1,068,480	0.8286
162	III	180cc(1)	405	642	289	8	1,320	808	1,066,560	0.9106
173	III	180cc(1)	405	642	360.5	6	1,760	606	1,066,560	0.8519
42	III	180cc(1)	326	563	315	7	1,036	1,029	1,066,044	0.8922
7	III	180cc(1)	326	484	289	8	792	1,344	1,064,448	0.9191
18	III	180cc(1)	326	484	360.5	6	1,056	1,008	1,064,448	0.8599
69	III	180cc(1)	326	642	289	8	1,056	1,008	1,064,448	0.9144
80	III	180cc(1)	326	642	360.5	6	1,408	756	1,064,448	0.8555
48	III	180cc(1)	326	563	354	6	1,204	882	1,061,928	0.8594
127	III	180cc(1)	405	563	263	9	1,015	1,044	1,059,660	0.9389
96	III	180cc(1)	405	484	263	9	870	1,215	1,057,050	0.9394
150	III	180cc(1)	405	563	412.5	5	1,820	580	1,055,600	0.8182
158	III	180cc(1)	405	642	263	9	1,160	909	1,054,440	0.9322
37	III	180cc(1)	326	563	282.5	8	896	1,176	1,053,696	0.9145
119	III	180cc(1)	405	484	412.5	5	1,560	675	1,053,000	0.8186

3	III	180cc(1)	326	484	263	9	696	1,512	1,052,352	0.9410
65	III	180cc(1)	326	642	263	9	928	1,134	1,052,352	0.9361
135	III	180cc(1)	405	563	315	7	1,295	812	1,051,540	0.8747
56	III	180cc(1)	326	563	406	5	1,428	735	1,049,580	0.8214
104	III	180cc(1)	405	484	315	7	1,110	945	1,048,950	0.8751
26	III	180cc(1)	326	484	412.5	5	1,248	840	1,048,320	0.8199
88	III	180cc(1)	326	642	412.5	5	1,664	630	1,048,320	0.8157
141	III	180cc(1)	405	563	354	6	1,505	696	1,047,480	0.8425
166	III	180cc(1)	405	642	315	7	1,480	707	1,046,360	0.8684
110	III	180cc(1)	405	484	354	6	1,290	810	1,044,900	0.8430
11	III	180cc(1)	326	484	315	7	888	1,176	1,044,288	0.8766
73	III	180cc(1)	326	642	315	7	1,184	882	1,044,288	0.8721
172	III	180cc(1)	405	642	354	6	1,720	606	1,042,320	0.8365
17	III	180cc(1)	326	484	354	6	1,032	1,008	1,040,256	0.8444
79	III	180cc(1)	326	642	354	6	1,376	756	1,040,256	0.8400
130	III	180cc(1)	405	563	282.5	8	1,120	928	1,039,360	0.8965
33	III	180cc(1)	326	563	256.5	9	784	1,323	1,037,232	0.9341
41	III	180cc(1)	326	563	308.5	7	1,008	1,029	1,037,232	0.8738
47	III	180cc(1)	326	563	347.5	6	1,176	882	1,037,232	0.8437
99	III	180cc(1)	405	484	282.5	8	960	1,080	1,036,800	0.8969
149	III	180cc(1)	405	563	406	5	1,785	580	1,035,300	0.8053
161	III	180cc(1)	405	642	282.5	8	1,280	808	1,034,240	0.8901
118	III	180cc(1)	405	484	406	5	1,530	675	1,032,750	0.8057
6	III	180cc(1)	326	484	282.5	8	768	1,344	1,032,192	0.8985
68	III	180cc(1)	326	642	282.5	8	1,024	1,008	1,032,192	0.8938
55	III	180cc(1)	326	563	399.5	5	1,400	735	1,029,000	0.8083
25	III	180cc(1)	326	484	406	5	1,224	840	1,028,160	0.8070
87	III	180cc(1)	326	642	406	5	1,632	630	1,028,160	0.8029
126	III	180cc(1)	405	563	256.5	9	980	1,044	1,023,120	0.9157
134	III	180cc(1)	405	563	308.5	7	1,260	812	1,023,120	0.8566
140	III	180cc(1)	405	563	347.5	6	1,470	696	1,023,120	0.8271
36	III	180cc(1)	326	563	276	8	868	1,176	1,020,768	0.8934
95	III	180cc(1)	405	484	256.5	9	840	1,215	1,020,600	0.9162
103	III	180cc(1)	405	484	308.5	7	1,080	945	1,020,600	0.8570
109	III	180cc(1)	405	484	347.5	6	1,260	810	1,020,600	0.8275
157	III	180cc(1)	405	642	256.5	9	1,120	909	1,018,080	0.9092
165	III	180cc(1)	405	642	308.5	7	1,440	707	1,018,080	0.8505
171	III	180cc(1)	405	642	347.5	6	1,680	606	1,018,080	0.8212
2	III	180cc(1)	326	484	256.5	9	672	1,512	1,016,064	0.9177
10	III	180cc(1)	326	484	308.5	7	864	1,176	1,016,064	0.8585
16	III	180cc(1)	326	484	347.5	6	1,008	1,008	1,016,064	0.8289
64	III	180cc(1)	326	642	256.5	9	896	1,134	1,016,064	0.9130
72	III	180cc(1)	326	642	308.5	7	1,152	882	1,016,064	0.8541
78	III	180cc(1)	326	642	347.5	6	1,344	756	1,016,064	0.8246
148	III	180cc(1)	405	563	399.5	5	1,750	580	1,015,000	0.7924
46	III	180cc(1)	326	563	341	6	1,148	882	1,012,536	0.8279
117	III	180cc(1)	405	484	399.5	5	1,500	675	1,012,500	0.7928
40	III	180cc(1)	326	563	302	7	980	1,029	1,008,420	0.8554
24	III	180cc(1)	326	484	399.5	5	1,200	840	1,008,000	0.7941
86	III	180cc(1)	326	642	399.5	5	1,600	630	1,008,000	0.7900
129	III	180cc(1)	405	563	276	8	1,085	928	1,006,880	0.8759
98	III	180cc(1)	405	484	276	8	930	1,080	1,004,400	0.8763
160	III	180cc(1)	405	642	276	8	1,240	808	1,001,920	0.8696
32	III	180cc(1)	326	563	250	9	756	1,323	1,000,188	0.9104
5	III	180cc(1)	326	484	276	8	744	1,344	999,936	0.8778

67	III	180cc(1)	326	642	276	8	992	1,008	999,936	0.8736
139	III	180cc(1)	405	563	341	6	1,435	696	998,760	0.8116
108	III	180cc(1)	405	484	341	6	1,230	810	996,300	0.8120
133	III	180cc(1)	405	563	302	7	1,225	812	994,700	0.8386
170	III	180cc(1)	405	642	341	6	1,640	606	993,840	0.8058
102	III	180cc(1)	405	484	302	7	1,050	945	992,250	0.8390
15	III	180cc(1)	326	484	341	6	984	1,008	991,872	0.8134
77	III	180cc(1)	326	642	341	6	1,312	756	991,872	0.8092
164	III	180cc(1)	405	642	302	7	1,400	707	989,800	0.8326
9	III	180cc(1)	326	484	302	7	840	1,176	987,840	0.8404
35	III	180cc(1)	326	563	269.5	8	840	1,176	987,840	0.8724
71	III	180cc(1)	326	642	302	7	1,120	882	987,840	0.8361
125	III	180cc(1)	405	563	250	9	945	1,044	986,580	0.8925
94	III	180cc(1)	405	484	250	9	810	1,215	984,150	0.8930
156	III	180cc(1)	405	642	250	9	1,080	909	981,720	0.8862
1	III	180cc(1)	326	484	250	9	648	1,512	979,776	0.8945
63	III	180cc(1)	326	642	250	9	864	1,134	979,776	0.8899
128	III	180cc(1)	405	563	269.5	8	1,050	928	974,400	0.8552
97	III	180cc(1)	405	484	269.5	8	900	1,080	972,000	0.8557
159	III	180cc(1)	405	642	269.5	8	1,200	808	969,600	0.8491
4	III	180cc(1)	326	484	269.5	8	720	1,344	967,680	0.8571
66	III	180cc(1)	326	642	269.5	8	960	1,008	967,680	0.8527
155	III	180cc(1)	405	563	445	5	NFS	NFS	NFS	NFS
179	III	180cc(1)	405	642	399.5	5	NFS	NFS	NFS	NFS
180	III	180cc(1)	405	642	406	5	NFS	NFS	NFS	NFS
181	III	180cc(1)	405	642	412.5	5	NFS	NFS	NFS	NFS
182	III	180cc(1)	405	642	419	5	NFS	NFS	NFS	NFS
183	III	180cc(1)	405	642	425.5	5	NFS	NFS	NFS	NFS
184	III	180cc(1)	405	642	432	5	NFS	NFS	NFS	NFS
185	III	180cc(1)	405	642	438.5	5	NFS	NFS	NFS	NFS
186	III	180cc(1)	405	642	445	5	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

B- FILLTYPE II

Table A08- Stage III solutions for all possible dimensions of a box filled by straight cups to be loaded in the first 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #1 Filltype II											
	Cup Type	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
51	V	Straight	370	514	377	1,398	0.2111	6	1,575	96	151,200
60	V	Straight	370	514	435.5	1,398	0.2032	5	1,890	80	151,200
83	V	Straight	442	514	383.5	1,398	0.2084	6	1,932	78	150,696
22	V	Straight	298	514	390	1,408	0.2089	6	1,316	114	150,024
69	V	Straight	442	514	292.5	1,470	0.2283	8	1,344	112	150,528
80	V	Straight	442	514	364	1,470	0.2130	6	1,806	84	151,704
114	V	Straight	298	586	383.5	1,470	0.2095	6	1,472	102	150,144
20	V	Straight	298	514	377	1,490	0.2125	6	1,260	120	151,200
29	V	Straight	298	514	435.5	1,490	0.2046	5	1,512	100	151,200
7	V	Straight	298	514	292.5	1,542	0.2308	8	896	168	150,528
46	V	Straight	370	514	344.5	1,542	0.2170	6	1,400	108	151,200
67	V	Straight	442	514	279.5	1,542	0.2337	8	1,260	120	151,200
77	V	Straight	442	514	344.5	1,542	0.2160	6	1,680	90	151,200
135	V	Straight	370	586	318.5	1,542	0.2224	7	1,440	105	151,200
141	V	Straight	370	586	357.5	1,542	0.2139	6	1,680	90	151,200
10	V	Straight	298	514	312	1,624	0.2257	7	980	154	150,920
24	V	Straight	298	514	403	1,624	0.2082	5	1,372	110	150,920
1	V	Straight	298	514	253.5	1,706	0.2465	9	728	207	150,696
96	V	Straight	298	586	266.5	1,758	0.2398	8	896	168	150,528
65	V	Straight	442	514	266.5	1,768	0.2377	8	1,176	128	150,528
99	V	Straight	298	586	286	1,778	0.2328	8	992	152	150,784
3	V	Straight	298	514	266.5	1,788	0.2404	8	784	192	150,528
158	V	Straight	442	586	266.5	1,912	0.2371	8	1,344	112	150,528
Others	V	Straight	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

Table A09- Stage III solutions for all possible dimensions of a box filled by star cups to be loaded after Straight cups in the first 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #1 Filltype II											
	Cup Type	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
129	VI	Star	375	594	338	1,782	0.4993	7	1,440	126	181,440
135	VI	Star	375	594	380	1,782	0.4888	6	1,680	108	181,440
143	VI	Star	375	594	436	1,782	0.4765	5	2,000	90	180,000
158	VI	Star	448	594	338	1,782	0.4980	7	1,728	105	181,440
164	VI	Star	448	594	380	1,782	0.4875	6	2,016	90	181,440
49	VI	Star	375	521	387	1,792	0.4867	6	1,505	120	180,600
20	VI	Star	302	521	387	1,865	0.4885	6	1,204	150	180,600
45	VI	Star	375	521	359	1,938	0.4923	6	1,365	132	180,180
53	VI	Star	375	521	415	1,938	0.4819	5	1,645	110	180,950
75	VI	Star	448	521	366	1,938	0.4914	6	1,680	108	181,440
83	VI	Star	448	521	422	1,938	0.4803	5	2,016	90	181,440
23	VI	Star	302	521	408	2,084	0.4840	5	1,288	140	180,320
111	VI	Star	302	594	415	2,084	0.4824	5	1,504	120	180,480
99	VI	Star	302	594	331	2,094	0.5016	7	1,120	161	180,320
105	VI	Star	302	594	373	2,094	0.4916	6	1,312	138	181,056
113	VI	Star	302	594	429	2,094	0.4798	5	1,568	115	180,320
14	VI	Star	302	521	345	2,167	0.4981	6	1,036	174	180,264
3	VI	Star	302	521	268	2,333	0.5291	8	728	248	180,544
159	VI	Star	448	594	345	2,386	0.4956	6	1,776	102	181,152
95	VI	Star	302	594	303	2,396	0.5118	7	992	182	180,544
89	VI	Star	302	594	261	2,406	0.5315	9	800	225	180,000
109	VI	Star	302	594	401	2,406	0.4842	5	1,440	125	180,000
Others	VI	Star	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

Table A10- Stage III solutions for all possible dimensions of a box filled by 200cc(1) cups to be loaded after Star cups in the first 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #1 Filltype II											
	Cup Type	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
106	I	200cc(1)	390	466	377	1,560	0.7287	6	1,260	120	151,200
114	I	200cc(1)	390	466	433	1,560	0.7178	5	1,500	100	150,000
27	I	200cc(1)	314	466	433	1,570	0.7194	5	1,200	125	150,000
41	I	200cc(1)	314	542	328	1,712	0.7401	7	980	154	150,920
55	I	200cc(1)	314	542	426	1,712	0.7211	5	1,372	110	150,920
144	I	200cc(1)	390	542	440	1,712	0.7190	5	1,785	85	151,725
6	I	200cc(1)	314	466	286	1,722	0.7537	8	696	216	150,336
44	I	200cc(1)	314	542	349	1,798	0.7329	6	1,092	138	150,696
63	I	200cc(1)	314	618	279	1,854	0.7554	8	896	168	150,528
67	I	200cc(1)	314	618	307	1,854	0.7451	7	1,024	147	150,528
80	I	200cc(1)	314	618	398	1,854	0.7252	5	1,440	105	151,200
158	I	200cc(1)	390	618	335	1,854	0.7365	7	1,440	105	151,200
164	I	200cc(1)	390	618	377	1,854	5.1581	6	90	1680	151,200
172	I	200cc(1)	390	618	433	1,854	0.7165	5	2,000	75	150,000
5	I	200cc(1)	314	466	279	1,864	0.7570	8	672	224	150,528
9	I	200cc(1)	314	466	307	1,864	0.7465	7	768	196	150,528
82	I	200cc(1)	314	618	412	1,864	0.7217	5	1,504	100	150,400
133	I	200cc(1)	390	542	363	1,864	0.7306	6	1,400	108	151,200
141	I	200cc(1)	390	542	419	1,864	0.7210	5	1,680	90	151,200
1	I	200cc(1)	314	466	251	1,874	0.7705	9	576	261	150,336
4	I	200cc(1)	314	466	272	1,874	0.7597	8	648	232	150,336
34	I	200cc(1)	314	542	279	1,884	0.7561	8	784	192	150,528
38	I	200cc(1)	314	542	307	1,884	0.7457	7	896	168	150,528
51	I	200cc(1)	314	542	398	1,884	0.7258	5	1,260	120	151,200
169	I	200cc(1)	390	618	412	2,016	0.7201	5	1,880	80	150,400
159	I	200cc(1)	390	618	342	2,178	0.7344	6	1,480	102	150,960
Others	I	200cc(1)	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

Table A11- Stage III solutions for all possible dimensions of a box filled by 180cc(2) cups to be loaded after 200cc(1) cups in the first 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #1 Filltype II											
	Cup Type	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
138	IV	180cc(2)	380	528	339	2,112	0.8930	7	1,435	84	120,540
145	IV	180cc(2)	380	528	384.5	2,112	0.8881	6	1,680	72	120,960
155	IV	180cc(2)	380	528	449.5	2,112	0.8838	5	2,030	60	121,800
107	IV	180cc(2)	380	454	339	2,196	0.8936	7	1,230	98	120,540
114	IV	180cc(2)	380	454	384.5	2,196	0.8887	6	1,440	84	120,960
120	IV	180cc(2)	380	454	423.5	2,270	0.8859	5	1,620	75	121,500
Others	IV	180cc(2)	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

Table A12- Stage III solutions for all possible dimensions of a box filled by 180cc(1) cups to be loaded in the second 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #2 Filltype II											
	Cup Type	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
37	III	180cc(1)	326	563	282.5	1,126	0.1781	8	896	112	100,352
48	III	180cc(1)	326	563	354	1,126	0.1674	6	1,204	84	101,136
146	III	180cc(1)	405	563	386.5	1,126	0.1622	6	1,680	60	100,800
14	III	180cc(1)	326	484	334.5	1,136	0.1700	7	960	105	100,800
30	III	180cc(1)	326	484	438.5	1,136	0.1591	5	1,344	75	100,800
35	III	180cc(1)	326	563	269.5	1,215	0.1820	8	840	120	100,800
107	III	180cc(1)	405	484	334.5	1,215	0.1689	7	1,200	84	100,800
123	III	180cc(1)	405	484	438.5	1,215	0.1582	5	1,680	60	100,800
128	III	180cc(1)	405	563	269.5	1,215	0.1809	8	1,050	96	100,800
169	III	180cc(1)	405	642	334.5	1,215	0.1680	7	1,600	63	100,800
176	III	180cc(1)	405	642	380	1,215	0.1636	6	1,880	54	101,520
157	III	180cc(1)	405	642	256.5	1,284	0.1841	9	1,120	90	100,800
165	III	180cc(1)	405	642	308.5	1,284	0.1722	7	1,440	70	100,800
171	III	180cc(1)	405	642	347.5	1,284	0.1663	6	1,680	60	100,800
104	III	180cc(1)	405	484	315	1,294	0.1723	7	1,110	91	101,010
110	III	180cc(1)	405	484	354	1,294	0.1660	6	1,290	78	100,620
119	III	180cc(1)	405	484	412.5	1,294	0.1612	5	1,560	65	101,400
3	III	180cc(1)	326	484	263	1,304	0.1833	9	696	144	100,224
65	III	180cc(1)	326	642	263	1,304	0.1823	9	928	108	100,224
81	III	180cc(1)	326	642	367	1,304	0.1666	6	1,408	72	101,376
97	III	180cc(1)	405	484	269.5	1,373	0.1815	8	900	112	100,800
Others	III	180cc(1)	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution

Table A13- Stage III solutions for all possible dimensions of a box filled by 200cc(2) to be loaded after 180(1) cups in the second 20ft Std Dry container for Filltype II. (Set in order to Ls)

CONTAINER #2 Filltype II											
No	**Cup Type**	**Name**	**x**	**y**	**z**	**Ls**	**U_{cum}**	**e**	**CN**	**BN**	**TCN**
31	II	200cc(2)	306	454	445.5	918	0.3205	5	1,344	75	100,800
38	II	200cc(2)	306	528	289.5	1,056	0.3388	8	896	112	100,352
49	II	200cc(2)	306	528	361	1,056	0.3284	6	1,204	84	101,136
129	II	200cc(2)	528	528	276.5	1,056	0.3414	8	1,050	96	100,800
139	II	200cc(2)	528	528	341.5	1,056	0.3294	6	1,400	72	100,800
16	II	200cc(2)	306	454	348	1,066	0.3293	6	984	102	100,368
36	II	200cc(2)	306	528	276.5	1,140	0.3425	8	840	120	100,800
46	II	200cc(2)	306	528	341.5	1,140	0.3304	6	1,120	90	100,800
81	II	200cc(2)	306	602	367.5	1,224	0.3276	6	1,408	72	101,376
Others	II	200cc(2)	**Other alternatives**			NFS	NFS	NFS	NFS	NFS	NFS

NFS: No Feasible Solution