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METHODS FOR THE DEPLOYMENT OF OBJECTS ON THE PALLET IN PROCESS OF AUTOMATED PALLETIZATION

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Abstract: In this paper deployment methods for two – dimensional automated palletization of prism and a cylinder shaped objects are described. For boxes block methods are created and for cylinders raster methods are created. In the second part of the paper the most used methods for four – block layout of boxes on pallet – Steudls and Smith methods are described. For various methods algorithms, conditions and formulas to calculate the positions of objects on the pallet are given. This knowledge is also used in three – dimensional palletization.

1 Introduction

In the process of palletization two basic groups of shapes are used: cylindrical – shaped objects and prism – shaped objects (boxes). From these two basic shapes complex component shapes are derived. The first step of creating the layer of objects is to determine the type of palletizing. There are two methods:

- Palletization respecting depalletization
- Palletization for optimal area using of pallet

If parts are depaletized in a certain order, for example during the process of assembly then we need to plan deployment of objects respecting the assembly procedure. Components which are first assembled need to be on the top of the load and components which are last assembled must be at the bottom of the load. However, mostly methods for optimal storing of an objects are used. There are many methods using dynamic programming and simple rules to find the appropriate deployment of the objects. Each shape of the object has its particular method of deployment.

2 Boxes

Prism is the most used shape in the process of designing a pattern on the pallet. Cuboid shape represents a shape of the box. This shape is very useful in the process of palletizing, because the small or fragile parts are usually stored in boxes. The final products are also packed in boxes and then exported on pallets. To find the optimal layout we need a good methodology and algorithms to generate the coordinates of the objects. Thanks to its three dimensions (length, width and height) we can create many combinations of storing boxes on the pallet.

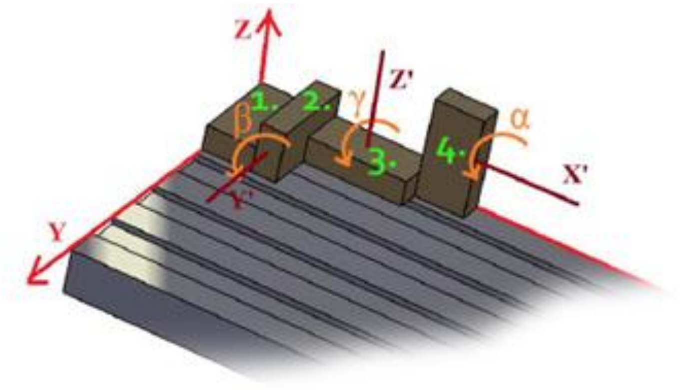


Figure 1.: ***Possible orientations of the boxes on the pallet***

In the process of planning the layout, a block method is used. Storage area is divided into blocks. We are trying to find optimal distribution of these blocks and minimize the unused area between them. Block is a specific area of the pallet which contains boxes of identical dimensions and direction (horizontally or vertically). We know single blockmethod, two blocks method, three blocks method, four blocks method and multiblock method.

2.1 1 block, 2 block and 3 block method

A method using a single block is the simplest method for resolving the pattern of boxes on the palette. There are only two options to place the boxes: *vertical* or *horizontal*. Block dimensions are identical to the dimensions of pallets.

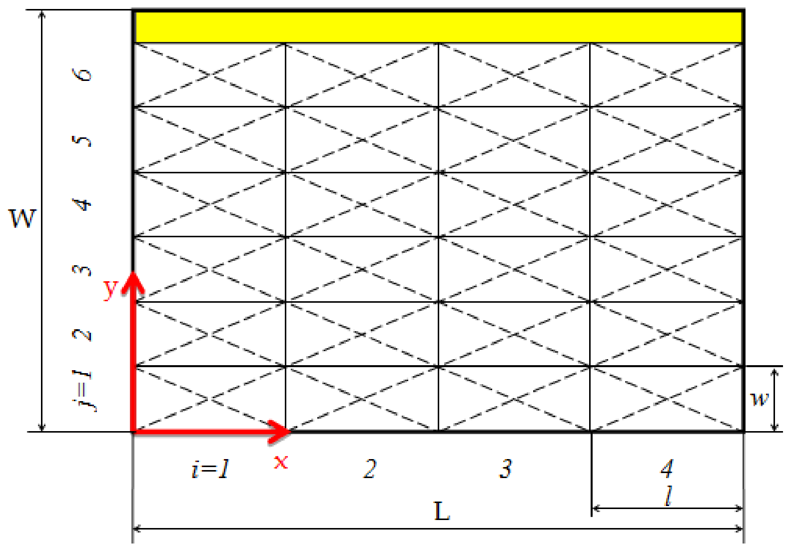


Figure 2.: ***Scheme of calculating the coordinates of single block of boxes***

If we use this condition we can find the best solution for our dimensions of boxes and pallet (1):

$$
\begin{gathered}
If\ \left\lfloor \frac{L}{l} \right\rfloor * \left\lfloor \frac{W}{w} \right\rfloor > \left\lfloor \frac{W}{l} \right\rfloor * \left\lfloor \frac{L}{w} \right\rfloor \text{ then} \\
place \left\lfloor \frac{W}{w} \right\rfloor horizontally\ oriented\ boxes\ along\ L\ side\ of\ the\ pallet \\
place \left\lfloor \frac{L}{l} \right\rfloor vertically\ oriented\ boxes\ along\ W\ side\ of\ the\ pallet \\
else \\
place \left\lfloor \frac{L}{w} \right\rfloor vertically\ oriented\ boxes\ along\ L\ side\ of\ the\ pallet \\
place \left\lfloor \frac{W}{l} \right\rfloor horizontally\ oriented\ boxes\ along\ W\ side\ of\ the\ pallet
\end{gathered} \tag{1}
$$

Calculation of coordinates for horizontally oriented boxes is (2):

$$P_{i,j} = \left[\frac{l}{2} + l(i-1)\ ;\ \frac{w}{2} + w(j-1)\ ;\ H\right] \tag{2}$$

Calculation of coordinates for horizontally oriented boxes is (3):

$$P_{i,j} = \left[\frac{w}{2} + w(i-1)\ ;\ \frac{l}{2} + l(j-1)\ ;\ V\right] \tag{3}$$

Where:

L – is the length of the pallet *l – is the length of the box*

W – is the width of the pallet *w – is the width of the box*

With this conditions: *L ≥ W and A ≥ B*

Method for using 2 or 3 blocks is basically an extension of single block method. In the method of 2 blocks we are trying to find the best combination of vertically and horizontally oriented boxes along the length of the pallet. Optimum combination contains smallest unused space between boxes. We can also use the third block to fill an empty area above the second columns (columns of vertically oriented boxes) using inverted boxes.

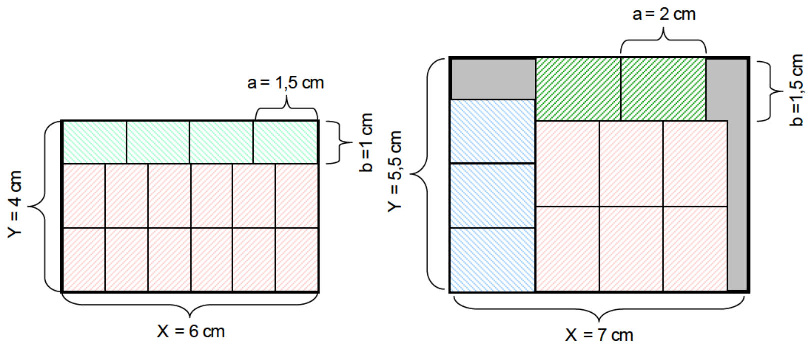


Figure 3.: ***Single, two and three block layer of boxes***

Analogically we can use this method for the width of the pallet and find the best solution for placing the boxes. The advantage of these methods is the simplicity and clarity. The disadvantage is that it does not provide an optimal solution for every problem.

2.2 Steudls 4 block method

This method divides storage area for four blocks located in the corners of the pallet. These blocks are rotated, depending on the direction of stored objects (horizontal or vertical). This method was described by Harold J. Steudel in 1979, therefore it is also known as Steudel algorithm. It is a recursive method and uses dynamic programming. Dynamic programming is used to optimize process. It divides a big problem on a little subproblems. These subproblems are solved and results for future potential use are stored.

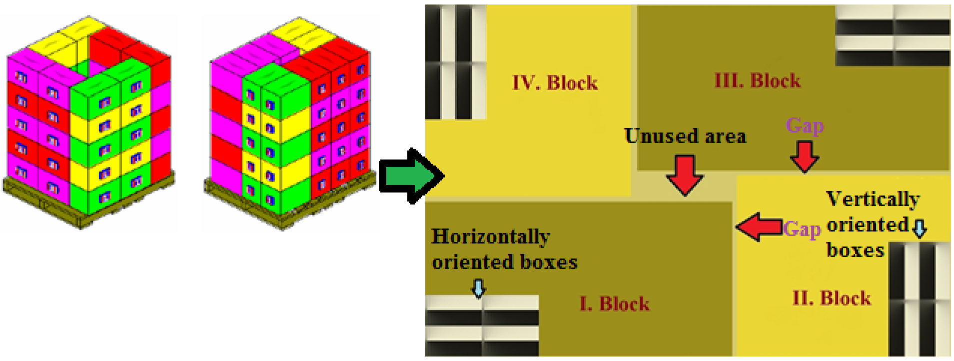


Figure 4.: ***Steudls four block method***

The first step of this method is finding an efficient combination of horizontally and vertically oriented boxes on a circuit of pallet. In other words, we are trying to find the smallest gap between combination of horizontal and vertical oriented boxes stored in length (width) of pallet. We can do this by using this objective function (4):

$$F_n(S_n) = Max[X_n * l + Y_n * w + F_{n-1}(S_{n-1})]$$
$$X_n * l + Y_n * w \leq D_n \qquad n = 1, 2, 3, 4 \qquad (4)$$

Where:

F_n (S_n) – max sum of horizontally and vertically oriented boxes on the n side with state variable Sn at the beginning of the side.

X_n– number of objects of length L placed along the side n

Y_n – number of objects of width W placed along the side n

D_n – length of the pallet

S_n – is a state variable that defines the initial conditions for the side n.

This state variable can take these three values:

- Boxes are only horizontally oriented along the side n of the pallet
- Boxes are only vertically oriented along the side n of the pallet
- Boxes are vertically and horizontally oriented along the side n of the pallet

Objective function is calculating each combination of three values from Sn. For the three possible values of Sn and four blocks of boxes we can use this calculation: $3^4 = 81$. So we have to choose the best result from 81 results.

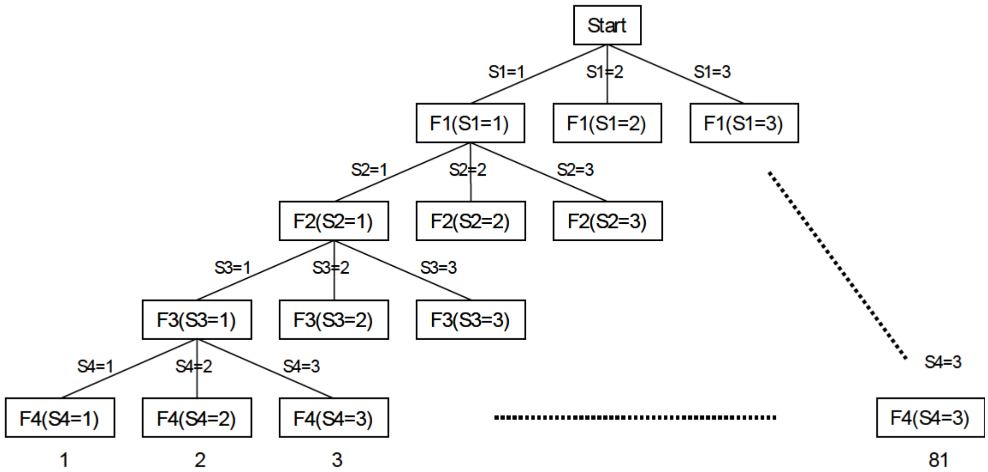


Figure 5.: Scheme of Steudl algorithm

Objective function Fn (Sn) can be described as maximizing the utilized length of each side. However we have to include the pattern of boxes on the previous side. It can also be defined as minimizing the unused circuit of the pallet.

In the second step we have to fill the unused area. This step is linked by 2 problems. The first one is filling of empty area which can hold one or more boxes. The second problem is overlap of individual blocks which can be identified for example in this case (5):

$$D_1 - X_1 l < X_3 l \quad and \quad D_4 - X_4 l < X_2 l \qquad (5)$$

Steudl's method is very good for creating eficient pattern of boxes on pallet, but we have to be careful not to create an overlaped areas.

2.3 Smith and DeCanis 4 block method

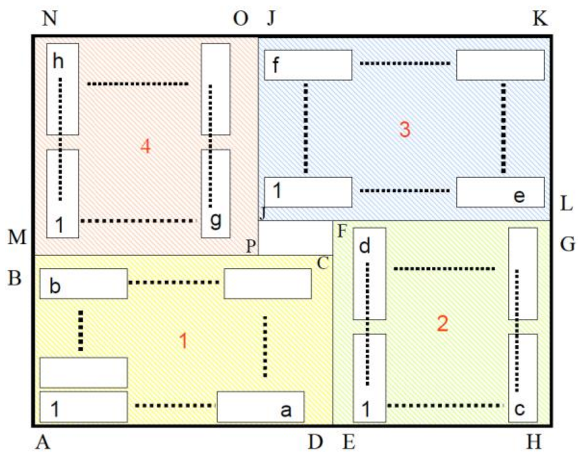


Figure 6.: Scheme of Smith and DeCanis 4 block method

The picture shows the layout of boxes on a pallet according to Smith and Decani. It is investigating all possible combinations of the shown layout. On a first sight, this method is similar to Steudl method, but the number of objects in the blocks 1-3 and 2-4 is not equal. The principle of determining the number of objects across the width and length of each block is different. The first step is to define the first block. The second block need to be higher than the first block. The third block need to be wider than the second block and fourth block is created in the remaining empty space. All possible dimensions of the first block and also dimensions of the other blocks are calculated. Then we can choose the best solution for our dimensions of boxes and pallet. This solution contains the highest number of boxes which we can store on one pallet.

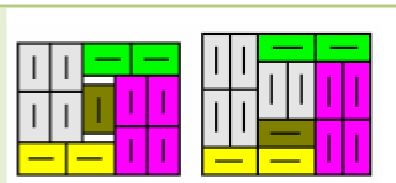
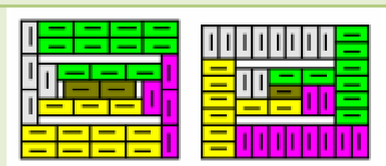
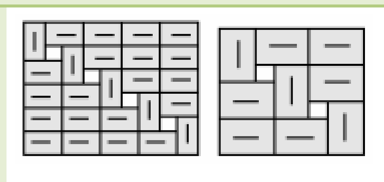
Objective function for this method is (6):

$$MaxZ = a.b + c.d + e.f + g.h \qquad (6)$$

Optimization is finished after generating all possible combinations. This method does not allow overlapping of blocks, as it can occur in Steudl method,. but we can find more unused space between blocks. This problem can be solved either by adding another block or several blocks into this empty space.

2.4 Multi block patterns

Table 1 shows five types of multiblock patterns with their schemes. These patterns are used in software TOPS pro from TOPSENG company.

5 block pattern – is often used in Steudls 4 blocks method. Another block of boxes is stored in unused area of pallet.	
5 block PLUS pattern - is used in Steudls 4 blocks method. If unused area of the pallet is very big, then we can run another cycle of Steudls algorithm and put another block of boxes to unused area.	
Diagonal pattern – this pattern contains many small unused areas on the diagonal of the pallet.	

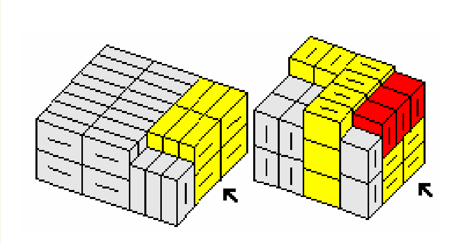
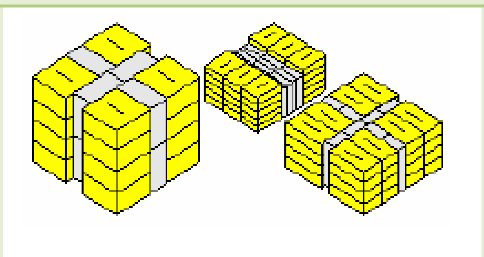
Multi surface pattern – blocks of boxes in three dimensional (3D) layout	
Soldiered pattern – blocks of boxes are in three dimensional layout and divided in the center with another type of boxes	

Table 1: Table of multi block layers

3 Cylinders

In terms of methodology, the deployment cylinders are the easiest shape for planning the layout on the pallet. On figure 7 are two simple layouts of cylinders, which are not so difficult. In the first case we can see loses among cylinders. In the latter case we are trying to eliminate these losses but not always successfully. This case is effective only if the number of cylinders in the first row equals to the number of cylinders in the second row. We cannot say which of these layouts is more efficient because sometimes the number of cylinders on the pallet is equal in both of them. More advanced software can evaluate both layouts and give the best solution to the user.

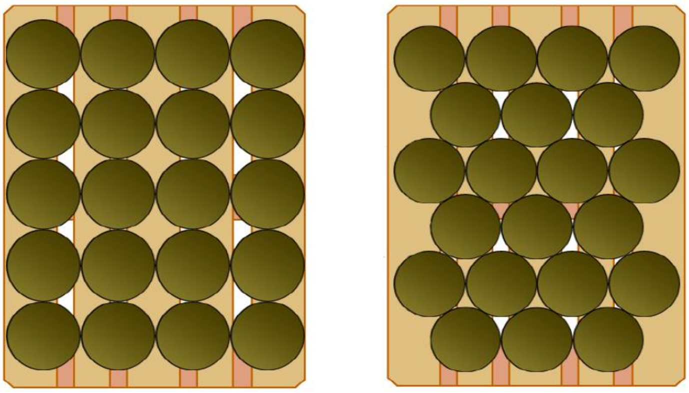


Figure 7.: „Raster" and „cross" alignment of cylinders

Calculation of coordinates for „raster" alignment of cylinders (7):

$$P_{i,j} = \left[\frac{d}{2} + d(i-1)\ ;\ \frac{d}{2} + d(j-1)\right] \qquad (7)$$

Calculation of coordinates for „cross" alignment of cylinders (8):

$$P_{i,j} = \left[d - \frac{d}{2}.\left(2\left[\frac{j}{2}\right] - j\right) + d(i-1)\ ;\ \frac{d}{2} + d\frac{\sqrt{3}}{2}.(j-1)\right] \quad (8)$$

After resolving the question of layout, it is necessary to answer the question of stability. Between the layers of cylinders the pads are inserted that enhance the stability of the whole system. It is inappropriate to combine both types of layout between layers. To ensure stability, we are using different accessories, such as walls, fences, packing washers, belts, etc.

4 Conclusion

Knowledge of methods used for two-dimensional layout is essential for creating a three-dimensional and mixed loads. Mixed load consists of one or more shapes. Many software products have implemented these methods in their algorithms. They use them for evaluation, calculation and creating optimal layout of objects on the pallet. When three – dimensional distribution is used then it is necessary to create a virtual reality model of pallet load. Thanks to this model we can analyze load and fill the empty area using methods for two – dimensional loading. This problem is solved in VEGA project.

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