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Storage location assignment: Using the product structure to reduce order picking times

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Abstract

This paper concerns the stock location assignment problem (SLAP) and describes a strategy for prestructuring components and information for the picking work in storehouses. This classification is derived from the product structures transformed to support a holistic perception aimed at the material handler/picker.

Our results imply a more efficient material handling through reorganising the components in the storage system, in order to support the work from the picker's point of view.

A storage location assignment strategy emanating from the product structure (SLASEPS) is proposed in this paper, and is exemplified by using empirical data from a case study. The result from this case study was a reduction in picking information of more than 75%, which in turn greatly reduced the amount of information to the picker.

Keywrods: Storage location assignment; Prestructuring components; Product structure

1. Introduction

In order picking systems, the characteristics of the components are often used for different purposes, for example, frequency, size, weight, part number, supplier, etc. One or more of these characteristics are usually used when assigning items to locations or zones.

In the literature, two main policies have been put forward in order to make the picking process more efficient. The first policy focuses on the assignment problem, which concerns allocating the stock keeping units (SKU) to specific locations in the storehouse. The second policy is to consider the assignment of the SKU as given, mainly focusing on choosing the most similar orders together in a batch. The objective is to group the orders in a way that reduces time spent on travel, reading information and other activities that could be shared between orders more efficiently than if randomised order selection were used.

There exist different heuristics for order batching. Elsayed and Unal [1] describe briefly the EQUAL algorithm, SL algorithm, MAXSAV algorithm and the CWright algorithm. Goetschalckx and Ratliff [2] proposed an algorithm to determine the optimal number and location of stops and to specify the items to be picked at each stop. The background was that pickers in many picking systems will stop the vehicle, pick and load items into

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the picking package and then drive to the next stop. In this algorithm the assignments of items are considered as given. In practice, a combination of assigning policies and batching policies is often used. However, our main focus in this paper concerns the stock location assignment problem (SLAP).

Dedicated storage, randomised storage and class-based storage are three different stock location assignment strategies [3]. In a dedicated storage, each item has its own and fixed storage location. A randomised storage derives its name from the fact that the locations of the SKUs are randomly chosen. Class-based storage partitions all the SKUs into several classes, assigning an usually fixed area to each class, and then use randomised storage within each class area [4]. Dedicated storage systems and class-based storage systems are the main focus in this paper.

The picking time can often be reduced by assigning SKUs to locations with respect to the characteristics of the items. The traditional way of assigning SKUs is to store materials based on their usage rates or turnover levels [1]. A common approach is to assign the most popular SKUs to locations near the input/output (I/O) point. Hesket [5] proposed the cube-per-order index (COI), which is expressed as the ratio of storage space required (cube) per SKU and the order frequency of the SKU. The COI assignment policy ranks the SKUs from low to high with respect to their COI, and then assigns the SKUs with the lowest rank to the set of locations in the warehouse with the lowest expected travel times (closest to the I/O point).

However, grouping according to characteristics of individual components often requires a long picking time. The reason is that the components to be included in the same order have many different characteristics, which could lead to the components being spread over a large geographical area. This statement is principally correct when the orders contain products that include many components or exist in many variants. However, the long picking time does not only depends on the distance, but also on the fact that the components do not seem to be placed in a logical order from the picker's point of view. This results in a longer time to find and identify components to be picked.

Assignment strategies have also been described by Frazelle and Sharp [6] and Frazelle [3] which deal with the problem of determining the assignment of components to locations in a warehouse so that the total picking tour time is minimised. The general idea is that components that are likely to appear together on an order should be stored together (dependent demand). To perform this, a statistical analysis of a sample of orders is made.

A problem is to determine the period of time a statistical relation is up to date. Today, computers can quickly determine a statistical correlation between items in old orders, and therefore the time consuming part should not be to perform a new statistical analysis but to realise the new locations that the analysis is proposing. The described strategies relate to warehouses where no fixed product structure (bill-of-materials) exists, and where it is not possible to take advantage of an existing variant codification. These dependencies obtained statistically do not help in building up general knowledge concerning the product being picked. The analysis is concerned with the problem of stating which components that are ordered together. For a picking system connected to an assembly system, this knowledge already exists in the picker's mind. The problem there is rather knowing where to locate the SKUs within one order (or variant) in relation to SKUs that are common for other types of standard orders (or variants).

Andersson [7] deals with the assignment problem in a picking system, and reports savings of the overall picking time by 17%, when common picking information was given for a number of components. Andersson has in this case, physically and in the information, grouped components according to the existing variant codification.

Using individual component characteristics when assigning items to locations in storehouses is not wrong when the order prediction is low. Low prediction means that the components that should be included in the same order are not known in advance. When there exists a higher prediction in the order, as when kitting components for assembly, another assignment strategy should be chosen. Otherwise, the relations (dependencies) between the components that are included in the assembly are lost, which implies that the components do not seem to be placed in any particular order in the aisles.

2. The storage location assignment strategy emanating from the product structure (SLASEPS)

In this section, a strategy is described for prestructuring components and information for the picking work in storehouses, using the product structure as a basis. This classification is derived from the product structure transformed to support the material handler/picker. Note that only the logical representation of the product itself, the so-called logical product structure [8], is focused in this paper.

2.1. Strategy for prestructuring components

Step 1: Identify the combination of components which will be included in the analysis. Only components included in one picking zone, picking tour, or similar, shall be included in each analysis. Each zone will then be analysed separately.

The demand i.e. the picking frequency, of each "product variant" are used when assigning components to locations. When the prognosis of the demands are not up to date, a new analysis should be performed. Thus, product lines with greatly varying demands should be analysed more often than a product line with stable demands. However, there is a trade-off between the improvement in the picking efficiency and the effort of reorganising the components. A specific variant of the defined assembly included in the study is in this paper denoted "product variant", while "variant" is used to denote certain properties or certain characteristics of a product.

Step 2: Establish a codification for every part number. One part number can be included in different product variants, and the codification of a part number shall be based on the characteristics of all these product variants.

The codification of a part number is based on the variant codification of the product variants that include the specific part number. For example, a part number that is included in variant "market Scandinavia" shall also be codified as "market Scandinavia". Examples of codifications could also be functional concepts or characteristics such as red, blue, etc. Examples of functional concepts could be "Turbo & ABS", which means that these part numbers are included in cars with both turbo and ABS. Another example could be part numbers included in cars with a turbo or an airbag, which are codified as "Turbo/Airbag". After the codification is performed, there should hopefully be components that have the same codification. Components with the same codification then form a variant group (VG). *A VG is a composition of one or several part numbers with the same variant characteristics.*

Note that the same part number could be used for different applications, which means that a part number could have more than one codification. For example, a part number with two different codifications will in the SLASEPS be treated as two individuals.

The codification process could be described as in Fig. 1, where each variant codification is represented by a circle (A, B, C). The codification for each area is done with lower-case letters. Thus, the variant codifications (A, B, C) should not be mixed up with the codifications for the VGs (areas). The area (a/b/c), which is common to all three circles, includes "common components" (shall be included in all variants of the final assembly). The codification of a specific part number is done with respect to the different areas. In Fig. 1, the codifications would have been a, b, c, a/b, a/c, b/c, a/b/c. For example, according to the theory of sets, the correct codification of VG a is a/b/c and the codification of VG a/b is $a \cap b$. However, in the proposed strategy, the codifications in Fig. 1 are used, in order to keep the names of the VGs as simple as possible. A variant codification of a product variant (in Fig. 1) could be A or B or C or AB or AC or BC or ABC, depending on the characteristics of the product variant.

Step 3: Identify every "concurrent demand" between the VGs. A concurrent demand is present when two different VGs include part numbers for the same product variant. Concurrent demands might seem to be similar to correlated assignments defined by Frazelle and Sharp [6]. However, correlated assignments originate from statistical relations between components that are frequently ordered together, while concurrent demands

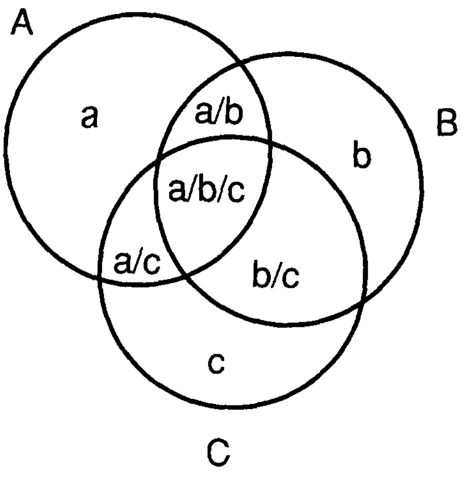

Fig. 1. Visualisation of a product structure where each circle represents variants codes and the seven areas represent variant groups (VGs).

emanate from the product structure and the demands that exist between VGs.

Concurrent demand exists for all VGs in Fig. 1, because there are common areas between the circles. Concurrent demands exist between VGs that have common character in the codification regarding the product variant being picked. For example, concurrent demand for product variant A exists between VG a, VG a/b, VG a/c and VG a/b/c because, when product variant A shall be picked, all of these four VGs must be visited.

Step 4: Determine the frequency of each product variant and calculate the frequency of each VG and each concurrent demand, with the aim to propose locations for the VGs in the order picking system. The objective is to identify the concurrent demands that occur most frequently in order to decide which VGs shall be stored next to each other, and to decide which VGs shall be placed closest to the I/O point.

The main idea in the location process is to locate the VGs so that the total numbers of passes needed of undesired VGs ("uVGs"), when picking, could be kept at the lowest possible level. This could be done intuitively or by using some kind of methodology. By passes of "uVGs" we mean *the necessary passes of one or several VGs that should not be included when picking two of the demanded VGs for a specific product variant.*

Our heuristic location methodology is to determine the frequency of every concurrent demand between the VGs and then locate the VGs with the most frequently occurring concurrent demands most properly. This is done after sorting the concurrent demands by frequency.

The maximum number of different pairs of VGs that can be formed is equal to: $(N*(N-1))/2$, where N is equal to the number of VGs. The maximum number of different pairs of VGs that can be formed in Fig. 1, is equal to $(7*(7-1))/2 = 21$. However, some of these pairs of VGs would have a frequency equal to zero, which means that there could not be a concurrent demand for these pairs of VGs, for example due to market restrictions.

When the frequency of each concurrent demand is determined, the VGs with the most frequently occurring concurrent demands shall be located together. The work procedure continues by locating the second most frequently occurring pair of VGs, etc.

This heuristic method is not optimal. A more precise method would be to evaluate each possible location, which is equal to $N!/2$. In practice, this is impossible. For example, the "small" assembly described in Fig. 1 has $7!/2 = 2540$ different layout combinations. Also, note that the solutions differ depending on the time period taken into account when calculating the concurrent demands, if these are not stable.

In Fig. 2, a possible location of the VGs in Fig. 1 can be seen. In this proposed location, product variants A, B and AB could be picked without any passes of uVG. When picking product variant C, however, two passes of uVGs are needed. The proposed location of the VGs indicates that product variant C has the lowest frequency and product variants A and AB the highest frequency, because VG a/c is located closest to the I/O point. Thus, if the picking tour starts from the right, the picker could start picking product variant A and product variant AB at the first location.

In practice, other variables influence the proposals for locations when grouping the VGs. Examples are size of storing packages, order of assembly (meaning that the picker has to pick in reversed order of assembly, if a structuring within the picking package is difficult to perform), size of the

c	b	b/c	a/b/c	a/b	a	a/c

Fig. 2. A possible location of the VGs in Fig. 1.

components (bigger parts at the bottom), picking system layout (for example a specific length of the aisles), etc.

However, it is preferable to start the analysis without taking this restrictions into account, in order to establish the most preferable layout. Economic analyses could then be performed, to compare savings in terms of picking time and picking errors with the cost of changing the picking system.

Table 1
Product variant names and manufacturing volume

Product variant	Manufacturing volume
L-steering Std	28.5'
L-steering AC	28.5'
L-steering ECC	59.5'
L-steering ELC	2.5'
R-steering Std	5.25'
R-steering AC	5.25'
R-steering ECC	10.5'

2.2. *Exemplification of the SLASEPS*

Step 1: Identify the combination of components which will be included in the analysis. We have tested the SLASEPS described above on a subassembly that belongs to a car. The chosen subassembly is stored, picked, delivered and assembled separately from other subassemblies included in the final product. In Table 1, the different product variants of the subassembly are given. It can be seen that there are seven product variants and six variant codifications (L-steering, R-steering, Std, AC, ECC and ELC).

In Table 2, empirical information is given for this subassembly. Note that 39 of the part numbers included in the subassembly could be excluded from the study, because they are not picked. These part numbers are small and cheap and ordered in large numbers, and for this reason not picked.

Step 2: Establish a codification for every part number. A codification is established for every component, indicating in what variants of the assembly the component will be included. For the analysed subassembly, there are 89 different part numbers to be picked. In the codification process, part numbers with the same variant characteristics were grouped together, which resulted in 20 different VGs (see Table 3). As an example, VG AC includes two part numbers and the demand for VG AC is 33.75' (28.5' + 5.25', see Table 1). There was only one part number that should be included in both product variant AC and ECC. This part number created a VG of its own named AC/ECC and the demand for this VG is 103.75' (33.75' + 59.5' + 10.5').

In Table 3, the codifications for some VGs are not performed in the same way as described earlier. For example, a VG codified as R-st (AC/ECC), should as described earlier be codified as "R-st & AC/R-st & ECC". It is, however, in most cases preferable to use a short code in order to speed up the identification process, as long as everyone involved understands what the codes mean.

Step 3: Identify every "concurrent demand" between the VGs. In Table 3, it could be seen that concurrent demands are present in terms of VGs that have similar names. As an example, components for product variant L-steering (AC) are included in "AC", "AC/ECC", "AC/Std", "AC/ECC/Std/ELC", "AC/ECC/Std", "Std/L-st (AC)", "L-st", "L-st (AC/ECC)", "L-st (AC/Std/ELC)" and "L-st (AC/ECC/Std)", which is equal to 10 different VGs. These VGs should then be located next to each other, if possible.

Our belief is that the manufacturing volume should be up to date for a year ahead. However, this manufacturing volume is an average for a whole year. If the manufacturing volume is believed to vary over the year, one can choose a shorter period of time. Here, the trade-off between cost of change and picking efficiency has intuitively been considered.

Step 4: Determine the frequency of each product variant and calculate the frequency of each VG and

Table 2
Empirical information concerning the components within the subassembly

	Number of components	Number of part numbers
Components needed for building all the product variants	242	128
Small components that should not be picked	145	39
Components *s* needed for building all the product variants[a]	99	89
Mean number of components for building a general product variant[a]	55	50
"common" components[a]	1	1
"Substitute" components (common components within one or more product variants)[a]	98	88
"Extra" components (Extra component within a product variant)[a]	0	0

[a] only the components that are picked are included.

Table 3
The table shows the 20 VGs resulting from a grouping process of 89 part numbers. For each VG the number of part numbers and the manufacturing volumes are given

Variant group	Number of part numbers within the variant group	Manufacturing volume (frequency)
1 AC	2	33.75′
2 AC/ECC	1	103.75′
3 AC/Std	2	67.5′
4 ECC	3	70′
5 R-st	10	21′
6 R-st (AC/ECC)	8	15.75′
7 R-st (ECC)	1	10.5′
8 R-st (Std)	2	5.25′
9 R-st (Std/AC)	1	10.5′
10 AC/ECC/Std/ELC	1	140′
11 AC/ECC/Std	26	137.5′
12 Std/L-st (AC)	1	62.25′
13 L-st	6	119′
14 L-st (AC/ECC)	9	88′
15 L-st (ECC)	1	59.5′
16 L-st (ELC)	5	2.5′
17 L-st (Std)	3	28.5′
18 L-st (Std/ELC)	2	31′
19 L-st (AC/Std/ELC)	1	59.5′
20 L-st (AC/ECC/Std)	4	116.5′

each concurrent demand, with the aim to propose locations for the VGs in the order picking system. Based on Table 3, a short description can be made. It seems logical that all VGs that are specific to L-steering create one area and that the R-steering creates another one. For example, if product variant L-steering (AC) shall be picked, components from VG 1, 2, 3, 10, 11, 12, 13, 14, 19 and 20 shall be located as near each other as possible. However, these VGs have components that are used for other product variants, making it necessary to consider all product variants in the location process and propose locations that are totally as close to the optimal solution as possible. In Table 3, the manufacturing volume for each VG is represented and will be considered in the location process.

We have used a heuristic location methodology in order to locate the VGs as close to the optimal solution as possible. We chose not to put any other restrictions that influence the proposed solution. As described earlier, there are often restrictions, such as size of storing package, order of assembly, size of the component, picking system etc., that influence the final locations. This will of course be of interest for further research.

When the frequency of each product variant is determined, the frequency of the VGs could be calculated. In Table 3 the manufacturing volume (frequency) of each VG is presented. The subassembly includes 20 VGs, and therefore it would not be preferable to give the VGs locations intuitively. The frequency of each VG is input to the heuristic location method, which calculates the demand for all possible different pairs of VGs and sort the pairs of VGs by frequency. The maximum number of all possible different pairs of VGs is equal to 190 ($(N*(N-1))/2 = (20*(20-1))/2 = 190$). When the pairs of VGs are sorted by frequency, 79 of them turn out to be zero. For example, there are not any concurrent demand between VG 1 and VG 4 because no existing product variant could include both of these VGs. The actual number of concurrent demands for the subassembly is equal to $190 - 79 = 111$. The most frequently occurring concurrent demand is between VG 10 and VG 11, which means that VG 10 and 11 should be located together. The second most frequent concurrent demand exists between VG 10 and VG 13, which implies that VG 13 should be located on the other side of VG 10.

The objective of the SLASEPS is to locate VGs, such that the total number of passes of uVGs needed when picking is minimised. Usually, a picking tour could not be performed without passes of uVG. For this reason, there ought to be a discussion about whether some VGs should be doubled or not.

Note, when picking a specific variant all components from a VG should always be picked, otherwise the VG would not be a composition of components with similar variant characteristics.

In Fig. 3, the proposed solution from the heuristic location method is shown. The location process resulted in three main sections. The combinations (relative positions) of the three sections do not influence the number of passes of uVGs in the picking process. However, it is important to locate the most frequently visited side of the section closest to the I/O point, in order to keep the average picking tour length at the lowest possible level.

Compared to the present locations of parts in this company, SLASEPS reduces the total number of passes of uVGs needed over the chosen period (1 yr) from 2 520 000 to 96 500.

In Fig. 3, it could be seen that the SLASEPS has combined the most frequently ordered product variants as appropriately as possible (with as few passes of uVGs as possible). Product variant L-st (Std) and L-st (ECC) could be picked without any passes of uVGs, product variant L-st (AC) could be picked with 1 pass of uVGs, L-st (ELC) could be picked with 2 passes of uVGs and R-st (ECC), R-st (Std) and R-st (AC) could be picked with 3 passes of uVGs.

A duplication of a VG could, however, reduce the passes of uVGs for one or several product variants. A duplication of VG AC/ECC (see Fig. 3) would for example eliminate 1 pass of a uVG for product variant R-st (ECC) and 1 pass of a uVG for product variant R-st (AC), if VG AC/ECC were located at one side of VG R-st. This duplication is equal to 15.75′ passes of uVGs in one year. Also VG ECC could be duplicated and located next to VG R-st (ECC), which would further reduce the number of passes of uVGs for product variant R-st (ECC) by 5.25′ in 1yr. The decision whether to duplicate these VGs or not is based on cost data for travel time, space, etc.

3. Discussion

When the VGs should be given locations, it could be discussed whether or not the VGs for a product variant should be picked without any passes of uVGs for a specific product variant, as in the SLASEPS. Another approach is to store the most frequently visited VGs as close to the I/O point as possible. However, this approach will imply that the logical location strategy is lost and more passes of uVGs are needed. In practice, a placement of the most ordered VGs as close to the I/O point as possible does not entail a shorter picking tour, since at least one VG for a product variant is located far from the I/O point. The choice of location strategy depends, among other things,

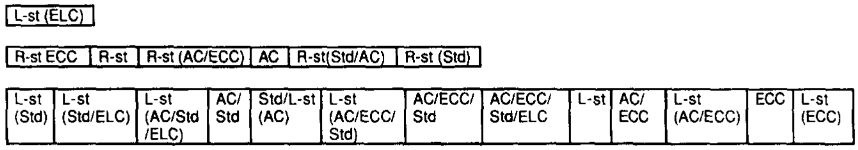

Fig. 3. The proposed locations of the heuristic location method for the subassembly.

on how big the storing package is, because this influences the span of the picking tour. However, our experience is that an easily understandable assignment policy should be preferred.

After the product structure in the case study had been analysed, it was noticed that the components could be grouped into 20 groups with different variant characteristics. This is equal to a reduction in picking information of more than 75%. By working with these 20 different groups instead of 89 different part numbers, the picking work could be simplified. By treating the components as a whole, these different groups could be obtained and usable, instead of treating them as individual and independent components.

The heuristic location method described in the paper is not optimal. However, our ambition for further research is to continue to improve the location method. How much the order picking time could be reduced, and most important, how much the picking errors could be reduced, has not been stated, as none of our case studies so far has realised a reorganisation of the SKU locations. This, however, will be our purpose of further research.

A frequently requested product variant has a greater opportunity of being picked with few passes of uVGs. However, one goal of the SLASEPS was to reduce the total number of passes of uVGs, which could mean that a product variant with a lower frequency than another product variant could be picked with fewer passes of uVGs.

In general, the main objective of the location process is not to shorten the travel distance. Often, an increasing picking accuracy means greater savings in terms of reduction of the rework caused by errors. Moreover, savings are possible in the assembly process, when the right parts are delivered and no waiting time for complementary pickings is needed. Also, the time allowed for reading picking information is decreased when VGs are used instead of single part numbers.

Results from case studies indicate that the use of the SLASEPS can reduce the number of passes of uVGs needed, which means savings in terms of order picking time and a reduction of picking errors. Earlier research shows that a more logical placement reduces the needed time for picking and increases the picking accuracy [7].

4. Conclusions

A strategy has been proposed in this paper for combining components into variant groups (VGs) and locating these VGs as appropriately as possible, considering that a picking tour could be performed with as few passes of undesired VGs (uVGs) as possible for the product variant being picked.

The storage location assignment strategy (SLASEPS) makes it possible to shorten the picking time by using the variant characteristics as picking information and establishing a logical assignment policy. When the picking information is minimised the picking errors ought to be fewer.

The SLASEPS was in the paper tested on a practical example and the result was a reduction by 96% of passes of undesired VGs. If the proposed solution is realised, the amount of picking information to the picker could be reduced by 75%.

Using the SLASEPS proposed in this paper, one does not have to find out if the components are ordered together or not. The objective is to execute one order at one place where the whole order could be picked without any passes of uVGs. However, a number of restrictions exist, which were identified in the paper.

The SLASEPS proposes locations horizontally. In some picking systems it is possible and preferable to store different VGs also vertically. In these cases it is even more easy to perform a layout with as few passes of uVGs as possible.

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