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Design and performance of kitting and order picking systems

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Abstract

This paper discusses the results from a number of case studies carried out within a research project concerned with the design and performance of materials kitting systems. The paper focuses on the design of the kitting systems in terms of location of the order picking activity, work organisation, picking method, information system and equipment. These design considerations are related to performance measurements, such as picking efficiency and picking accuracy, and are discussed in relation to the preconditions of the kitting system. In kitting systems, results show that picking efficiency and accuracy can be improved by making better use of the product structure when designing the picking information and when deciding the storage assignment policy. Also, batching of picking orders is cost efficient when extensive sorting and administration can be avoided. In general, combining the work roles of assembly and picking results in less administration.

Keywords: Design and performance of materials kitting systems; Order picking activity; Performance measurements

1. Introduction

Kitting means that the assembly process is supplied with kits of components. According to the definition by Bozer and McGinnis [1], a kit is "a specific collection of components and/or subassemblies that together (i.e., in the same container) and combined with other kits (if any) support one or more assembly operations for a given product".

According to Johansson [2], the reasons for implementing such systems usually involve parallelized assembly systems, product structures with many part numbers, quality assurance of the assembly and high value components.

Bozer and McGinnis [3] present fundamental differences between kitting and line stocking, including a list of advantages and limitations of kitting. Kitting as a method of supplying materials to the assembly process is quite common and, for reasons mentioned above, often discussed [4]. However, uncertainty in the industry concerning costs and revenues of this supply method is considerable and documented experience is to a large extent lacking. Beck [5] describes positive effects of kitting in an automated retrieval system. Improvements were noticed in the form of higher picking accuracy and less need for storing space.

Kitting systems have rarely been described in the literature, and many uncertainties regarding the performance and design options of these systems exist, leading to assembly systems providing kitting

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sometimes being rejected. Kitting requires order picking to be performed somewhere in the system. However, the preconditions for this type of order picking differ from those in ordinary order picking systems, mainly in the sense that there is a product structure to be followed and that a production schedule is sometimes known at an early stage.

2. Design options of kitting systems

When designing or redesigning kitting systems, there are design considerations affecting the picking efficiency that have to be addressed. These considerations are the composition of orders in a batch (batching policy), the sequence in which the items will be retrieved from the storehouse (picking policy), and where to store each part number (storage policy). These policies are defined by Goetschalckx and Ashayeri [6]. Other design considerations are: the geographical location of the kitting process, the division of the picking area into zones, work organisation, layout design, material handling equipment and design of picking information. The design considerations were verified and identified by zero-based analysis[1] of kitting systems and studies of literature in the area of kitting and order picking. Also direct observation of the cases included in the project helped in identifying these considerations.

2.1. Location of kitting process and work organisation

The choice of design at a high level involves decisions regarding the work organisation and the geographical location of the kitting process. The kitting can either be performed by an assembler or by a special category of operators (pickers), and the kitting process can be performed in a central picking store or in decentralised areas close to the assembly stations, the so-called materials markets. In some cases, assemblers produce kits for other assemblers, most often belonging to the same team. If this job is performed in a centralised picking store, there is a potential risk of great balancing losses within the team. However, there are several reasons for integrating the kitting process into the assembler's job, usually by means of materials markets. First, there is the idea of obtaining higher picking accuracy when the operator is responsible for the whole job. Second, integration and job enlargement will enhance the overall productivity by reducing balancing problems and giving better possibilities regarding job designs that promote ergonomics and the quality of working life. Also, the administrative work tends to decrease when the assemblers are responsible for the picking work. Moreover, the design process, as well as the resulting design of the system, will often be straightforward and simple, thereby reducing the uncertainty during the design phase.

Another way of classifying order picking systems is whether the picker is travelling to the picking locations (picker-to-part) or whether the materials are brought to the picker (part-to-picker). However, most of the cases presented in this paper are picker-to-part systems.

2.2. Batching policy

The existence of a product structure and a production schedule most often offers opportunities for an effective batching policy, i.e., picking orders (individual kits) are grouped and picked together, resulting in decreased travel distances and shorter picking times. The batching policy has to be taken into account as early as in the design phase of the system and relates strongly to both storage policy and picking policy, as well as to the picking technique and equipment.

Other ways of improving the picking process emerge when a geographical grouping of the part numbers is carried out in the storage. Moreover, if

[1] Zero-based analysis was a further development by Engström and Karlsson [7] of Wild's method [8] for measuring the level of efficiency in mass production systems and Brynzér et al. [9] applied the zero-based analysis to kitting systems. The basic idea of the zero-based analysis is to divide the resource consumption into "necessary work", "losses" and "system costs". The necessary work represents the resource consumption in an ideal production system without waste of any kind.

the picking information is common for all the components within "the group", different part numbers could be picked together. Frazelle and Sharp [10] discussed this under the heading of correlated assignment, reporting great savings in travelling times. Gibson and Sharp [11] compared different batching procedures and showed that intelligent batching yields significant reductions in average batch tour lengths.

However, in some sense batching also causes a more complex picking, including the design of the picking information, which can have a negative effect on the picking accuracy. A preliminary conclusion from the case studies is that the higher picking efficiency, resulting from these batching policies, is in many cases offset by an increased amount of sorting and administration. If extensive sorting and administration can be avoided, for example, by mechanising these processes, the effect of batching will be considerable. In one of the case studies, the effect of going from batches containing four orders with approx. 50% common parts to batches of four almost identical orders was a reduction in picking time of approx. 35%. Further savings could be obtained by switching to a totally different picking method, exposing approximately 100 picking packages, picking and distributing one part number at a time to all the picking packages. Experiments showed that it was possible to achieve a reduction in picking time of more than 50% compared to the case with four orders in the batch, using a conventional picker-to-part system. However, restrictions in the existing storage equipment prevented the implementation of this method. Also the planning horizon can restrict this solution.

An important task is to choose a proper time horizon for the batching. The batching horizon is affected by (1) tied-up capital, (2) available buffer space, (3) flexibility concerning changes in the order, (4) potential completion of shortage components and (5) the probability that all components needed are in stock.

2.3. Zone picking

The picking policy concerns the sequence in which the items will be retrieved from the picking system. By introducing zone picking, this sequence is affected. Zone picking divides the storehouse into different picking zones and an order is divided between these zones and often picked simultaneously, which makes a short lead-time in the storage possible. The items from each zone are then brought together. The alternative is to pick the whole order in just one picking tour. The choice of picking method depends on (1) the time needed to complete an order, (2) the resources needed to complete an order and (3) the characteristics of the components. Different characteristics of the components make it possible, for example, to use different types of picking techniques, taking advantage of the characteristics of each group (size, planning horizon, etc.). An example of this is given in [12].

There are examples among the case studies of storage policies that separate parts of different sizes (up to three categories), allowing smaller parts to be picked in larger batches using other techniques. More zones permit larger batches, but will also in many cases lead to increased sorting and administration. More zones may also lead to a conflict regarding the way in which the assembly department wants the parts to be displayed and sorted, and one of the main ideas of kitting is to display the parts to the assembly department in a functional way. In a picker-to-part system, the "trade-off" above has to be carefully considered when deciding the number of picking zones. Zone picking and batching are often combined in varying ways (the number of zones and objects in a batch). These combinations depend on (1) the characteristics of the components, (2) the production process, (3) the amount of part numbers for one object and (4) the picking time for each order.

In summary, zone picking could be an efficient picking method on the assumption that the different parts could be properly brought together. However, when separating work, there is always a risk of balance losses. This risk increases the more zones there are and consequently the smaller the zones are. Balance losses should always be considered when deciding upon the type of zone picking system. A reason for using a combination of batching and zone picking is that the resulting "picking lists" consist of fewer line items than they would have done for one single object, still containing the same

Table 1
A classification of case studies included in the paper

	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H	Case I
Assembled product	Trucks	Cars	Chassis	Engines	Heater	Gear lever	Electric apparatus cubicles	Dashboard	Doors for cars
Picking operators	A specific picker	A specific picker	A specific picker	Some of the assemblers	Some of the assemblers	The assembler	The assembler	The assembler	The assembler
Number of pickers in the kitting system at the same time	4	3	3	6	2	1	1	2	2–3
Location of the kitting process	Picking work stations	Storage	Storage	Material market	Material market	Material market	Material market	Material market	Material market
Number of kits in the batch	24	4–30	5–75	2	1	9	2–15	1	4
Number of picking zones	3	3	3	1	1	1	3	2	1
Type of picking information	Picking list	Picking list	Truck-terminal	Logical placement and picking list	Colour codifications	Variant schedule	Picking list and picking labels	Displays and picking list	Car specification with common names for a number of components
Are the pick and refilling aisles separated?	No	No	No	Yes	Yes	No	No	Yes	Yes
Picker transportation method	–	Walks and rides	Rides	Rides	Walks	Walks	Walks	Walks	Walks
Is passing in the picking aisles possible?	Yes	Yes	No	No	No	No	Yes	In one of the zones	Yes

number of individual components. This may influence the picking efficiency and the risk of picking errors.

3. Aspects of design and performance in some case studies

In Table 1, nine cases included in the project are roughly classified by a number of vital kitting system characteristics that have proved important and distinguishable concerning the function and performance of kitting systems. All systems presented in Table 1 are followed by a parallel assembly system. The cases were chosen in order to be able to study a number of kitting systems with differing characteristics. Using case studies was a necessity in order to determine all picking activities performed on the shop floor and to determine a classification of the shop floor data which was as general as possible. In Table 1, the cases have been grouped according to which persons are responsible for the picking work. The three alternatives are specific pickers, some of the assemblers or the assembler himself.

3.1. Travelling time and distance

Traditionally, a great deal of attention has been paid to minimising the travelling distances within the picking tours, in order to reduce the resources needed. Of course, this is as important in kitting environments as in ordinary order-picking systems. Frazelle [13] claimed that travelling time corresponds to 60% of the order picker's time in a typical picker-to-part system. However, our studies of the distribution of time spent on different activities in the kitting process show that travelling time ranges from 15% to 25%. One explanation for this large difference is that there are more part numbers in a kitting batch, which increases the time spent on picking in a picking tour. Moreover, kitting for assembly increases the possibilities of a logical placement of the components that decreases the travelling time.

3.2. Picking information

One of the most interesting areas is the design of the information system, including the way in which the picker receives and understands the information regarding which parts to pick for each order. The traditional picking information reaches the picker in the form of a picking list, specifying the identification, numbers, location, etc., of the parts to pick. In kitting, because of the product structure, this information is too often neglected by the picker. The problem is that the information is designed for "beginners", which is why the trained pickers do not use it. The risk of inaccuracy is great due to, e.g., product design changes or the picker's conception of the product structure being wrong. Moreover, even if the list is not used, time has to be allowed for reading and identification. One possible solution is the use of displays at the storage locations showing what to pick. In case H, a small lamp indicates when a specific component shall be picked and a display shows how many are required. Picking errors are unusual in this system. However, the equipment requires large investments when there are many part numbers, and the system sometimes tends to increase the risk of idle time because of queues of pickers.

Another example of picking information on storage location is used in case F. Each variant of the final product has a number and, when picking, the picker looks for this number on a variant scheme at every storage location. Fig. 1 shows an example of a variant scheme where all possible variant numbers are represented. Fig. 2 shows a variant scheme for a part number that should not be included in every variant. In case E the same idea is used but instead of numbers, each variant has a colour. When the picker, for example, picks a variant which is represented by a blue colour, he picks every component marked with a blue colour at the storage location.

The picking information could also be displayed on a screen as in case C, where the screen is placed in the picking truck telling the picker what, where and how many components shall be picked.

Case E uses a combination of colours to mark which parts to pick for each variant as well as "picking information" where the storage packages

121	122	123	301	302	303
304	560	561	562	563	564

Fig. 1. A picking variant scheme where each variant has a number and a dedicated place in this scheme.

			301	302	303
		561			564

Fig. 2. This shows the picking information for one part number. It shows that this specific part number shall be included in variants 301, 302, 303, 561 and 564. Notice that the variant number shall always be represented in the same position in the scheme.

that contain inappropriate part numbers for the variant being picked are covered. Of course, this cannot be done in every picking system, because the batches have to be quite large if long set-up times are to be avoided. In this specific case, seven variants of the final product are produced and each variant takes up between 4 and 12 h to be produced. The final product in this case is quite small, which makes it possible to store an average amount of finished assemblies corresponding to 3 days' demand.

Perhaps even more interesting is the reorganisation of the information, enabling the pickers to use the product structure as information during the picking tour. In these cases, the storage policy also has to be considered at the same time. Savings can be considerable, at the same time as picking accuracy is improved. In case D, the calculated time required for reading and identification was reduced by 79%, which was equal to a 17% reduction in the total picking tour cycle time.

Another example is case I, where the articles have been structured in such a way that no information besides a product specification is needed, which the picker only gives a quick glance at the beginning of the tour.

An attempt to improve the picking list is to shift to a picking list that functions more like a map. On the picking list, the storage locations are reproduced and the storage locations where picking is to be performed are marked. Alternatively, the positions of the objects (picking packages) included in the batch can be reproduced on the picking list, which is appropriate in part-to-picker systems. This design of picking information has quite recently been installed in case A. All objects in the batch that shall have a specific part number have been marked with a number in the list. These numbers are aimed to inform the picker about which objects require the specific part as well as the correct amount thereof.

In the cases where traditional picking lists are used, the pickers often read the information for one part number but picks two or more. The reason is that there often exist relations, dependent demands, between components. The picking information is particularly interesting in these cases, because picking errors often occur when the relations that the pickers have learnt are not valid any more. Here, it is fundamental that the true product structure is communicated to the picker. One solution is to place important information in a specific position on the picking list. By doing so, the pickers quickly notice if something has been changed.

3.3. *Design of picking package*

Another area of great importance is the design of the picking package, which has to be functional in the picking process as well as in the assembly process. The picking package also helps to maintain the picking accuracy at a high level. A possibility is to design the picking package as a cassette, dedicating a space to each part. The problem is the low flexibility of these packages and for this reason such packages have been designed but not implemented in some case studies.

3.4. *Picking accuracy*

Other ways of improving the accuracy in the case studies have been to count the parts after the picking tour or to check the weight of the complete kit. In case B, the number of picking errors was decreased by approx. 40% by counting the parts afterwards. Check-weighing is preferable in terms of the possibilities of mechanisation, but is dependent on the distribution of weights among the parts and the variability of weights for each part number. However, there exist more proper ways of improving accuracy, for instance, by a proper information system and a logical placement of the parts. Our opinion is that a large portion of the picking errors can be characterised as structural faults, emanating either from an incorrect conception of the product structure or from an inappropriate exposition of the parts in the picking process. In the case studies, frequent causes of picking errors were:

- Mixed components in the batch, which means that a component intended for a certain object is placed in the wrong kit.
- Components with similar part numbers or similar appearances are stored next to each other.
- The picker is interrupted or disturbed. People ask him something and when he starts to work again it is difficult to know where to begin. A frequent cause of an unconscious disturbance is, for example, hearing an interesting news item on the radio.
- Incorrect conception of the product structure. When the same composition of components is used over a period of time, the picker starts to think that this composition is the only one possible. The picker then wrongly decides to pick a part on the basis of another part appearing in the picking document instead of reading the information for every individual component.
- Inappropriate exposition of the parts. The picker uses the exposure of parts as picking information, but this exposure is not well designed. There must be a visible difference in the storing area between components that are always ordered together and those that are sometimes ordered together.
- The picking confirmation is done for another component in the picking list than the intended one.
- Reading mistakes, e.g., reading the part number for one part, but the amount for another part.
- Picking packages are often slightly slanted in order to alleviate the picker's job. However, there is a danger of the components falling out.
- The pickers forget their own picking information and pick the same components as the picker ahead.

In order to increase the accuracy of components for which mistakes are frequently made, structured information is difficult to give or a visible difference between the parts is lacking, case D uses a bar-code on the picking list and the same one at the picking place. When the component is to be picked, the component and the picking list codes are scanned and a signal is given if it is the right one. If such scanning is not done, the picking order cannot be finished. In case B the components which are most difficult to replace in the assembled product are marked with "#" both in the picking list and at the picking place.

3.5. Manual picking techniques

One area that seems to be of great importance to the picking efficiency is how the picking was performed in detail. We noticed different kinds of picking techniques. The most common technique was to count the components while picking at the storing location and afterwards place the exact number of components in the picking package. We call this technique "sort-while-pick". When many components of each part number were ordered, the picker often chose another technique, which is to take a "full hand" of components without knowledge of the amount, distribute them to the picking packages, take more if needed or putting "scrap" back into the storing package. We call this method "sort-while-place". By using this method, picking time can be decreased. Sort-while-place was practised in case B and was shown to reduce the time needed for picking by 19%, which was equal to a 13% reduction in the total picking time.

4. Valuation and implications from some case studies

To exemplify different kinds of problem areas, time distribution diagrams for some of the case

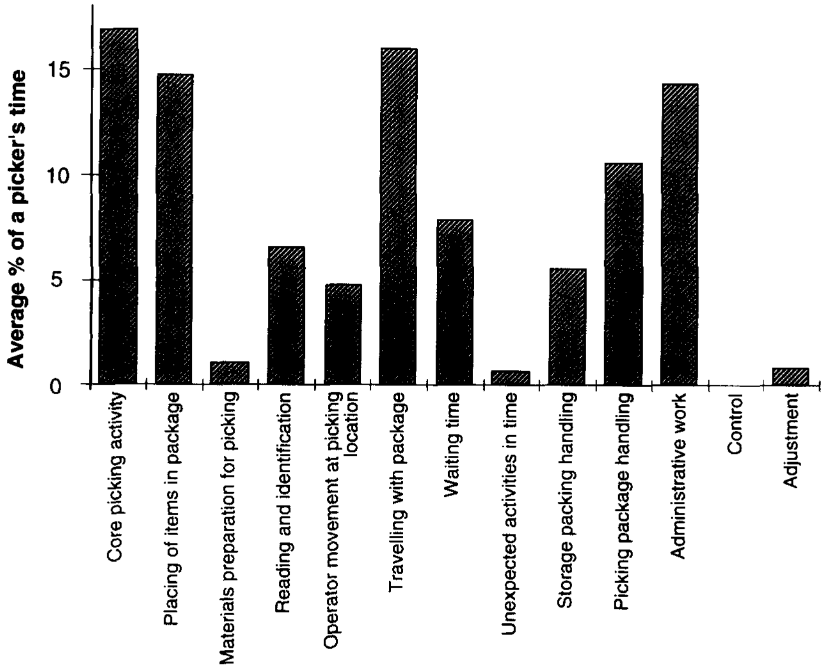

Fig. 3.

studies included in the project are presented. Each case represents one example from the grouping of the cases performed in Table 1. When deciding which cases should represent each group, cases were chosen that had characteristics of specific interest which could be discussed.This is done in the following.

The diagrams were drawn based on video recordings of the work, using a new type of analysing equipment [14]. The analysing equipment consists of a computer and a videotape recorder that can be monitored by the computer.

Fig. 3 shows an example of a central storage (case B) where special operators (pickers) are responsible for the picking. Worth mentioning is that the core picking activity only represents 16% of the total picking time, which means that many other activities are present. Could these activities be minimised? Looking at this case we can see that travelling with package, waiting time and administrative work account for quite a considerable share of the total picking time, which tasks can probably be rationalised.

Fig. 4 shows an example of a storage (case D) where assemblers produce kits for other assemblers. It can be seen that waiting time accounts for a larger share of the total picking time compared to case B above. The reason is that the pickers are not able to pass each other in the picking tour, implying that the storage policy might also be improved. Placing of items also represents quite a considerable share, which might be an indication that the picking package could be improved. Much time is also spent travelling with package. Is the picking tour longer than it needs to be?

In Fig. 5, the time distribution diagram of case F is shown. This is an example of a decentralised storage where the assemblers are responsible for the picking work. Here, all the activities that support the picking activity are minimised. However, worth mentioning is that the placing of items in a package represents much time. The reason is that the batch contains nine objects, allow the pickers to use the picking technique "sort-while-place". Using this technique means that placing of items accounts

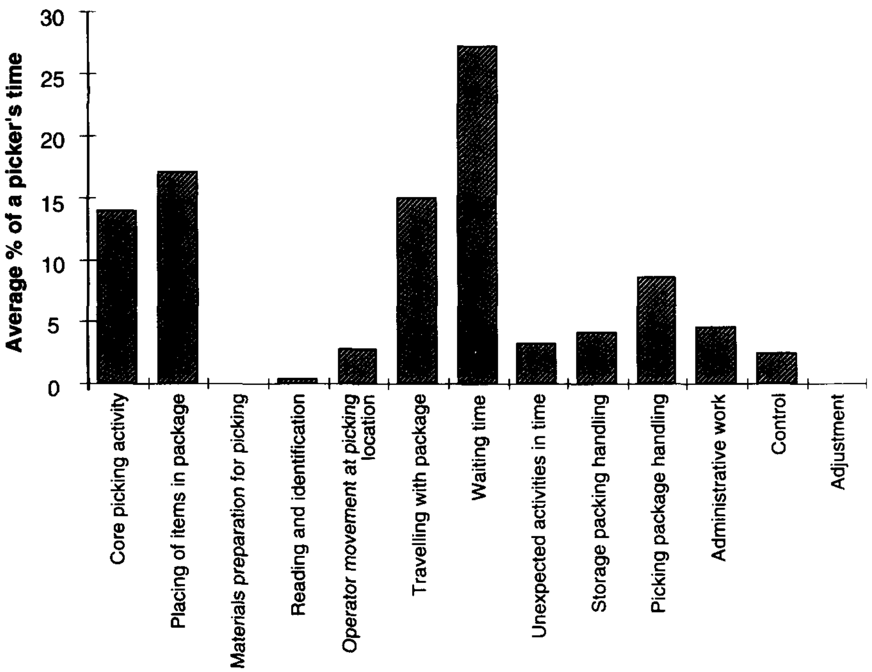

Fig. 4. Time distribution diagram in case D.

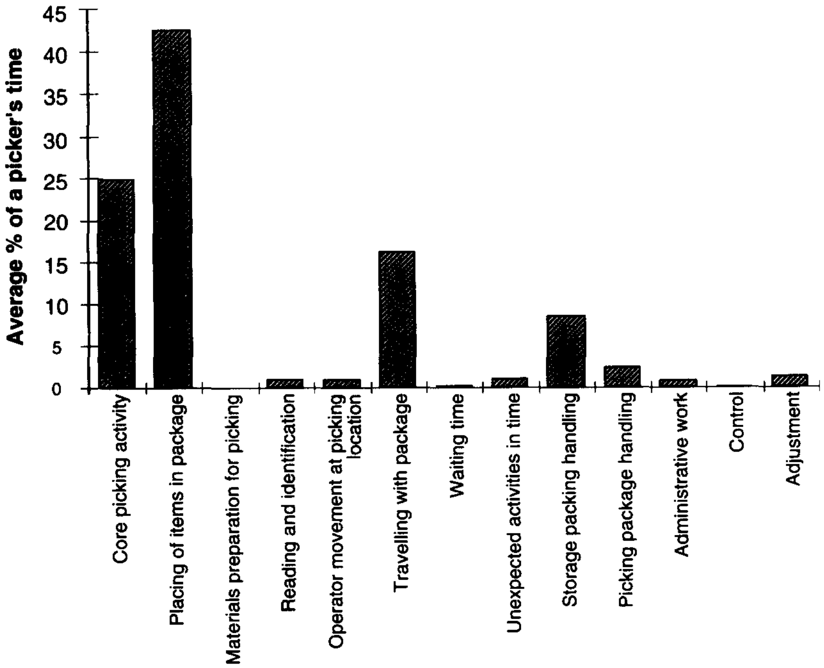

Fig. 5. Time distribution diagram in case F.

Table 2
Percent distribution of a pickers time in cases B, D and F

Picking activity	Case B	Case D	Case F
Core picking activity	16.9%	14.0%	24.9%
Placing of items in picking package	14.7%	17.2%	42.5%
Materials preparation for picking	1.1%	0.0%	0.0%
Reading and identification	6.6%	0.4%	0.9%
Operator movement at picking location	4.8%	2.8%	0.9%
Travelling with package	16.0%	15.1%	16.3%
Waiting time	7.9%	27.3%	0.2%
Unexpected activities in time	0.7%	3.3%	1.0%
Storage packing handling	5.6%	4.2%	8.5%
Picking package handling	10.6%	8.7%	2.4%
Administrative work	14.3%	4.6%	0.8%
Control	0.0%	2.5%	0.1%
Adjustment	0.8%	0.0%	1.3%

for longer time compared to the core picking activity.

A common tendency was that in storages where assemblers pick, they spent less time on other activities than picking, compared to cases using specialized pickers. When the picker and the assembler are the same person, the demand for buffers and administrative work decreases. This means that the core picking activity corresponds to a greater share of the picking activities. In case F, also the time needed for handling of the picking package is lower than in the rest of the cases, since no specific equipment is used for delivering kits or for putting them into a buffer. The picker merely moves to the assembly station after the picking process is finished.

In Table 2, the percentage distributions of pickers' time from the case studies B, D and F are presented in a comparative table. Each case represents one example from the grouping of the cases performed in Table 1. According to our experience, the time distribution in Case B represents a typical picker-to-part kitting system where specific pickers are responsible for the picking work. However, case D which represents a kitting system where the picking work is alternated between the assemblers was not typical of the group of systems. The reason is that waiting time is not a typical problem in these systems. The time distribution in case E is more similar to case F with the difference that administrative work tends to increase when more persons are involved.

Case F is a typical system where the assemblers are responsible for their own picking work. Special characteristics in these cases are that the assemblers are responsible for a minor part of a product (subassembly), or for a product that in the cases described here contains less than 200 part numbers in total and less than 50 for a specific variant. The transportation is often done manually, mainly because the material market is near and does not represent much area.

In summary, the basic results were; (1) the storage policy could be improved in all of the studied cases as well as take greater advantage of the product structure when assigning items to storage locations, (2) batching and zone picking were shown to be efficient if extensive sorting and administration could be avoided, (3) the travelling time ranged from 15% to 25% in kitting systems compared to earlier research, which reported 60% in picker-to-part order picking systems, (4) kitting systems provide possibilities when designing picking information, i.e., take advantage of the product structure, and (5) materials markets where the assemblers are responsible for the picking work were shown to have a higher level of picking efficiency. However, the markets should be located next to the assembly stations and only occupy a limited area.

5. Discussion and further research

Comparing the case studies, it seems that the cases differ to a great extent concerning kitting system characteristics, i.e., selection of equipment and work organisation, etc. This indicates lack of general advice (a base for the practitioners) concerning the design of picking systems.

When the video recordings from the case studies were analysed, there was in many of the cases a remarkable difference between the calculated time for the activities performed and the time distribution obtained. This demonstrates the importance of knowing exactly where a modification would have the greatest effect in terms of overall productivity in the picking storage.

A proper and easily used method concerning grouping of part numbers should be realised. Until now, storing assignment methods have used statistics, often combined with sophisticated mathematical modelling. Moreover, these statistical calculations are temporary and often time-consuming to perform. However, order picking systems for assembly could use the product structure as a base concerning decisions for locations, which is a more static and less time-consuming source of information. Common to the case studies is that a great deal of man time could be saved with more logical information systems and a more logical storage policy.

Up until now the main aim has been to improve the picking productivity in picking systems and for this reason activities, such as travelling time, picking time, etc., have been focused. However, picking errors were shown to cause the most serious disturbances in the storehouse and in the production process as well as irritation from the customers. In most of the cases, an inappropriate information system influenced the picking accuracy. It is of prime interest to design information systems that reduce the possibility of picking errors without lowering the picking productivity. Remarkable in the case studies was the varying design of the picking information.

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