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Batch Order and Discrete Order Picking Integrated with Vehicle Routing Decisions

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Abstract **– In a business-to-consumer (B2C) context, customers order more frequently and in smaller quantities, resulting in a high number of consignments. Moreover, online shoppers expect a fast and accurate delivery at low cost or even free. To survive in such a market, companies can no longer optimise individual supply chain processes, but need to integrate several activities. In this article, the integrated order picking-vehicle routing problem is analysed in an e-commerce environment. In previous research, a mathematical programming formulation has been formulated in literature but only small-size instances can be solved to optimality. Two picking policies are studied: discrete order picking and batch order picking. The influence of various problem contexts on the value of integration is investigated: a small picking time period, outsourcing to 3PL service providers, and a dynamic environment context.**

Keywords **– Logistics integration, production distribution problem, production scheduling, vehicle routing.**

I. Introduction

Production and distribution are two functions in a supply chain. In both functions, decisions need to be taken and optimization models emerge. Production scheduling is a widely studied topic, involving numerous optimization problems. In distribution, one might think of vehicle routing problems, which appear in many variants. In most studies, production scheduling and vehicle routing are studied separately, while production and distribution are linked in practice as goods can be shipped only after being produced. The integration of production and routing decisions into a single decision support model can avoid inefficiencies in the determined schedules [1], which can result in higher operational costs, lower customer service levels, or poor utilization of the resources [2].

Due to the rise of e-commerce, more complex distribution problems arise. For instance, goods are often transported from a distribution centre (DC) to a postal office depot from where the goods are delivered to customers by a mailman, or even delivered from a DC to the end customer [3]. As such, compared to traditional distribution networks, wholesalers and retailers are often bypassed. Furthermore, in an e-commerce context, customers order more frequently in smaller quantities [4].

After the (e-commerce) orders are picked in a warehouse, they need to be delivered to locations requested by the customers. The picking and delivery processes are mostly considered to be independent operations [5]. However, in retail practice, order picking and distributions are interconnected. Instead of solving an order picking problem (OPP) and a vehicle routing problem (VRP) separately and sequentially, these two problems can be integrated into a single optimization problem. In the integrated problem (I-OP-VRP), both subproblems are solved simultaneously to obtain an overall optimal solution. The integrated planning makes it possible to start delivery tours as early as possible, allowing more customers to be served within the tours [6]. The literature on integrated order picking and vehicle routing is limited. Some examples are: [7]–[9].

Order picking is the most labor-intensive activity in a warehouse because most operations are executed manually, especially when a picker-to-part method is applied. Manual picker-to-part order picking systems account for over 80 % of all order picking systems in Western Europe [10]. The picking process consists of the following operations: the picker receives a picking order from the dispatching area, walks or drives to the right storage location, collects the item, and returns to the unloading area or directly to a waiting vehicle. The order picking time is the time needed by an order picker to complete a route in a warehouse to pick the items requested in a specific order. The order picking time is composed of different components: setup time for preparing a picking tour, travel times between picking locations, search times to find the requested items, pick times to grab the required quantity of items from their storage locations, and loading time into the vehicle. The travel times between the different locations, which need to be visited, account for approximately half of the total picking time [11]. To save on labour costs, the total time required for the order picking activities needs to be minimized.

Furthermore, nowadays, customers expect a short delivery time when they purchase goods online. Consequently, companies have to offer a cut-off time as close as possible to the preferred delivery time. As a result, a large number of orders need to be picked in a short period of time. In order to be able to offer this service level to customers, picking operations have to be performed efficiently such that throughput times of orders are reduced [12].

In the order picking problem, the number of order pickers per shift has to be determined and assigned to different warehouse areas [13]. Either from a cost minimisation perspective or from a service level maximisation perspective, total picking time

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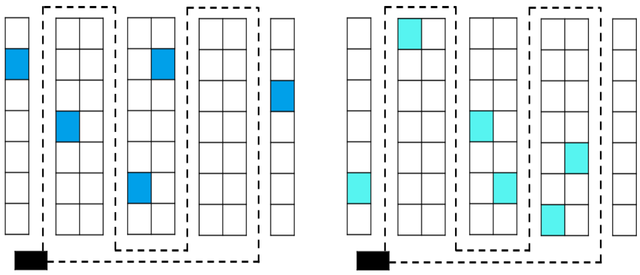
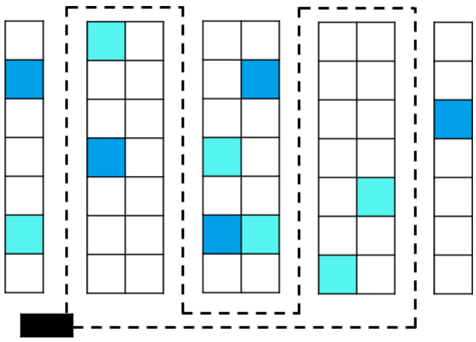
needs to be reduced in order to pick orders as efficiently as possible. The only component of the total picking time on which savings can be gained is the travel times, which have no value adding function. One way to reduce travel times is to implement a batch picking policy in which multiple customer orders are combined into a single route. In previous publications [14], [15], a discrete order picking policy in which products ordered by a single customer are picked in an individual route is implemented. Since batch picking avoids that order pickers have to travel several times to the same picking locations to pick items that are requested by multiple customers, the reduction in travel time can be significant, especially for fast moving goods which are ordered by a large number of customers. Therefore, batch picking is introduced in the I-OP-VRP considered so far.



(a) Discrete order picking policy for two orders.



(b) Batch picking for two orders.

Fig. 1. Comparison of picking routes with discrete order picking and with batch picking.

The difference between a discrete order picking policy and a batch picking policy is illustrated in Fig. 1. The coloured boxes indicate the storage locations of the items requested by customers. The dashed lines represent the picking routes through the warehouse. In Fig. 1a, the picking routes are individually performed for two customer orders using a discrete order picking policy, resulting in an order picker travelling the same route twice. In Fig. 1b, the two customer orders are combined into a single batch. The order picker has to travel the route through the warehouse only once. Thus, in this example, the picking time with batch picking is approximately half of the picking time compared with a discrete order picking policy. A disadvantage of batch picking is that items of different customer orders need to be sorted when they are picked in the same route. Two types of sorting can be applied. Orders can be sorted either during the picking route, i.e., a sort-while-pick, or at the end of the picking route, i.e., a pick-and-sort [16].

The difficulty of the batching problem is to decide which orders are grouped into a single batch. Different strategies such as priority rule-based algorithms, seed algorithms, and savings algorithms, are developed in literature to solve the problem of assigning orders to batches. For detailed information on these strategies, the readers are referred to [17], [10], [18]. The assignment procedure is not the focus of this paper. It is assumed that all demand is known at the beginning of the planning horizon.

Thus, all feasible batches can be created in advance and are used as input for the I-OP-VRP. The decisions, which have to be made in the order picking part of the I-OP-VRP are: (1) to select the batches that are picked such that each order is included in a batch, and (2) to determine the sequence in which batches are picked for each order picker. Several studies examine the impact of implementing a batch picking policy instead of a discrete order picking policy. In [12], it has been found that combining a number of small orders in the same picking route can lead to a reduction in total order picking time of on average 19 %. Consequently, a lower number of order pickers is required for the picking activities. The data in the study are based on a large retail organisation in the Netherlands. The study [19] compares five picking policies in a mail order company. When a batch picking policy is used instead of a discrete order picking policy, the travel times decrease by 60 %. The paper [20] investigates the picking activities of an online/catalogue retailer using a discrete order picking policy. The authors examine the impact of using a different batching, routing, and storage policy. Experiments reveal that batching leads to the largest reduction in total fulfilment time, with savings up to 29 %.

The goal of this research is to conduct an exploratory study on the impact of a batch picking policy on the value of integration. An integrated problem applying a batch picking strategy is compared with one using a discrete picking policy. Experiments on small-size instances are executed to quantify the difference between both approaches. Moreover, conceptual scenarios are introduced in which batch picking can enlarge the value of integration compared to discrete order picking. This paper is the first step towards research on integrated order picking-vehicle routing problems with a batch picking policy.

Data instances are created in the next section. Experiments on the impact of batch picking in comparison with discrete order picking are conducted in the following section. The value of integration in case of batch picking is further quantified. A problem context is described in which I-OP-VRPs with batch picking are compared with I-OP-VRPs with discrete order picking. The goal is to identify what the effect is of a batch picking policy in specific circumstances on the value of integration.

II. Data Generation

The integrated OP-VRP is studied for the first time, so no benchmark instances exist. Instances have been generated in [15]. In that paper, 100 instances are generated for the case of discrete order picking with problem sizes of 10, 15 and 100 customer orders. The first 50 instances of each class are used for parameter tuning and sensitivity analysis. The remaining 50 instances are used for the experiments. Implementing a batch picking policy leads to a higher complexity of the I-OP-VRP. Consequently, the computation times to solve the problem to optimality by CPLEX increases. To get a first insight into the impact of batch picking, only the 50 instances with 10 customer orders are transformed into instances with batch picking. For instances with 10 customer orders, two regular order pickers, one temporary order picker, and three vehicles are available. The data with respect to the delivery operations, e.g., time windows and customer locations, remain the same. The data related to the picking operations are adapted from individual order data to batch data. The number of possible batches is calculated as follows:

$$\sum_{r=1}^{n} \frac{n!}{r!\,(n-r)!}$$

with n the total number of orders and r the number of orders in a batch. The total number of possible combinations with $n = 10$ is equal to 1023.

The batch capacity utilisation wb_b is the sum of the number of items w_i in each customer order included in the batch. The order time of a batch ot_b is the maximum order time ot_i of the orders assigned to the batch. Since the focus is not to select the best batching and routing policy, the picking time of a batch pt_b is randomly generated based on the picking times of the orders included. In more detail, the picking time of a batch with a single order ($r = 1$) is equal to the picking time of that order. The picking time of a batch with multiple orders ($r > 1$) is randomly generated between the maximum picking time over all subbatches with $r - 1$ orders selected out of the orders in the batch and the sum of the picking times of the orders included. For example, the picking time of the batch with order 1, 2, and 3 is randomly generated within the range of the maximum picking time of the subbatches, i.e., (1, 2), (1, 3), and (2, 3), and the sum of the individual picking times, i.e. $U\,[\max(pt_{(1,2)}, pt_{(1,3)}, pt_{(2,3)}), pt_1 + pt_2 + pt_3]$. Thus, picking a batch takes at least as long as picking a smaller batch with some of the orders inside a larger batch, but no longer than the sum of picking each order individually. The time needed to sort the different customer orders in a batch is assumed to be negligible.

The batches with an infeasible weight utilisation with respect to the picking device capacity of 20 items and a picking time greater than the picking time available for a single order picker are excluded from the input data in the computational experiments. Since, by using a batch picking policy, the total picking time needed decreases, the time period available for the picking operations is shortened in comparison with the discrete order picking policy.

III. Impact of Batch Picking

In this section, the impact of implementing a batch picking policy on total cost is examined. The results of an I-OP-VRP with batch picking and of an I-OP-VRP with discrete order picking are compared. The experiments are executed on a 12-core Xeon E5-2680v3 CPUs with 128 GB RAM. The optimisation software ILOG CPLEX 12.7.1 is used to solve the mathematical formulation to obtain the optimal solution for the instances with batches. In Table I, the changes per cost component and in total cost are presented.

TABLE I
Comparison of Discrete Order Picking and Batch Picking

$\Delta\ TC$ (%)	$\Delta\ TC_{\mathrm{creg}}$ (%)	$\Delta\ TC_{\mathrm{ctemp}}$ (%)	$\Delta\ TC_{\mathrm{ctly}}$ (%)	$\Delta\ TC_{\mathrm{ctty}}$ (%)
−12.07	−37.60	0.00	0.00	0.00

Implementing a batch picking policy instead of a discrete order picking policy leads to savings in total cost (TC) of approximately 12 %. Costs related to the delivery operations (TC_{ctlv} and TC_{cttv}) are not influenced by changing the picking policy for these instances. The labour costs of the regular order pickers (TC_{creg}) decrease by 37.60 % on average. While in an I-OP-VRP with discrete order picking on average 1.16 regular order pickers are needed, in an I-OP-VRP with batch picking a single order picker can pick all orders on time. In both integrated approaches, no temporary order pickers are used.

The investigation of an I-OP-VRP with batch picking leads to a higher number of possible picking schedules compared to an I-OP-VRP with discrete order picking. The computation time required to obtain the optimal solution by CPLEX increases. Solving instances with discrete order picking has an average computation time of approximately two minutes, while the average computation time for instances with batch picking is two hours.

IV. Value of Integration

Due to the large computation times to solve such an I-OP-VRP, experiments are conducted using instances with only 10 customer orders. In the uncoordinated approach, a picking due date after 60 min needs to be respected. Such a small time period for the picking operations is considered because by implementing a batch picking policy the total picking time needed is less than in case of a discrete order picking policy.

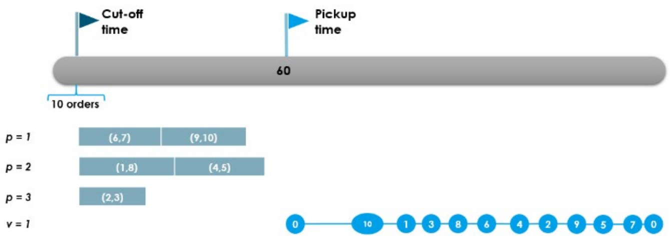
The value of the integration, indicated by the changes in total cost ($\Delta\ TC$) in Table II, is on average 0.32 %. By integrating the subproblems, savings on the labour costs of the order pickers are achieved. In the integrated approach, a single regular order picker can pick all goods on time.

TABLE II
Cost Difference between an Uncoordinated and an Integrated Approach

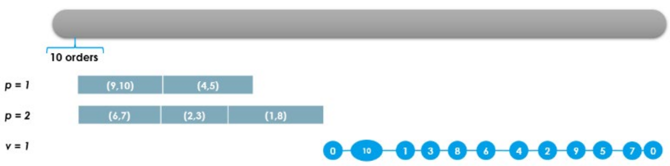
$\Delta\ TC$ (%)	$\Delta\ TC_{creg}$ (%)	$\Delta\ TC_{ctemp}$ (%)	$\Delta\ TC_{ctlv}$ (%)	$\Delta\ TC_{cttv}$ (%)
–0.32	7.70	–46.00	0.00	0.00

In the uncoordinated approach, however, in all instances, two regular order pickers are needed and, in 23 instances, an additional temporary order picker needs to be hired to avoid violating the picking due date. The labour costs of the regular order pickers (TC_{creg}) in the integrated approach are on average 7.70 % higher than in the uncoordinated approach since all orders are picked by regular pickers in the integrated approach. The labour costs of the temporary order pickers (TC_{ctemp}) decrease by 46.00 %. Thus, the increase in the labour costs of the regular order pickers is compensated by the decrease in the labour costs of the temporary order pickers.

The general results described in this section are illustrated by examining the specific results of one instance in more detail. In the uncoordinated approach, two regular pickers both pick two batches of two orders (Fig. 2a). Order pickers 1 and 2 work 47 min and 55 min, respectively. The pick time of the remaining batch of two orders is 20 min. Consequently, this batch needs to be assigned to a temporary order picker to avoid violating the picking due date. In the integrated approach (Fig. 2b), the order pickers can work 240 min without fixed end time of a shift since it is no longer restricted by the picking due date. The batch, which is picked by a temporary order picker in the uncoordinated approach, can be picked by a regular order picker in the integrated approach. No additional order pickers need to be temporarily hired, which may lead to lower labour costs. Order picker 1 works 50 min and picks two batches of two orders. Order picker 2 has a working time of 72 min and picks the remaining three batches. Thus, the same batches are picked, but fewer order pickers are needed for the picking operations. The same delivery route is conducted in both approaches.



(a) Uncoordinated approach with a temporary picker (p = 3).



(b) Integrated approach.

Fig. 2. Comparison of an uncoordinated approach with a single temporary picker and an integrated approach.

A critical remark has to be added on the relatively low value of integration indicated in the experiments when a batch picking policy is applied. A reason for the low value can be the way in which the batches and the associated picking times are created. All feasible combinations of customer orders with respect to the picking device capacity are created. The picking times of the batches are randomly generated. The picking time of a batch with r number of orders is randomly generated between the maximum picking time of all subbatches with $r-1$ orders and the sum of the picking times of the individual orders in the batch. The storage locations and picking routes are not considered since these data are not available in the artificially generated instances.

In literature, batches and their picking times are generally created using batching policies. Examples of batching policies are proximity batching and seed algorithms. In proximity batching, customer orders are combined in a batch based on the proximity of their storage locations in the warehouse. In a seed algorithm, first an order is selected as seed order. Then, orders are added to the current batch based on a distance measure [10]. Thus, when using such batching rules, orders which are located close to each other are combined.

Consequently, more travel distance is saved in comparison with a discrete order picking policy and a random batch policy. The first step in further research has to be conducted to investigate the value of integration when such batch picking rules are applied. Furthermore, higher efficiency improvements can be obtained when order batching, picking routes,and picker scheduling are optimised in a coordinated way instead of each problem individually [21]. Therefore, the second step in future research is to examine the value of integrating order picking and vehicle routing decisions when the internal warehouse operations are conducted in a coordinated way.

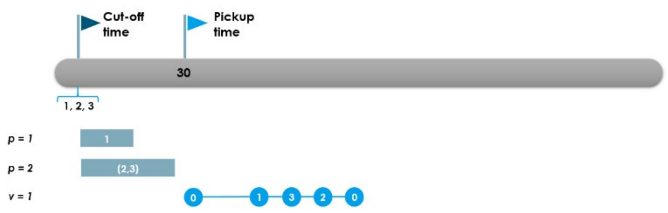
V. Problem Context: A Small Picking Time Period

In an e-commerce environment, customers expect fast delivery. Thus, the time period between the purchase of goods and their delivery needs to be small. To offer this service level, the cut-off time has to be close in time to the picking due date in an uncoordinated approach. Consequently, the time available for picking goods that are ordered close to the cut-off time is limited. To pick all orders on time, multiple orderpickers need to work at a time. Additionally, batches which require a larger picking time than the time available cannot be selected. Therefore, when determining picking schedules, a lower number of possible batches are available to select from. Probably a higher number of batches consisting of a small number of orders need to be picked.

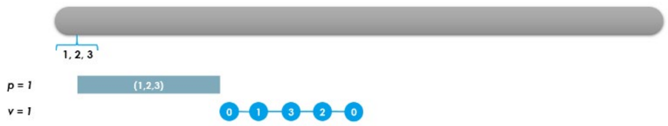
In the *uncoordinated* approach, the delivery operations are outsourced to a 3PL service provider. A picking due date is negotiated with the 3PL service provider. At the due date, the 3PL service provider arrives at the DC and picks up the goods. This picking due date is fixed and the same for every day. The e-commerce company and the 3PL service provider do not contact each other daily to discuss the due date for that specific day based on the customer orders requested.

In the *integrated* approach, the only time restriction is the maximum working time of an order picker during a single shift. No picking due date has to be respected. The entire time period between the request of an order and the departure time of the vehicle delivering the order can be used for picking the order. The batches with a large picking time which cannot be considered in the uncoordinated approach are no longer excluded in the integrated approach. These batches, which probably combine a higher number of orders and lead to a lower total time for picking all orders, can be selected.

A numerical example with three customer orders is presented. The three orders are requested by customers at the cut-off time. After the cut-off time, 30 min are available before the picking due date in the uncoordinated approach (Fig. 3a). The smallest possible total picking time is 42 min. Order picker 1 picks customer order 1 (15 min). A batch consisting of orders 2 and 3 is picked by order picker 2 (27 min). In the integrated approach, however, a single order picker picks all three customer orders in a single batch (Fig. 3b). The picking time is 41 min. The batch with the three orders cannot be picked in the uncoordinated approach since the picking time is larger than the time available between the cut-off time and the pickup time. In the uncoordinated approach, the picking due date is fixed at the same time every day. It is not possible to change the due date in order to be able to reduce the total picking time for a specific day, especially because the goods are ordered close in time to the picking due date. Thus, by integrating order picking and vehicle routing decisions, the total picking time can be decreased in case batch picking is applied, and the number of order pickers required decreases.



(a) Uncoordinated approach with a small picking time period available.



(b) Integrated approach.

Fig. 3. Comparison of an uncoordinated approach with a small picking time period available and an integrated approach.

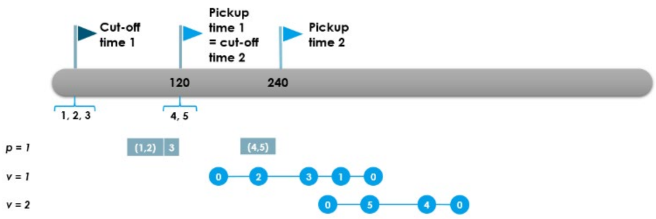
In case a discrete order picking strategy is implemented, the problem of a small time period available for picking only leads to hiring more order pickers in an uncoordinated approach. The smaller the time period between the cut-off time and the picking due date, the higher the number of temporary order pickers needed in the uncoordinated approach. When the time period is too small and the number of order pickers available is insufficient to pick all goods on time, the uncoordinated problem becomes infeasible. Orders are picked by a lower number of order pickers when the order picking and vehicle routing problems are integrated, and in most cases no additional order pickers need to be hired. In contrast to a discrete order picking policy in which the sum of the individual picking times remains the same after integration, the total picking time decreases by integrating the two subproblems in case of batch picking. Thus, not only the number of order pickers needed decreases, also the total picking time is reduced in an integrated problem with batch picking.

VI. Problem Context: Outsourcing to Multiple 3PL Service Providers

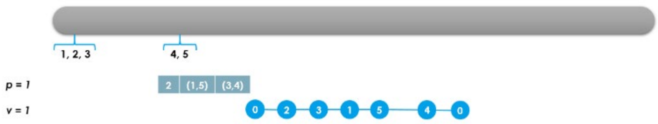
An e-commerce company can outsource its delivery operations to more than one 3PL service provider in an uncoordinated approach. The e-commerce company negotiates with each 3PL service provider a pickup time at which the goods are picked up that are delivered by a specific 3PL. For each pickup time, an associated cut-off time, before which goods need to be ordered, is determined. Suppose, a contract is negotiated with two 3PL service providers leading to two pickup times and two cut-off times. The second cut-off time is equal to the first picking due date. All goods ordered before the first cut-off time need to be picked before the first pickup time in such a way that the 3PL can deliver these goods to the customers. The goods ordered after the first cut-off time have to be picked before the second pickup time. Thus, only orders which are picked in the same period can be combined in a batch. In this situation, two picking schedules are determined: one for the time period between the first cut-off time and the first pickup time and another for the time period between the first pickup time (second cut-off time) and the second pickup time.

In the integrated approach, however, no fixed pickup times occur. The delivery operations are conducted by the e-commerce company itself or the 3PL service providers collaborate with the e-commerce company. A picking schedule is determined for the entire period. All possible combinations of orders can be assigned to a batch as long as the capacity of the picking device is not violated. The picking process of orders which need to be delivered in a late time window, i.e., after pickup time 2, can be postponed. The system is updated regularly and new orders become available. In this way, new batching combinations with orders from both time periods are possible. Combinations with newly arrived orders can result in a lower picking time than combining orders which are requested earlier. Furthermore, whereas in the uncoordinated approach each 3PL service provider determines its delivery route, in the integrated approach, vehicle routes for the entire delivery period are determined. Thus, all orders can be considered at the same time when establishing vehicle routes resulting in more consolidation possibilities. The number of routes needed to deliver all goods can decrease.

In Fig. 4, an uncoordinated and integrated approach are shown. In the uncoordinated approach (Fig. 4a), orders 1, 2, and 3 need to be picked before pick due date 1 at 120, while the picking process of orders 4 and 5 has to be completed before pick due date 2 at 240. In the first time period, orders 1 and 2 are combined in a batch (28 min), and order 3 is picked in an individual tour (17 min). In the second time period, orders 4 and 5 are combined in a single batch with a picking time of 31 min. The total picking time of the uncoordinated approach is equal to 76 min. Two vehicle routes are conducted. The first route leaves the DC at picking due date 1 and delivers all goods ordered before cut-off time 1. The second route leaves the DC at the second picking due date and delivers the remaining orders. In the integrated approach, different orders are combined into batches (Fig. 4b). Order 1 and 5 are assigned to a batch with a picking time of 20 min. A second batch is composed of orders 3 and 4 and has a picking time of 21 min. Order 2 is picked individually (24 min). The total picking time is equal to 65 min. As can be seen, orders requested in different time periods in the uncoordinated approach are combined in batches in the integrated approach. Thus, by postponing the picking process of orders 1 and 3 until additional orders have arrived in the system, the total picking time is reduced by 14.5 %. Consequently, lower labour costs are incurred. Additionally, all orders are delivered by a single vehicle. In the uncoordinated approach, each 3PL service provider conducts a delivery route. In the integrated approach, however, by collaborating all orders can be delivered in a single route.



(a) Uncoordinated approach with multiple 3PLs.



(b) Integrated approach.

Fig. 4. Comparison of an uncoordinated approach with multiple 3PLs and an integrated approach.

These savings cannot be achieved when a discrete order picking policy is applied in the DC. In such a situation, no orders are combined in a batch, and the total picking time is the sum of all individual picking times. The total order picking time is not influenced when orders are postponed to be picked. Thus, integration can be more beneficial when batch picking is applied in a situation with multiple 3PL service providers with multiple cut-off times in an uncoordinated approach.

VII. Problem Context: Dynamic Environment

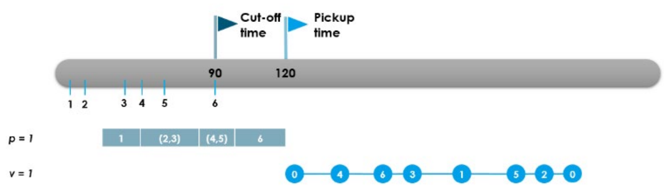
A typical characteristic for e-commerce sales is that goods can be ordered on the Internet 24/7. Orders arrive in the system of the e-commerce company at any moment in time. Every time a new order is placed, the existing picking schedules and vehicle routes need to be updated. The picking process of the newly arrived order has to be added to the picking list of one of the pickers, and the order needs to be inserted in one of the vehicle routes. In contrast to the previous problem context in the uncoordinated approach, the system is no longer updated only at the cut-off times.

In the integrated approach, the picking process of orders can be postponed. By postponing, orders can be batched with orders that are requested later. More batching possibilities are created. Some of these can lead to a lower total picking time needed. In the uncoordinated approach, all orders have to be picked before the due date. Postponing the picking process of all orders can be risky as the possibility exists that the picking due date will be violated. In the integrated approach, a decision rule has to be determined that indicates which orders can be postponed and to what extent. For example, the picking process of an order can be postponed until no later than two hours before the upper bound of the delivery time window of the order.

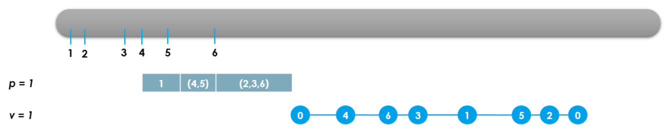
An example of a dynamic situation in both an uncoordinated and integrated approach is presented in Fig. 5. Only orders placed in the time period before the cut-off time in the uncoordinated approach are considered. Six orders are placed in this time period. Order 6 is requested on the last possible moment in the uncoordinated approach, i.e., at the cut-off time. After the cut-off time 30 min are left for conducting picking operations. The time needed to pick order 6 in an individual tour is 27 min.

As can be seen in Fig. 5, orders are combined in different batches in the uncoordinated and integrated approach. In the uncoordinated approach (Fig. 5a), order 2 is combined with order 3, while in the integrated approach (Fig. 5b) orders 2, 3, and 6 are combined in a single batch. The picking process of batch (2,3) is postponed in the integrated approach. The postponement creates the opportunity to combine batch (2,3) with order 6 in a single batch which has a picking time of 49 minutes. When batch (2,3) is postponed in the uncoordinated approach, the batch (2,3,6) would violate the picking due date since order 6 is requested at time 90 and the picking due date is at 120.

In case of discrete order picking in a dynamic environment, postponing the picking process of orders has no impact on the total time required to pick all orders. Each customer order is picked in an individual tour through the DC. Postponement does not change the picking time of an individual tour. Consequently, integrating order picking processes and vehicle routing operations in a dynamic environment has a higher value in case a batch picking policy is applied instead of a discrete order picking policy.



(a) Uncoordinated approach.



(b) Integrated approach.

Fig. 5. Comparison of an uncoordinated approach and an integrated approach in a dynamic environment.

VIII. Conclusion

In this study, a batch picking policy is introduced in the I-OP-VRP. Instead of picking each customer order in an individual picking tour through the warehouse, multiple orders are combined in a batch to be picked in the same tour. Batch picking reduces the total picking time needed. Consequently, total labour cost decreases by approximately 37 % on average for the instances with 10 customer orders. Total cost is reduced by approximately 12 % on average. The value of integration is quantified in case batch picking is applied to the order picking part of the problem. Experiments with instances of 10 customer orders are executed. Similar results as in case of a discrete order picking policy are obtained. In an integrated approach, a lower number of order pickers are required to pick all goods since there is more flexibility for conducting the picking operations. Consequently, total labour cost of the order pickers decreases. The paper also describes a specific problem context. If the time period between the cut-off time and the picking due date is small in the uncoordinated approach, then integration can have a larger value if batch picking is applied instead of discrete order picking. If the subproblems are integrated, then different orders can be batched than in the uncoordinated approach leading to a lower total picking time. In discrete order picking, the total order picking remains the same as it is the sum of the individual picking times.

An exploratory study has been conducted on the impact of implementing a batch picking policy in an I-OP-VRP. The aim has been to gain a first insight into the effect of batch picking on the value of integration. In further research, the value of integration for larger problem sizes has to be examined. The problem contexts provided indicate first impression of which benefits can be obtained when integrating an order picking problem using batch picking with a vehicle routing problem. The savings obtained by integrating order picking and vehicle routing decisions depend on the batching policy, routing policy, and storage policy used in the DC.

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