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Simulation and order picking in a very-narrow-aisle warehouse

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ABSTRACT

The revolution of information brought new possibilities for the business organisations: new management methods for managing supply chains, logistic processes and warehouses appear as well as innovative process management methods in the sense of knowledge management. The order picking process in the warehouse should be emphasised as one of the most laborious activities, since it consumes ~55% of the warehouse labour activities. This study pays special attention to the order picking process in a very-narrow-aisle (V.N.A.) warehouse, with the aim to identify solutions for the reduction of total travel distance and costs. The methods of the scientific literature analysis and synthesis simulation were applied. The results of the simulation confirmed the application of a pick-by-article strategy that is implemented with ‘seed’ sorting by order solution in low-income countries.

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1. Introduction

The scientific literature lacks the research of the V.N.A. warehouses, especially of different strategies of the order picking, their comparison and the application of the actual case studies. The development of information and communication technologies (I.C.T.) enables business organisations to manage business processes more efficiently, so reducing logistic costs is an important issue for any company. In general, logistics expenses are approximately 12–15% of the global G.D.P. It is often stated that, next to transportation, warehousing is one of the peak cost drivers in the supply chains. It should also be emphasised that the order picking process (a selection of products from different warehouse locations according to customer orders) is the most laborious of all warehouse activities. On average, order picking costs comprise a big share of the warehouse operational costs (~55%) (Oudijk, Roodbergen, Koster, & Mekern, 2013). Therefore, it is vital for the organisations to take measures that reduce the order picking costs. Recent tendencies of warehouse

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planning are affected by the new I.C.T. possibilities as well as new management solutions, as is stated in Jorge, Kokkinogenis, Rossetti, & Marques (2012). Today the design and management of order picking are achieving higher importance and complexity.

One of the ways to improve the order picking process is to redesign it. Attention should be paid to the facts that there are only so many order fulfilment methods that can be employed for such a task: methods of combining several customer orders, picking batches and applying immediate sorting according to the customers. Other order picking methods are used for the picking of the original customer orders. All of the aforementioned methods are well known and used independently for the reduction of the total travel distance. Picking several customer orders at once is mostly used for the picking of promotional items (for example, Albert Heijn, I.C.A. Norway, etc. (proven by personal author visit to mentioned D.C.s). Batch picking and sorting according to the customers is applied in the fields of food, fashion, non-food and e-commerce. Such a method of picking has been applied by ‘Amazon’, ‘Staples’, ‘Game Stores’, ‘Euro Shoe’, and others (Vanderlande, 2016).

The choice of best order picking method depends on different variables, such as the size of order, the flexibility of the warehouse management system (WMS), product location, number of items, and other conditions. Human factors are very important as well, but are difficult to measure (Grosse, Glock, Jaber, & Neumann, 2015). Often regular order picking is used, because other alternative picking methods lack the proper software system. This leads to a less efficient picking process. The simulation can be chosen as one of the most efficient tools for the optimisation of the warehouse processes. Scientific publications since 1984 in the research area of warehouse efficiency, simulations for this purpose and management solutions related to aisle order picking focus more on layout subject and the least number of publications on the topic of narrow aisles (Basile et al., 2012; Bozorgi et al., 2014; Chan, 2002; Gademann & Velde, 2005; Hong, Johnson, & Peters, 2012; Logistics Simulation Ltd., 2005; Petersen & Schmenner, 1999; Perl & Daskin, 1985; Roodbergen & De Koster, 2001; Rosenwein, 1996; Rouwenhorst et al., 2000; Vaughan, 1999). Narrow-aisle-warehouses were detected as a gap in the research and most studies analysed blocking the aisle issues, V.N.A. trucks, systems (such as A.S.R.S.) with narrow aisles and batch picking in V.N.A. Among the analysed studies, the amount of research on batching and aisle subjects is significantly low and more attention is paid to order picking. In order to fill the gap of knowledge in picking in very-narrow-aisle warehouses in low income countries, the research and modelling were planned.

The aim of this article is to present an adopted simulation model for analysis of the particular business case and to apply it in the case study of a very-narrow-aisle warehouse. The simulation model provides tools for the comparison of order picking strategies, such as picking-by-article, in comparison with the regular picking in the V.N.A. warehouse, and this would be the added value for scientists and practitioners in simulation of various situations. To achieve the aim of the article, methods like scientific literature analysis, synthesis, and simulation were employed.

2. Literature review

Recent research directions have focused on an integrated approach to the warehouse analysis (Dotoli, Epicoco, Falagario, Costantino, & Turchiano, 2015). These studies
focus on the Lean concept in the warehouse operations. The development of the optimising routing and picking algorithms (Chen, Wang, Qi, & Xie, 2013) and travel-time modules (Xu, Zou, Shen, & Gong, 2015). Most studies focus on reduction of the travel time. Most of them are ignoring other time components that occur during the preparation, item search and picking of such picking. Throughput analyses at the picking process (Pan & Wu, 2012; Pan, Shih, & Wu, 2012) are dedicated to the performance of the system in general. Most of these studies cover the day-to-day planning and control processes. The number of scientific research dedicated to the topic of sustainability analysis is growing (De Koster, Le-Duc, & Zaerpour, 2012). The researchers are directed to get the answer to the question of how to make a warehouse more sustainable.

The study falls to the optimisation of the order picking process. As Dukic & Cedomir (2007) state, more than 50% of the travel time is consumed by unproductive movement. The algorithms that solve the vehicle routing problem were proposed by Clarke & Wright (1964), much earlier and, according to the algorithms, a reduction of the travel distance was obtained by putting together a bigger set of shorter trips into a smaller set of longer tours. The time conservation can be obtained by combining different tasks instead of executing them separately, so the conserved times are calculated. All scientific papers dedicated to the topic are oriented to the single type of very-narrow-aisle (V.N.A.) warehouses, where the pallets are picked without changing position inside the aisle.

In many of the labour-intensive warehouses, there is constant pressure to reduce the travelling time. De Koster, Roodbergen, and Van Voorden (1999) state that that a reduction of the total travel time in the aforementioned warehouse means a reduction of labour. The researchers recommend different measures for travel distance analysis: the average measure (or average length of the trip) and the absolute measure. Clearly, the minimisation of average measure (or, equivalently, of the absolute measure) is limited to the vehicle operations. Another task could be the minimisation of the picking costs (De Koster, Le-Duc, & Roodbergen, 2006) (which may include both the investments into the vehicle and related infrastructure and operational costs). In this research the minimisation of the costs will be revised for the V.N.A. warehouse.

During the calculation of time conservation, different routing algorithms could be used. De Koster et al. (2006) promoted one of the following: S-shape, Combined, Largest gap, return, mid-point and also the optimal one. Goetschalckx & Ratliff (1988) developed the polynomial-time optimal algorithm that solves the problem of routing inside the narrow-aisle warehouse as well. However, in practice, only the simple routing heuristics are used, as S-shape and return (data presented in accordance with the W.M.S. market report (Moeller 2011)). The methods that are used usually involve the ‘Largest gap’ return and ‘Mid-point’ return strategies or ‘S-shape’ strategy. In a V.N.A. warehouse, case items are picked from the picker’s position both sides (no extra movements to the left or right side).

Another problem of the routing may arise if the products are stored in multiple locations of the warehouse (De Koster et al., 2006). In this case, a choice by the warehouse management system has to be made before directing the vehicle to the location from which the pallet has to be retrieved. Usually the first-in-first-out logic is used.
Consequently, the distance is often determined for planning the warehouse (Petersen & Aase, 2004). Different factors impact the reduction of travel distance: the type of warehouse (wide or narrow aisle), storage strategy (random or zone allocation of items), routing strategy, order allocation to picking, and other factors.

There are two ways how to organise the order picking: ‘pick-by-order’ (called discrete picking) or ‘pick-by-article’ (known as batch picking) (De Koster et al., 2006; Le-Duc, 2005). Additionally, the process for combining several customer orders into one or more picking lists could be used (all customer orders that have to be collected are joined together). This means that, in one picking tour, several parts of customer orders are picked. Many studies focus on the combination of several customer orders. Elsayed & Unal (1989) proposed an algorithm which combines small and large orders: at first they classify the orders to ‘large ones’ or ‘small ones’ and only after assigning them into groups. De Koster et al. (2006) treat each customer order (especially large ones) that can be picked individually (i.e., in the order picker route) (such a method is single picking or discrete picking), so in such a case only small ones have to be combined to multiple-order picking (in particular, immediate sorting during picking is required). Some other variants exist as well, picking of combined orders (batch picking) and distribution into the single order (Le-Duc, 2005) (separation to the different picking carts) during the picking, or the distribution after in a special sorting area, this one is called ‘sort according to the customers’. The first method is called ‘sort-while-pick’ (sequentially), the second one ‘pick-and-sort’ (simultaneously).

In the situation of ‘sort-while-pick’, the items have to be separated into different picking carts. This is not difficult to realise in a wide-aisle warehouse, where four customers are picked at once, but in a V.N.A. area only two containers are possible in man-up lifted operations. In general, grouping of several customer orders into a combined order reduces the average travel distance (order-based calculation). During the distribution process, the items are sorted into the original customer orders (De Koster et al., 2012).

Some order aggregation methods that are practically known: first-in-first-served is a very simple order grouping algorithm. This algorithm adds orders using the sequence in which they are placed in the W.M.S. When the picking trolley is full, then a new combination is started. The ‘seed’ algorithm has the following steps: primary order selection is initiated according to the ‘seed’ rule and allocation of other coming orders to the group is done according to the ‘seed’ increase logic. Savings algorithms are used for the comparison of two cases: when combined two client orders are collected during the single tour vs each of them picked individually (Dukic & Cedomir, 2007). The algorithm is quite advanced among others used in the area because it leads to significant performance improvement. This implies that different order grouping and picking strategies may be tested to find-out the level influence of the order picker’s performance.

Most scientific studies usually focus on the comparison of routing methods in rack (wide-aisle) warehouses or in V.N.A. pallet pick (high-bay or low-bay) warehouses. In scientific literature there is a lack of research for V.N.A. shelf warehouses, especially those which involves costs analysis and system improvement to reach day-to-day effect. The differences of V.N.A. shelf-area operations from wide-aisle warehouse are
vertical picking and special V.N.A. vehicles, which are used for them. The differences of V.N.A. shelf-area operations from pallet pick high-bay and low-bay warehouses are picking in smaller quantities and man-up operations linked to V.N.A. vehicle.

Concerning the performance of order picking methods (pick-to-order and pick-to-article) it is proven by Hong et al. (2012) that pick-to-article method delivers better results in the V.N.A. shelf-area warehouse, especially from the operational point of view. This study was linked to the S-shape routing method and ‘seed’ sorting during picking, which in man-up lifted case limits the number of sorted orders because of the small quantity of picker carts lifted. At the same time, Hong et al. (2012) found-out that ‘seed’ sorting while picking delivers a relatively poor solution quality because of the time spent inside the aisles. This study is performed to answer unanswered questions and focuses on a V.N.A. shelf-area warehouse (further on V.N.A. warehouse).

The Travel-time and Travel-distance simulation models used to analyse the logistical situations are well-known. Different factors can be analysed with the travel-time models, such as trip speeds and the amount of equipment driving in the warehouse. Some of these models estimate the time aimed to complete tasks, also including the non-efficient time (Cormier, 2005). Finally, the aggregated travel time of all movers is analysed in order to minimise the influence of inefficiency factors. Travel-distance models are dedicated to the calculation of the driven distance. Usually, travel-distance models are used for the analysis of the movement of the order pickers and picking equipment. Many approaches had been proposed for the travel-distance because there are some difficulties when making simulations in travel-time models for several reasons: complexity, path routing problem in the warehouse and a lack of other real-time event considerations. To explore new ways of working for the reference warehouse operations, a simulation model was suggested.

3. Research methodology

The main questions in this research are: what is the order picking performance in a V.N.A. warehouse when composite routing is used; what are the possibilities to improve the order picking costs?

The study delivered by Hong et al. (2012) will be extended in research looking for new practical applications. The authors selected a different routing strategy (i.e., composite route), in addition another sorting policy was selected (‘pick-and-sort’). Due to the advantages mentioned in Hong et al. (2012), batch picking and the ‘seed’ sorting algorithm will be incorporated into the study.

For the analysis, the two scenarios, pick-to-order (discrete picking) and pick-by-article (batch picking) with ‘seed’ sorting on the ground scenario, are employed, paying attention to the advantages of each for low income countries (L.I.C.). In comparison to high income countries (H.I.C.), herein the salary level is at least twice as low.

In the research the model of travel-distance will be employed, since this can help to estimate the performance of order picking in the V.N.A. warehouse; the investments and labour costs are taken into account for finding the best scenario to minimise the total costs in countries of lower wage.
After analysis of the simulation possibilities, the need of a model for a one-block V.N.A. warehouse, that will allow one to apply the analysis of both the travelling of the operator (horizontally and vertically) and the travelling of the vehicle is detected, in particular when the study is limited and handles tests in best order allocation for picking and composite routing.

While factors such as warehouse layout, the size of aisles and the picking strategies affect the overall productivity and accuracy, the use of the V.N.A. vehicle and information management systems also plays an important role. The authors suggested the system model to deliver the best possible system profiles for the improvement of order picking on a daily basis (as an advanced planning technique).

Different options are studied, where travel distance is the key component. Therefore, the results were applicable only to the V.N.A. warehouses located in countries with lower wages of the warehouse workers. When comparing different scenarios, it is necessary to examine the effect of the order size on the travel distances. For that matter, statistical analysis was employed.

An experimental warehouse environment was built using Microsoft Excel and Visual Basic macros. The developed simulation model is dedicated to estimate an average routing distance per order picking, based on historical data about fulfilled customer orders. In the model, the vehicle’s horizontal and vertical movements are taken into account.

The model layout (Figure 1) presents shelf area horizontal locations for different floors (880 locations per floor), or storage levels, in a 2-D environment. By performing the cursor operations ‘move up’ and ‘down’, storage levels in the model can be consequently changed and the model layout is automatically updated. The Excel warehouse environment also includes the following components (Burinskiene, 2010):

![Figure 1. Simulation model: simulation of order (on the left) and routing algorithm (on the right).](image_url)
Warehouse plan; The database of the picked orders; Client orders are entered for testing purposes; and a Simulation of the order picking environment (Figure 1).

One order picker fulfils all tasks. The algorithm itself searches and proposes the shortest option for the vehicle, based on return strategy or ‘S-shape’ strategy. The route is known as the composite route (Figure 2). The output of the simulation tests is an absolute measure. In order to start the simulation, the Visual Basic (V.B.A.) macro command button is inserted. The component of the order picking process (dynamic) is activated on the warehouse layout. The movements such as those of the order picker (vehicle and operator) inside aisles, front and rear end aisles and when the order picker goes back to the depot are simulated by the V.B.A. macros.

The order picker starts the route from the right side and then it is adjusted on the basis of ‘the shortest way to cross (front or rear end) the aisles’ logic called by a composite route. To change a corridor, an order picker moves in a direction which is closer to the last picking location in the current corridor. Composite route logic combines both heuristics ‘S-shape’ and ‘return’. The method is based on the logic that the vehicle crosses every aisle (where the locations of the client items are) from front to end. Only aisles without client items are skipped. In case the number of aisles to be traversed is odd, the last aisle is crossed entirely. This means that there are cases when the last aisle has to be visited additionally. From the front aisle the vehicle crosses the aisles where the items of the client are stored. Picking distance is calculated as a sum of horizontal and vertical distances in metres. Horizontal distances are calculated on the basis of the picker movements that are simulated in the model, and vertical ones are defined by positive distances between floors corresponding to previous and current locations (Figure 3) for lifting man-up.

The model summarises the absolute measure of travel distance, the number of processed pick orders and the number of locations; it also allows the calculation of the average measures. The model could be used for the scenario analysis in order to analyse the different improvement options for the picking process.

Figure 2. Composite route (grey-specified locations, black-depot) (according to Oudijk et al. 2013).
Three V.B.A. macro commands are involved for the routing algorithm. The first two commands are provided for the movements between the warehouse locations. The order picker follows the schematic picture of the particular warehouse. The third command is used only in cases when the order picker has to return to the depot.

According to V.B.A. macros, the order picker gets to pick the order and takes two picking carts on the V.N.A. vehicle at the depot, and then he starts the retrieval of products based on a pick order and at the end returns back to the depot, there he places the picking carts and confirms the picked order and the quantities of the picked items (Figure 4). During the experiments the authors analyse the travel distance and order picking costs.

The tests were performed in order to ascertain if the simulated model presents ‘real processes’ that are common for the V.N.A. case analysis. Before the aforementioned experimental set-up was made, a comparison of order picking in the simulation model and the picking in the real environment for it was done:

- In both environments, pick orders are formed by including such components: date, client, the number of pick lines and the number of picking locations;
- In actual cases several vehicles’ operators are retrieving large orders, but the output of the simulation is the summary of the separate trips delivered by all of them;
- Practically, the V.N.A. vehicle guided by the operator may take another route, which is longer, but the route algorithm is choosing the shortest way in the one block warehouse; and
- By looking at the historical data of the company, it can be seen that the processed orders correspond with the current observations.
The configuration of a warehouse management system has to take a very important role for delivering the best possible reduction in travel distance. The system architecture supports the decision-making process (Erkan & Can, 2014) for V.N.A. vehicle management. So, to implement composite route logic into the W.M.S. (built-in-house) is suggested. The underlying brief algorithm, which is developed during research, is provided next.

Notation:
- $C_p = \text{Priority index}$
- $s, t = \text{Locations}$
- $r = \text{Vehicle (in the Appendix: Vehicle id)}$
- $D_{st} = \text{Distance between two successive task locations, } X, Y, Z = \text{Coordinates of vehicle, } X_{s,t}, Y_{s,t}, Z_{s,t} = \text{Coordinates of locations, } X_{a1}, a2, \ldots, an \text{ and } Y_{a1}, a2, \ldots, an = \text{Coordinates of cross-aisles (front and end aisles)}$

The equation used to calculate the shortest travel distance (1), is proposed by Lawler, Lenstra, Rinnooy, & Shomy (1985):

$$\text{Min} \left( D_{r_1}, D_{r_2}, \ldots, D_{r_n} \right)$$  \hspace{1cm} (1)

Herein it is adopted to the in-house situation by providing the mathematical solution, where (2):

$$D_{st} = |X_s - X_t| + |Z_s - Z_t| + \min\left\{ \begin{array}{ll} |Y_s - Y_{a1}| + |Y_{a1} - Y_t|; & \text{If front aisle 1} \\ |Y_s - Y_{a2}| + |Y_{a2} - Y_t| & \text{If end aisle 2} \end{array} \right\}$$  \hspace{1cm} (2)

Both options are mentioned in the second equation, in case the front (No. 1) or the end (No. 2) aisle is used for crossing between the aisles. It presents the practical application of the suggested model. Three locations, K094-3, K023-2 and L094-3 were used to test the model:

- **K094-3**: $X_S = 45.8; Y_S = 43.102; Z_S = 1.79$
- **K023-2**: $X_t = 41.4; Y_t = 10.307; Z_t = 1.52$
- **L094-3**: $X_{t1} = 40.1; Y_{t1} = 43.102; Z_{t1} = 1.79$
  - $Y_{a1} = 0; Y_{a2} = 70$

The distance between the first and the second locations due to the use of the crossing at the end of the aisle, means the trip is shorter:

$$D_{st} = |45.8 - 41.4| + |1.79 - 1.52| + \min\{|43.102 - 70| + |70 - 10.307|\} \text{ If end aisle 2}$$

If end aisle 2 : $D_{st} = 4.4 + 0.27 + 32.795 = 37.465$

The distance between the first and the third locations when due to the use of the crossing at the end of the aisle, is shorter:

$$D_{st} = 5.7 + 0 + 53.796 = 59.496$$

It is evident that the difference between $Z$ coordinates represents the vertical picking distance in the reference warehouse, the formula in the existing information management system is formed according to such logic used in Eq (3):
\[
\text{Min} \left( D^f_{r_1}, D^f_{r_2} \right) \cdot <0; 1 > + |Y_s-Y_t| \cdot <1; 0 > + |X_s-X_t| + |Z_s-Z_t| + C_p
\] (3)

The equation is valid if \( C_p = 0 \) (which means that there are no urgent pickings in the priority list)

\[
<0; 1 > : \text{ aisles } 10 = 11 \rightarrow 0; 10 = / = 11 \rightarrow 1;
<1; 0 > : \text{ aisles } 10 = 11 \rightarrow 1; 10 = / = 11 \rightarrow 0.
\]

In the reference warehouse, the tested formula shows the double calculation of some parts of the distance, such as presented in the second case below:

\[
\text{Min} \left( D^f_{r_1}, D^f_{r_2} \right) \cdot <0; 1 > + |Y_s-Y_t| \cdot <1; 0 > + |X_s-X_t| + |Z_s-Z_t| + C_p
\]

\[
\text{Min}(37.465, 59.496) \cdot <0; 1 > + |43.102-10.307| \cdot <1; 0 > + 4.4 + 0.27 + 0 = 37.465
\]

Inside the aisle the position of the vehicle is always in the middle of the aisle, so there should not be a difference if the location on another side is further because of \( X \). The final formula (4) is suggested for the shortest distance analysis in the reference warehouse:

\[
D^f = |X_s-X_t| \cdot <0; 1 > + |Z_s-Z_t| + \min \left\{ |Y_s-Y_{a_1}| + |Y_{a_1}-Y_t|; \right\} \text{ If front aisle } 1
\]

\[
\left\{ |Y_s-Y_{a_2}| + |Y_{a_2}-Y_t| \right\} \text{ If end aisle } 2
\] (4)

In addition, it provided the implementation of the vehicle composite routing algorithm in the information management system. Such an algorithm is presented in the Appendix. The aforementioned fourth equation is incorporated into the block ‘vf 03’ and has to be used to provide the shortest total travel distance.

For the experiment several strategies are selected: Pick-by-order (first scenario); Pick-by-article and sequentially then sort-by-customers (second scenario). In such a case, all customers’ orders that consist of slow-moving items, are grouped by article at the end of day. First, one client order is allocated to a single pick order (single order picking) and, later, batch picking is used for the analysis. Client’s orders are entered into the database of the picked orders (kept for a month), it includes all of the following: the number of the pick orders and the warehouse location, the name of the client and the amount ordered by the client per item. A pick order represents one client order. These data are calculated on the basis of historical picking lists and could be automatically updated in the model. In most cases the range in the V.N.A. warehouse is most stable and there are rare cases when some slow-moving items become fast-moving for a short period.

In order to perform the experiments the orders of 2667 customers were entered into the system. Customers’ orders included 40,724 picking lines. There are small customer orders (1172 orders) that contain up to 10 picking lines, medium customer orders (1078 orders) that contain from 10–50 picking lines and large customer orders (417
orders) that contain more than 50 picking lines. This data represents a 1-month period of customers’ orders. As the assortment in the V.N.A. warehouse is most stable with rare cases when some slow-moving items become a fast-moving item for a short period (mainly for short assortment promotions), such represents V.N.A. operations well.

The pick-by-article process is simulated under the condition that one vehicle is assigned to the picking of a single picking list in one aisle and after such returned back (one way driving and the return route, only from the front aisle). The pick-by-order process is simulated with two possibilities for changing aisles (driving in on both sides of the composite route, from front and end aisles).

4. Results and discussion

The research was delivered by applying the simulation model for an order picking process with the aim to minimise costs in the warehouse. The data representing customers’ orders were entered into the model to find out the evidence of practical application. This model was used for the simulation of different strategies application in order picking processes.

For the efficiency application, batch picking has to be combined with a sorting strategy, in particular, ‘seed’ sorting is used before the delivery of orders to the customers. Usually in wide-aisle-warehouses the ‘sort-while-pick’ policy is applied, but in very-narrow-aisle warehouses such a policy is technically not possible, therefore sorting is applied afterwards.

The results of the simulation show us that the absolute distance is reduced by 10.2% (and the total travel distance is 212,592 metres), when ‘pick-by-article’ is compared to the ‘pick-by-order’ (when total travel distance is 236,846 metres). Later the sorting of the articles into the original customer orders is performed. The sorting increases the total travel distance by 36.4%. After the re-calculation, the total travel distance because of sorting is increased by 111,556 metres. For sorting on the ground, ‘seed’ logic is used. Still such results provide a big improvement in the costs of the V.N.A. warehouse, i.e., 6.4% (as calculated below). Two types of costs are calculated for the V.N.A. warehouse: order picker (vehicle operator) costs and V.N.A. vehicle costs.

According to Gray et al. (1992), who proposed to calculate the daily costs of the order picker, one order picker costs 40 Euros per day, and 0.29 minutes per stop that is required to perform the sorting activity. This means that during the month 1.2 full-time pickers are required to sort 40,724 articles because of the sorting activity. These costs associated with handling order picking in the warehouse. The largest component is the travelling which is required to handle the customer order.

The average price for the V.N.A. vehicle is 100,000 Euros (1666 Euros per month, when the depreciation period is 5 years); 8% or more of the V.N.A. vehicle’s price will be required for maintenance and repair annually (9000 Euros a month). Equipment costs include costs which are associated with the V.N.A. truck taken to handle orders in the warehouse, such as the depreciation of equipment and the cost of electricity required to support the power of the truck.

One order picker with the V.N.A. vehicle is able to perform 120 tasks during the working day (depending on the workload); one task takes at least 1 minute. For picking 40,724 articles 4.2 one-shift or 2.1 two-shifts of working V.N.A. vehicles are
required; also 4.2 pickers working with the V.N.A. vehicles on those shifts for the whole month. After the comparison of both scenarios, some results, which show the benefits of usage of the second scenario as presented (calculation is provided in Euros) in Table 1, were obtained.

The comparison of several salary level cases shows that the costs of the warehouse picker (M) have a linear impact on savings (S). For the upper bond, the Canada and US salary level was taken and for the lower level Portugal salary level was incorporated.

In order to provide any grouping of customer orders for a V.N.A. warehouse, W.M.S. has to be developed accordingly. The configuration of the warehouse management system is taken as a very important role for delivering the best possible system-based optimisation.

Based on research results, it is foreseen that the concept of pick-by-article and sort-by-customer opens up new possibilities for modern distribution material solutions and information management, helping to deliver picking efficiency improvement in the V.N.A. warehouse. Different factors affect the reduction of travel distance: the type of the warehouse (wide or narrow aisle), storage strategy (random or zone allocation of items), routing strategy, and other factors.

A stochastic relationship was indicated between the travel distance and order size. However, it should be emphasised that it is evident only for the first scenario.

In the examination of the first scenario, the relationship is quite strong. The correlation coefficient is significant and the regression equation is adequate to the real situation. Table 2 presents the travel distance in various aspects for each scenario. Herein the authors received such results.

The first one, pick-to-order – the retrieval of products from specified locations according to customer orders – is the most laborious and costly process in a warehouse. It consumes almost 60% of all warehouse labour activities.

In pick-to-article – the picker travel distance can be reduced if each article is picked from storage locations only once. Each pick list must be formed from many

---

**Table 1. The comparison of scenarios.**

<table>
<thead>
<tr>
<th>Lines</th>
<th>Scenario No. 1 (pick-by-order)</th>
<th>Scenario No. 2 (pick-by-article &amp; sort-by-customer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs of the V.N.A. vehicles (T)</td>
<td>( T_1 = (16666 + 9000) \times 2.1 = 22624 )</td>
<td>( T_2 = (16666 + 9000) \times 2.1 \times 0.898 = 20316 )</td>
</tr>
<tr>
<td>Costs of order pickers (M) in L.I.C.</td>
<td>( M_1 = 40 \times 20 \times 4.2 = 3393 )</td>
<td>( M_2 = 40 \times 20 \times 4.2 \times 0.898 \times 40 \times 20 \times 1.2 = 4031 )</td>
</tr>
<tr>
<td>Savings (S) in L.I.C.</td>
<td>( S = (22624 + 3393) - (20316 + 4031) = 1670 ) (6.4%)</td>
<td></td>
</tr>
<tr>
<td>Costs of order pickers (M) in H.I.C.</td>
<td>( M_1 = 95 \times 20 \times 4.2 = 7980 )</td>
<td>( M_2 = 95 \times 20 \times 4.2 \times 0.898 \times 95 \times 20 \times 1.2 = 9446 )</td>
</tr>
<tr>
<td>Savings (S) in H.I.C.</td>
<td>( S = (22624 + 7980) - (20316 + 9466) = 842 ) (2.8%)</td>
<td></td>
</tr>
</tbody>
</table>

\( T \), costs of V.N.A. vehicles; \( M \), costs of vehicle operator; \( S \), savings; 1 indicates the first scenario and 2 the second one.

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**Table 2. Comparison of scenarios.**

<table>
<thead>
<tr>
<th>Lines</th>
<th>Scenario No. 1: Pick-by-order</th>
<th>Pick-by-article</th>
<th>Sort-by-customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average travel distance (m)</td>
<td>88.7942</td>
<td>60.4313</td>
<td>95.1851</td>
</tr>
<tr>
<td>Dispersion</td>
<td>51.4983</td>
<td>25.0699</td>
<td>19.5416</td>
</tr>
</tbody>
</table>
customer orders instead of a single one. To deliver a pick-to-article picking method, changes must be made in the warehouse management system.

In the case of the second scenario, the travel distance is not increasing per order (no matter what the quantity of articles per order is). In the case of the first scenario, the orders are not accumulated, during the day the picker returns to the same article many times; in the case of the second scenario, the customer orders are accumulated on the article level at the end of the day, so that the picker would travel to a particular article once per day and, after that, on the ground floor the picker takes the ‘seed’ sorting of accumulated quantities by the customers.

The scientific and practical implications of the research is a methodology for modelling of order picking in a very-narrow-aisle warehouse in low income countries. The possibility to do a simulation of different scenarios and strategies in order to compare the options, taking into account various issues related to the process would lead to more efficient solutions, when companies cannot rely on most innovative technologies and still rely on low cost resources.

5. Conclusions

In scientific literature scholars describe the picking and sorting strategies, but most of the authors research focus on efficiency increase in wide-aisle warehouse. More of the methods are compared in terms of efficiency, but their practical application is not widely discussed. This study incorporates the salary level into existing order picking studies, which also proves a ‘pick-and-sort’ strategy for the allocation of slow moving items to customers’ orders. The minimisation of costs effect depends on the country of warehouse location. As labour costs for order picker varies among countries the investigation was done using different salary levels. The comparative analysis of the total travel distance revealed that batch picking is the best choice in low income countries. From an operational point of view, batch picking has advantages – it also reduces the time the V.N.A. vehicle is in the aisle, during which the aisle is blocked for other operations.

The proposed model of order picking in a very-narrow-aisle warehouse in low income countries, where the architecture of the vehicle routing algorithm for picking customers’ orders in a reference warehouse was implemented, also proposed the configuration of a warehouse system for the implementation of a composite route (i.e., shortest-way for crossing aisles) strategy to gain economic efficiency.

5.1. Scientific and practical implications

The research findings could be useful for scientists, private enterprises and system developers. Research results show 6.4% of costs reduction when a pick-to-article picking method is selected. The efficiency is reached due to minimisation of V.N.A. machine usage in the process. That value is applicable to a minimum of 4.2 V.N.A. vehicle operations of the single shift and only in the countries of low income. The proposed model could be used for evaluation and comparison of different cases in order to optimise processes.
5.2. Research limitations and future research recommendations

The optimisation of the V.N.A. warehouse costs requires an additional revision, as well as the investments (or rent costs) into the sorting space. The criteria used in research did not examine the storage strategies, size of warehouse and customers’ orders, S-shape and return routing and zone-picking strategies. Further research areas could extend the presented study in the following directions, such as evaluation of an automatic solution for a V.N.A. warehouse serving large markets and application of the model for different sectors.

Disclosure statement

The authors report no conflicts of interest.

References


Appendix: Suggested vehicle routing algorithm implementation for picking customer orders in the reference warehouse

Launch picking

- Pick list
  - Article info
    - GOODSID
    - From -> To
      - From, To -> v
    - r,b

- Pick info
  - From > Location
    - To > Container,
      - r,b,m

- De-assign batch
  - r,b

Main menu
- Or jump to next tasks list

- N:0
- vf 05.spt

Pick Nmax list
- By default r for pick list=1. Which Pick list to allocate r if?
  - Quantity of r
    - Pick list
      - NMax

- vf 07.spt

GOODSID->To container
- <Enter> Done
- Reason code or [Esc] Cancel

- Pick_done [s]
  - Count as lead
    - No

- Update pick list
  - set end date
    - le

Parameters:
- r: Vehicle id
- E: Person id
- v: pick
- b: pick/batch id
- k: Size of pick list (number of articles)
- NMax: article which has the maximum number of pick locations in pick list
- v: scan code
- s: volume (quantity in m3)
- GOODSID: Article assigned to location

f=0 -> click done = 1
f=1 -> click done = 2

WAIT