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Order-picking Methods and Technologies for Greener Warehousing

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Green supply chain management is a concept that is gaining popularity all over the world. Besides, it is a way to demonstrate commitment to sustainability and to be fully adopted by the organizations it should contribute to better economic performances and competitiveness. Recently there have been many incentives for more sustainable warehousing in supply chains. In order to improve efficiency of order-picking in warehouses, there are many methods, models and technologies developed and used. This paper presents, after a brief overview of green supply chain management, an overview of order-picking methods and technologies and their potentials in improving order-picking efficiency, based mainly on reducing traveling distances. In this way energy consumption is reduced, influencing also greening of warehousing too.

Metode i tehnologije komisioniranja za "zelenije" skladištenje

Izvornoznanstveni članak

"Zeleni" menadžment lanca opskrbe (Green supply chain management) je koncept koji dobija na popularnosti širom svijeta. Osim što je način demonstriranja posvećenosti održivosti, da bi bio u potpunosti prihvaćen od strane poduzeća nužno mora pridonijeti boljim ekonomskim pokazateljima i konkurentnosti. U posljednje vrijeme ima mnogo inicijativa za održivije skladištenje u opskrbnim lancima. S ciljem povećanja učinkovitosti komisioniranja u skladištima razvijene su i koriste se mnoge metode, modeli i tehnologije. U ovom radu se, nakon kratkog pregleda "zelenog" menadžmenta lanaca opskrbe, daje pregled metoda i tehnologija komisioniranja te njihovih potencijala u poboljšanju učinkovitosti, temeljenih uglavnom na skraćenju vožnje prilikom komisioniranja. Time se smanjuje potrošnja energije, te utječe i na "zelenije" skladištenje.

1. Introduction

Nowadays there is more and more ecological awareness among people and every day there are more people who think and act *green*. There are many ways how one can go *green*. For example, going *green* means buying products that are produced from recycled material, other people want to buy products that are more energy efficient or in their production use resources that are friendlier to the environment.

Apart from end consumers, *green* thinking emerged also in the various initiatives adopted by companies. There are three main reasons why companies implement the *greening* process into their businesses [1]. They have to comply with environmental regulations (*legislation*), address environmental concerns of their customers (*marketing*), and mitigate the environmental impact of their production activities (*ecological awareness*). The concept that encompasses environmental initiatives in all stages of supply chain is called *Green* Supply Chain Management (GSCM), defined in [2] as integrating environment thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to consumers, and end-of-life management of the product after its useful life. Despite GSCM evidently gaining popularity all over the world, the goal of every company is to make a profit. To be fully adopted by organizations, the *greening* of supply chains should contribute to better economic performances and competitiveness (*economy*). Therefore it is necessary to understand the elements and roots of the concept, with positive linkage between environmental impact and economical performances and competitiveness.

Green warehousing is definitely a part of the broader picture of green supply chain management, and lately many distribution centers and warehouses around the world are aiming green, "faced with a lot of tough choices between economy or eco-friendliness, discovering that much of good logistics engineering is not only compatible with greener business practices, it's actually synonymous with it." [3]

2. Green warehousing

2.1. Green warehousing as a segment of green SCM

Environmental awareness and ecology are not so new in industrial systems and supply chains. The term and field "Industrial ecology" is now almost 40 years old, concerned with tracking the flows and stocks of substance and material, especially those whose cycles are heavily influenced by industrial activities, as the basis for reducing the impact of the production process on the environment [4]. Comparing it with green supply chain management, we could conclude that Industrial ecology and green supply chain management are practically the same thing with a difference in scope. We can say that Industrial ecology is mainly a field of study and research for a cleaner manufacturing process while GSCM is a field of implementation of green thinking in all segments of companies' supply chain activities.

For the purpose of highlighting segments of GSCM as they often appear in literature as methods or approaches to sustainability in supply chains, one formal definition of Supply Chain Management (SCM) is used. According to an American professional association **(Council of Supply Chain Professionals)**, "supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies." Making SCM green is simply implementing environmental thinking into its activities. Focusing on the three basic groups of activities from the definition – sourcing and procurement, operations (conversion) and logistics activities, *green* supply chain management could be illustrated as in Figure 1.

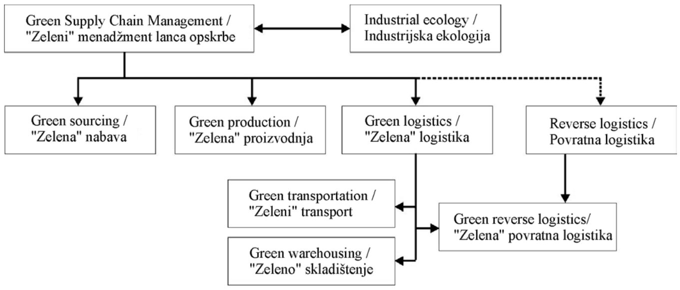


Figure 1. Segments of Green Supply Chain Management

Slika 1. Segmenti "zelenog" menadžmenta lanca opskrbe

2.2. Elements of green warehousing

Green warehousing is a relatively new approach which implements *greening* into warehouses and distribution centers. There are many elements that you can implement in a warehouse, but in short, each element which reduces energy consumptions or material usage/ waste is a *greening* element. Some elements which are frequently mentioned in literature and also used in practical examples are [5]:

- Implementation of paperless warehouse management system (WMS),
- Using an energy efficient lightening,
- Using doors with sensor which automatically close,
- Using wind turbines or/and solar energy,
- Using ventilators to push hot air from the top to the bottom of a warehouse,
- Using sensors for lightening so the light is turned on only in the passage/area where needed,
- Using building materials which are better insulator,
- Using equipment with less carbon emission and less energy consumption,
- Using returnable/recyclable containers and packaging materials,
- Forklift fleet improvements, etc.

There are many benefits to be derived simply by revamping the lighting in your facility. A shift to more current fluorescent lighting technologies could help reduce your light-related electricity requirements by as much as 70 %. Also you could reduce your consumption even further by placing motion sensors in key areas of your warehouse to trigger lights to turn on only when needed. [3]

You can use better insulation material for your roof and you will reduce energy losses. In addition you can put ventilators on top of warehouse which can push hot air to the ground. In this way, you can use hot air, which naturally would not be used.

There are now many new forklifts available on the market that could be used for forklift fleet improvement in terms of greening. There are plenty of new technologies for propane forklift fleet that allow the vehicles to burn cleaner and be more fuel-efficient. AC powered electric lift truck are more energy efficient then DC powered. Electric hybrid forklifts (like Komatsu "New ARION" series [6]) and forklifts powered by hydrogen fuel cells [7] are also great examples of using new forklift technologies available on the market, solving environmental concerns and providing better energy efficiency and/or operational performances.

Implementing Warehouse Management System in distribution center or warehouse could greatly reduce overall warehouse costs, which is achieved mainly by optimizing various activities. Optimizing activities performed with transportation equipments could have significant impact on reducing energy consumption and CO_2 emission. Paperless WMS, providing even higher possibilities for more efficient operations, reduces also paper consumption thus giving even more green image to warehouses.

Of course, not all *green* initiatives focus on reducing energy consumption. Some are focused on creating energy from what is already readily available — sun and wind. For example, many newly constructed DCs are increasing their use of skylights and windows so they can use natural light in many parts of their facility. And those that are especially visionary are placing solar panels on portions of their roofs, an ideal scenario since warehouses are so flat. [2]

3. Order-picking efficiency for greener warehousing

3.1 Basic characteristics of order-picking process

It is well known that logistic costs have an important influence on the final success of any company. According to the Logistics Cost and Service 2007 study [8], in western countries, these costs represent almost 10 % of sales. Warehousing, along with transportation and inventory carrying, is one of the three major drivers of total logistics cost, with 21 % in US and 37 % in EU. Order-picking process, defined as the process of retrieving items from storage locations in response to a specific customer request, is the most laborious and the most costly activity in a typical warehouse, with up to 55 % of warehouse total operating costs [9]. With a direct link with speed of delivery, it also influences the service level. Therefore, it is very important to put some effort into reducing order-picking costs and cycle time, *i.e.*, to improve order-picking efficiency.

It is possible to improve operational efficiency of order-picking using appropriate operating policies. The research in this area has grown rapidly recently and considerable literature exists on various methods of picking an order as efficiently as possible [10]. The time to pick an order can be divided into three components: time for traveling between items, time for picking the items and time for remaining activities. The fact that about 50 % of total order-picking time is spent on travelling [9] gives a potential to improve order-picking efficiency by reducing travelling distances. Most methods of improving operational efficiency of order-picking focuses on reducing travel times, and can be categorized into one of three groups of operating policies: routing, storage and batching [11].

Analysis of those methods showed non negligible influence of layouts on performances of particular method or mix of methods. Additionally to various traditional layouts of order-picking systems, some radically new, innovative warehouse layouts that could reduce retrieval times in pallet picking were proposed [12].

There are also technology achievements that significally aid the order-picking process. Using WMS with RF handheld terminals, voice technology terminals or pick-to-light system enable further improvements in efficiency – raising productivity by reducing search time and travel time, while greatly improving accuracy.

The overview of order-picking methods and technologies given further aims to present the possibilities and potentials in reducing routes for order-pickers, simultaneously implementing greening process into warehouses. The influence of reduced traveling distances for order-picking in warehouses on green level depends naturally on type of forklifts used, and could be expressed in saved energy or reduced CO_2 emission.

3.2. Order-picking methods

As already mentioned, several order-picking methods could be used with the goal of reducing travel time. Routing methods determine the sequences and routes of traveling, trying to minimize total travel distances. Storage methods, assigning items to storage locations based on some rule, could also reduce travel distances compared to random assignment. Order batching methods, grouping two or more customer orders in one picking order, are also very efficient in reducing total travel distances. All methods mentioned are well known and proven in improving order-picking efficiency. However, the performances depend greatly on the layout and size of the warehouse, the size and characteristics of orders and the order-picker capacity. Additionally, the performance of a particular method depends also on the other methods used, therefore it is important to understand their mutual interactions [13].

3.2.1. Routing methods

There are several routing methods (policies) developed and used in practice. They range from the very simple to the slightly more complex. The performance of these heuristics depends on the particular operating conditions of the system under study due to their definitions. The simplest routing heuristic is *S-shape* policy. When this policy is used, the order picker enters every aisle where an item has to be picked and traverses the entire aisle. Aisles where nothing has to be picked are skipped. An exception is made for the last aisle visited in case the number of aisles to be visited is odd. In that case a return travel is performed in the last aisle visited. Another very simple routing heuristic is *Return* policy. The order-picker enters and leaves aisles containing item(s) to be picked from the front aisle. A *Midpoint* routing policy, also one simple heuristic, looks like a return method on two halves of a warehouse. Only the first and last aisle visited are traversed entirely. Similarly to the last heuristic, with *Largest Gap* policy all aisles that contain even one item to be picked are also left at the same side as they were entered, except the first and last visited which are traversed entirely. The gap represents the separation between any two adjacent picks, between the first pick in the aisle and front aisle, or between the last pick in the aisle and the back aisle. If the largest gap is between two adjacent picks, the picker performs a return route from both ends of the aisle. Otherwise, a return route from either the front or back aisle is used. The largest gap is therefore the portion of the aisle that the order picker does not traverse. This policy is a slightly more complex routing heuristic than the first three mentioned. The resulting route is somehow similar, but definitely at least equal or better than the route defined by Midpoint policy in all possible situations. Two relatively new policies developed are *Composite* policy and *Combined* policy. Composite routing heuristic combines features of the S-shape and Return heuristics, minimizing travel distance between the farthest picks in two adjacent aisles for each aisle individually. Combined heuristics is also a combination of S-shape and Return policies, but a small component of dynamic programming gives it the possibility to look one aisle ahead. The decision about return or traversal route in the aisle depends not only on minimized travel in that aisle, but also on a better starting point for the next aisle. This in turn leads to a better overall result than Composite heuristic. All routing policies described above by their definitions have some restrictions of creating a route. An optimal algorithm [14], combining a graph theory and dynamic programming, results in a shortest possible, thus optimal route. Examples of routes created by mentioned routing heuristics and an optimal algorithm are given in Figure 2.

According to one case study [15], with routing order-pickers efficiently using routing methods it is possible to obtain a reduction between 17 and 34 % in traveling distance. The amount of reduction depends on the particular method used. Although algorithm for an optimal route has been invented, in practice heuristics are predominantly used to route the fork lift trucks [10].

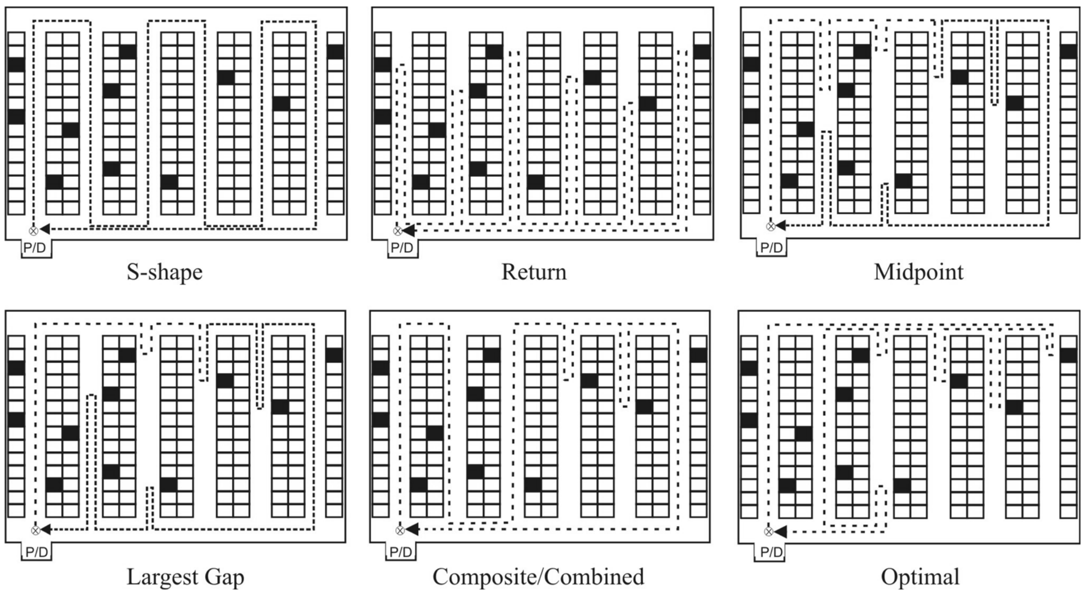


Figure 2. Examples of routes by routing heuristics and optimal algorithm

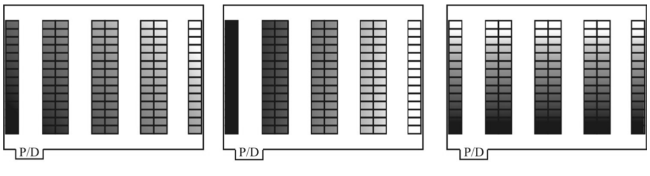
Slika 2. Primjeri ruta heuristikama usmjeravanja i optimalnim algoritmom

The reason for that is that heuristic policies may provide near optimal solutions and avoid the confusion inherent in optimal solutions. It is true that a specific heuristic policy could in some situations results in near optimal route, but in some other situations it could perform badly. Therefore, it is important to know in what situations some heuristics are good or bad. Even more, which are better than another and how much better in particular situations. A more detailed overview of routing methods and analysis of performances are given in [16-17].

3.2.2. Storage methods

Storage methods assign items to warehouse storage locations, based on popularity, demand, size, hazard etc. In order-picking systems, storage methods are usually based on rule of assigning the frequently accessed items to the locations near depot [18]. Volume-based storage policy assigns items to storage locations based on the expected order or picking volume [19], while *Cube-per-order index* (COI) based storage policy assign items to the locations based on the ratio of the item's required storage space to the item's order frequency. The items with the lowest COI are stored in the locations nearest to the depot. In case items are stored in any available location (randomized rule), such a method is called random storage or floating slot storage.

There are several different types (patterns) of storage used in practice, most relevant for order-picking shown in Figure 3. Items with a higher volume (or smaller COI) are stored in darker locations. They are all proven in reducing the total travel distances in order-picking compared to random storage assignment, but the performance of a particular storage type greatly depends on the routing method implemented. The question is which type of storage suits the best particular routing method.



a) diagonal type b) within aisle type c) along front aisle type

Figure 3. The types of volume-based storage

Slika 3. Tipovi odlaganja prema protoku

More details of the evaluation of storage methods and analysis of performances of routing methods in combination with different types of storage are given in [17, 20-21]. The result of analysis showed that large savings are possible using storage methods, with even in some cases 45-55 % of travel distance reduction compared to random storage.

3.2.3. Order-batching methods

Methods of organization of order-picking, called also pick strategies, determine how orders are picked in warehouses. Most basic method is *single order-picking*. Pickers pick one customer order at a time (in one route). This method can work well in operations with a small total number of orders and a high number of picks per order. Operations with low picks per order will find the travel time excessive. In *batch picking*, multiple customer orders are grouped into batches – picking orders. Therefore, the items from several customer orders are picked in one route, which generally reduces the travel distances per order.

There are several orderbatching methods (algorithms) developed and used in practice, which could be divided into three main groups: simple, seed and savings algorithms. *First-Come First-Serve* (FCFS) is the most obvious of the simple orderbatching algorithms. This algorithm adds orders to a group in the sequence they arrive. If the picker is full (capacity reached), a new group is started. Seed algorithms consist of two steps. First, the initial order is selected based on some seed selection rule. Second, the remaining orders are added to a group based on some seed order addition rule, up to the picker's capacity. Savings algorithms, variants of Clarke and Wright routing algorithm, are based on travel savings that can be obtained by combining two particular orders in one route as compared to the situation where both orders are collected individually. For an overview of many different seed and savings algorithms readers are referred to [22], while for analysis of various order-batching algorithms in combination with different routing methods and storage methods to [13, 23]. The results showed that the potential savings using orderbatching in comparison with single order-picking (picking by order) depend mostly on the number of customer orders per group, and ranged from cca. 40 to 70 % in conducted simulations. The analysis of orderbatching algorithms with volume-based storage showed that savings are cumulative, with potential savings in travel distances up to 80 % compared to random storage and single order-picking.

3.2.4. Warehouse layouts

Traditional warehouse/order-picking area layouts are layouts we could find today in the majority of warehouses. The basic form is with parallel aisles, a central depot (pick up/delivery point), and two possibilities for changing aisles, at the front and rear of warehouse, shown in Figure 4 left. Modifications of this basic form are usually with adding one or more additional cross aisles. In this case we refer to a layout with multiple cross-aisles. The layout with one middle cross aisle is shown in Figure 4 right.

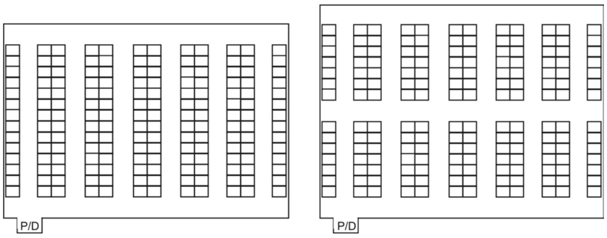


Figure 4. Basic traditional layout (left) and traditional layout with one (middle) cross aisle (right)

Slika 4. Osnovni tradicionalni prostorni raspored (lijevo) i tradicionalni prostorni raspored s jednim (središnjim) poprečnim prolazom (desno)

As already stated, evaluation of routing policies showed that layouts of order-picking area have significant influence on resulting traveling distances. For a given storage capacity, one can find optimal layout regarding number and length of aisles [11]. Results of previous researches showed also that adding one or more cross aisles could benefit the total traveling distances, and that it is also possible to find an optimal number of cross aisles [24]. Although please note that adding additional cross aisles increases required storage area (and therefore related costs).

The traditional design of warehouse layout is based on a number of unspoken, and unnecessary, assumptions. The two most restrictive are that cross aisles are straight and must meet picking aisles only at right angles, and that picking aisles are straight and are oriented in the same direction. In Gue and Meller [12] the authors show that those design assumptions, neither of which is necessary from a construction point of view, limit efficiency and productivity because they require workers to travel longer distances and less-direct routes to retrieve products from racks and deliver them to designated pickup-and-deposit points. In layout that maintains parallel picking aisles, but allows the cross aisle to take different shape, the expected distance to retrieve a single pallet is 8-12 % less than in an equivalent traditional design, depending on the dimensions of the warehouse. They named such layout Flying-V layout. Relaxing a second assumption that picking aisles must be parallel, they derived so called fishbone layout. The fishbone layout also incorporates the V-shaped cross aisles, with the V extending across the entire warehouse. The picking aisles below the V are horizontal, while the aisles above the V are vertical. The expected travel distance in a fishbone design can be more then 20 % less than in a traditional warehouse. Similarly to traditional layouts with cross aisles, these alternative layouts also require a facility 3-5 % larger than the basic traditional layout, which was designed to minimize the footprint of a warehouse.

Despite the great potential of new innovative unit-load warehouse designs in reducing traveling distance in pallet picking (single command), the question is what would be the distances of routes for case and item picking from multiple locations in such layouts (multiple command), compared to the traditional layouts. To address this question, an analysis was done in [25] with the simplest and commonly used in practice S-shape routing method, and also extended for this paper with more complex Composite routing method. Figure 5 illustrates one example of a routing using S-shape method modified to be adapted for analyzed fishbone layout.

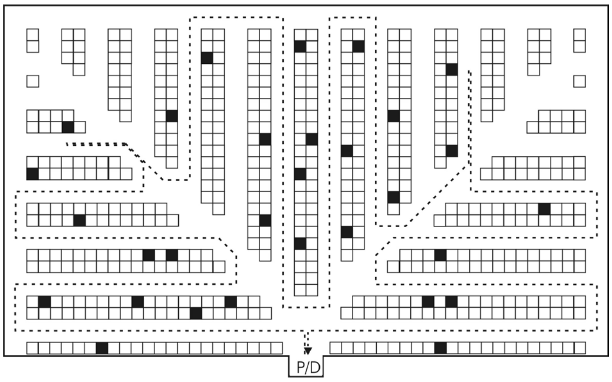


Figure 5. Example of picking route in examined fishbone layout

Slika 5. Primjer rute komisioniranja u analiziranom prostornom rasporedu "riblja kost"

The simulation was conducted on tree warehouse layouts with 576 locations per layer: basic traditional, traditional with one (middle) cross-aisle and fishbone. Due to the simplicity of distance calculation, dimension of a location is 1x1 meter and the width of all aisles is 2 meters. The traditional layout was with 12 main aisles (total width across aisles 48 meters) and the length of main aisles 24 meters (24 locations per row). With the location of a depot in the middle, it is the optimal layout for single command picking. Comparable fishbone design is shown in Figure 5. Order size was set to 10 picks per travel and 30 picks per travel. The simulation results showing average distance travel of picker is shown in Table 1.

Table 1. Simulation results of average travel distance (in meters)

Tablica 1. Rezultati simulacija za prosječne duljine puteva (u metrima)

S – shape routing method / S-oblik metoda		**Order size / Veličina narudžbe**		***Composite routing method / Kompozitna metoda usmjeravanja***		**Order size / Veličina narudžbe**	
		10	30			10	30
Warehouse layout / Prostorni raspored skladišta	Traditional (basic) / Tradicionalni (osnovni)	**258,7**	**375,8**	**Warehouse layout / Prostorni raspored skladišta**	Traditional (basic) / Tradicionalni (osnovni)	**228,2**	**363,9**
	Traditional (one cross-aisle) / Tradicionalni (jedan prprečni prolaz)	**193,9**	**329**		Traditional (one cross-aisle) / Tradicionalni (jedan prprečni prolaz)	**182,8**	**309**
	Fishbone / Riblja kost	**227,5**	**351,9**		Fishbone / Riblja kost	**213,1**	**317,3**

The simulation results show that the traditional layout (without cross-aisles) produces the largest travel distances. The fishbone layout will give less travel distance (around 9.5 % in conducted simulations, depending on routing method and order size), while the traditional layout with one cross-aisle is going to shorten the travel even more (around 18 % less travel time than a traditional layout without cross-aisles in conducted simulations).

The fishbone layout is without any doubt an excellent layout for pallet picking, already implemented in real warehouses. However, the presented analysis leads to the conclusion that in a warehouse with case and item picking from multiple locations the fishbone layout results in larger routes than the traditional layout with a straight, right angled cross aisle. Finding the optimal number or cross aisles in a traditional layout would probably result in an even shorter route. According to [24], the addition of an optimal number of cross aisles generally decreases the picking travel distance by 20-30 % of associated route in layout with no cross aisles.

3.3. Technologies for order-picking

The technology that is obviously necessary to be able to implement mentioned methods is information system in warehouse, apropos Warehouse Management System (WMS) with built-in algorithms for routing, storage and orderbatching. Although we mentioned paperless WMS as an element of greening warehousing, paper-based WMS would be satisfactory. One could imply that paperless WMS encourages greening of warehousing mainly by reducing paper usage in warehouses. However, technologies enabling paperless WMS have also additional capability of greening through increased efficiency, explained hereafter. The 3 technologies that are used in order-picking systems inherent with paper-less directing order-pickers are *RF scanning*, *Voice Technology* and *Pick to light* systems. RF scanning and Voice systems link to the WMS via a Radio Frequency network. RF scanning is based on barcode scanning, thus every picker has a bar code reader. Voice technology pickers have a small, portable computer and a head-set with a microphone through which a picker communicates with the WMS. Pick-to-light technology has a light signaling system on every single location and also an interface port where a picker updates his picks. All three systems can offer increased speed and accuracy compared to paper-based WMS, but choice depends on the nature of the business and products being handled [26]. Increased speed directly improves productivity. For instance, RF scanning orders are issued at the terminal, eliminating the need to physically take the pick-list, while improved accuracy will reduce the number of returns in order to correct picking errors. Voice Technology provides significant benefits over RF scanning because it is "hands- and eyes-free". Voice operators visually focus on assigned tasks, so errors due to keying in RF hand held terminal are eliminated. RF scanning device limits freedom of hands and makes picking heavy and awkward items more difficult, thus slowing down picking. Pick to Light can provide even better productivity than Voice, because a picker can see simultaneously all the items to be picked, rather than being given sequential instructions. However, please note that those systems are more likely used for picking small fast-moving items from a relatively small area, while RF scanning and Voice are more suitable for case picking. Figure 6 shows the characteristics of those three technologies in terms of accuracy and productivity gains over paper-based picking (data from [26]), which are also interesting from the "*greening* your warehouse" point of view.

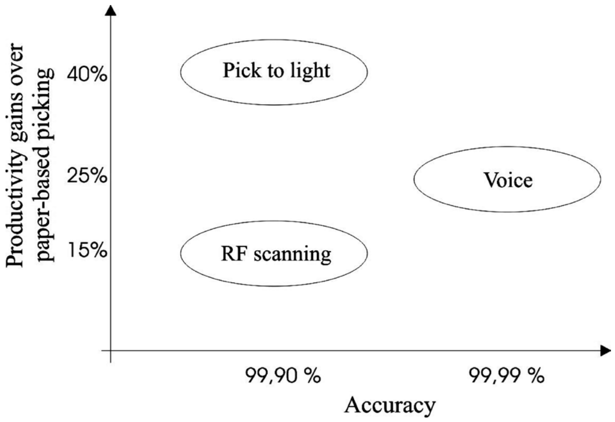


Figure 6. Comparison of order-picking technologies
Slika 6. Usporedba tehnologija za komisioniranje

4. Conclusion

Making warehouses more green definitely is worth the effort from an ecological point of view. But for warehouse managers and company owners, it can not be viewed without implications for operational and economic performances as well competitiveness. In this paper we showed that improving efficiency of order-picking process in warehouses using operational methods and advanced technologies is not in confrontation with greening. Moreover, since gains in productivity are mostly achieved by reduction of travelling distances, the implications on saved energy for order-picker trucks could be trendmenous. Large savings are possible by setting a suitable routing method, storing and picking strategy, choosing the right picking technology and most suitable layout, all together making warehouse work more efficient and greener at the same time.

Although the *greening* process is a relatively modern philosophy, example of order-picking methods and technologies showed that well-known techniques of improving business processes could be in compliance with greening. There are many similar examples, which are probably the reason why *green* is becoming more popular every day.

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