Smart Trolley Apps: A Solution to Reduce Picking Error

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***Abstract*— An order picking activities refers to an act of retrieving any items from the storage locations in the warehouses. In common situation, these activities is often performed by human. Due to that condition, high human error and high cost impact were spotted on a manual order picking activities. Thus, previous studies have developed various methods to support the practitioners especially in creating a more efficient order picking process. In spite of the vast discussion and evidence that shows an order pickers tend to deviate from its optimal routes and putting the efficiency of these routing approaches at stake, very little discussion were focus on the implementation of smart application through IT usage and device to reduce the problem faced in the warehouse. Thus, it is the main intention of this this paper to presents a detailed analysis on the relative factors affecting the efficiency of order picking activities in the warehouse and suggest the smart trolley as a solution to overcome the problem. The smart trolley apps is then proposed to increase the picking process in warehouse. The results of this paper indicate that extensive use of smart trolley apps as a solution to a more effective ways of order picking.**

***Keywords*—** *Order Picking, Warehouse, Smart Trolley, Lead time, Reduce Error*

1. Introduction

Due to current rise of new trade model through e-commerce activities, it is agreed that one of the important role in recent logistics has radically changed [1]. Due to the current nature of todays logistics scenario, where almost all customers increasingly request to purchase and order at any time of the day and wanting to delivered at a time convenient to them, there is an urgent need to review and revamp the current method of delivery especially to shorten the process [2]. The most crucial point of warehouse activities is not only storing and delivering goods but a proper system to maintain the overall inventory is now becoming crucial. This is further supported by [3] who had indicated that in today scenario where customer are legally allowed to cancel the order even after they place it, create a huge challenge in the logistics industry. Failure to handle the issue might resulted in wrongly product being delivered. Hence an efficient warehouse managing systems through IT integration must be capable of dealing with an increasing number of disturbances.

Among all the important activities in the warehouse, the order picking process were spotted as the most laborious and time wasting [4]. As a consequence, there is an urgent need to look at how time could be reduce during the process. Although many study agree that reducing the labour intensive during the picking process is important in improving the operational efficiency[5] but lack of study did mention on the smart trolley as a solution to order picking process in the warehouse. Where as, it is well noted that in a new business environment, changes of the operation method is much needed.

It is being reported by [6] that many leading production philosophies are now using smaller batch sizes, and start to focus on producing a customs products. Some had also focus on reducing the cycle times. This was then supported by [7] who then sum up that, this new changing business environment has brought in a mass product mix in the market, thus the time taken in warehouse should be shorten to fulfil the fast changing customer demand through order picking. It is also agreed by [8] that the changing of order behaviour can be ascribed to upcoming e-commerce markets, thus they reported that the situation had forces warehouses to handle a larger

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number of orders, while the time available for order picking has shortened.

2. Issues of investigation

A study done by [9] had conducted an in-depth investigation between a conventional and interventionist order picking strategies being implemented. They had summarize the process as being depicted in Figure 1. However, their analysis still did not focus on the implementation of the technology such as smart trolley as one of the ways to solve the picking problem in the warehouse. This has created a gap where this study try to fulfil.

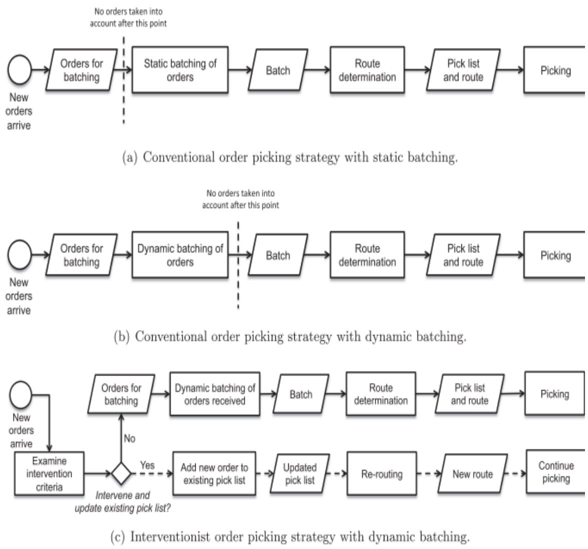

Figure 1. Comparison between picking strategies in warehouse. Source: [9]

It was also found that in early 2009, a group of logistics researcher had reported on the system used in the warehouse to enhance the efficiency of the warehouse.

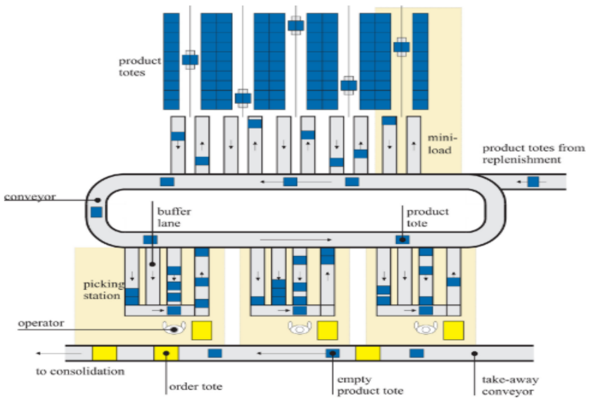

Figure 2. Automated order-picking system workstations. Source: [10]

They focus their discussion on an automated order picking which depend on the remote manual workstation [11] (see Figure 2). However, their study just focus on the storage area (also called automatic storage/retrieval system (AS/RS)), a closed- loop conveyor and order-picking workstations. None of the discussion were made on the use of smart trolley application as a solution to reduce picking errors in warehouse. Thus, this had created another gap for the study.

Recent study by [12] had also focus on the details discussion on order picking operation and tactical strategy that should be consider by all logistician handling goods in the warehouse. The discussion can be summarized in the following Table 1.

Table 1. Investigated of order picking planning problem.

	Zone location	Zone assignment	Storage location assignment	Workforce level	Workforce allocation	Job assignment	Batching	Zone picking	Routing	Order cons. & sorting
Zone location		-	1	-	1	-	2	-	-	-
Zone assignment			1	-	-	-	-	-	-	-
Storage location assignment				2	2	1	**15**	1	**24**	2
Workforce level					1	3	**6**	-	**4**	2
Workforce allocation						-	2	-	-	1
Job assignment							**9**	**5**	**6**	1
Batching								2	**27**	**4**
Zone picking									1	-
Routing										-
Order cons. & sorting										

From the investigated variables of warehouse activities, none of the discussion were focus on the usage of information technology as a solution to the order picking problem faced. Thus it is the intention of the study to suggest the possible solution to overcome the most costly and labour intensive spot that occur in the warehouse especially on the order picking activity. This in turn will result in a higher satisfaction of the customer.

3. Concept of Smart Trolley

Smart trolley application is an equipment proposed used for material pick up and put away designed based on the robotic technology. It is believed that with the adoption of smart trolley, it will contribute to a 300 percent improvement in a picking efficiency while at the same time fully utilise the floor space in the warehouse [13]. The utilisation of smart trolley will allow automatic orders assigned to print pick lists and packing slips that match with the customer demand. It consists of a touch screen, a bar code system, radio-frequency identification

(RFID) system , a bag module, a trolley module and other optional systems that designed to minimize human error and improve multiple orders tasks efficiency. The system are able to handle complex order and urgent order and cancellation from the customer. High usage of smart trolley in order picking may speed up the warehouse picking route without required the picker to waste time in finding the material at the desired shelves. Additionally, smart trolley leads to minimize the human error [14]. Thus, with the application of the smart trolley, it will improves efficiency, speed, transparency and creates more convenience for an order picking process in the warehouse.

Smart trolley has been programme with an important security measure to monitor and predetermine the item to be picked. It has been programme to detect any discrepancy or dishonest picking activity. Additionally, smart trolley also will automatically map the list of item and directed the picker to the intended item location. This will eventually improve picking efficiency, speed and more transparent in picking activity [15].

4. Order Picking Efficiency

A recent study by [16], had investigated on the three different compact storage systems to improved the effectiveness of the order picking activities in the warehouse. This include, puzzle-based storage, the live-cube system, or 3D ASRS (automated storage and retrieval system). One of the main discussion were made on the mobile rack system (see Figure 3)

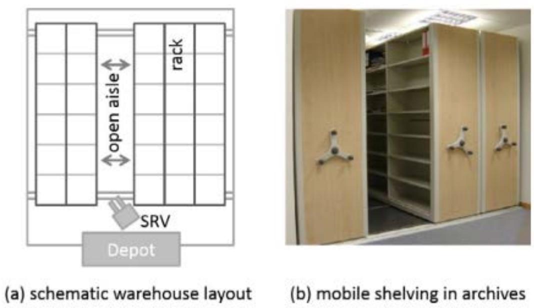

Figure 3. Mobile Rack System. Source: [16]

Among major discussion made on the current mobile racks is that the parallel racks are normally densely packed and mounted on rails. This is design in such so that the adjacent racks need to be moved aside to access a specific aisle. In the most dense form, the total width of all racks is only slightly shorter than the rail tracks. But one of the major drawbacks of the system is that it can only moved and open a single aisle at one time. Thus, this will increase picking time. Moreover, lack of the information technology integration with the current rack will results in errors and time consuming in the warehouse.

4.1 Picking Error Reduction through Smart Trolley Application in Warehouse.

It is widely agree that with the adoption of information technology application in the warehouse activities especially on order picking, will contributes to a numerous of benefits. This include superior picking efficiency, cost reduction, faster order fulfilment and provide real time information [17]. Thus the adoption of smart trolley apps, may reduce the picking error in various check points. Picking error preoccupy time needed to complete customer order. Due to inaccurate picking, it will also affect the imprecise quality control point. Undetected errors can have serious consequences especially to the company performance and customer negative perception. Hence, smart trolley will overcome all the unnecessary error. The next section will draw in details the dominance factors resulted from the smart trolley adoption.

4.1.1 Current Software Usage in Warehouse for Order Picking

According to [17] the most prominent picking error occur in the warehouse is wrong picking items, shortage or excess of items and casualty items being picked due to mass order that need to fulfill within a short time period. Thus, as note by [18] an integration of information techmology in order picking activities helps to improve picking performance and it is imperative to address the human needs so that the errors can be minimised.

Another study by [19] had stated that an automation for order picking processes in warehouses is only deployed to a limited extent – where large and long ranging investments are necessary. Moreover, he agreed that dynamic market demand requires more and more systems flexibility, and the products characteristics like size or weight may change significantly over time. Thus he mention that, for that reason, manual order picking will still represent the majority of order picking in the warehouse. He also sum up that over 80% of all order-picking systems in Western Europe belong to the type of low-level, picker-to-parts order-picking systems which employ only humans.

[19] also highlighted that the current software systems that are used to support the warehousing processes are known as Inventory Control Systems. However, he did mention that major decision problems in design and control of order picking processes concern optimal layout design, storage assignment, zoning, order batching, routing and order accumulation and sorting are main problem that needs further attention in order to successfully implement the system in the warehouse. Nevertheless, none of the discussion were made on the usage of smart trolley as an innovative solution to solve the pressing issues in the warehouse.

4.1.2 Lead Time Improvement

The shorter the time taken for the picker to fill the order, the better the lead time of the logistics operations as a whole. Lead time acts as a competitive advantage for any firms. A better lead time management will result in a win-win situation that benefit the firms as well as the suppliers and consumers. Manual picker capability is very limited due to so many reasons. Thus, there is a need to integrate the use of technology in order to makes a complex and ordinary task become effortless.

With the emergence of the e commerce industry and practice together with the tight delivery schedules that came along with next- or even same-day deliveries promised to the customers, had increase the stress on order fulfilment processes [20]. Failure to integrate and adopt certain technology will result in decrease on the efficiency in warehouse operation.

A study conducted by [21] on the solution to reduce the lead time in order picking is through the implementation of the highly automated system. These solutions reach from highly-automated systems like A-Frames or KIVA systems. This two system then proposed a schematic layout to kick off with the implementation in the warehouse. This can be seen in Figure 4.

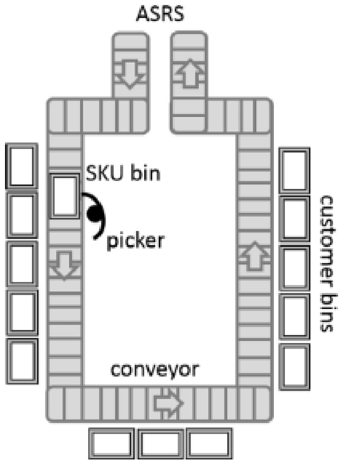

Figure 4. Schematic layout. Source: [21]

Even with the implementation of the software in the warehouse, they still reported that, most of the activities in the schematic layout propose in Figure 4 were still manually executed.

Another study done by [22] had also focus on the lead time improvement in the warehouse activity especially for order picking. They suggest that the flow directions of conveyors are arranged in a way so that totes can traverse from one zone to another. This conveyor network allows totes to travel from one zone to another zone directly with- out having to visit any other unnecessary zones in between. They believed that by doing so the total lead time could be improved (see Figure 5)

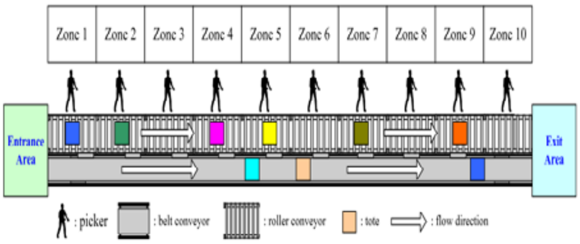

Figure 5. Sequential Zone Picking Line. Source: [22]

Much of their discussion were focusing on the layout of the warehouse to reduce the lead time. None of the discussion were made on the implementation of the special apps to reduce the lead time in order picking activities.

A study by [23] list a few reasons why technology integration has become so dominant. These include, certain apps and software development to allows pickers to perform multiple orders in a very short period of time with greater efficiency and speed. It is believed that with the implementation of the smart trolley in warehouse, it will allows a quick and easy way to perform an order picking activities. According to a survey of wireless indoor tracking systems, researchers have developed various applications using Wi-Fi to increase the efficiency of the warehouse management [24].

With the integration of information technology and its application adoption in the logistics industry, it had solved few existing issues, especially on the order fulfilment and payment element.

5. Proposed Solution

From the review of literature we found while there are similar systems in operation, the majority of these are Infrastructure-based solutions. These require the deployment of additional specialized equipment, which may consist of proprietary transmitters, beacons, antennas and additional cabling in order to provide the signals needed for the location estimation. The additional infrastructure such as the use of beacons also means higher implementation costs [25].

This is why our solution takes the infrastructure-free approach to location services. This approach obtains location-dependent measurements from pre-existing wireless communication infrastructure including Wi-Fi access points and cellular base stations [26]. Some even utilize sensory data from the on-board *Inertial Measurement Units (IMU)*, which includes accelerometers, gyroscopes and digital compasses [27].

5.1 Picking Assistance App

To provide a cost-effective solution to improve order-picking efficiency we propose a mobile-based application (hereafter mentioned as the app) aptly named Efficient Intelligent Picking Assistant (EIPA). This app can be installed on any mobile device running the Android operating system. EIPA makes use of Internet-based Indoor Navigation (IIN) services technology. IIN services utilizes geolocation databases which store indoor models consisting of floor-maps and points-of-interest with the help of wireless, light and magnetic signals to pinpoint user location [28].

The current state-of-the-art IIN implementation is provided in the form of the freely available Anyplace IIN Service has been tested for use in inside-building and inter-building navigation assistance software [29]. Anyplace is a free and open indoor information service that offers GPS-less indoor localization, navigation and search that can be enable on any mobile device such as smartphones. Moreover, the availability of the Anyplace API under the MIT Open Source License provided opportunities for customisation of the service such as the one we are implementing for EIPA. One of the main features of the Anyplace system is the use of points-of-interest or POI for indoor navigation. It also has other advance features such as crowdsourcing that could provide incremental improvements over time. Figure 6 shows the Anyplace indoor information service architecture.

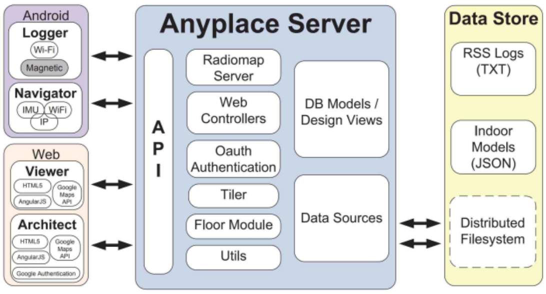

Figure 6. Anyplace Architecture. Source: [29]

5.2 Implementation Framework

Our proposed solution is to enable a traditional or non-smart to transform into a smart trolley only by using a mobile device such as a smart phone or tablet. Using non-specialized off-the-shelf technology will lower the costs of deployment. This will ensure wider adoption across many types of stakeholders ranging from consumers to small and medium enterprise. We do not target the larger organisations due to the fact that they would most likely have a dedicated system in place therefor having less need for our add-on solution. Any organisation or any individual with a mobile device can take advantage of the app, transforming a normal day-to-day device such a shopping basket, cart or trolley into a smart trolley (see Figure 7).

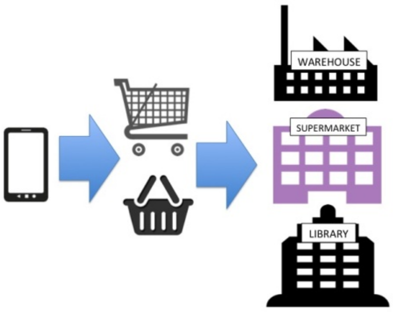

Figure 7. Possible Applications of EIPA

Picking is not only limited to order picking in a warehouse. Shopping for groceries with a shopping list also symbolises a picking activity. This is also true for picking a list of books to borrow from the library. All these activities can make use of the app to provide a more efficient, convenient, accurate and error-free picking experience. The app hopes to transform the dumb-trolleys used for order picking and shopping into smart trolleys that will help the picker and shopper in completing their tasks in a more intelligent manner. It also is meant to be able to help with other activities that does not use trolleys such as book picking in the library (as shown in Figure 7)

5.2 Floor Mapping

In order to effectively provide location information, the app requires importing existing metadata from each site before it can be used for that particular site. The required metadata includes layout of the shop floor (a image/map of the shop floor), which provide data on the layout of the area and inventory information that designates the items being stored and their location on the shop floor (inventory item and location mapping list). Using this information, the app will map the item location to its real location on the map of the shop floor.

Each item is mapped as a POI representing its location on the shop floor (see example in Figure 8). When the app reads through a picking list or shopping list, it will match each item on the list to an item in the inventory and guide the user to the POI where that item is located. The user then follows the navigation direction to the exact item location without wasting valuable time manually searching through each isle or row of the shop floor. This helps to reduce time to locate as well as energy to locate thus improving the efficiency of the shopping or picking activity.

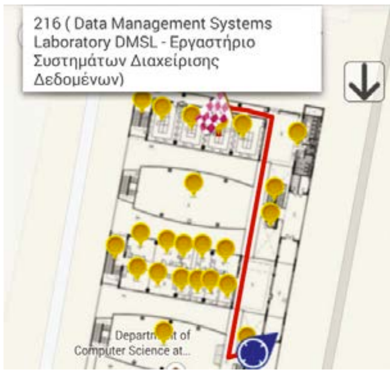

Figure 8. An example of using POI for indoor location tracking at Data Management Systems Laboratory, University of Cyprus (yellow markers represent a unique location within the building). Source: [29]

5.3 List Integration

Transforming a mobile device into a smart trolley assistant requires the ability to process picking orders or shopping lists. The app is designed with the ability to import shopping list from various sources. The main input will be in text format (as shown in Figure 9) where each line in the list represents an item to be picked or shopped. As the user goes through the list by following the direction provided by the app to an item location and then confirming item has been picked, the list will cross out the picked items and proceed to the next until all the items in the list has been picked.

The pervasiveness of mobile devices and the advent of personal digital assistance (PDAs) such as Alexa, Cortana and Google Home can also be catered to as users use these devices to create, edit and manage various lists. Currently only Alexa is known to be capable of exporting shopping lists through email. This list can then be used as input for the app to assist the user with the navigation while completing their shopping activity (see Figure 9). When the list export feature becomes available for Cortana and Google, their lists may also serve as input for the app.

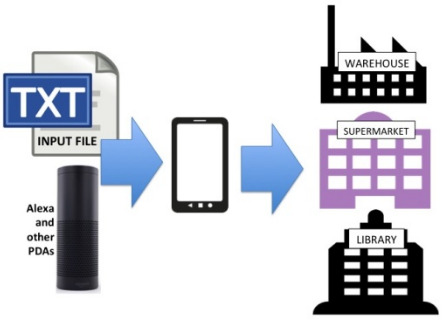

Figure 9. List Integration

5.4 *The Complete System*

Essentially in order for the app to be applied to the potential scenarios shown in Figure 10, the floor mapping and list integration needs to be implemented to make deployment of the app a success. Turning a normal container or trolley into a smart trolley first involves the digitisation of the floor plan or map, importing the inventory from either an input file or a database and importing the picking list or shopping list. Once the EIPA app on the mobile device has been configured with the data, it can be used in with a container for example a trolley (see Figure 10).

Figure 10. EIPA in Action

Using this combination, the users of the app can proceed with the picking activity guided by the software location and information service. The app will inform the user which item is next on the pick list then provides a navigation path for the user to follow to locate the item in at the particular place or location. Once user arrives, picks the item and updates the system, it will make changes to the original picking list by removing the item already collected. When the app reads the input list this time, the item already picked with no longer appear. This cycle continues until the picking list is empty and the app will advice the mobile device user that picking is complete.

6. Conclusion

The current advancements in technology and gadgetry facilitates in the realization of indoor location services, thanks to the presence of sensor-rich mobile devices in indoor environments. Mobile devices can be used to gather data from various signal types including wireless, magnetic, sound and light. In doing so they can measure these signal relative to known locations in space through cell-towers, Wi-Fi *Access Points (APs)* [30] or beacons technology [25]. These signals could then be complied and organized into big-data geolocation databases. This can be accomplished by fusing the signals to provide accurate location either at room-level (less than 5 meters) or in some cases less than a meter. A version of the Anyplace IIN was presented at the 14th International Conference on Information Processing in Sensor Networks and was able to achieve a localization accuracy of 1.96 meters [31].

The research by [29] found combining indoor signals with detailed indoor context data, such as Points-Of-Interest (POI) helps is part of the main concept of an Internet-based Indoor Navigation (IIN) service. As such, usage of POIs to provide item location for picking helps to extend the usefulness of a normal IIN with a value-added service that could potentially reduce or solve the numerous problems we found during the survey of literature. It is hope that EIPA will reduce picking lead-time, eliminate or reduce picking errors and provide convenience and ease of use for the users.
For future work, we will be extending this research to measure the effectiveness and user acceptance of the EIPA app. This will help us to understand whether the implementation is able to solve or meet the objectives originally outline for it.

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References

[1] McFarlane, D., Giannikas, V., Lu, W, "*Intelligent logistics: involving the customer"*, Comput. Ind., Vol. 81, pp. 105–115, 2016.

[2] Zhang, J., Wang, X., Huang, K., "*Integrated on-line scheduling of order batching and delivery under B2C e-commerce"*, Comput. Ind. Eng., Vol. 94, pp. 280–289, 2016.

[3] Gong, Y., de Koster, R.B.M., "*A review on stochastic models and analysis of warehouse operations"*, Logist. Res., Vol. 3, pp. 191–205, 2011.

[4] Manzini, R., Accorsi, R., Gamberi, M., Penazzi, S., "*Modeling class-based storage assignment over life cycle picking patterns"*, Int. J. Prod. Econ., Vol. 170 (Part C), pp. 790–800, 2015.

[5] Thomas, L.M., Meller, R.D., "*Developing design guidelines for a case-picking warehouse"*, Int. J. Prod. Econ., Vol. 170 (Part C), pp. 741–762, 2015.

[6] Lam, H., Choy, K., Ho, G., Cheng, S.W., Lee, C., "*A knowledge-based logistics operations planning system for mitigating risk in warehouse order fulfilment"*, Int. J. Prod. Econ., Vol. 170 (Part C), pp. 763–779, 2015.

[7] Li, J., Huang, R., Dai, J.B., "*Joint optimisation of order batching and picker routing in the online retailers warehouse in China*", Int. J. Prod. Res., Vol. 55, pp. 447–461, 2017.

[8] Van Gils, T., Ramaekers, K., Caris, A., De Koster, R.B.M., "*Designing efficient order picking systems by combining planning problems: state-of-the-art classification and review*", Eur. J. Oper. Res., Vol. 0, No. 0, pp. 1–15, 2018.

[9] Giannikas, V., Lu, W., Robertson, B., & McFarlane, D., "*An interventionist strategy for warehouse order picking: Evidence from two case studies"*, International Journal of Production Economics, Vol. 189 (March), pp. 63-76, 2017.

[10] Andriansyah, R. , Etman, L.F.P. , Rooda, J.E, 2010. Flow time prediction for a sin- gle-server order picking workstation using aggregate process times. Int. J. Adv. Syst. Measure. Vol. 3, 35–47.

[11] Dallari, F., Marchet, G., & Melacini, M. (2009). Design of order picking system. International Journal of Advanced Manufacturing Technology, 42(1–2), 1–12.

[12] Gils, V.T., Ramaekers, K., Caris, A., & de Koster, R. B. M., "*Designing efficient order picking systems by combining planning problems: State-of-the-art classification and review"*, European Journal of Operational Research, Vol. 267, No. 1, pp. 1–15, 2018.

[13] Vertical Shuttles With Pick To Light Picking Trolleys, http://www.southwestsolutions.com/ssg/pick-to-light-picking-trolleys-automated-warehouse-storage-for-online-orders, 21-May-2018

[14] Grosse E. H., Glock C. H., "*An experimental investigation of learning effects in order picking systems"*, Journal of Manufacturing Technology Management, Vol. 24, No. 6, pp. 850-872, 2013.

[15] Kim, M. K., Lee, E. Y., & Chang, Y. S., "*A study on the human factors for a smart cart system*". 6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, Elsevier B.V, US, pp. 566-573, 2015.

[16] Boysen, N., Briskorn, D., & Emde, S., "*Sequencing of picking orders in mobile rack warehouses"*, European Journal of Operational Research, Vol. 259, No. 1, pp. 293–307, 2017.

[17] Richards, G., "*Warehouse Management – A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse"*, Kogan Page, London, 2011.

[18] Boamah D., Jalloh A.B., Ali S., Tembi I.T., Riaz M., Sun M.Z., & Fernando H., "*Smart Trolley*", MSc thesis, London south Bank University, 2015.

[19] Moeller, K., "*Increasing warehouse order picking performance by sequence optimization"*, Procedia - Social and Behavioral Sciences, Vol. 20, pp. 177–185, 2011.

[20] Yaman, H. , Karasan, O.E. , Kara, B.Y. , 2012. Release time scheduling and hub location for next-day delivery. Oper. Res. 60, 906–917 .

[21] Füßler, D., & Boysen, N., "*Efficient order processing in an inverse order picking system"*, Computers and Operations Research, Vol. 88, pp. 150–160, 2017.

[22] Ho, Y. C., & Lin, J. W., "*Improving order-picking performance by converting a sequential zone-picking line into a zone-picking network"*, Computers and Industrial Engineering, Vol. 113, pp. 241–25, 2017.

[23] Zhao, Z., Zhang, M., Yang, C., Fang, J., and Huang, G.Q, "*Computer and Industrial Engineering"*, International Juornal of

Production Economics, Vol. 189, pp. 63-76, 2018.

[24] Feng, C., Au, W. S. A., Valaee, S., Tan, Z., *"Received Signal Strength based indoor positioning using compressive sensing"*, IEEE Transaction on Mobile Computing, Vol. 11, No. 12, pp. 1983-1993, 2012.

[25] The Hitchhikers Guide to iBeacon Hardware: A Comprehensive Report by Aislelabs, http://goo.gl/eCsUp9, 04-May-2015.

[26] Ferris B., Fox D. and Lawrence N., *"WiFi-SLAM using Gaussian process latent variable models"*, In IJCAI, 2007.

[27] Li C. -L., Laoudias C., Larkou G., Tsai Y.-K., Zeinalipour-Yazti D., and Panayiotou C.G., *"Indoor geolocation on multi-sensor smartphones"*, In ACM MobiSys, 2013.

[28] Zeinalipour-Yazti, D., Laoudias, C., Georgiou, K., & Chatzimilioudis, G., *"Internet-based indoor navigation services"*, IEEE Internet Computing, Vol. 21, No. 4, pp. 54-63, 2017.

[29] Zeinalipour-Yazti, D., and Laoudias, C., *"The anatomy of the anyplace indoor navigation service"*, SIGSPATIAL Special, Vol. 9, No. 2, pp. 3-10, 2017.

[30] Gu Y., Lo A. and Niemegeers I., *"A survey of indoor positioning systems for wireless personal networks"*, In IEEE Comm. Surv. Tutor, Vol. 11, No. 1, pp. 13-32, 2009.

[31] Lymberopoulos D., Coudhury R.R., Liu J., Handziski V., Yang X., Sen S., *"A realistic evaluation and comparison of indoor location technologies: Experiences and lessons learned"*, In ACM/IEEE IPSN, 2015.