# Order Picking: A Survey of Methods and Problems

Sankalp Sinha, Mayank Kumar Nagda and E. Poovammal*

***Abstract---*** *Order picking is the single most expensive activity in warehouse management. Without tackling order picking successfully and efficiently it is almost impossible for any business to have a sustainable supply chain. Business around the world understand this and hence a lot of academic and research effort have gone into making the process of order picking as efficient as possible. Over the years many solutions have been devised and implemented. This paper presents a literary survey of the most used solutions and examines their salient limitations and problems faced during real world implementation.*

***Keywords---*** *Order Picking, Inventory Management System, Warehouse Management, Logistics Managemen*t.

## I. INTRODUCTION

In an increasingly globalized and interdependent world, trade is one of the largest sources of employment [Hoekman and Winters (2005)]. Domestic and international trade employs thousands of people across different sectors of the economy [Hoekman and Winters (2005)]. Firms across the world manufacture goods that are sold in both domestic and international markets. However, globally competitive and profitable trade is not possible without the efficient implementation of warehouses and distribution centers [Linton et al. (2007)]. Warehouses are an integral part of supply chain management and that is why companies are constantly looking to reduce their cost of operation while improving their efficiency, safety and productivity[De Koster et al. (2007)].

Over the years academic research in the area of supply chain management, focusing on improving the efficiency of warehouse operations have pointed to order picking as thesinglemost time and labor-intensive task in warehouse operations[De Koster et al. (2007)] [Goetschalckx et al. (1989)].

With the advent of the age of e-commerce the industry has seen a shift towards greater adoption of technology. Leading to development of new methods to improve the productivity of their supply chain, warehouses and distribution centers. These new methods and models of order picking are more complex and favors a greater degree of automation. As warehouses and distribution centers move towards greater levels of automation, they enjoy a reduction in per-unit cost of operation[Raja and Srivastava (2017)]. However, the implementation of such methods is greatly influenced by local factors and there exists a point beyond which automation ceases to remain viable especially in low-margin sectors like electronic commerce [Raja and Srivastava (2017)].Moreover, the method of order picking employed in a warehouse or distribution center has a direct impact on its throughput. As each picking method has its own characteristic advantages and disadvantages.

*Sankalp Sinha, Department of Computer Science and Engineering, SRM University, Chennai, Tamil Nadu, India.*
*E-mail: sankalp.sinha05@gmail.com*
*Mayank Kumar Nagda, Department of Computer Science and Engineering, SRM University, Chennai, Tamil Nadu, India.*
*E-mail: nagdamayank05@gmail.com*
*E. Poovammal*, Department of Computer Science and Engineering, SRM University, Chennai, Tamil Nadu, India.*
*E-mail: poovammal.e@ktr.srmuniv.ac.in*

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The remainder of this paper is structured as follows. In Section 2 we highlight the importance of order picking as a logistic warehouse process. We then briefly mention how order picking methods have been classified by other authors and how this classification has evolved. In section 3-5 we discuss the various order picking methods under each classification and discuss their salient limitations and problems faced during real world implementation.

## II. ORDER PICKING: A LOGISTIC WAREHOUSE PROCESS

Order picking is the process of picking or collecting items in a specified quantity to fulfil an order and to allow easy and efficient shipment of the same. It is an integral part of warehouse management and a basic warehouse logistics process, which has a huge influence on the supply chain productivity. The process of order picking alone accounts for close to 55% of the total operational cost of the warehouse [De Koster et al. (2007)].There have been many proposed classifications of order picking methods. The methods where originally classified by [Sharp (1992)], reviewed by [De Koster et al. (2007)] and expanded more recently by [Dallari et al. (2009)].

Order picking methods can be broadly classified into three main categories, manual picking, machine-aided picking and automated picking [Sharp (1992)] [De Koster et al. (2007)] [Dallari et al. (2009)].

While on the other hand, the exercise of order picking can be broadly divided into two subtasks namely: path-finding and picking. Path finding refers to the process of locating the correct shelf and picking refers to the process of finding the correct bin on a shelf [Schwerdtfeger and Klinker (2008)].

## III. MANUAL ORDER PICKING METHODS

In the subsections 3.1 - 3.4 we discus some of the most commonly used manual order picking methods in detail.

### *A. Manual Picker-to-Parts*

Manual Picker-to-Parts is an order picking method which conventionally consisted of a list of items on a piece of paper that are to be picked by a picker. The items on this list are sorted as per a customer order *pick-by-order* or type of item *pick-by-article*[De Koster et al. (2007)]. The warehouse has a picking region which consists of a large array of shelves that are arranged in a way to best optimize the picking process. There are many proposed arrangements of shelves, the most widely used includes class-based-storage, random storage, dedicated storage and closest open dedicated storage [De Koster et al. (2007)]. The picker has to manually find the shelf associated with the individual item or such related items, followed by manually verifying the product code to the one listed in his/her list. Then striking that item off the list and moving on to the next item. In this method the picker moves to get the parts hence the name 'picker-to-parts'.

### *B. Put Systems*

Put Systems is another widely used manual order picking method. It consists of two phases namely: picking and distribution. The picking phase involves the manual picking of the items on a list by the picker. This list has items that fulfill multiple customer orders and the items on the list are aggregated based on the type of item.In the distribution phase each order is assigned a box or crate and the picked items are sorted according to the individual customer orders [De Koster et al. (2007)]. This sorting is done by hand.

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### *C. Parts-to-Pickers*

This is another order picking method in which specialized bays called ‘picking bays’ are established on the warehouse floor. These picking bays are periodically populated with items form the storage area of the warehouse. The pickers are then tasked to pick the items required form the picking bays to fulfill their orders. The ‘picking bays’ are designed according to requirements and use-case of the warehouse. While the equipment used ranges from convey or belts and carousels to bins, totes and forklifts [De Koster et al. (2007)].

## IV. LIMITATIONS OF MANUAL ORDER PICKING METHODS

This section discusses some of the limitations of manual order picking methods which were discussed in section 3. This detailed study on the limitation suggests that order picking is still a challenging task in the Inventories and Logistic Management.

### *a) Limitation of Manual Picker-to-Parts*

Manual order-picking methods are strenuous, time taking and prone to frequent human errors. The conventional manual ‘picker-to-parts’ method has an exponential learning curve to become an efficient piker. As it is easy for a new comer to quickly grasp the picking process, but on the other hand it takes time for a picker to become efficient at picking, as this requires experience and practice with the picking routes of the warehouse. Choosing the most efficient picking route is problem that can be reduced to the famous travelling salesman problem [Shmoys (1985)].

### *b) Limitations of Put Systems*

Put systems have the highest efficiency of around 500 picks on average, when the warehouse has a large number of customer order lines that have to be picked in a short time span [De Koster et al. (2007)]. Making 'put systems' feasible only for high volume warehouses.

### *c) Limitations of Parts-to-Picker*

The manual ‘parts-to-picker’ method does manage to reduce the time wasted by a picker in locating the correct item on the correct shelf as the items come directly to the designated picking bays. This time saving property of the method is its major strength. However, as the number of orders rise, the probability of a bottleneck occurring in the ‘picking bays’ rises as bringing large loads of items from the storage area to the ‘picking bays’ is a time taking process. This results in idle time (time wasted as pickers wait for the items) for the pickers and hence reducing their effective utilization and the overall efficiency of the system [Dallari et al. (2009)].

## V. MACHINE AIDED ORDER PICKING METHODS

Over the years as the global volume of trade rose, the size of warehouses has grown and medium to large warehouses are more popular [Connolly (2008)]. In these new, medium to large sized warehouses it was infeasible to apply the conventional methods of order picking.

Soon the industry realized that systems that support the picker by providing the relevant information and instructions while keeping the system intuitive and simple to use were needed.

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To this end many attempts were made, but the solutions and ideas where limited by the technology of the time. Yet over the last decade steady advancements in camera technology and miniaturization of electronic components have allowed cameras to become progressively smaller in size while still packing a high resolution. The smart phone industry stands as a testament to the revolution brought to it by smaller, cheaper and high-resolution cameras and miniaturized electronic components.

These advancements in camera technology have opened up doors for many new applications in various fields. One such application is in the field of logistics management in medium and large warehouses. In medium to large warehouses precise and reliable order picking is a big challenge for pickers using conventional methods of order picking [Connolly (2008)].

In the subsections 5.1 to 5.4 we discus some of the most commonly used machine aided order picking methods.

***a) Pick by Light***

Pick-by-Light [Sharp and Handelsmann (1996)]. systems typically employ a set of small displays and some form of proximity sensor that is associated with each bin. All these displays are wired to a CMS (Central Management System). The displays for each bin show how many items have to be picked. The picker picks the items in the required quantity and the acknowledgement for the same can be given manually by pressing a button, or automatically by the use of laser sensors, that sense that the picker has picked the required items from the correct bin, when a beam of laser light is blocked by his hand [Sharp and Handelsmann (1996)].

Another method acknowledgement are proximity sensors, each bin has a proximity sensor that detects the presence of a picker, hence acknowledging a successfully pick. Still manual confirmation through a press of a button is the most used method of acknowledgement. As it is simpler and cheaper to implement and does not miss-fire due to other environmental objects as is the case with laser or proximity sensors.

***b) Pick by CMD***

A CMD (Cart-Mounted-Display) is basically a digital version of a paper list. The picker has a digital representation of the paper list displayed on a screen that is mounted on his picking cart. Some versions of CMD also employ a barcode scanner to facilitate the picking process. The list shows the item and its quantity the picker must pick, after picking the required item the picker scans the barcode of the item and the system strikes the item of the list and displays the next item to be picked. This process is shown to be more efficient than paper lists [Guo et al. (2014)]. Other systems show a graphical representation of the shelving lay- out, from which the item is to be picked, this representation is usually color coded with the quantity of items to be picked clearly shown [Guo et al. (2014)].

***c) Pick by Voice***

Using speech to interact with machines and automated systems is perhaps the most natural way of interaction. Pick-by-Voice systems are body worn devices that read out the picking instructions to the picker and the picker can interact with the system using pre-programmed voice commands [Funk et al. (2016)]. These systems allow both the hands of the picker to remain free and the system's usage can be picked up easily by inexperienced pickers. E.g. one of the pick-by-voice solutions is Dematic pick-to-voice [Berger and Ludwig (2007)].

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### *d) Pick by Vision*

Recently with the advent of cheap display technology, HMD (Head Mounted Display) based solutions have become quite popular [Schwerdtfeger (2010)]. There are different approaches used by HMD systems to provide just the right amount of information to the picker at the right time to make the process of picking as efficient as possible [Reif and Günthner (2009)]. Some HMD systems show the same graphical shelving layout as seen on CMD systems. These systems display a mini graphical representation of the shelving layout on the HMD of the picker allowing easy access to required information, at the same time allowing both the picker's hands to remain free [Reif and Günthner (2009)].

Other systems employ a far more sophisticated approach to both path-finding (Finding the correct shelf) and picking (Picking from the correct bin). For path-finding these HMD systems use retro-reflective markers to precisely track the picker's body and head movements, then using Augmented Reality provide 3D markers such as a Bezier curve-based tunnel, to guide the picker to the correct shelf and bin [Reif and Günthner (2009)] [Reif and Walch (2008)] [Schwerdtfeger and Klinker (2008)].

## VI. Limitations Of Machine Aided Order Picking Methods

In this Section we discuss some of the salient limitations machine aided order picking systems and also mention the problems faced in their real-world implementation. This detailed study on the limitation suggests that order picking is still a challenging task in the Inventory and Logistic Management.

### *a) Limitation of Pick by Light*

Pick-by-Light [Sharp and Handelsmann (1996)]. systems use lights to inform the picker what to pick and how much to pick. These systems are efficient in a high-density order picking warehouses where there are multiple picking regions that are densely packed together. These systems take some time for the pickers to master and efficient picking decisions are made with experience and practice. These systems lose their efficiency when the warehouse is spare.

### *b) Limitations of Pick by CMD*

As CMD are basically a digital representation of paper lists. They have some common limitations. The picker has to memorize the details of the item while finding the correct bin in which the item is kept. Inexperienced pickers usually have to cross refer the CMD multiple times while searching for the correct bin. This results in loss of precious time and unforced human errors. The use of barcode scanners along with the CMD systems does reduce the overall human error rate, but the system still requires time to master.

### *c) Limitations of Pick by Voice*

There are many factors that limit the performance and effectiveness of Pick-by-Voice systems [Guo et al. (2014)]. The noisy environment of the warehouse floor is a major limiting factor, as pick-by-voice systems rely on a clear voice signal, the noisy environment of the warehouse floor limits the system's ability to correctly pick up voice commands.

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As the rate of failure rises the system can quickly become frustrating for the picker. Pick-by-Voice systems have a limited range of pre-structured and pre-programmed voice commands; the picker needs to give commands in only these predefined ways so the system can correctly recognize the intentions of the picker. Hence for the picker to interact with the system effectively requires some time, training and experience.

Furthermore, the languages and dialects supported by such systems is limited, this is a huge problem for companies that operate warehouses around the world and want to deploy a single pick-by-voice system in all their facilities.

### *d) Limitations of Pick by HMD and Augmented Reality*

HMD systems that employ Augmented Reality for vision picking are highly sophisticated and employ multiple sub-systems that need to work together perfectly to achieve the desired results. These systems are also expensive as the technology used to build them is new and rarely mass produced.

The process of retro-fitting these systems in existing warehouse is time consuming, challenging and expensive. Also, Augmented reality systems do not provide a significant advantage when compared to similar 1D or 2D HMD systems [Schwerdtfeger and Klinker (2008)]. Augmented Reality systems also need high processing power to generate the 3D virtual markers and objects that guide the picker in picking process [Schwerdtfeger and Klinker (2008)] [Funket al. (2016)].

## VII. AUTOMATED PICKING METHODS

The emergence of robotics and advanced automated technology has transformed business operations across the supply chain for many businesses. These transformations are especially apparent in the manufacturing sector, where companies are increasing their use of specialized automated systems for handling manufacturing processes that are too strenuous, time taking or hazardous for humans to carry out efficiently.

The development of advanced automated technology has given rises to new methods of order picking. The most used methods are mentioned below.

### *a) Automated Storage and Retrieval Systems*

In the context of warehouse management Automated Systems are a combination of Automated Storage and Retrieval Systems (AS/RSs). AS/RS are complex computer-controlled systems that are a combination of integrated equipment and control systems, which allows them to handle, store and retrieve warehouse material with greater accuracy, speed and efficiency [Vasili et al. (2006)].

AS/RS systems comprise of automated S/R machine (also referred to as a stacker crane.) which is responsible to stack and retrieve items from multi-tiered racks which may have a single or multi-aisle arrangement. These items are then passed onto a conveyor belt system or P/D stations for further processing.

AS/RS systems are classified based on their configuration, handling capacity and application. They are classified as:

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(1) Handling Capacity

(i) **Unit-load AS/RS**: Unit-load automated storage and retrieval systems are usually large computer-controlled systems. These systems are designed to handle large pallet-size loads in one cycle. The warehouses employing these systems are configured with pallet racks. The AS/RS system lies in the narrow aisle between the racks. The system consists of a tall mast stacker crane, which can move vertically and horizontally in the aisle to reach the storage and retrieval spots. The automated picking mechanism uses shuttles to place and pick pallets from the respective racks.

(ii) **Miniload AS/RS**: These systems are computer controlled and smaller compared to unit-load AS/RS systems. The system is designed for small or individual items that can be picked from bins, cases or totes. The system uses pallet racks that have rails mounted on them. The system lies in the narrow aisle between to racks. The system has a stacker crane that uses the rails on the racks as a guide to reach a target position on the rack. Extractors mounted at the end of the stacker crane use a robotic arm or vacuum to grasp the individual items from containers.

(2) Configuration

(i) **Deep-laneAS/RS**:These systems are designed for high volume and high-density warehouses that have limited variety of items while having large stock of each variety. High density warehouses are characterized by fewer number of pallet racks that have greater depth than conventional multi-aisle AS/RS systems. As a result, the loads can be stored at a greater depth. The stacker crane and shuttle configuration is the same as that ofUnit-load AS/RS system.

(ii) **Vertical lift modules (VLMs)**: Most conventional AS/RS systems have a horizontal configuration of pallet racks. The system uses the same central principles as that of a conventional AS/RS system, just the pallet racks are arranged vertically. The stacker crane has a tall mast with a shuttle at its end to handle the picking and placing of loads. Most VLMs have a height of 10 m (30 foot) or more [Vasili (2012)]. VLMs are popular for warehouses that have a limited floor area for product storage. The systems are capable of storing large inventories while saving valuable floor space [Vasili (2012)].

(iii) **A-Frames**: A-Frames are automated machines, designed to handle less than unit-load orders. The system can handle complex orders that have multiple individual items as its part. The system consists of a series of vertical channels that are configured in an "A" shape. The channels hold multiple pieces of an item and act as gravity dispensers. Each order has a bin, tote or bucket assigned to it and is placed on a conveyor belt which runs under the system. As the bin moves along the conveyor belt, individual items in their required quantities are released by the channels to complete an order. The entire system is computer controlled and is ideal for complex high volume or high variety orders with a picking rate of 1,200 to 2,400 orders per hour [Caputo and Pelagagge (2006)].

(3) Application

(i) **Man-on-board AS/RS**: The system is similar to a unit-load AS/RS, instead it has a human operator on board the stacker crane to handle individual items and oversee the storage and retrieval process [Vasili (2012)].

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(ii) **Fully Automated**: These systems have little to no human involvement in any phase of order fulfilment. These are large and complex systems that are custom designed for large warehouses or fulfilment centers. The systems are fully automated and handle tasks like order initialization, order picking, order packaging and sorting on their own using an array of sensors, sub- systems and control systems. Fully automated systems consist of multiple self-contained and modular sub systems that are easy to maintain, resulting in low down times and maximum efficiency at peak load. These systems usually have a human monitored central control system.

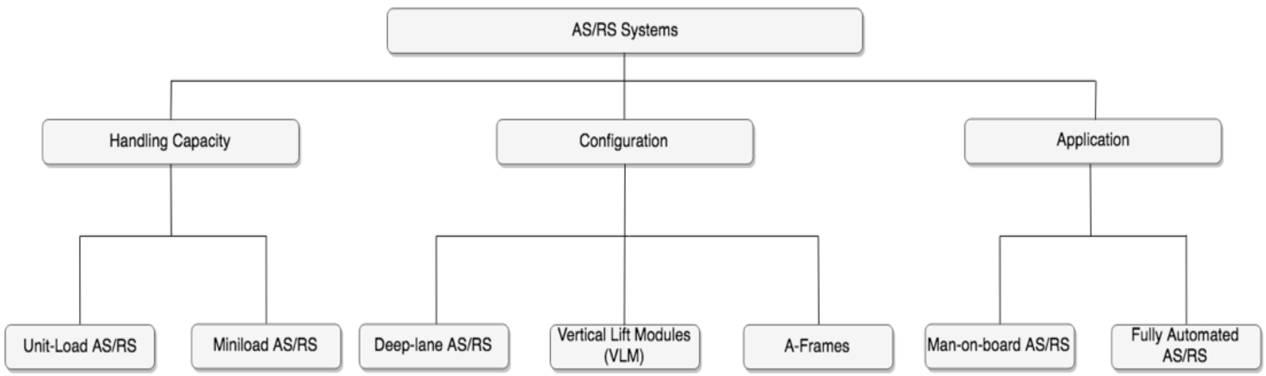


Fig. 1: Classification of AS/RS Systems (based on Vasili et al. 2012)

### *b) Limitations of Automatic Storage and Retrieval Systems*

Automation in the industry as such has many advantages such as reduced labor cost, improved efficiency and tracking of operations, improved overall safety and reduction of human errors, greater flexibility of operations and low downtimes. However widespread use of Automatic systems in warehouses and distribution centers has many barriers and limitations. The high cost of initial investment is a major limitation. Most medium capital companies do not have the capital to invest in an Automated system. Even bigger corporations find it difficult to implement warehouses with fully automated AS/RS. Furthermore, automated systems show maximum efficiency when they are used in large, high density and high-volume warehouses or distribution centers, which are supported by good rail and road connectivity.

AS/RS systems are not robust in terms of handling different types of items on short notice. These systems are designed to handle only a certain range of items and loads, they require reconfiguration if the nature of items or their packaging changes. Hence these systems face issues in adapting to the changing requirements or circumstances of the supply chain as the systems are not designed to be dynamic.

As any machine these systems requires constant monitoring and maintenance.This means stocking up on replacement parts, ensuring proper usage and timely maintenance, training and hiring technical staff etc. Warehouses with AS/RS systems take time to set up and use little to no local resources, conventional warehouses on the other hand use local construction material, labor and are generally faster and cheaper to set up due to their simplicity.

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## VIII. CONCLUSION

The academic research in the field of logistics and inventory management, over the years has focused extensively on devising different methods and approaches, to tackle the problems posed by order picking. Order picking is largely the single point of bottlenecking in any warehouse. It is a choke point that causes delays and is prone to unforced errors. Conventionally the process of order picking was handled manually. This had its obvious disadvantages as any other human driven system. While as other process in the warehouse reached higher efficiency through the use of technology and automation. Order picking lagged behind due to both the technology of the time and the fact that order picking is computationally a difficult task.

With the advent of the 21st century we begin to see systems that aid the picker to reduce the work load and prevent unforced errors. Although even these systems suffered from the limitations imposed by the nature of the warehouse environment and initial financial costs. Most machine aided systems have seen limited use around the world. Their use is limited to more developed and industrialized nations who can bear the initial cost of investment. This also means that these systems are specifically for the conditions faced in these countries. This is especially true for Pick-by-Voice systems that recognize only a limited set of languages and dialects.

More recently with the advent of the age of e-commerce and emergence of e-commerce giants like Amazon, Walmart, eBay etc. The industry has seen a push towards large, high density, centralized, fully automated warehouses. These new generation of warehouses employ fully automated order picking and management systems. These systems are complex and very expensive to implement and only very few companies actually employ them.

All of the current order picking systems have their specific use cases where they perform at their highest efficiency. In the future we need order picking systems that are modular, scalable, robust and efficient for small, medium and large warehouses. While also being affordable and cost effective for different sized business and economies.

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