MOBILEROBOTGUIDE

Autonomous Mobile Robot

Buyers Guide

Warehouse Solutions Edition

October 30, 2020 Edition

The Mobile Robot Buyers Guide®
2020 Warehouse Solutions Edition®

Published by
The Mobile Robot Guide, a division of Market Spec Media
mobilerobotguide.com

Printed in the United States of America

Content and product reviews by Mike Oitzman and Medha Sandill
Illustrations by Mike Oitzman
Editing by Shari Oitzman

Special Edition: October, 2020
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Automation Makes Your Warehouse Competitive

Hello and welcome to this first edition of the Warehouse Solutions Buyers Guide.

First, thanks for purchasing this guide and supporting the work that we do at The Mobile Robot Guide. Our mission is to educate buyers about the technology, applications and vendors of autonomous mobile robotic solutions.

This guide represents countless hours of research to compile the most complete list of autonomous mobile robot based warehouse solutions. We've classified this market around the warehouse workflows that move products into and out of storage in your warehouse.

We assume that you are a warehouse professional and understand the basics of managing a warehouse. We also assume that you know nothing about autonomous mobile robots. This guide exists to bridge the knowledge gap and help you understand how autonomous mobile robots enable you to improve the processes in your warehouse.

This Buyers Guide covers all of the autonomous mobile solutions currently on the market as of October 5, 2020, however, you are entitled to updates of this version as new vendor information becomes available.

We appreciate your feedback on the contents and design of the document. Please contact me using the information below if you have any suggestions about how we can make this document more valuable to you.

Thanks for your trust in the Mobile Robot Guide.

Mike Oitzman

Mike Oitzman

Founder & Publisher

The Mobile Robot Guide

mike@mobilerobotguide.com

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Disclaimer

Disclaimer: This publication is designed to provide accurate and personal experience information in regard to the subject matter covered. It is sold with the understanding that the author, contributors, publisher are not engaged in rendering counseling or other professional services with regard to warehouse processes. If consulting advice or other expert assistance related to your specific facility is required, the services of a competent professional person should be sought out.

All of the information presented in this Buyers Guide was collected through interviews with product manufacturers or directly from their websites/documentation.

Information contained herein is subject to change without notice.

Availability of certain products may be limited by region or market conditions or by local regulations. Not all of the products reviewed are currently available worldwide. Please contact the manufacturers directly to determine availability in your region.

All of the Mobile Robot Guide Recommended™ solutions are products from established vendors with existing credibility in the marketplace. While some of these suppliers may be sponsors or advertisers of The Mobile Robot Guide, we are not receiving any compensation directly from the recommendations in this guide.

Opinions are by the staff of The Mobile Robot Guide.

Table of Contents

How to Use the Buyers Guide

Who Is This Guide For?

This document is designed for anyone interested in purchasing a warehouse automation solution. It is written specifically to educate solution buyers. This guide explores all of the various automated or semi-automated solutions for workflow automation within a warehouse.

This guide will help you:

- Understand the technology
- Map out your needs
- Complete a return on investment (ROI) calculation
- Narrow your vendor choices
- Select a suitable solution
- Begin the procurement process

This guide provides specifications for all of the covered products and presents the information to help you with your research for a warehouse automation solution. This effort included the collection, collation, and reconciliation of vendor and product data.

Warehouse Operations and Logistics Leaders

Are you a warehouse operations or logistics leader who is looking for autonomous solutions to help improve the throughput or reduce fulfillment costs in your warehouse?

Are you struggling to meet the seasonal demands of your business?

Do you struggle to find and keep the labor necessary to operate your warehouse?

If so, then this Buyers Guide is designed to help you quickly understand all of the autonomous mobile robotic options available. These solutions will assist your warehouse staff while improving accuracy, throughput, efficiency, and reducing costs.

The scope of this guide does not cover all of the options for your warehouse. However, armed with the information in this guide, you'll be able to compare autonomous mobile robot (AMR) based solutions to the other productivity-enhancing options that you may be considering.

Resolving Common Constraints

Warehouse managers struggle with a variety of concerns in operating an efficient warehouse:

- Inaccurate Inventory
- Redundant Activities
- Suboptimal Picking
- Poor Layout
- Product Diversification
- Peak Seasonal Demands
- High Labor Costs
- Avoiding Product Damage
- Handling Returns

Filling In The Gaps In Your Workforce

Hiring and training seasonal workers is a time consuming task for warehouse managers. In some cases, there may not be enough local labor to support your hiring needs.

Automation can help to cover these gaps by enabling your existing staff to be more productive.

Can you scale quickly to fill gaps in demand during peak season? Many automation providers offer a subscription type service that can scale with your demands.

Are you able to quickly integrate new workers and bring them up to speed? Automation may help decrease learning time by interactively teaching new workers on the job.

Take Our Advice: Recommended Solutions

We've done months of research to compile the most complete and thorough list of vendors and solutions for warehouse automation. After numerous interviews with company representatives and careful integration of product specs, this document represents the most extensive overview of the warehouse automation solutions market at this moment in time.

Upon the completion of our analysis, we selected several "Recommended Solutions". Recommended Solutions meet our minimum criteria for a mature, complete solution, including:

- Inclusion of vendor pricing
- Fully autonomous operation (including battery charging and travel between rooms and building floors)
- Demonstrated market leadership
- Minimum unit production of 50 units

*Look for the "***Recommended Solution***" badge in the vendor reviews for the top solutions.*

Recommended Solution Providers

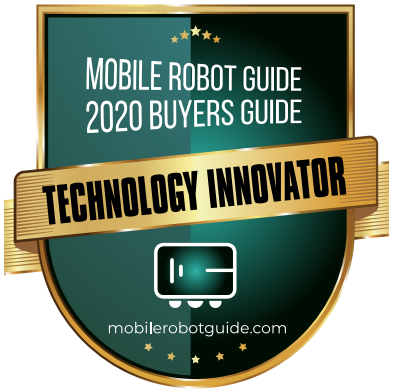
After reviewing all of the solution providers, two solutions made our recommended list. These companies were evaluated based on completeness of solution, company maturity and market readiness. You will find solution pricing for all of the recommended solutions.

Here are our picks for **Recommended Solutions** in this edition of the Buyers Guide:

Locus Robotics [Person-to-Goods] - Locus Robotics is a market leader with thousands of AMRs deployed in hundreds of customer warehouses worldwide. Their solution to person-to-goods workflow has been optimized and hardened after more than six years of development. Locus has a pedigree of ecommerce operations that has enabled them to develop their solution. The user interface is simple to use and easy to learn for new Associates. Gamification in the interface keeps Associates engaged throughout their workday.

6 River Systems [Person-to-Goods] - 6 River Systems (6RS) was acquired by Shopify in early 2020. The vision for Shopify is to leverage the 6 River Systems solutions in 3PL warehouses to fulfill inventory for Shopify ecommerce customers. The good news is that 6 Rivers Systems person-to-goods solution remains generally available to the open market. We like the 6RS Chuck robots because they are highly configurable, fast and easy to deploy, and can easily scale — starting from a small pilot implementation.

Take Our Advice: Technology Innovation



The pace of innovation in this market is moving fast. While several AMR-based warehouse automation solutions have been on the market for more than four years, many new companies have launched solutions to the market in the last two years.

Innovative solutions distinguish themselves with a novel capability or feature that is not seen in other competitors. Of if the feature is seen in multiple solutions, this award distinguishes the most refined implementation.

Some of the key areas of innovation include:

- Design of the robot payload
- Robot operating software and fleet management
- Integration to Warehouse Management Systems (WMS)
- Optimization of warehouse workflow
- Integration of artificial intelligence and machine learning algorithms
- Reporting and statistics
- User interfaces

In the Buyers Guide, we highlighted several products for their technology innovation. While these units may not yet meet all of the criteria for a Recommended Solution, the products show promise due in part to their Technology Innovation at either the software or hardware level.

*Look for the "***Technology Innovator***" badge, for vendors with unique solutions.*

Technology Innovation Winners

The Mobile Robot Guide reviewed the features of all of the autonomous solutions currently on the market. In doing so, we reviewed some solutions that are delivering new innovation to the market. The Technology Innovation Award Winners represent companies and solutions that are pushing the boundaries of what's possible.

Here are our picks for **Technology Innovation** in this edition of the Buyers Guide:

IAM Robotics - IAM Robotics was the **first AMR on the market to feature a mobile manipulator** for acquiring individual piece parts from shelves. The pioneering solution uses vision to guide the robot arm to pick items from the shelf. The entire solution is collaborative and safe for human workers to operate in the same workspace as the AMR.

Ware Robotics - Ware offers a unique solution for inventory counting leveraging the off-the-shelf Skydio drones. Skydio was the first drone maker to release a drone capable of vision guided, real-time obstacle avoidance. Ware Robotics is **deploying the Skydio robots into warehouses**, and they have developed an application that leverages the onboard camera to acquire and then process images of inventory from the warehouse shelves.

InVia Robotics - InVia was an innovator in deploying their solutions with a **Robots-as-a-Service (RaaS) business model**. With this subscription-based pricing you pay only for what you use as the robot work in your warehouse. With a "surge" option in your RaaS contact, you can request additional InVia robots to be delivered/deployed to your warehouse during peak fulfillment periods (e.g., holiday seasons), to help with additional throughput of your warehouse.

Hai Robotics - The HaiPick A42D solution is unique in the marketplace due to its capability to reach deep into a second row of bins stored on a warehouse shelf. With the **HaiPick A42D** and the HaiPick proprietary shelving, you can deploy some of the densest inventory storage capacity per area of your warehouse. (see image to the left).

The Haipick A42D robot and shelving units.

Technology Innovation Awards (cont)

Prime Robotics - The AutoShelf is a unique G2P solution that leverages an integrated shelf and AMR unit. With the **AutoShelf** you are able to configure the inventory on the shelf for a variety of use cases including the workflow of bringing inventory from a retail store back of house to front of house delivery for customers. This is currently the only system of its kind on the market.

Caja Robotics - Caja Robotics designed their warehouse fleet management software to leverage the power of a scalable cloud-based architecture. **Simulation** is a foundation of the Caja Robotics architecture that leverages the vast computing power of the cloud to help control the system. Caja creates a simulated warehouse layout and then uses this to accurately calculate and predict the system throughput. The use of simulation enables Caja to accurately configure a new fleet of picking robots for a customer and then to optimize the performance of the actual system once it is deployed.

How To Use The Mobile Robot Buyers Guide

This Buyers Guide contains product specifications for all of the products on the market as of September 18, 2020. The Mobile Robot Guide solicited each vendor for accurate product specifications. Our staff then normalized all of the product data to put it into a format that is organized and easily searchable. The results of our analysis are presented in this document.

With your purchase of the Buyers Guide, you already received:

1. The Buyers Guide (this document) — including vendor reviews
2. Access to the Vendor Database (optional)
3. Return on Investment (ROI) Calculator/Spreadsheet
4. Sample Vendor Questions (PDF)

Buyers Guide Publication

This document is the formal Buyers Guide publication. It contains a narrative of information about each vendor, along with our analysis and recommendations. You'll learn about autonomous mobile robots and the features that are important to consider as you evaluate each product during your buying process.

Vendor Information

In the vendor section of the Buyers Guide, you will be provided with **vendor contact** and **website information** that enable you to reach out to your vendor of choice to begin the sales process. This information will be enough for you to narrow your choices to a shortlist, based on your needs.

Several vendors are omitted from the Buyers Guide at their own request, due in part to the immaturity of their solutions. We will add these vendors to the Buyers Guide when they formally release their products to the market.

Vendor Database (Optional Purchase)

As a companion to this Buyers Guide, you can also purchase the Vendor Database. This is an online database of vendors and products. This electronic data is easily searchable and with your subscription, you can download output from the database to help you narrow your solution search. The online vendor database will be updated as new solutions are launched into the market.

Return On Investment Calculator

Included with your purchase is a Return on Investment (ROI) Calculator that you can use in your purchasing process to help you determine the value of a solution for your particular needs. The ROI Calculator is provided as a spreadsheet that is editable and customizable for your needs. All of the instructions are in the spreadsheet.

Recommended Ratings

Look for the “Recommended Solution” badge on products that stand above the competition. These solutions were selected after careful analysis of all of the solutions in this version of the Buyers Guide. Note: vendors who could not provide solution pricing were not considered for a recommended rating.

Innovative Solutions

Look for the “Innovative Solutions" badge on products that offer some innovation in their solutions. Innovation can come anywhere in the solution.

Warehouse Technology

A Deep Dive To Learn How It All Works

Warehouse Automation Technologies

The Buyers Guide exists to educate you about all of the different types of autonomous mobile robot (AMR) based automation solutions that are available to help you improve your warehouse workflow. The Buyers Guide will introduce you to new automated workflows that can improve the throughput and efficiency of your warehouse or distribution center.

Even small warehouses can benefit from automation. New financial models such as Robots as a Service (RaaS) make automation affordable because the costs are allocated based on the work that the systems do. With a RaaS financing, you'll pay for the solution using your operating budget rather than your capital budget.

There Are Many Options For Automation

Both hard and flexible automation options exist for moving material through your warehouse. The Buyers Guide does not cover fixed conveyors and racking solutions, nor does it cover large scale, vertical Automated Storage & Retrieval Systems (ASRS).

This edition of the Buyers Guide only covers warehouse automation solutions that leverage some form of an autonomous mobile robot (AMR) in the solution.

In our research for this Buyers Guide, we've uncovered a tremendous amount of innovation that is occurring in warehouse automation solutions leveraging autonomous mobile robots. These solutions automate many of the operations that have previously been completed either manually or with fixed automation.

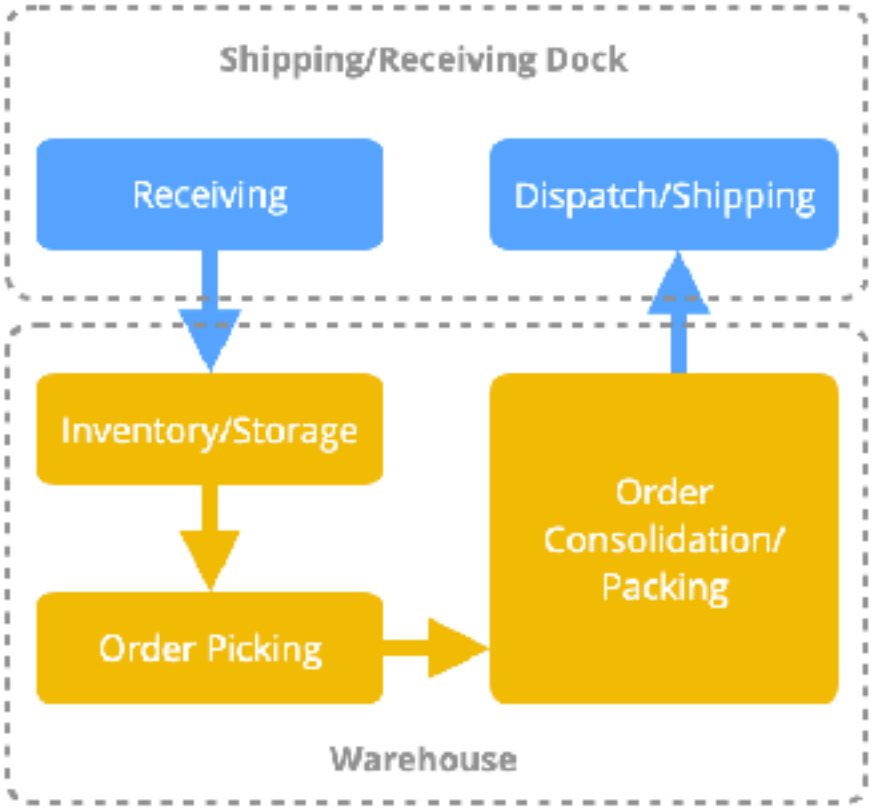


Figure 1 - The basic material flow diagram of an inventory and fulfillment workflow.

As shown in Figure 1, we've organized the market around five primary warehouse workflows:

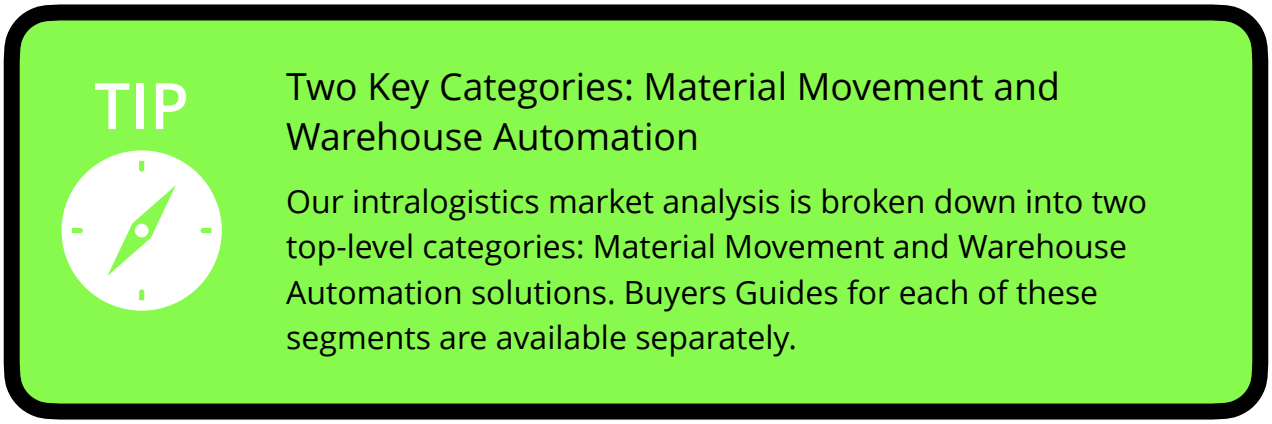
1. Bulk Receiving/Shipping
2. Inventory Storage (including put away and reverse logistics workflows)
3. Order Picking
4. Order Consolidation/Packing
5. Inventory Counting

Intralogistics Processes

All of the material handling workflows within a company might aptly be called “intralogistics”. Intralogistics broadly covers everything from the movement of large, heavy “unit-load” pallets to and from the shipping docks, all the way to the movement of a single product order from the inventory bin to the shipping box.

For a product manufacturer, intralogistics may also include movement of raw materials or parts to the factory floor, handling of work in process (WIP), and movement of finished goods to the warehouse for storage until shipment.

We’ve made this categorization to help separate and define the specific solutions within each subcategory and help you quickly drill down to the areas that are most important to improving the efficiency of your workflow.



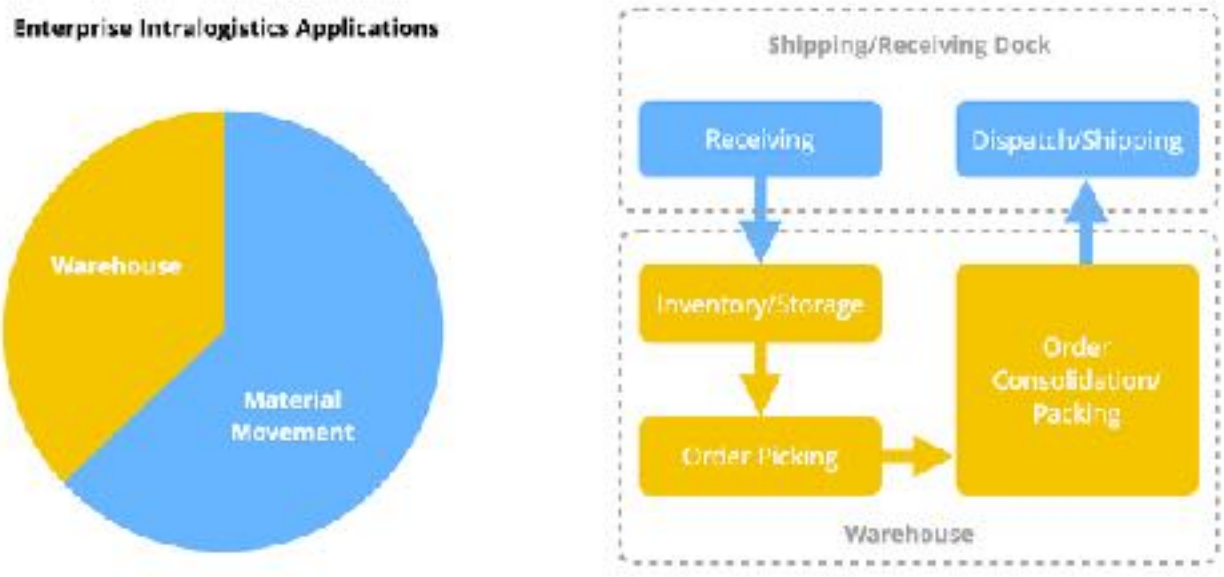


Figure 2 - The Enterprise Intralogistics Application market consists of two subcategories: Warehouse Applications and Material Movement.

This **Warehouse Solutions Buyers Guide** covers the warehouse segments (the gold shaded items in Figure 2) including picking/replenishment, sortation, and inventory counting workflows. This subsegment currently includes over 100 solutions.

The **Intralogistics Solutions Buyers Guide** covers bulk logistics and material movement workflows (the blue shaded items in Figure 2). The Intralogistics Solutions Buyers Guide will ship in October 2020. The intralogistics segment includes over 170 solutions.

Classes Of Warehouse AMR Solutions

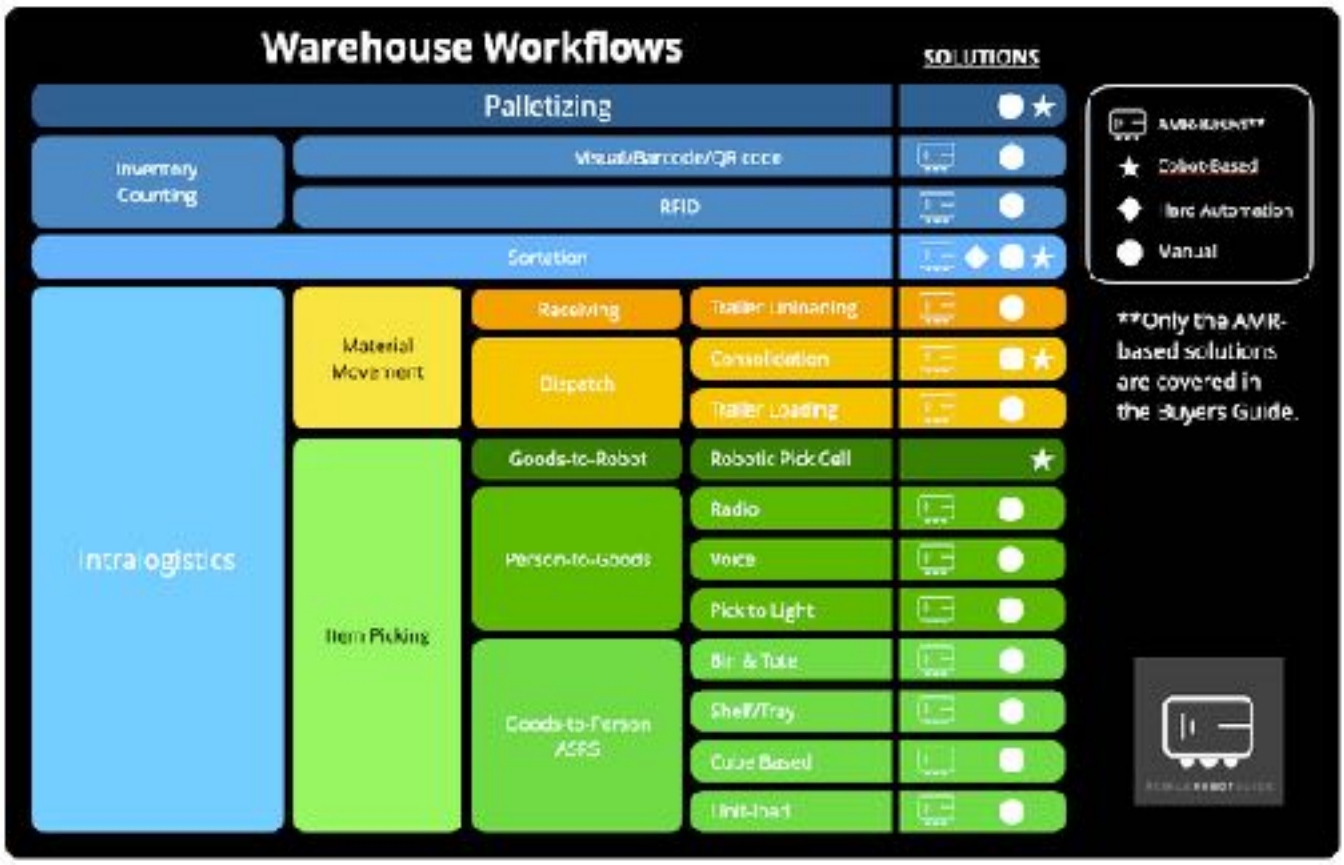


Figure 3 - Diagram of warehouse workflows that are solved with robotics-based solutions.

There are five categories of AMRs in this edition of the Warehouse Solutions Buyers Guide:

1. Person-to-Goods Solutions
2. Goods-to-Person/Robot Solutions
3. AMR-based Automated Storage and Retrieval Systems (ASRS) and micro-fulfillment solutions (a subclass of ASRS)
4. Inventory Counting Solutions
5. Sortation

Depending on how you've organized your warehouse, or how you're re-engineering your warehouse workflow, you'll want to focus on one of these specific classes of solutions.

The key subclass of warehouse workflows not covered in this Buyers Guide is material movement. As seen in Figure 3, material movement is an important subclass for the

warehouse and generally involves the movement of heavier payloads and large volume, pallet-based unit loads. While these workflows may be critical for your warehouse, the material movement represents the largest subclass of AMR-based solutions and we are covering this separately in an upcoming Intralogistics Buyers Guide (to be published in October 2020).

Cost Versus Performance of Warehouse Automation Solutions

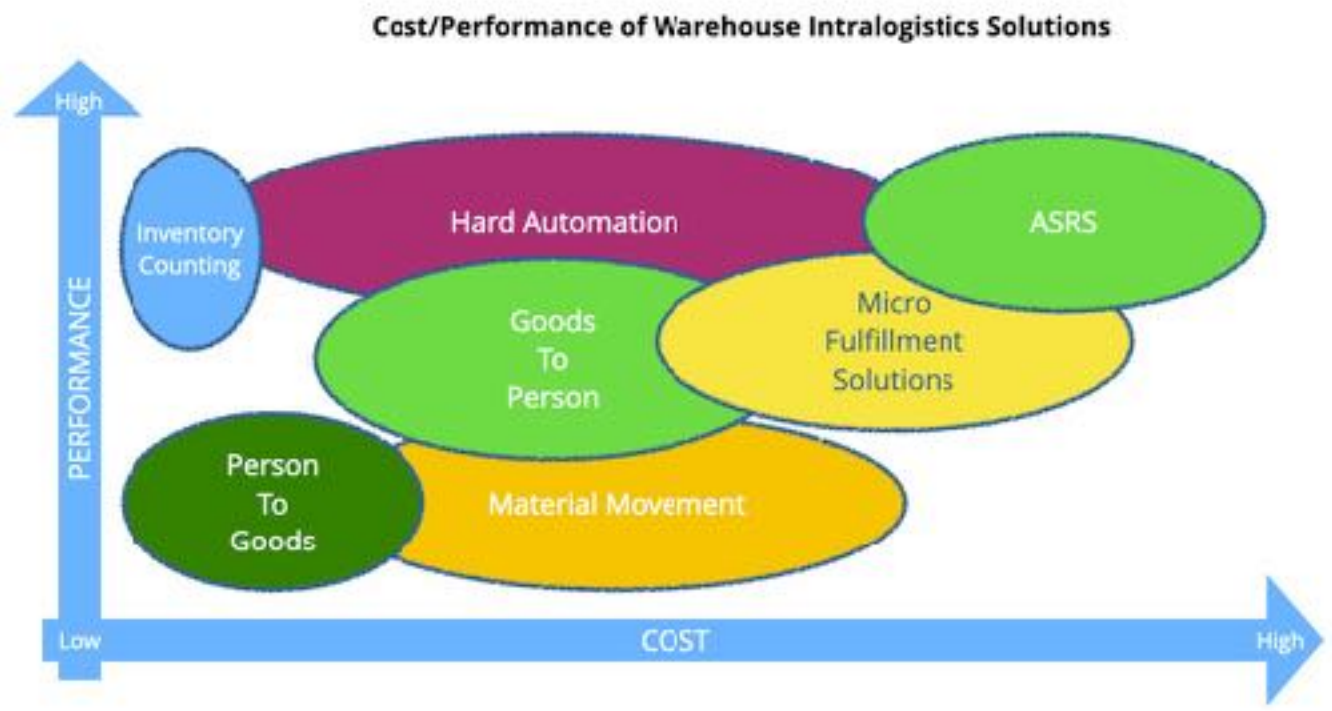


Figure 4 - Chart with cost versus performance of warehouse automation solutions.

As shown in Figure 4, there is a correlation between the implementation costs and the performance (i.e., throughput) of the system. We'll explore this relationship in the following subsections describing each subcategory of warehouse automation.

Person to goods systems are at the lower end of cost and performance because they are the easiest to deploy by starting with a single robot and then scaling with your needs. At the other end of the spectrum, ASRS systems require a large investment into the facility to deploy the ASRS storage structure.

Flexibility Versus Throughput

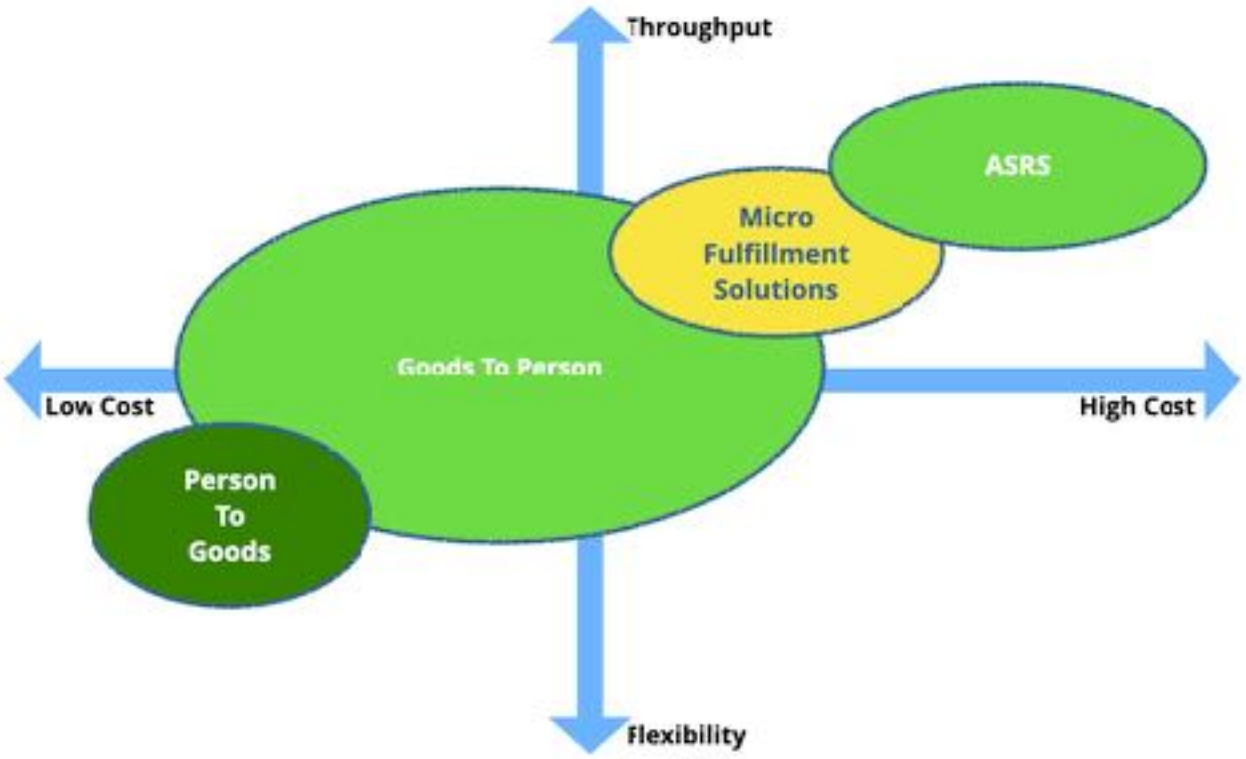


Figure 5 - Throughput and flexibility versus cost.

Another way to compare solutions is to look at system throughput versus flexibility. In Figure 5, we've constructed the graph to compare solutions areas to throughput and flexibility. Flexible automation is a concept that has been deployed in manufacturing for four decades (with industrial robotics). With the maturity of autonomous mobile robots, flexible automation processes for material movement are now possible. Within the warehouse, flexibility is measured by the ability of the system to adapt and scale as needed for the changing needs of your business. Adaptive systems can start small and evolve to meet your needs. Figure 5 provides an illustration of this relationship for the various subclasses of warehouse automation.

Goods-to-Person (G2P) Solutions

G2P is a contemporary method of order fulfillment workflow. Automation plays a key role in this process with the handling of individual or bulk items.

In this category, we are going to take a look at the various forms of G2P workflow in which product SKUs are delivered to an Associate (or robotic-based) picking station. This sub-segment contains the largest number of solutions on the market.

With G2P, product SKUs are stored in either bins, totes or a portable storage unit (PSU). A PSU is typically a shelving unit with open-access space for a low-profile AMR to maneuver under the bottom shelf, lift the PSU, and move it around the warehouse floor.

We've classified Automated Storage and Retrieval Systems (ASRS) under this category.

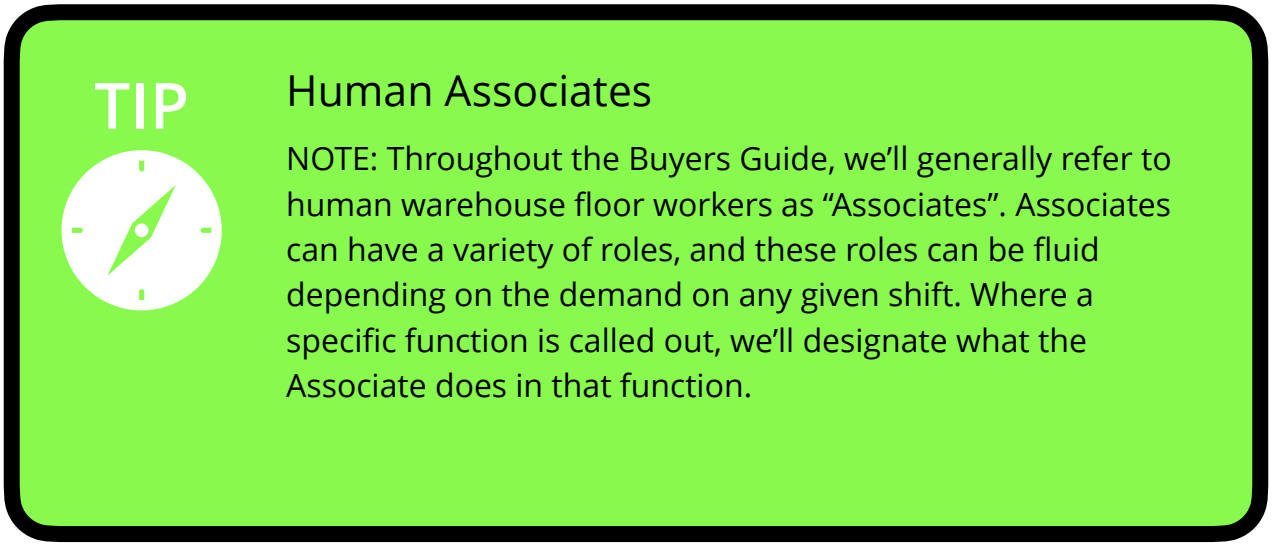


Figure 6 - This image illustrates a portable storage unit being moved with a Kiva Systems AMR. (Image courtesy of Amazon Robotics)

PSU shelves (shown in Figure 6) are initially filled with products and then the PSUs are stored in a grid pattern on an open floor plan in your warehouse. This workspace is reserved exclusively for the goods-to-person (G2P) operation. The concept of G2P was pioneered by Kiva Systems. Kiva was later acquired and is currently used exclusively by Amazon. Since the Kiva acquisition, several competing G2P solutions have emerged to replace Kiva in the general warehouse solutions market.

Complex Orchestration Software

The software required to run a G2P warehouse is complex and often involves machine learning or other artificial intelligence algorithms (Figure 7). The cornerstone of the supervisory aspects of a G2P solution is that it is self-organizing. This means that the supervisory software decides where to store all of the PSUs on the warehouse floor.

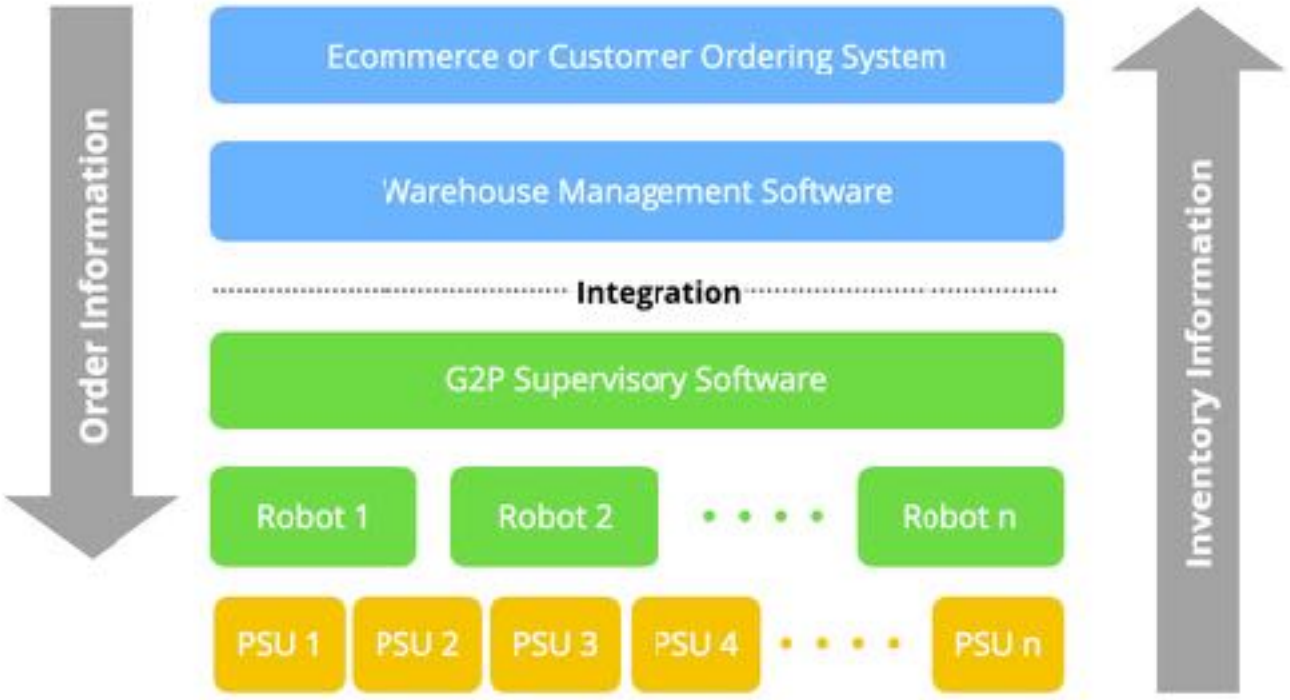


Figure 7 - Architecture of a typical G2P software solution.

Inventory is tracked as it is ingested into the G2P system. The system knows exactly where each product SKU is located and exactly how many items are available. As the PSUs are stored, moved, or queued for picking, the orchestration software continues to keep track of where every PSU is located and what every AMR is doing on the floor. The G2P software coordinates the storage and movement of PSUs and all of the AMRs so that no collisions occur.

Figure 8 - Goods-to-person robot fleet with Associated product storage units. (istockphoto)

When a customer order is processed with a G2P solution, an AMR is directed to acquire the specific PSU containing the target product. The PSU is then picked up and moved by an AMR from its storage location to a picking station where an Associate is directed to pick the proper SKU required to fulfill the order. As shown in Figure 8, a large fleet of AMRs is required to manage the PSU-based inventory. The Associate never leaves the picking station.

Associates can also replenish the inventory contained in a PSU. This task is completed in reverse. An empty PSU is presented to the Associate. The Associate then scans the new SKU, enters the quantity, scans the destination shelf/PSU where the product is stored, and puts the inventory onto the shelf. AMRs then return the full PSUs to a storage location until the product SKU is scheduled for another customer order.

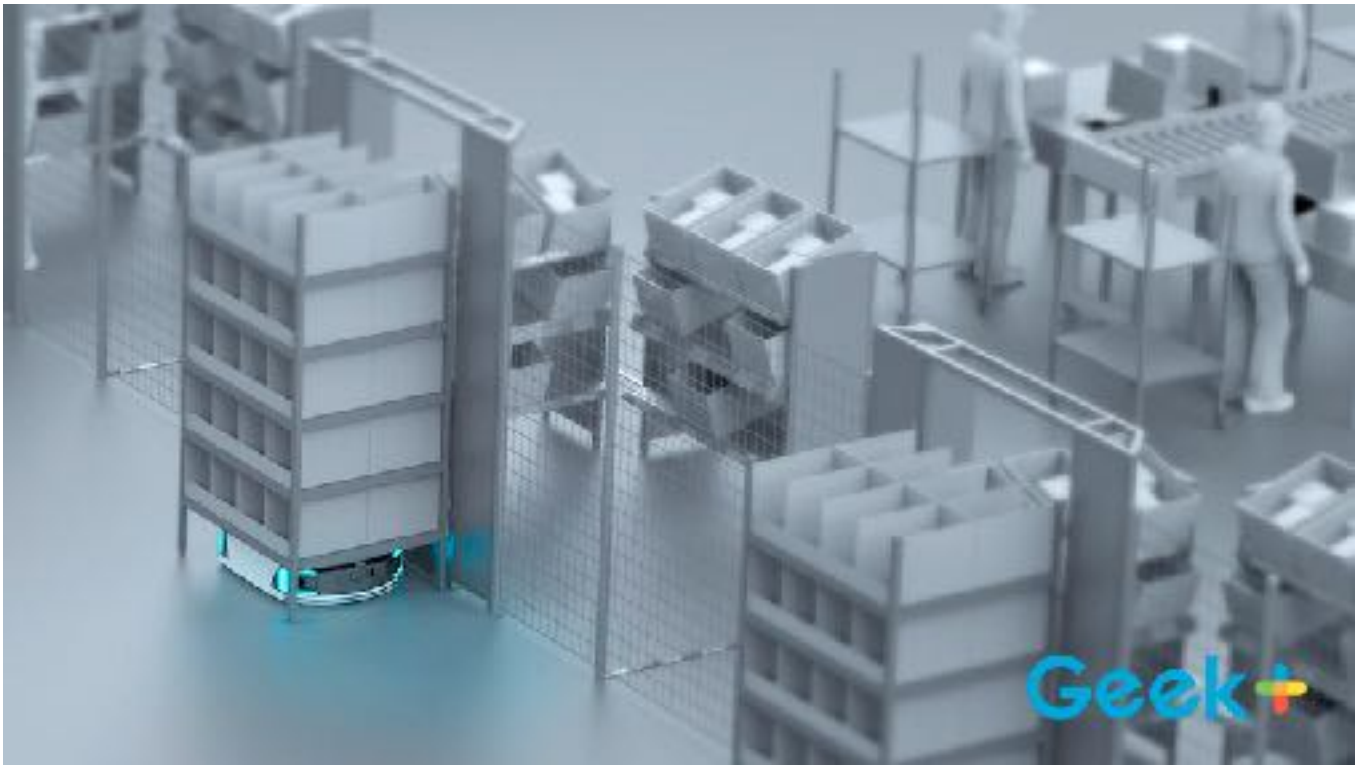


Figure 9 - Example of a typical picking station (image courtesy of Geek+ Robotics).

The advantage of G2P workflow is that Associates don't have to walk the warehouse floor to acquire products for orders. The Associates remain at designated picking stations while the AMRs acquire and queue specific item SKUs for specific orders (Figure 9). The supervisory software manages the entire order picking and order fulfillment processes within the warehouse. Associates are directed to pull an order specific number of item SKUs from a PSU, scan the item(s), put the item(s) into a shipping tote/box, and then move to the next item. In the time that the Associate processes one item, the next PSU and item has been indexed within reach of the picking Associate.

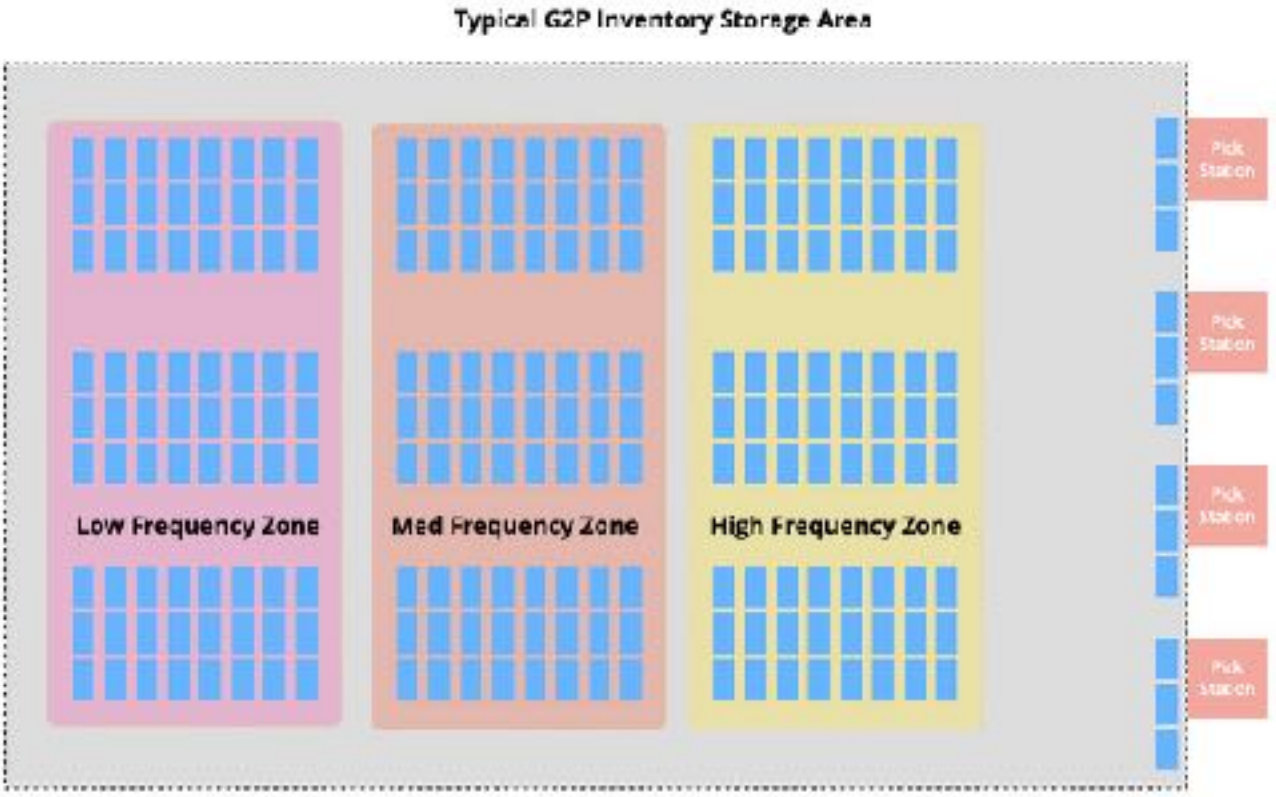


Figure 10 - Floor diagram of a typical G2P warehouse layout illustrating the location of high/med/low frequency SKUs (PSUs).

Figure 10 illustrates how the G2P supervisory software can also dynamically arrange the inventory on the floor so that PSUs with frequently ordered or fast-moving items are stored closer to the pick stations, while less common items are stored at locations further away. This is illustrated in figure 10 above, where you can see the product stored in consumption zones, placing more frequently ordered SKUs closer to the pick stations.

The downside to the G2P workflow using PSUs is that it requires a substantial portion of dedicated warehouse floor space to lay out all of the PSU parking locations. This will be a substantial allocation of floor space. Furthermore, this floor space needs to be dedicated only to robot traffic. While the AMRs can detect obstacles and avoid collisions when moving PSUs around, they are not optimized for replanning movement paths with humans present in their work environments. Therefore, the G2P inventory area is typically fenced off from any general warehouse foot or vehicle traffic. A G2P solution is also a single point of failure if the solution goes offline. Also, the layout continually changes, so there is no easy way for a human picker to locate SKUs stored in the system.

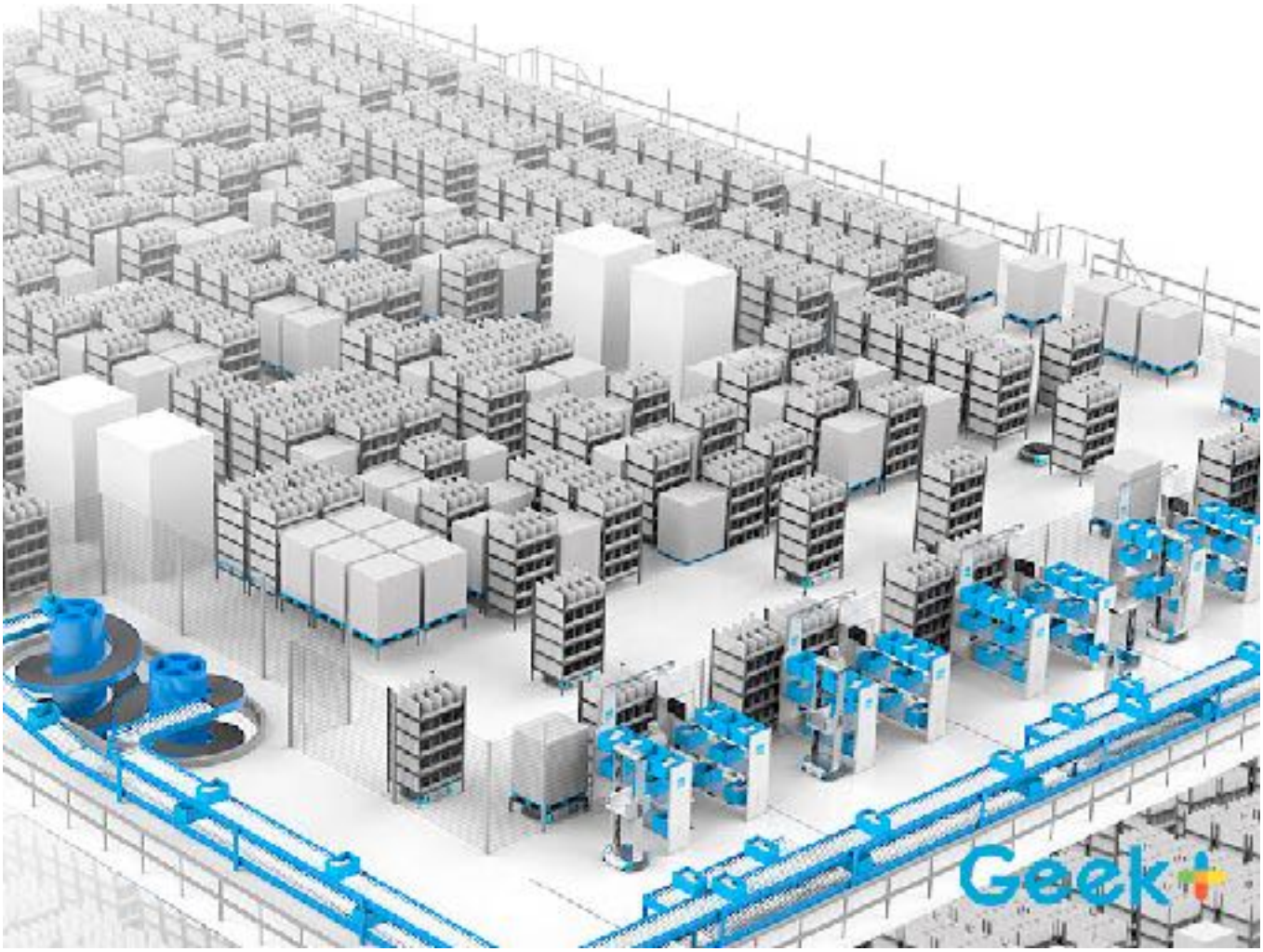


Figure 11 - Here is an example of Geek+ Goods-to-Person warehouse layout. (Image courtesy of Geek+)

Figure 11 illustrates how G2P solutions can be deployed on mezzanine floors. In a tall facility, vertical space can be leveraged if one or more mezzanine floors are built.

Automatic Storage and Retrieval System (ASRS)

Both G2P and Automated Storage and Retrieval Systems (ASRS) operate on the principle that the picker remains stationary while product is brought to the picker to consolidate into customer orders.

There are three additional subcategories (Figure 11) to consider within Goods-to-Person:

1. Bin-to-Person or Bin-based ASRS (bASRS)
2. Cube-based ASRS (cASRS)
3. Unit-load ASRS for larger items, stored on pallets (uASRS)

Figure 11 - The three categories of ASRS solutions. (l — bASRS, m — cASRS, r — uASRS)

bASRS Solutions

Bin ASRS (bASRS) workflow is focused on the movement of smaller sized inventory items. These items are contained in bulk within a bin, tote, or box of maximum size and weight. The process starts with the acquisition of a bin of parts from an inventory location. In a bASRS solution, there is typically an AMR that is specialized for acquiring bins (or boxes or totes) directly from shelves. These AMRs have the capability to change their height to the level of a warehouse shelf and then pull the bin from the shelf. The bin is then transported to the picking station where the proper product count is removed to fulfill a customer order. In some solutions, the “lifting” AMR may transfer the bin to another “relay” AMR that moves the bin from the aisle location to the picking station.

Figure 12 - Caja Robotics is an example of a bASRS solution that leverages existing warehouse shelving and bin storage to automate this workflow. (image courtesy of Caja Robotics)

bASRS can be implemented at a smaller scale than G2P as only a single bin/box of items is pulled from a shelf and moved to the picking station (Figure 12). In addition, there are a variety of ways that bins can be stored and retrieved, resulting in a spectrum of potential solution configurations.

Some vendors restrict their solutions to operations without humans present on the warehouse floor, while other solutions can operate collaboratively with humans. Many of the bASRS solutions on the market can easily be scaled up and down in terms of the number of robots deployed. This means that you can start small and grow as your needs grow.

In this Buyers Guide, we are only covering bASRS solutions that leverage an AMR in some portion of the material transfer.

The advantages of bASRS workflow are:

1. Can utilize existing racking without the need for new shelves or racking investment.
2. Can utilize existing box/bin infrastructure for storing product SKUs.
3. Replenishment and put-away can be automated.
4. Less walking for Associates.

The disadvantages of bASRS workflow are:

1. Only bulk items are pulled from inventory locations.

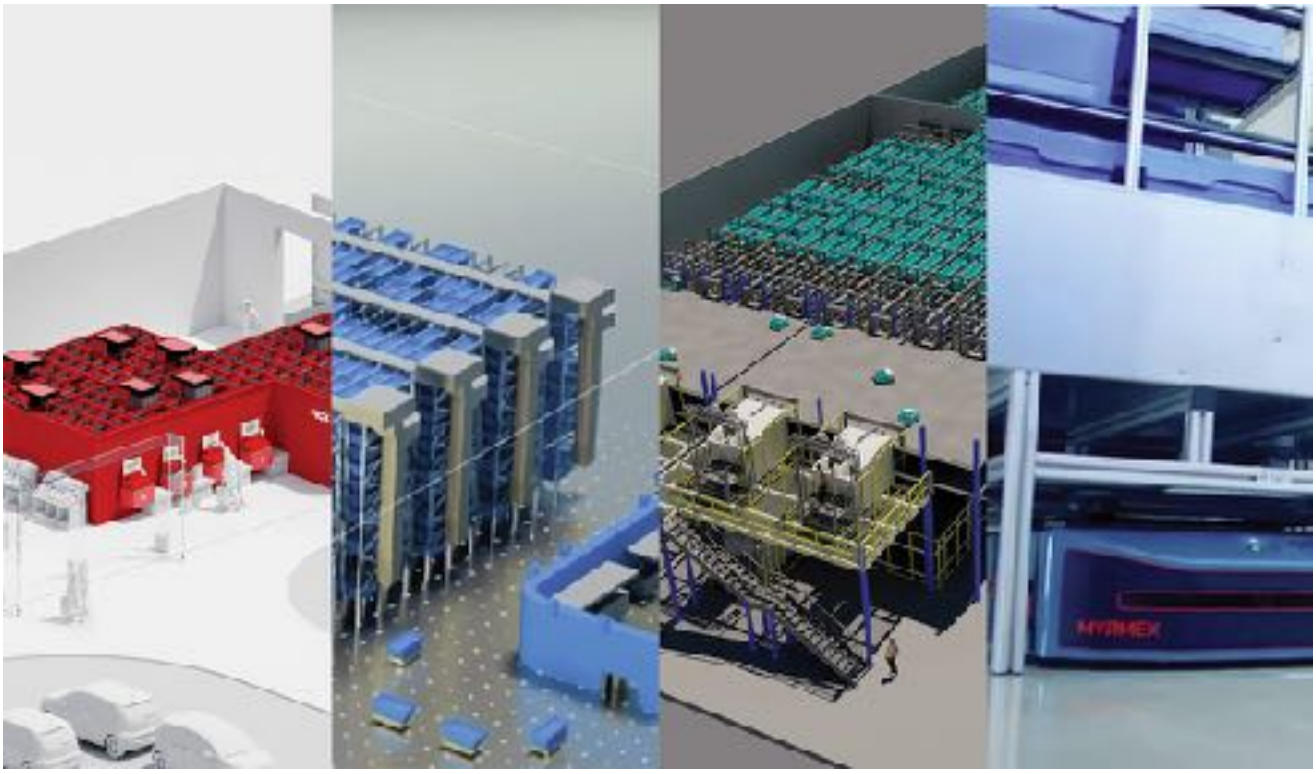


Figure 13 - Cube-based microfullment solutions. (images courtesy of Swisslog, Fabric, Alert Automation and Myrmex)

cASRS Solutions

Cube-based ASRS systems are the subsegment of the G2P workflow that provides some of the densest item storage possible (Figure 13). With cube-based storage, bins or totes are stored in a dedicated storage array. The storage racking system is inaccessible by a human, however, it contains autonomous “shuttles” that can move along a track system to acquire and replace the bins. It’s called “cube-based” storage because all of the inventory is stored inside the volume of a large “cube”.

Several cube-based storage systems have emerged in the last couple of years specifically for grocery fulfillment. The grocery fulfillment use case is particularly optimized for cube-based storage because the system is designed to be capable of operation within a cold room (refrigerated storage). It is also optimized for the high-mix, high-volume operations necessary for fulfilling grocery orders. Many of these cube-based storage solutions integrate AMRs to move the bins between the storage array and the order picking stations.

The advantages of cASRS workflow are:

1. The highest density of product storage possible.
2. High throughput.

The disadvantages of cASRS workflow are:

1. Requires dedicated floor space for the storage structure.
2. Can scale, but requires a minimum floorspace to start.

uASRS Solutions

For storage of unit-loads or for the handling of bulky and/or heavy products (such as hard goods, auto parts, etc), you have the option of unit-load ASRS (uASRS). An AMR-based uASRS can leverage existing multilevel warehouse pallet racking and aisle space, and perform all of the pallet movement with autonomous fork trucks. uASRS solutions have historically been implemented using dedicated autonomous cranes and this is an option for very tall racking areas that will be dedicated to 100% autonomy. However, we're only going to outline the uASRS solutions that leverage AMRs in this Buyers Guide.

Figure 14 - Unit loads can contain either large, bulky, heavy items on a pallet or high-volumes of smaller items stored in boxes.

To put or get the product out of the racking, an AMR overhead fork truck will move to the location of a specific item and then maneuver the forks to acquire the pallet (Figure 14) from any level in the racking. Returning to ground level, the overhead lift will place the

items at a staging point at the end of the aisle for a transfer AMR fork truck or AMR tugger, to acquire and move the pallet to the shipping or manufacturing area.

Many of the existing electric fork truck companies have successfully converted their manual trucks to autonomous vehicles. Therefore, it's entirely possible that you can take advantage of using your brand of fork truck supplier for this new type of automation. Autonomous fork trucks will leverage the existing parts and components as the manually driven versions. In addition, the majority of these vehicles can be converted to manual drive with the flip of a switch, giving you more options for how you operate your warehouse.

The advantages of uASRS workflow are:

1. Can utilize existing racking without the need for new shelves or racking investment.
2. Can be quickly switched from autonomous to manual if necessary.
3. Put-away can be automated.
4. Safer than manual fork trucks as fewer humans are in danger if shelving collapses.

The disadvantages of uASRS workflow are:

1. Requires a large initial investment to begin.

Summary

In summary, G2P workflows bring a specific order item to a picking station where the item is pulled from bulk, scanned, and packed for a customer order. There are numerous methods to store and retrieve inventory, but the hallmark of G2P is that the picker remains stationary while the bulk product is presented for order picking.

The advantages of G2P workflow are:

1. Can utilize existing racking without the need for new shelves or racking investment.
2. Can utilize existing box/bin infrastructure for storing product SKUs.
3. Replenishment and put-away can be automated.
4. Less walking for Associates.

The disadvantages of G2P workflow are:

1. Individual items are not pulled from inventory locations (with the exception of unit-load ASRS solutions).

Person-to-Goods (P2G) Solutions

In P2G workflow, order picking Associates walk the aisles to pull order-specific quantities from in-aisle inventory locations. SKU items remain at their inventory locations until it's pulled for a specific order.

You may already have Associates pushing carts through the warehouse as they pull items for specific orders. Bins, totes, or boxes are placed on the carts to help singulate specific customer orders. In addition, P2G fulfillment also covers mixed picking methods such as discrete, cluster, batch, zone, or wave.

- **Discrete Picking:** With discrete picking, or single order picking, Associates fulfill each order one at a time.
- **Cluster Picking:** With cluster picking, Associates group multiple orders into one unit and process them simultaneously.
- **Batch Picking:** With batch picking, Associates compile a batch of the orders by picking from a single SKU or one SKU at a time.
- **Zone Picking:** With zone picking, the entire picking area is divided into different zones and each picker is assigned to a particular zone. So, the pickers perform order picking on multiple orders within their zone.
- **Wave Picking:** With wave picking, orders are grouped into waves and assigned to specific pickers who process the orders based on a variety of variables. Your WMS evaluates all sorts of these variables including delivery times, transportation schedules, and labor schedules to break up the orders into waves.

When you automate your existing P2G processes with an AMR, there are two immediate impacts to your order picking Associates:

- First, they no longer have to walk the long distances between the inventory aisles and the order pack out stations. The AMR takes over this long-walk process.
- Second, all of your manual pushcarts are replaced with either autonomous carts or AMRs with boxes/totes. In an automated P2G workflow, customer orders are sent to a specific AMR. That AMR then moves to the inventory location of the SKU, and guides the Associate to pick the correct SKU.

The P2G vendors deploy a variety of methods to interact with the Associates during this guiding process. Some vendors leverage tablet screens to alert the picker to the correct SKU number, other vendors employ pick to light or voice solutions. To ensure quality, onboard RFID or barcode scanners confirm that the Associate has picked the correct SKU and placed it into the correct order bin before they can move on to the next order pick.

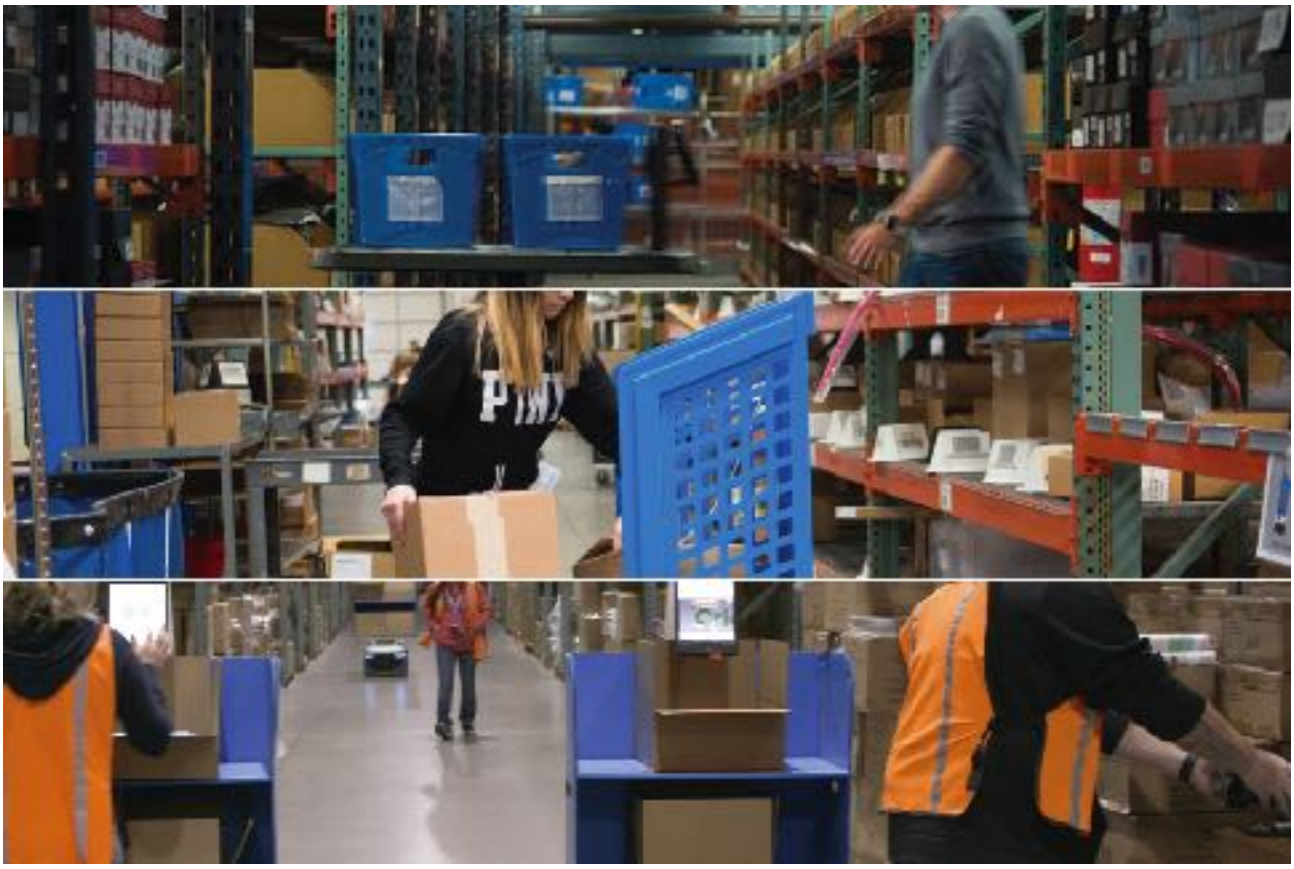


Figure 15 - With P2G solutions, the robot leads the Associate to an inventory location. (Images courtesy of 6River Systems, Locus Robotics and Fetch Robotics)

The advantages of P2G workflow are:

1. Training of new Associates can be completed in a short period of time. They can learn on the job with limited options to make mistakes (system checks work at each step).
2. P2G systems are easy to deploy with a small pilot to test feasibility, with minimal impact on warehouse operations. The system can then easily scale as needed.
3. Inventory SKUs remain at source locations, reducing inventory disarray.

4. Utilizes existing racking without the need for new shelves or racking investment.
5. Utilizes existing box/bin infrastructure for storing product SKUs.
6. Human order pickers are removed from long-distance walking which can help reduce exhaustion and improve productivity.
7. Reverse logistics (put away) can function within the course of normal operations.

The disadvantages of P2G workflow are:

1. Associates continue to walk aisles (they are not completely removed from the workflow).
2. Hard to optimize inventory locations to react to seasonal needs or marketing demands.

Inventory Counting

Automated and near real-time inventory counting is every warehouse manager's dream! Automated solutions have emerged that make it possible to have near-real-time inventory information. There are a variety of methods for counting inventory, some of which are better than others for certain classes of product.

Let’s look at a few.

RFID Tag Reading

If you attach RFID tags to your products, then you’re in luck. There are a variety of proven solutions already on the market for warehouse RFID tag reading. These solutions operate by deploying an RFID reader array on top of an AMR and then simply driving around on the warehouse floor to survey and count all of the product RFID tags. This can be a continuous process, or it can be deployed between shifts or overnight (in the dark!). Ground-based RFID AMRs may have trouble scanning the RFID tags on items stored in inventory locations above the first level in your racking. This is due to the nature of the antennae on the data collection device. However, we’ve included at least one drone-based RFID tracking solution in our solution list, as drones are uniquely designed to help solve this issue. If you have multi-level racking, you might consider this solution.

Visual Inventory

Counting items that do not use RFID tags is a little more challenging. However, with the help of machine learning and camera/lens enhancements over the last several years, it's now possible for a vision camera-based solution to drive (or fly) around your warehouse and visually count inventory items. These solutions can visually read barcodes, SKU numbers, inventory location codes, QR codes, product names or they can be trained to visually identify specific items. There are many factors that can affect the accuracy of these visual-based solutions, including lighting, the orientation of individual items, and interference by racking/shelving.

Figure 16 - Images of warehouse inventory counting robots/drones. (images courtesy of Keonn, Fetch Robotics, Ware Robotics and Corvus Robotics)

Visual inventory of front-of-house items in retail and grocery has evolved quickly over the last two years. These AMRs work next to the general public to inventory items on the shelf and alert store managers to stock out situations. Currently, there are only a small number of viable, warehouse inventory counting solutions (see Figure 16). However, we expect this market to grow in the coming years.

Sortation

Sorting of items is a specialized workflow with multiple uses. In large distribution centers, items can have multiple starting/ending points. For high volume sorting applications, hard automation may still be the requirement to meet throughput requirements. When flexibility is important, AMR-based sortation is now a viable option.

You may be able to remove existing fixed conveyors and replace that structure with an AMR-based sortation solution. This may enable you to reallocate the floorspace to other uses. Sorting AMRs typically either have a tilt-bin or a short conveyor on top of the base AMR platform. The tilt-bin concept can be used to both consolidate SKUs into customer order boxes/bins as well as consolidate shipping boxes/envelopes into outgoing logistics.

Figure 17 - Tompkins Robotics has developed a unique sorting robot solution (image courtesy of Tompkins Robotics)

These solutions can be used in order consolidation or work in process (WIP) workflows where one or both endpoints of material movement varies often. When fitted with a conveyor topper, these AMRs can pick up items from one conveyor out-feed and put it as another conveyor in-feed point.

Autonomous Sortation and Piece Picking

Several autonomous sortation and piece picking solutions have emerged in recent years. This application is also known as singulation, where individual items are separated from a bin of items. For decades this was a “holy grail” application: it was impossible to do repeatedly, and robustly outside of lab environments. However, the combination of robotic arms, end-effector evolution, machine vision and artificial intelligence (see figure 18) have solved this problem.

Figure 18 - Bin picking robots use vision and AI to identify items (Image courtesy of Berkshire Grey)

We’re not covering bin picking solutions in this edition of the Buyers Guide, however, here is a short list of autonomous bin picking and sortation solutions:

- Ambidextrous.ai — https://www.ambidextrous.ai/
- Berkshire Grey — https://www.berkshiregrey.com/
- Covariant.ai — https://covariant.ai/
- Dexterity.ai — https://dexterity.ai/
- Kindred.ai — https://www.kindred.ai/
- Right Hand Robotics — https://www.righthandrobotics.com/
- Soft Robotics — https://www.softroboticsinc.com/

A Primer On Autonomous Mobile Robots

Learn What An Autonomous Mobile Robot Is Made Of

What Is An Autonomous Mobile Robot?

A Quick Introduction To Autonomous Mobile Robots

Let's dig into the details of exactly what an autonomous mobile robot (AMR) is. Along the way, you'll learn the basic things that will help you differentiate the various vendors and solutions available on the market. Armed with this information you can make a more informed buying decision.

Basic AMR Anatomy

The basic components of an AMR are simple. Each AMR base has motors and wheels to drive it around. It may also include additional casters to support the weight of the robot and the payload. The AMR has sensors to see or sense its surroundings. These sensors may include vision cameras, lasers and even sonic (sound) range sensors. Each robot has its own onboard processor responsible for controlling the safe operation and navigation of the robot. All of this technology is packaged onto some type of chassis which can support the weight of both the robot and its payload. Figure 19 highlights some basic features.

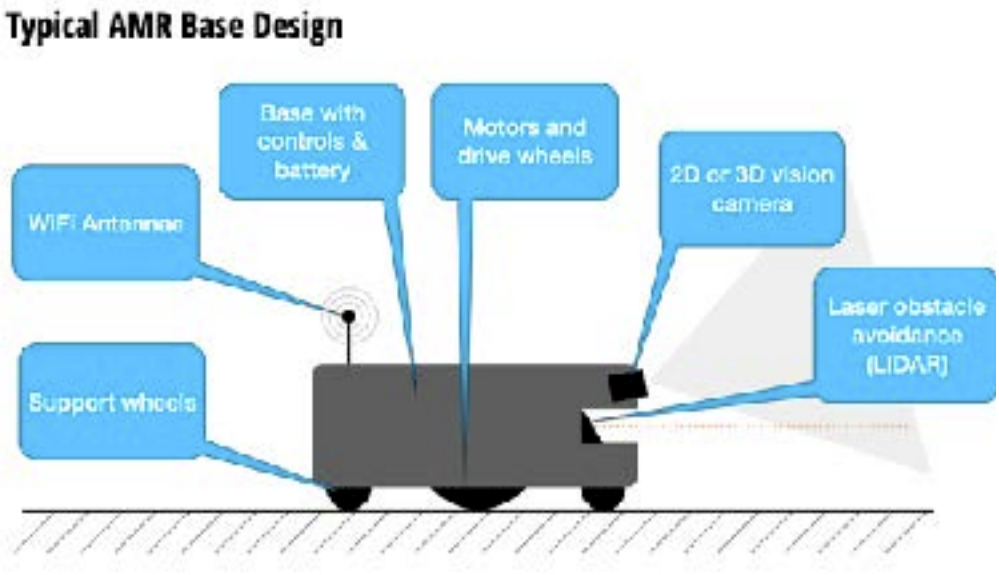


Figure 19 - Illustration shows basic AMR features.

The AMR Battery Powers Everything Onboard

Lastly, each robot includes an onboard battery that powers both the robot and any payload. Examples of powered payloads include user interface tablets, barcode scanners, active conveyors, PSU lifting mechanisms, robot manipulators, cameras, lights or other sensor packages.

Automated battery charging is one differentiator between solutions. With automated charging, the AMR is completely autonomous and can plan for, and reserve enough robot battery power so that the AMR can return to its charging station autonomously, park on the charger and initiate a charging cycle. Some solutions also include “opportunity charging”, in which the AMR will sneak over to a charging station and “top off” its battery when it's not scheduled for a warehouse task.

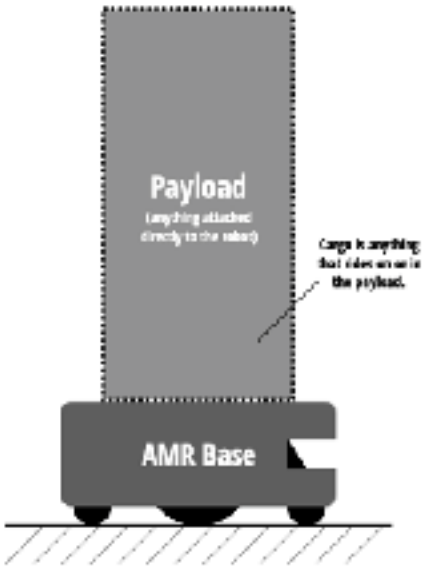


Figure 20 - The payload is defined as anything permanently affixed to the robot.

The majority of solutions outlined in this guide consist of an AMR platform combined with a specialized payload. For most vendors, the AMR platform is a mature solution that was engineered, manufactured, and released for general purpose applications. As shown in Figure 20, the payload area is where cargo, in the form of boxes, bins, or totes is carried. The simplest warehouse solutions are an AMR with an affixed shelving unit. More complex payloads include PSU or cart moving interfaces, or even robotic manipulators (to pull items from shelves).

Collaborative Robotics

AMRs belong to a class of robotics called collaborative robotics or “cobots”. Cobots have emerged in the last decade and are differentiated from the classic “industrial robots” which required guarding and other safety measures to separate humans from the robots.

Cobots are designed to safely operate in the same workspaces as humans (as shown in Figure 21). For AMRs, this means that the autonomous mobile robots will stop their progress or plan a path to avoid running into a human or other obstacles.

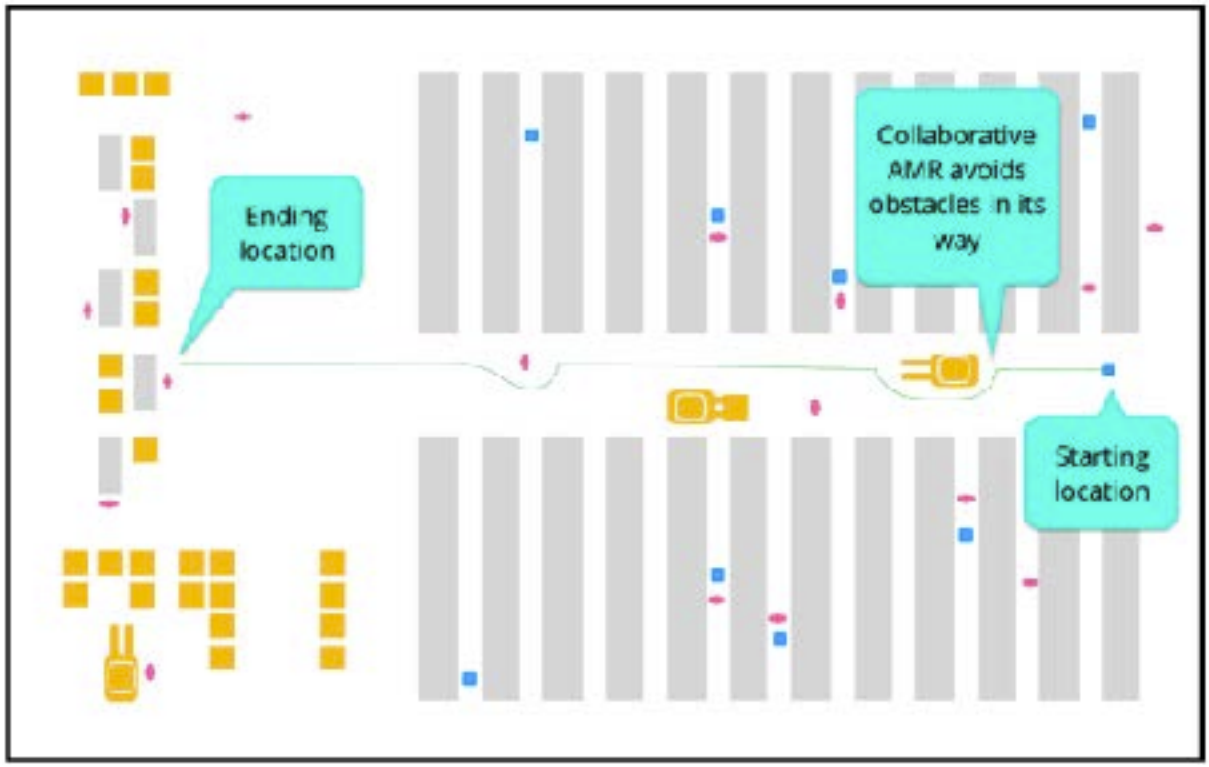


Figure 21 - AMRs can replan and avoid obstacles during material movement.

AMRs will avoid obstacles that they see in their path. If the AMR doesn’t have a clear path around an obstacle (like a human, or a fork truck, or a pallet), then it will plan another path through the facility to get where it needs to go. This may include reversing course and taking another (open) hallway or aisle way. IF there are no alternative paths, the AMR may decide to wait until the path clears, or cause an alert to the operator or supervisor.

Basic AMR Functionality

Here's a short list of basic functions that every AMR includes:

- Facility mapping function (enables free-roaming).
- Obstacle avoidance (so that it doesn't hit anything or anyone).
- Localization (i.e., keeping track of where it is on the building map).
- Emergency stop button (to "kill power" to the robot).
- User control function (may be onboard the AMR or in an app for your PC, tablet or smartphone).
- Autocharging (AMR can find charger and recharge when the battery gets low).

Figure 22 - Autonomous charging is a key feature that enables the AMR to keep its battery charged throughout its workday.

Advanced Features

- Opportunity charging (AMR can grab a few minutes of charge between tasks).
- Fleet Management (control more than one AMR in the building at a time).
- Cloud-based, remote monitoring/operations.

Calculating Your Return On Investment

Included with the Buyers Guide is a spreadsheet for calculating your return on investment (ROI). The spreadsheet was designed for the buyer to enter a few unique parameters and then quickly calculate a time period for the return on the investment.

This tool is fully editable and will be useful for you during your buying process.

The Warehouse Solutions Database

The data contained in the products database represents over 100 hours of intensive research. Our research team pulled all available data from each product page, reconciled it into a standard format and then normalized all of the data. The result is this resource which is easily searchable, sortable and efficient for narrowing your search.

If you would like access to our solutions database for your unique market research needs, please contact our sales team for a project quote: sales@mobilerobotguide.com

Vendor Websites

Both the product database and the solution pages include live links to vendor websites so that you can quickly link to more specific information about each solution. All of the links were accurate at the time of publication, however the content is subject to change at any time.

Some information contained in the Buyers Guide is not available on the vendor websites. This information was acquired through interviews directly with the vendors and is (currently) exclusive to the Buyers Guide.

Buying Process

This section includes a useful set of questions to help you through the buying process.

Start by answering the following questions about your facility before you interview vendors.

General Questions:

- Do you currently have any automation in your warehouse? If so, what have you already automated?
- Do you have any fixed conveyors in your warehouse? Are you planning to keep or replace this conveyance with automation?
- Which warehouse functions do you want to automate?
- What is the typical throughput of your warehouse during non-peak periods? (number of orders and/or picks)
- What is the surge throughput of your warehouse during peak periods? (number of orders and/or picks)
- Do you have capital budget approved for this project, or are you interested in leasing or subscription-based solutions? (Will you lease or buy?)
- Do you expect the solutions to operate safely with other human workers?
- Will fork trucks and tuggers operate in the same area as the AMRs?

Facility Specific:

- What is the floor surface? Is it flat? Do you have any significant transitions between floor areas (gaps or sills)?
- What are the environmental conditions in the warehouse? (Humidity, temperature)
- Do areas exist with power outlets for robot charging stations?
- Do you have multiple floors? If YES, is there an elevator between floors?
- Do you expect the robot to use the elevator?
- Do you have multiple buildings?
- Do doors need to be open/closed along the path between rooms?

Questions for Solutions Providers

Use this set of questions to learn about vendors solutions.

Capabilities:

- What's the maximum speed of the robot?
- What's the stopping distance of the robot? How quickly can it stop when it detects something in its path?
- What's the maximum payload for each robot?
- Can the robot see empty pallets on the floor and avoid hitting them?
- Can the robot see fork truck tines and avoid hitting them?
- Can the robot avoid hitting overhanging items in the path of any payload?
- How long can each robot run on a single battery charge?
- How long does it take to recharge the battery if it's completely run down?
- Can the system take advantage of opportunity charging? What's the cost of additional chargers?
- Does your system have wireless charging?
- What are the networking and WiFi requirements for the solution? Can the system operate without WiFi?
- Can the robot operate outside the facility?
- Can the robot operate in the dark (lights out)?

Deployment Questions:

- How long does it take to map a new facility?
- What (if any) localization features are required to be added to the facility? (QR/barcode, laser targets, other navigation devices)
- How long does it take to deploy the first robot in a new facility?

- Is it easy to relocalize the robot if it gets “lost”? How do you do this?
- How do you integrate to our enterprise software systems? What’s the cost for this integration? Is it customizable?
- How easy is it to add a new robot to the system for extra throughput and capacity?

Software And Reporting:

- Do you have online reporting with daily/weekly/monthly reports? Is this customizable?
- Can I control the robot remotely through a web interface or phone/tablet app?
- Does the system connect to the cloud/internet? What security protocols do you implement to prevent unauthorized access to our network? How much bandwidth does your solution consume?
- How does the job scheduling software work? Is it easy to interrupt the job flow and reschedule or reorganize tasks?
- How does the system recover from an error?
- How do you ensure that no customer orders are either lost or duplicated?
- How often do you release software updates? How are these updates installed? Do you have rollback capability if something goes wrong?
- Do you have a facility map that shows me where the robot is and what it is doing?
- Do operators get alerts if there is a problem or as tasks are completed?
- Do you have remote troubleshooting capabilities if something goes wrong?
- Does the solution include fleet management to easily schedule and control multiple robots running in the same facility?

Field Service / Repairs / Preventative Maintenance

- How long will the battery last before it needs to be replaced? What is the battery replacement cost? Does the software track when the battery is starting to fail?
- What other items need to be maintained on the robot on an ongoing basis?
- Do you have local field service agents?
- How quickly can you send a field service agent to our facility if there is an issue?

Product Data For Person-to-Goods AMR Solutions






6 RIVER SYSTEMS

Chuck/Chuck+

Market: Person-to-Goods
Traction: Differential
Guidance: LIDAR
Localization Method: SLAM
OS: UNKNOWN

6 River Systems

Waltham, Massachusetts
Founded: 2015
Employees: 190
Investment: $46M
Price: Starts at $400,000

USA based 6 River Systems brings you Chuck, a robot that uses Artificial Intelligence and Machine Learning to help your Associates work faster. Chuck leads your Associates through their work zones to help them minimize walking, stay on task and work more efficiently.

Chuck+ is similar in every specification to Chuck, with the exception of an additional 150 mm (5.9 inch) to its width. Chuck is useful when you need more area on the AMR for holding boxes or totes.

Chuck can be used in all put-away, picking, counting, replenishment and sorting tasks. Chuck doesn't need wires, cables or stickers to move around. State-of-the-art sensors help it navigate in any warehouse without any new infrastructure. Chuck is aware of its surroundings, moving swiftly around boxes and racks and slowing down when equipment or people are in the area.

Product Name	Chuck	Chuck+
Length (mm)	1067	1067
Width (mm)	600	750
Height (mm)	1600	1600
Payload (kg)	90.7	90.7
Towing (kg)	-	-
Lift Load (kg)	-	-
Weight (kg)	**-**	**-**
Speed (mm/s)	-	-
Robot Runtime (hr)	16	16
AMR	Y	Y
AS/RS	N	N
RaaS	Y	Y

Chuck doesn't get tired and can run 24/7 with the latest in battery technology for rapid recharging. With large, modular and multi-level workspaces, Chuck is one of the most configurable collaborative mobile robots in the industry and can handle up to a 90.7 kg (200 lb) payload.

Sales Contact: info@6river.com

Website: https://6river.com/meet-chuck/

Visit our website to keep up on the latest autonomous mobile robot news and information.

mobilerobotguide.com