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Indoor Autonomous Mobile Robots: A Maturity Framework

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The market for robotics is growing rapidly, which is leading to the emergence, and subsequent maturity, of mobile service robots across a broad range of industries, applications, and use cases. Mobile service robots are gaining ground in manufacturing, logistics and distribution, hospitality, healthcare, and retail, among other areas. As the market for these robots evolves and these devices are used in new ways, it becomes important to look at what it means to be an autonomous mobile service robot and evaluate the differences relative to the terms "autonomous" and "mobile." This paper defines the levels of maturity for these machines to help buyers better understand what separates these robots in terms of navigation, tools, and interfaces required to be truly autonomous as well as to help the manufacturers of these devices benchmark the capabilities of their own robots and plans for future development.

Introduction: Not All Autonomous Mobile Robots Are Created Equal

Mobile automation devices have been in place in certain industries (e.g., manufacturing, warehousing, and distribution) for several decades. Today, however, we are seeing an explosion in new applications as a result of the increasing levels of autonomy for indoor mobile robots given the rather recent and rapid increase in their capabilities and levels of maturity. It is important to note that while mobile robots are deployed in various environments, this paper focuses exclusively on indoor mobile robots (we refer to the robots only as autonomous mobile robots in the remainder of the paper). The evolution of this technology has brought up an interesting question around how to define the term "autonomous" relative to mobile robotics, or rather how to differentiate between different levels of autonomy. Different types of devices from different manufacturers (in some cases, even technology additions to more traditional vehicles such as forklifts) have introduced new ways in which an autonomous mobile robot will navigate and interact with its environment; there are also new and different tools and interfaces that enable automation.

Akin to the levels of autonomy for self-driving cars, where level 0 is entirely human operated and level 5 requires no driver, different levels of autonomy exist for mobile robots. For this model, we are looking at the following elements as factors in determining the levels of autonomy for autonomous mobile robots:

- **Navigation:** The manner and capacity with which the autonomous mobile robot navigates its movement throughout a facility and the degree to which it is autonomous and can accommodate for the complexity and variability of the environment on its own
- **Material handling:** The capability to autonomously handle material (Material handling consists of two key characteristics: material transport and material transfer. Material transport relates to the robot's ability to move material throughout a facility; material transfer relates to the robot's ability to load and unload material.)

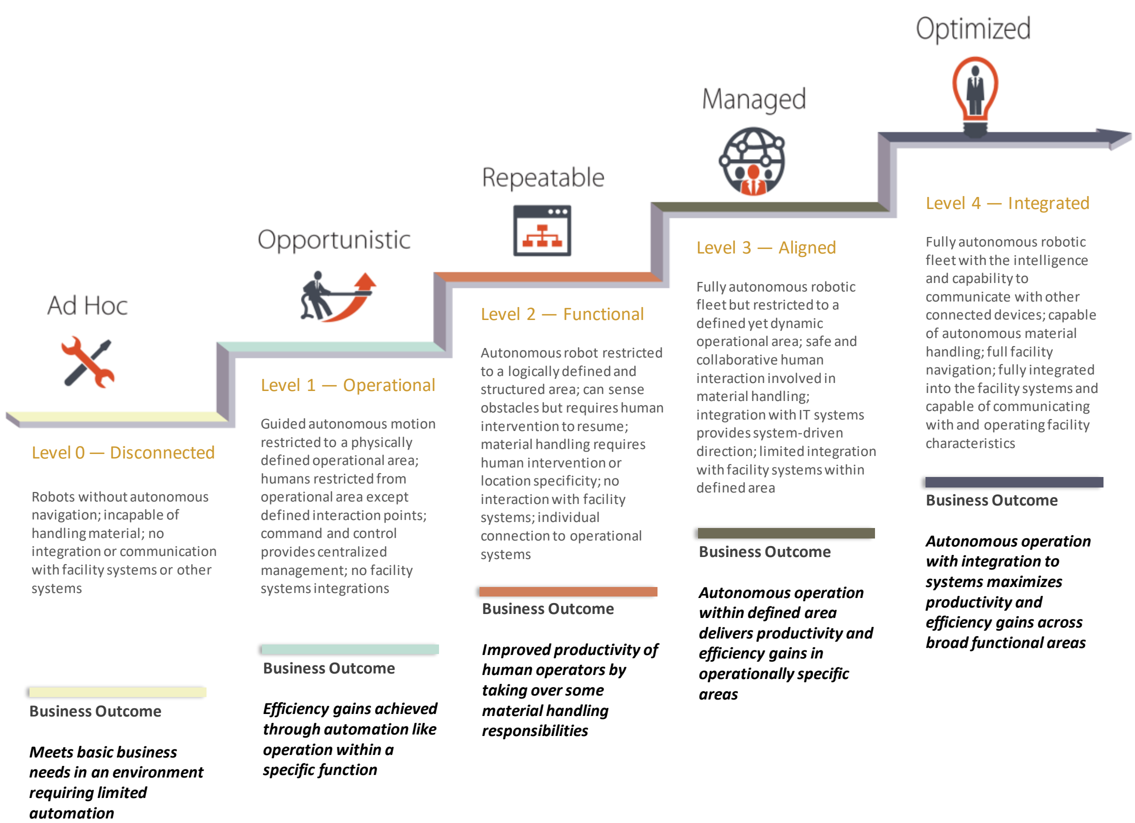
- **Facility systems integration:** The ability of the autonomous mobile robot to interact with, communicate with, and understand the physical environment in which it operates
- **Machine-to-machine (M2M) communication:** The ability of the robot to communicate multidirectionally with other machines and IT systems
- **Unattended management:** The degree to which the fleet can manage itself and the ability to handle unresolvable conditions externally

Autonomous mobile robots are in use in a variety of industries and types of facilities, with some robots better suited for certain uses than others. Indeed, the requirements of a robot operating within a distribution warehouse will differ from those of a robot operating within a hospital, which is why it is important to develop a model to classify different robots and better align the capabilities to different job roles.

Figure 1 outlines the characteristics of mobile robots at each of the five defined levels of maturity.

FIGURE 1

Levels of Maturity for Indoor Autonomous Mobile Robots



Source: IDC, 2017

Defining the Levels of Autonomous Mobile Robots

Autonomous mobile robots come in a variety of sizes, shapes, and designs and have varying features and functionality. In addition to the purpose-built robot, there are automatic guided vehicles (AGVs) and even the capability to add sensors and computational navigation to vehicles such as forklifts to turn them from manually operated machines into autonomous vehicles. In developing the maturity model, we have identified the following five elements to create a reasonable comparison across the broad range of robots:

- **Navigation:** The way the robot determines how and where to move throughout a facility. In some instances, the robot is guided by beacons, markers, painted grids, or guidewires, and this would reflect a lower level of autonomy. In other instances, the robot is driven by a robust mixture of software and sensors to locate itself independently in the space for navigation. In addition to facility navigation, this element also considers the ability of the robot to detect and avoid obstacles within its path. Relative to obstacle avoidance, several approaches exist that evolve with the level of maturity. Some installations require "no go" space where only robots operate, some robots will detect an obstacle and stop operations until a human signals that it is safe to continue, and the most mature robots detect and identify the type of obstacle and appropriately respond.
- **Material handling:** The capability for robots to pick up and deliver material. This feature can take on several forms, such as the autonomous forklift that picks up and delivers pallets but is less sophisticated in other areas. Some robots can automatically pick up and drop off loads and place them in precise locations. Some robots have onboard bins that require a human to perform the pick-and-pack function; others are equipped with robotic arms and other electro-mechanical effectors that enable them to autonomously handle material.
- **Facility systems integration:** The capability for a robot to interact with the physical environment in which it operates. This includes the ability to autonomously open and close doors, call and operate elevators, and respond to building alarm conditions.
- **M2M communication:** The capability for individual robots to communicate multidirectionally with IT systems, other robots, and other equipment within a facility. More mature robots take direction from IT systems and communicate the status of jobs, location, and other information back to the IT systems. Multidirectional communication increases the level of automation. Additionally, this effort considers the ability of the robot to communicate with other robots while in operation to orchestrate the movement of material and tasks.
- **Unattended management:** The capability to run unattended and without human interaction. The most mature robots will be selected for the most complex environments, which introduces the risk of encountering unforeseen situations. In these instances, the most mature robots will have the ability to autonomously understand their situation, properly communicate their status, and allow external control and intervention to overcome any extreme issues.

This maturity model considers each of these five elements when defining the levels of autonomy described in Table 1. However, some devices may exhibit characteristics of higher maturity levels in one or more areas but remain in a lesser category of autonomy because of a lack of functionality in other areas. A robot's ranking must take into account the robot's capabilities across all criteria and may be only as mature as the lowest level the robot has achieved across any of the five criteria. For example, a robot that is at level 4 for navigation, material handling, M2M communication, and unattended management but is only at level 3 for facility systems integration is classified as a level 3 robot.

TABLE 1

Autonomous Mobile Robot Characteristics

Autonomy Level	Navigation	Material Handling	Facility Systems Integration	M2M Communication	Unattended Management
0*	Mobile, but no autonomous navigation capabilities	Not capable of handling material	No integration into facility systems	No connection to other devices	No capacity for remote management or error signaling
1	Guided by markers, beacons, floor grids, etc.; not capable of autonomous obstacle avoidance; unsafe to operate in the same space as humans	No capability for automatic material handling, only capable of handling material that meets specific design characteristics	Sensors read navigational markers, but no interaction with other aspects of the physical facility	Robotic command-and-control system provides a central management platform that manages the robotic fleet; individual devices do not communicate directly with other devices	No capacity for remote management but can provide visual signals to human operators when encountering an error
2	Autonomous operation within a defined area, capable of identifying obstacles but requires human intervention to resume operation when faced with an obstacle	Can handle various shapes and sizes of material, requires human intervention to load and unload, may require positioning specificity, requires human intervention to resume movement when stopped to load or unload material	No capability to interact with facility systems such as doors and elevators; at times of need, can signal a human operator when it is in position and provides visual alerts via onboard beacons or touchscreen display when operating around facility characteristics	Integration with operational systems allows for data sharing about job status; robots can communicate with other robots on the same command-and-control system but cannot communicate with any other connected devices	Can send a digital signal that it has encountered an obstacle but requires onsite manual intervention to correct any issue
3	Autonomous operation within a defined area, capable of safely avoiding obstacles and human operators, can autonomously optimize its path	Can be configured to handle a variety of shapes and sizes of material, requires human intervention to load and unload, recognizes when it is loaded/ unloaded and autonomously resumes movement	Restricted integration with facility systems, capable of interacting with authorized doors to enable freedom of movement within its defined area of operation	Integration with IT systems enables system-driven direction to the devices and communication of task-related data; robots communicate with other robots in the fleet to optimize robotic tasks based on location and current situation	Can send a digital error signal and be remotely operated by a human operator onsite, but there is no capacity for offsite remote operation; no active status monitoring via computer algorithms

TABLE 1

Autonomous Mobile Robot Characteristics

Autonomy Level	Navigation	Material Handling	Facility Systems Integration	M2M Communication	Unattended Management
4	Autonomous operation throughout a facility, capable of safely avoiding obstacles and humans, can optimize its path throughout the facility	Capable of autonomously loading, unloading, and transporting material; can manage a variety of different sizes, shapes, forms of material	Fully integrated with facility systems enabling movement throughout a facility; capable of interacting with facility characteristics such as doors elevators, and other equipment to enable freedom of movement throughout the facility	Fully integrated with IT systems and other connected operational equipment, receives and performs tasks without human intervention, communication is enabled across a fleet of robots and other connected devices to optimize end-to-end processes, captures and communicates information enabling advanced analytics and robotic systems optimization	Robot fleet is connected to a self-monitoring system to detect operation anomalies; robots are equipped with the capability for offsite remote management to take over in the instance that an unresolvable obstacle is encountered

*No robot will meet all level 0 characteristics. If it did, it would not be a robot. However, any robot that meets any level 0 characteristics is classified as a level 0 robot.

Source: IDC, 2017

Benefits: The Value of Autonomous Mobile Robots

In the modern business environment, companies across verticals are looking at robotics to inject automation into their operations. Indeed, as the level of autonomy increases, so does the level of value received. Buyers of mobile robots should match the level of desired value with the level of autonomy when making a purchasing decision. While the use of robotics in different verticals will vary depending upon application, there are several areas where the benefits span vertical and use case:

- **Ability to augment human labor:** Robotics is often associated with the replacement of human labor. However, this is not true in all cases; many organizations are looking at robots to augment human efforts. Mobile robots can and should be looked at to automate certain processes to free humans to work on value-adding activities that are not suitable for automation. For example, a lot of time in manufacturing environments involves the movement of components and semifinished goods between manufacturing stations and the movement of finished goods to staging and packing locations. Often this movement is facilitated by a human, but robots can relieve the human operator of this function and allow that worker to focus on adding value in the manufacturing process. Additionally, the movement of material in the manufacturing environment can involve heavy loads, adding strain on the human operator. Using a robot to move such material can relieve the human operator and help reduce the risk of an injury. There is also the issue of employee turnover in the manufacturing environment, which is a significant cost to employers. Introducing robotics allows companies to better manage the impact of turnover because the robots will remain in place and can easily be added into the environment when necessary.

- **Efficiency:** A primary objective of any automation effort is delivering gains in efficiency that are not possible with a manual process. This is especially true when considering lean manufacturing, where any movement or transportation that is not adding value is considered waste. With modern levels of autonomy available, a significant amount of material handling is considered waste because it can be automated with the support of robotics. Additionally, the connected nature of autonomous mobile robots enables a business to capture movement data and thus run analytics and simulations that are not possible when the movement is conducted by human operators.
- **Cost:** Cost savings is a high priority in today's hypercompetitive market. Organizations that are better able to reduce costs are creating a competitive advantage and positioning themselves for competitiveness into the future. Robots carry an up-front cost as well as some ongoing expense, but the ongoing expense is often a fraction of the cost of full-time employees, and the initial expense can be depreciated over time. Robots are also helping reduce the cost to serve by taking on functions that would otherwise be an ineffective use of a human, thus reducing the cost of service.
- **Productivity:** Increasing productivity is closely aligned with the idea of augmenting labor. Utilizing robots to do tasks that would otherwise go to humans frees humans to focus on more value-adding efforts. For example, instead of a nurse or another healthcare professional within a hospital delivering material to patients in their rooms, a robot can take on this task, which allows the hospital staff to focus on providing care to patients.
- **Flexibility:** Robots inject a layer of flexibility into the manufacturing operation. These devices not only are capable of working around the clock and handling a variety of material but also do not require the training and learning curve of humans when taking on a new task.

Overall, growth in the market for robots and the need for the market to attain higher levels of competitiveness through automation are helping manufacturing companies achieve significant value. From a maturity perspective, the higher a robot's level of autonomy, the greater the value. And the more a robot can do for itself, the more value it delivers to the business.

Considerations: Getting It Right

The market for autonomous mobile robots is growing; at the same time, the devices and technology are evolving. Every organization will have a different perspective on the use of robotics within its operations. Despite the value associated with the use of autonomous mobile robots, there are certainly some risks and considerations to keep in mind when evaluating the applicability of robots within an operation.

The first step in evaluating the use of any autonomous mobile robot system involves determining what the business need is and developing the business case. Selecting the wrong robot with the wrong set of capabilities can be worse than not bringing in robots at all. Incorporating autonomous mobile robots into an operation requires a well-defined strategy and selection process to ensure that the decision does not result in a disruption to operations and a negative perception of the robots. The best scenario is one where there is little disruption in the integration process and the robots are user friendly and make the job of human operators more efficient.

Safety is a top priority, especially when introducing an autonomous mobile piece of equipment into an area where people are working. Tremendous advancements in sensors and mobility have helped bring to market robots that are safe and collaborative. The market for robots is shifting as we see the emergence of smart collaborative robots designed to work with people.

Cost must also be considered. An investment in robotics is just that, an investment. These devices must be purchased, leased, or delivered as a service. Organizations must ensure that the value to be delivered is worth the cost of deployment. Simply deploying robots does not deliver value; the value comes from appropriately selecting robots that meet the needs of the organization and help generate value in the form of efficiency and productivity.

Organizations must consider reliability when deciding on the deployment of robots into their operations. No piece of equipment is effective if it cannot be relied upon to efficiently, effectively, and consistently complete the tasks for which it is responsible. In IDC's maturity model for autonomous mobile robots, the higher levels of maturity relate to a device that is more reliable in its capacity to deliver results in a consistent manner.

Trends: A Look at the Market

The market for autonomous mobile robots is growing rapidly. Two factors driving this growth are the increasing acceptance for the use of robots and the improving capabilities and functionality being delivered by manufacturers of these devices. IDC forecasts that the worldwide market for commercial service robots will grow at a compound annual growth rate of more than 16% through 2020. Autonomous mobile robots are one element considered in this segment of robotics, but we see this segment as one of the more rapidly growing markets. We also see a shift in the manufacturing industry where manufacturers are seeking to improve competitiveness and even third-party logistics companies are looking to expand the value-added services that they offer by including light manufacturing and assembly. Manufacturers must consider robots as a means to deliver efficiency, productivity, and cost savings in their effort to grow and remain competitive. However, this is just one area of growth. These devices are increasingly being looked at within retail stores, ecommerce fulfillment centers, hospitals, and other locations to automate the movement of material throughout facilities.

Conclusion

Not all autonomous mobile robots are created equal. They differ in form, function, and technology. As the market increasingly accepts the use of robots, organizations must understand that there is an abundance of vendors out there with robots that span the differing levels identified in this maturity model.

Not all applications or environments will require a level 4 device; for some, only a level 4 device will do. It is incumbent upon buyers to understand their needs and map those needs to the maturity model to identify what kind of device is most appropriate for their application. The bottom line is this: Robots are proliferating across all areas of business, and organizations that accept this and develop a comprehensive plan will be better equipped to successfully introduce robots into their operation.

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