The Business Case for **AMRs in Manufacturing**

CHANG ROBOTICS

OTTO MOTORS

Contents

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01 EXECUTIVE SUMMARY

In the United States, manual forklifts represent the backbone of material handling operations across manufacturing facilities nationwide, with over 1 million estimated active units currently in operation[1]. This staggering number underscores the critical role these powered industrial vehicles play in American manufacturing and logistics. Despite the growing trend toward automation, manual forklifts remain the predominant choice for manufacturers, with the U.S. forklift market valued at $9.11 billion in 2023[2] and projected to reach $35.7 billion by 2034[3]. However, this widespread reliance on manual operation comes with significant challenges - these vehicles are responsible for over 20,000 accidents annually, resulting in nearly 100 fatalities each year[4]. With 25% of OSHA recordable incidents attributed to improper operator training and a growing shortage of qualified drivers, manufacturers face mounting pressure to reconsider their material handling strategies while balancing productivity demands, safety concerns, and the evolving landscape of industrial automation.

Chang Robotics partnered with OTTO motors to implement one of the world's largest deployments of Autonomous Mobile Robot (AMR) technology. The OTTO material handling platform was deployed at a billion-dollar company that is a household name in consumer goods. The choice to implement OTTO rested on AMR solutions ability to provide economics, flexiblility, reliability, and safety for movement of materials in a manufacturing setting.

The following conclusions were drawn after a detailed analysis of the OTTO platform vs alternative material handling methods for the customers. When compared for productivity and costs:

- OTTO was 15% the cost of a full-time equivalent for manual cart movement
- OTTO was 30% of the costs associated with a driver and a forklift
- OTTO was 66% the cost of an AGV equivalent
- OTTO was 50% the cost of a conveyor equivalent

The project resulted in an ROI of less than two years and an IRR of >50%. Payback drivers included labor savings, increased productivity, improved safety and ergonomics for operators, lower workers' compensation premiums, reduced turnover costs, and lower capital costs.

1: https://www.nist.gov/document/permis-09-forklift-safety-whitepaperpdf
2: https://www.grandviewresearch.com/industry-analysis/us-forklift-market-report
3: https://finance.yahoo.com/news/us-forklift-market-expected-reach-164500835.html
4: https://www.cdc.gov/niosh/docs/2001-109/default.html

02 COMPETITIVE ADVANTAGE THROUGH AUTOMATION

Automation has long been used to improve efficiencies within manufacturing as a way to gain a competitive advantage. To see how automation has made an impact, we need only look at the automotive industry, where automation made Ford's mass production possible and profoundly changed the world.

Today, lights-out production–where entire factories are automated–promises the highest efficiencies, but remains elusive for many manufacturers. One of the last forms of automation to make its way onto factory floors is material handling. Moving materials has remained predominantly a human task. And because it has been considered one of the lowest valued tasks on the factory floor, material handling has been ripe for automation.

Advancements in robotics, computing power, and AI have made way for a new class of automation for material handling to emerge. The Autonomous Mobile Robot or AMR combines the flexibility of a human with the efficiency of a conveyor while safely moving materials in pedestrian-heavy areas. The first industrialized implementations of the technology have occurred in the last decade. Yet, there have been few examples of meaningfully scaled deployments in manufacturing.

03 ONE COMPANY. TWO SCALED AMR DEPLOYMENTS.

OTTO Motors, one of the pioneers of the AMR industry, partnered with the team to implement one of the world's largest deployments of AMR technology.

Chang Robotics was initially retained to evaluate various material handling technologies for two facilities, one greenfield and one brownfield. AMRs, conveyors, forklifts, and automated guided vehicles (AGVs) were evaluated for comparative productivity and costs. The OTTO Material Handling Platform was selected for both sites.

OTTO Autonomous Mobile Robots

15% THE COST
of a full-time human labor equivalent

30% THE COST
of a driver and forklift

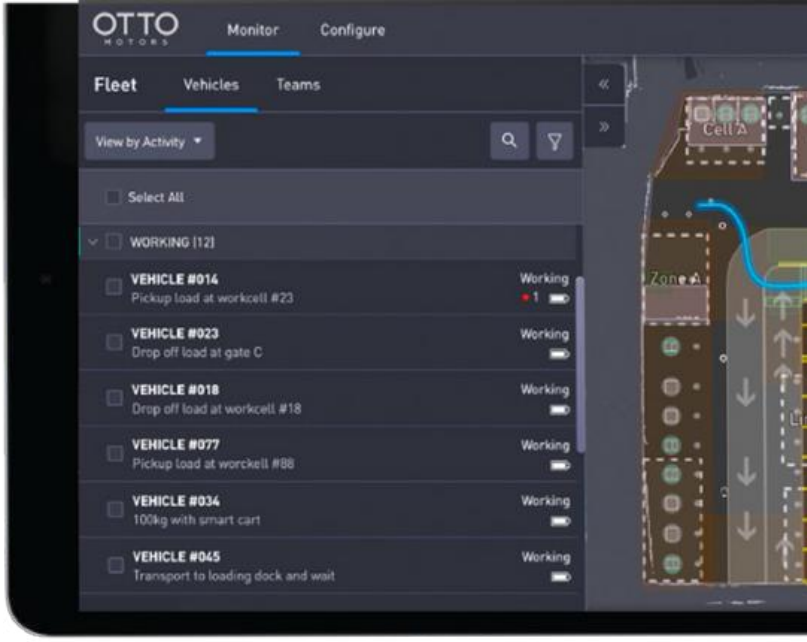
Cost savings resulted in:

ROI OF <2 YEARS
and
IRR OF >50%

OTTO Autonomous Mobile Robots were found to be 15% the cost of a full-time equivalent for manual cart movement and 30% of the costs associated with a driver and a forklift. OTTO was also compared against fully automated technologies and was a fraction of the cost of traditional conveyance and automated guided vehicles (AGV). These cost savings resulted in an **ROI of less than two years and an IRR of >50%.**

What follows is the team's look inside both facilities and the associated business cases that made the deployment possible.

04 GREENFIELD FACILITY

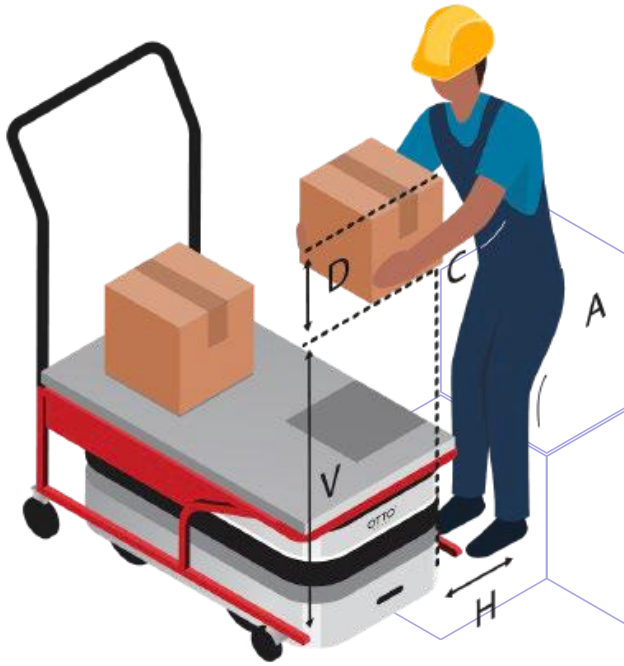


The 1 million square foot facility was designed from the ground up with state-of-the-art technologies to optimize efficiencies and save costs while maintaining an environment safe for workers.

The automated workflow transported work-in-progress (WIP) materials between human workers and automated machining cells. OTTO AMRs were used to move materials in a round-trip pick-up and drop-off cycles. The facility operation is 100% reliant on AMR technology and 400,000SF have been dedicated for this purpose with AMRs traveling 1,100 miles and completing 5200 missions each day.

In advance of the actual AMR deployment at both facilities, Chang Robotics and OTTO Motors worked with the client on the system design. Simulation was used to test the process, performance, and behavior of the AMR fleet. AMRs were then tested in a physical off-site space to validate simulation results.

The design process also took into account the National Institute of Occupational Health and Safety (NIOSH) guidelines for ergonomic design of worker interfaces with the AMRs. With thoughtful design of the work process, material handoffs at the client site minimized repetitive loading and delegated automated picking off to AMRs.



Form Factor
Chang Robotics selected the OTTO 100 with a maximum payload of 300lbs. The OTTO 100 automatically docks with a collection of custom tooling carts, enabling the transport of materials and worker ergonomic interaction with the carts. Custom fixtures were attached to the carts to enable interfacing with automated packaging equipment.

OTTO 100 is roughly the size of a carry-on luggage piece laid flat. The compact form factor allows for the creation of narrow vehicle aisleways and precision navigation in tight spaces.

Greenfield Alternative Transport Methods: Cost Comparisons
The team conducted a cost comparison of human transport with carts (before) vs automated transport with OTTO 100 (after). The result was that OTTO was a tenth of the cost of its labor equivalent.

OTTO vs Labor
At the greenfield, OTTO AMRs were compared against hiring people to move materials. OTTO was found to achieve an ROI savings of 1.25 years in a fully integrated system

OTTO 100 - 3 Shift Business Case Metrics			
Shifts / Day	3	OTTOs per Human	1.5
Hourly Burdened Rate / Hour	35	Total OTTOs For 1 FTE 3 Shift Operation	4.5
Hours / Shift	8	Cost per OTTO with integration	$ 85,000
Operating Days / Year	363	Total OTTO Cost for 3 Shift Operation	$ 382,500
Cost per Year	$ 304,920	ROI	1.25

OTTO vs Conveyor
Conveyors were also originally evaluated for intraplant transport.

	Fixed Conveyance	OTTO
Flexibility	Cannot be easily retooled	Flexible in tooling, format, and routing
Productivity	250 Linear Feet	1 OTTO
Capital Cost Ratio	2	1
Cost Comparison	OTTO is half the cost of a conveyor system equivalent. When conveyor systems are sub-optimally loaded for throughput, the benefits of OTTO can be even larger.	

05 BROWNFIELD FACILITY

The second AMR deployment took place at a brownfield facility. The conversion to AMR intraplant logistics allowed for a safer facility with transport occurring around people and operators in legacy aisleways and machine centers. The 750,000SF facility was retrofitted to optimize for transport efficiencies with AMRs. As part of the project, 350,000SF was converted to AMR transport in lieu of forktrucks.

Like the greenfield facility, this operation is 100% reliant on AMR technology. 175 vehicle miles per day are traveled, representing 900 pallet load missions for unique round-trip pick-up and drop-off maneuvers. All manual forklift traffic and pallet staging has been eliminated from the AMR zone, which has increased safety and allowed for LEAN material distribution.

AMRs provide pallet transport for three mission-critical workflows: Raw Material (RM), Work in Progress (WIP), and Finished Goods (FG). AMRs collect materials from pallet stands or conveyor interfaces and deliver them to equipment cells for interface with AGV systems.

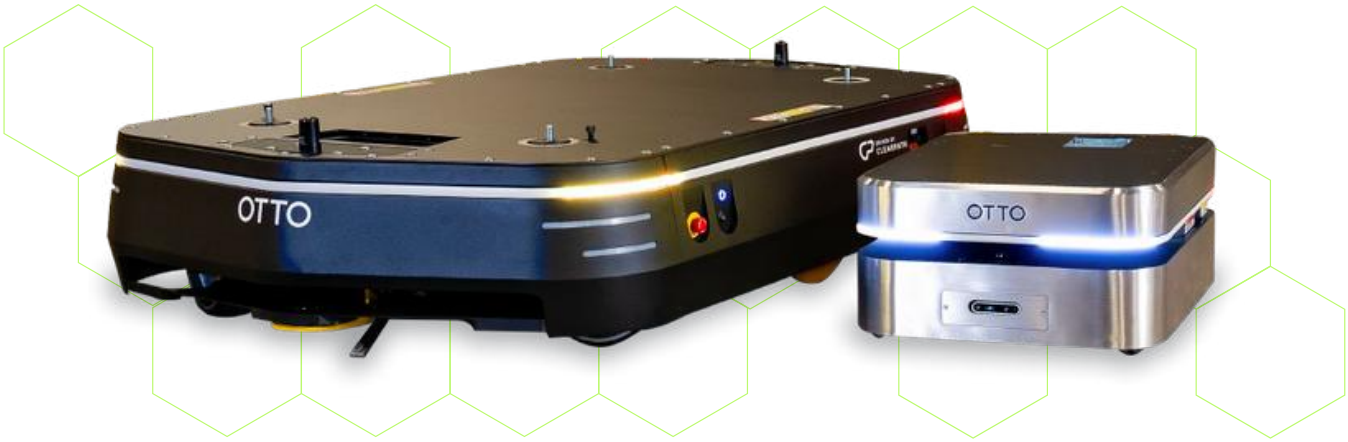
To convert the brownfield facility for AMR use, existing legacy equipment was modified to enable automated pallet exchange with OTTO. At the software level, OTTO was integrated with the site's Central systems to allow for batching, ordering, and Kanban replenishment. Goods are delivered just-in-time, thereby reducing buffer stock.

Form Factor

The technology selection was the OTTO 1500 with a maximum payload of 3300lbs. OTTO 1500 interfaced with all pallet types required in the facility, including CHEP, PICO, and GMA. The OTTO 1500 automatically docks with custom-built pallet stands or roller conveyors. Automated conveyor ports interface with the OTTO 1500, enabling mechanical automation that relies on the vehicle's power, sensors, and communication capabilities.

Brownfield Alternative Transport Methods: Cost Comparisons

Two cost comparisons were considered as part of the business case for AMRs at the brownfield facility.



OTTO vs Traditional Forklift Labor Equivalent

OTTO 1500 - 3 Shift Business Case Metrics			
Shifts / Day	3	OTTOs per Human	1.5
Hourly Burdened Rate / Hour	35	Total OTTOs For 1 FTE 3 Shift Operation	4.5
Hours / Shift	8	Cost per OTTO with integration	$ 135,000
Operating Days / Year	363	Total OTTO Cost for 3 Shift Operation	$ 607,500
Cost per Year	$ 304,920	ROI	1.99

OTTO was found to achieve an ROI savings of 2 years in a fully integrated system

OTTO vs AGVs

AMRs are often considered to be 'smart' AGVs, because they allow for dynamic routing in changing spaces. Some of the key differences between AGVs and OTTO AMR are detailed in the table below. From a cost perspective, OTTO was found to be 66% of the AGV equivalent for this brownfield facility.

	AGV	OTTO
Footprint	Requires a footprint larger than the pallet	Navigates within the footprint of the pallet
Commissioning & Ongoing Support	AGVs require more extensive commissioning and calibration due to fork tine accuracy, pallet pocket sensing, and rack slotting	OTTO 1500 can self-route around obstacles and pedestrians, making it ideal to interface with work cells or production machinery
Ergonomics	AGVs can access loads on the ground	OTTO requires the pallet to be at lifting height
Productivity	AGVs obtain better productivity in picking and manipulating pallets	OTTO works better in dynamic spaces
Cost Comparison	1.5	1
	OTTO is 66% of the cost of an AGV in a brownfield facility.	

The general conversion factor for an "at scale" design is 4 AMRs for every 3 forklifts, making the ratio of AMRs to manual forklifts 1:0.75. AGVs are roughly equivalent to manual forklifts in terms of productivity, however, they require more space for lanes and maneuvering.

06 DEPLOYMENT CONSIDERATIONS

A number of deployment considerations were taken into account for the deployment of the OTTO Material Handling Platform.

Design
System design is critical for the success of AMR implementations. Simulation was used to compare machine and material staging configurations to aid the layout simulation. Simulating the process options ahead of time de-risked the deployment well before the commissioning of the fleet started.

The team also used simulation sensitivity analysis to test various AMR scenarios. For example, the physical layout was modeled and tested against various parameters like vehicle speed, traffic management, and opportunity charging.

Safety
The downside to manual material handling goes beyond poor utilization of a limited human workforce, it also presents health and safety risks. According to the US Department of Labor, material handling is the number one cause of compensable injuries. The various mechanisms for transport that are human-powered, such as traditional fork trucks, are fraught with safety issues that can result in injury or death.

OTTO AMRs are pedestrian-safe robots that utilize safety-rated sensors. Simply put, OTTO is designed to work around people and other vehicles. This is made possible through sensor fusion and onboard AI to enable local route planning and collision avoidance. OTTO routinely navigates traffic with other vehicles at intersections and passing scenarios using OTTO Fleet Manager. “Rules of the road” can be custom configured per site, including speed limits, queuing, and zoning. OTTO can also accommodate overhanging loads. 3D cameras can be utilized to detect obstacles outside of the lidar footprint.

OTTO was designed to work around people and other vehicles.

07 CONCLUSION

At the greenfield facility, OTTO 100 was used to replace the human labor of transporting carts of materials and goods. AMRs travel faster over long distances, and their maximum speed is 4.5 miles per hour (a light jog). In short transports and docking maneuvers, humans are faster and more nimble.

As a general conversion factor for a large workspace (>100,000 SF), a designer can use an AMR to Human equivalency factor of 1:1. For smaller spaces (<50,000 SF), a more detailed study of maneuvers may be needed to establish the true relationship.

At the brownfield facility, OTTO 1500 was selected to replace forklift labor of transporting loaded pallets of Finished Goods and Raw Materials. OTTO 1500 can carry a payload of 3,300 lbs on a pallet. OTTO 1500 is compatible with all of the pallets in the facility which included:

- Common wooden pallet types
- Plastic pallets
- Supersack on pallets
- Vendor supplied raw material pallets
- Manufactured WIP and finished goods pallets

The OTTO 1500 is capable of interfacing with manual or automated forklifts via the use of pallet stands, which enable load transfer by driving underneath the pallet load and lowering their lift attachment.

The Network Effect of Scale

As more AMRs are deployed in the system, the more efficient the entire fleet becomes. In an operation with substantial human labor, the humans cannot simultaneously communicate with each other. Humans rely on hearing, line of sight, and communication devices like radio. One human that is idle is not instantaneously alerted to a condition of extra work being required somewhere else in the operation. With AMRs, the communication is immediate and the dispatch from Fleet Manager to an idle AMR is done using a combination of computer logic and artificial intelligence. Therefore, as the AMR fleet size grows the efficiency of the fleet improves. For large footprint operations at scale, AMR efficiency can exceed human efficiency.

Chang Robotics and OTTO transformed our customer's operations by providing a flexible, reliable, and safe solution that would optimize materials movement throughout the manufacturing space. OTTO AMRs were found to be more flexible than a conveyor and safer than a forklift. AMRs operate 24/7, 365 days a year and do not lose productivity based on fatigue or delay factors. The deployment resulted in an ROI of less than two years in both the greenfield and brownfield projects, and yielded significant cost savings for our customer as they developed their factory of the future and created new resiliency for their business.

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