Material Handling Solutions: A look into Automated Robotics

For: Wunsch Materials Handling Prize

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January 9th, 2010

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Abstract

Material handling is a necessary, but wasteful and expensive activity in manufacturing and distributing. Insufficient material handling accounts for additional costs in two main ways: idle time and cost of labor. Effective material handling solutions can reduce a production or distribution facility's cost by significant amounts. This paper looks at two automated material handling solutions: **Automatic Guided Vehicle Systems** (AGVS) and **Autonomous Mobile Robots** (AMRs). Each of these is described in their applications to either manufacturing or distributing. This paper recommends that companies perform various types of analysis, including simulation, before investing in any type of material handling system. It concludes that AMRs are a more cost effective material handling solution compared to AGVS because AMRs have a lower cost of ownership and can see a full return on investment much quicker.

Keywords: **Automatic Guided Vehicle Systems, Autonomous Mobile Robots, Material Handling**

List of Illustrations

Introduction

Effective material handling is the most important part of manufacturing and distributing operations because without it, a final product cannot be turned into profit (Sims, 1991).

Although, the direct cost of material handling cannot be measured, the main factor attributing to material handling costs are wasted time. An idle machine operator is essentially being paid while not producing value. This is not the operators fault, however, as the company should address ways to reduce this idle time.

The second main cost associated with material handling is labor costs. The transportation of the materials is essential, but it does not directly add to the finished product. In addition, increasing labor and employee compensation costs make material handling alternatives even more desirable.

Material handling has improved immensely since it started as fully manual operations, where men were employed to lift, stack, tote, and count (Pence, 1994). Employees transporting materials using powered equipment, such as a powered-jack or pallet truck, result in additional non-value added costs to a product. Please refer to **Figure 1** to see examples of traditional human operated material handling. The purpose of this document is to inform the reader about alternative material handling solutions. These solutions include **Automatic Guided Vehicles** (AGVs) and **Autonomous Mobile Robots** (AMRs). This document provides a technical background for AGVs and AMRs with in-depth cost-benefit analyses to better understand the applications of robotic material handling systems.

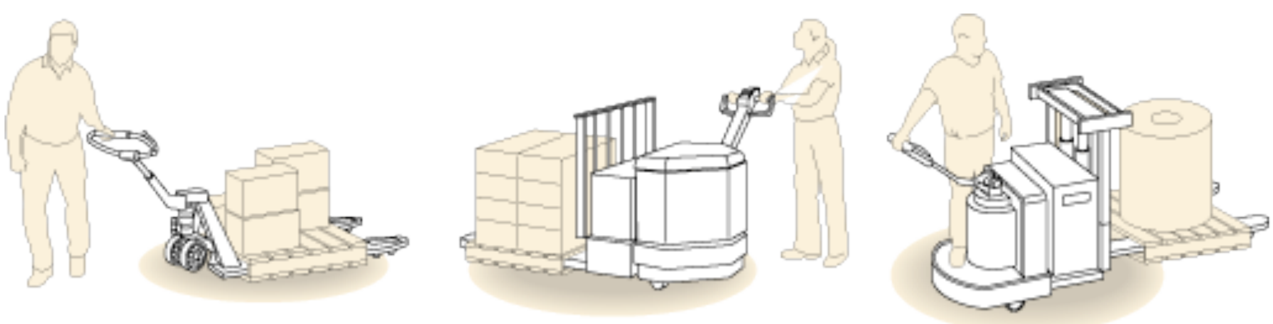


Figure 1. *Examples of human operated materials handling.* The work that these employees are doing is essential; however, alternative methods do exist. http://www.forkliftnet.com/news/newsimg/200707101121416530.gif

1. The Problem

As previously stated, material handling systems can always be improved, but rarely eliminated. In most operations, material handling can account for 30-75% of an item's total production cost (Kulak, 2005). Moreover, in a typical manufacturing company, material handling accounts for 25% of employees, 55% of all factory space, and 87% of the production time (Gamberi, Manzini, Regattieri, 2009). Streamlining material handling systems can greatly reduce costs across all fields.

The main cost associated with material handling is the labor cost. An average material handling forklift costs between $18,000 and $25,000; the labor cost for operating this machine for an entire year, assuming a wage of $20 per hour, is about $41,600 per year. If the forklift is being used for a 24 hour per day operation, that yearly labor cost triples to $ 124,800. According to Dileep Sule, an Industrial Engineering professor at Louisiana Tech University, effective material handling solutions combined with efficient manufacturing system design can reduce a plant's operating cost by 15-30% (Sule, 1994). This document is going to explore two options that aim to reduce labor costs associated with material handling: automatic guided vehicles and autonomous mobile robots.

2. Automatic Guided Vehicle Systems

The first step in automating material handling occurred in the 1950s with the implementation of **Automatic Guided Vehicle Systems** (AGVS). AGVS are defined as battery-driven industrial trucks with contactless steering (Müller, 1983). These trucks operate by following a guided system to transport materials throughout a facility. Please refer to **Figure 2** to see an example of a floor guided AGVS.

Figure 2. *Automatic Guided Vehicle System.* This AGVS is guided by a floor path. http://www.vahleinc.com/images/sys_bc.jpg

As defined by Müller (1983), the main components of AGVs consist of:

- "The truck or tractor, pallet truck, tow skid basic type;
- The floor system with the installation of the wire guidance system and the information transfer system;
- The load transfer equipment which can be both on board the truck and/or in a stationary position, including the station structure;
- The truck and traffic control system"

2.1 Types of Automatic Guided Vehicles

According to the Lindkvist (1985) of the Swedish Transport Research Commission, there are 3 main types of trucks or tractors: towing vehicles, load collection from floor, and load collection from shelves or racking. Refer to **Figure 3** below for basic illustrations of these types of vehicles. Most AGVS are variations of these 3 types.

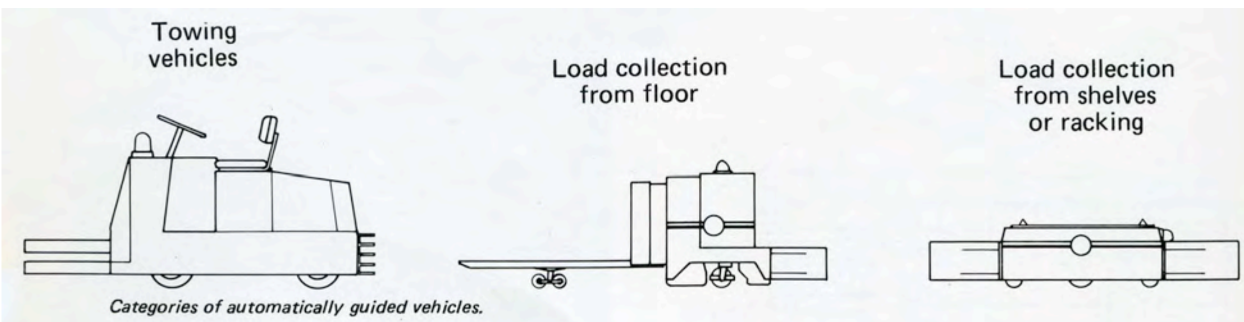


Figure 3. *The 3 main types of truck or tractor AGVS.* These 3 designs are the basis of AGVS variants seen today. (Lindkvist, 1985)

Towing vehicles consist of a tractor with load carrying trolleys. The trolleys are either loaded by humans, conveyor belts, cranes, or other material handling devices. The tractor will follow its designated path making stops along the way. Please refer to **Figure 4** for an example of a towing automatic guided vehicle (AGV). This example in the figure is carrying different types of loads. This type of AGV can be programmed for automatic decoupling if necessary.

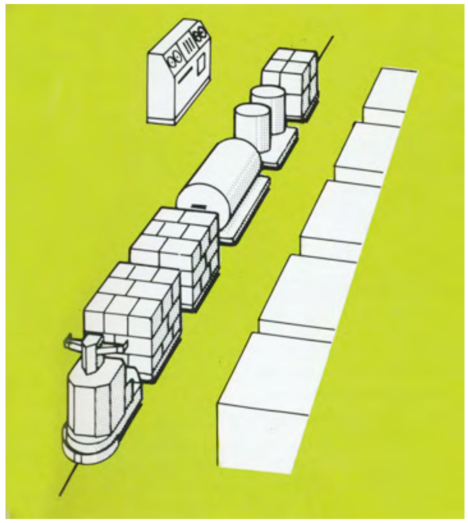


Figure 4. *Towing AGV.* This AGV is has been loaded with different types of material. (Lindkvist, 1985)

Floor collection AGVS come in either automatic forklift or automatic sideloader fashions. These AGVS are suitable for applications where greater flexibility is required and can vary based on their application. Many AGVS manufacturers offer custom designs. An example of a custom AGVS is a forklift which can be found in **Figure 5**. The forklift AGVS is particularly interesting because it can load and unload pallets by itself. It utilizes sensors to see which pallets need to be moved. The downside to these forklifts is that they are limited to the guide path.

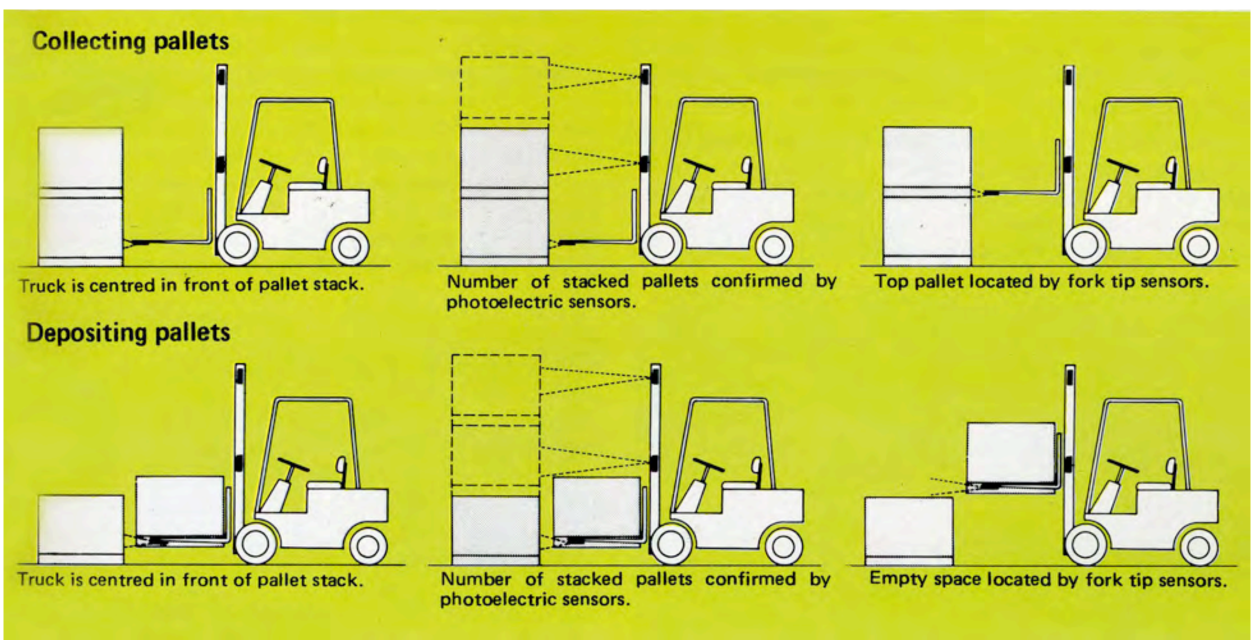


Figure 5. *Forklift AGVS.* This forklift has sensors to detect the appropriate pallet that needs to be moved to another location. (Lindkvist, 1985)

2.2 Wire Guidance

The key to an AGVS lies within the guidance system. Tracks or floor markings, such as painted lines or glued on reflective tape, can be used as a guidance system for AGVS. The permanent track is not desirable and constant wear on markings can cause system reliability issues. If the AGVS does not know where to go, it cannot operate. A majority of AGVS use a wire based guiding system, which can be seen in **Figure 6**. Clayton (1983) provides in detail the principles of wire guidance:

> The optimum route for the automated guided vehicles is selected and a circular disc cutter is used to cut a groove approximately 2mm/3mm wide and 15 to 20mm deep. A normal plastic coated copper wire is laid in the groove and grouted in. A high frequency transmitter feeds the wire with a 10 Khz alternating current which creates a magnetic field from the with AGVS scanning head takes its route instructions.

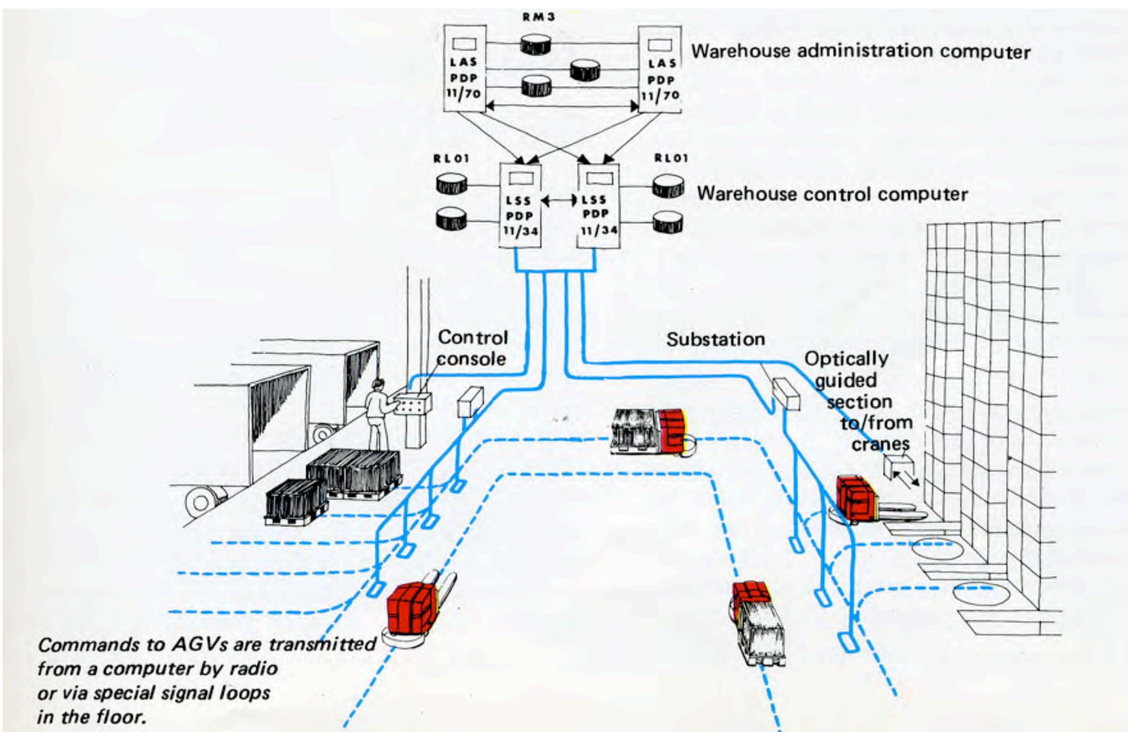


Figure 6. *The control system for an AGVS.* The dotted blue lines represent wire guides mounted in the floor. Solid blue lines represent information relays. Lindkvist (1985)

2.4 Control Systems

The control systems for the AGVS can be a centralized control system or a decentralized control system (Lindgren, 1985). Please see **Figure 7** for an analysis comparing the two systems. Each of the two systems is broken down into three levels: central control, assignment control or distributed traffic control, and AGV control. The centralized control system uses the assignment control, while the decentralized control system utilizes the distributed traffic control. The difference between the two systems is that the distributed traffic control utilizes several sub-station hubs to control the AGVs, where as the assignment control uses one station to command the AGVs. Each of the different control systems has their own advantages:

- The decentralized system has better AGV position detection and fault finding capabilities, and can allow for more AGVs in the system.
- The centralized system requires less track cutting and communication wiring, and allows better communication between AGVs.
- The decentralized system tends to be more effective with higher material flows, many AGVs, and complex layouts.
- The centralized flow tends to be simpler, but it is more effective when there is a large layout with low material flows and fewer AGVs (Lindgren, 1985).

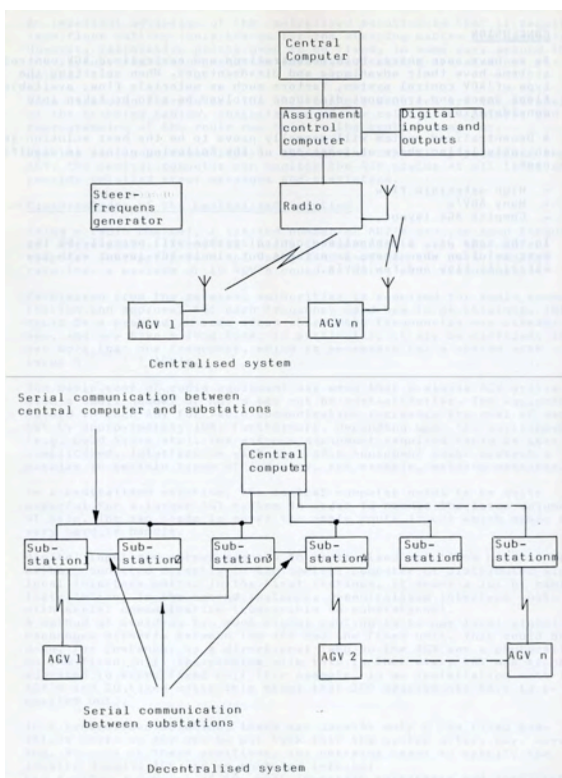


Figure 7. *A comparison between a centralized and decentralized control system.* The decentralized system is primarily used to coordinate systems with many vehicles. (Lindgren, 1985)

2.5 AGVS Advancements

There have been advances in AGVS. As Kevin Staines of Excel Automation, an AGVS manufacturer, points out, AGVS have become more user-friendly and more flexible with Window-based control systems and laser guiding (Rooks 2001). Laser guiding is a new alternative to the wire guide system, which can be seen in **Figure 8**. A rotating laser scanner uses optical reflectors sited in the operating zone to calculate its position. The bearing, or measurement device on the AGV, calculates the AGV's position relative to the beacon. The downside to this is that the position of the beacons must be known (Oskarsson, Åström, 1998). The first time that a new location is encountered, the AGV must assert itself with the new beacon locations. Oskarsson and Åström (1998) developed a system to make this procedure almost completely automatic. However, laser guided vehicle systems run into problems in dusty environments because it is difficult to establish lines of sight with the reflectors (Brooks 2001). Additionally, creating an alternate route by changing reflector positions may result in additional costs.

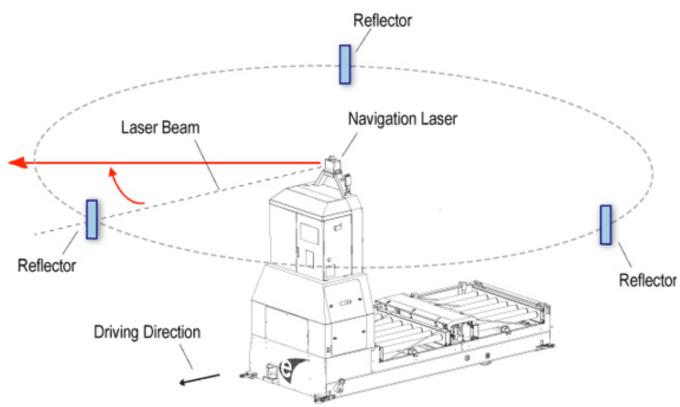


Figure 8. *Rotating laser beam and reflectors determining the AGV's path.* This new technique has increased the flexibility of AGVS. (Enegin Automation, 2009).

3. Autonomous Mobile Robots

The complete elimination of guide paths, wires or lasers, has resulted in autonomous mobile robots, also known as AMRs. AMRs use computer-based vision systems to navigate through their environment. According to Banerji, Ray, and Datta (2007), "the advantage of this type of robot is that existing manufacturing environment does not have to be altered or modified as in the case of conventional automatic guided vehicles where permanent cable layouts or makers are required for navigation." This type of robot is free to roam and perform tasks anywhere in the facility. This is a clear advantage over AGVS.

3.1 Vision Chips

The idea behind vision guided robots is that they understand where there are and where they need to be. The most common technology for creating vision sensors is **complementary metal oxide semiconductor** chip (CMOS). (Siegwart, Nourbakhsh, 2004). The CMOS chip, seen in **Figure 9**, contains an array of pixels that accumulate charge.

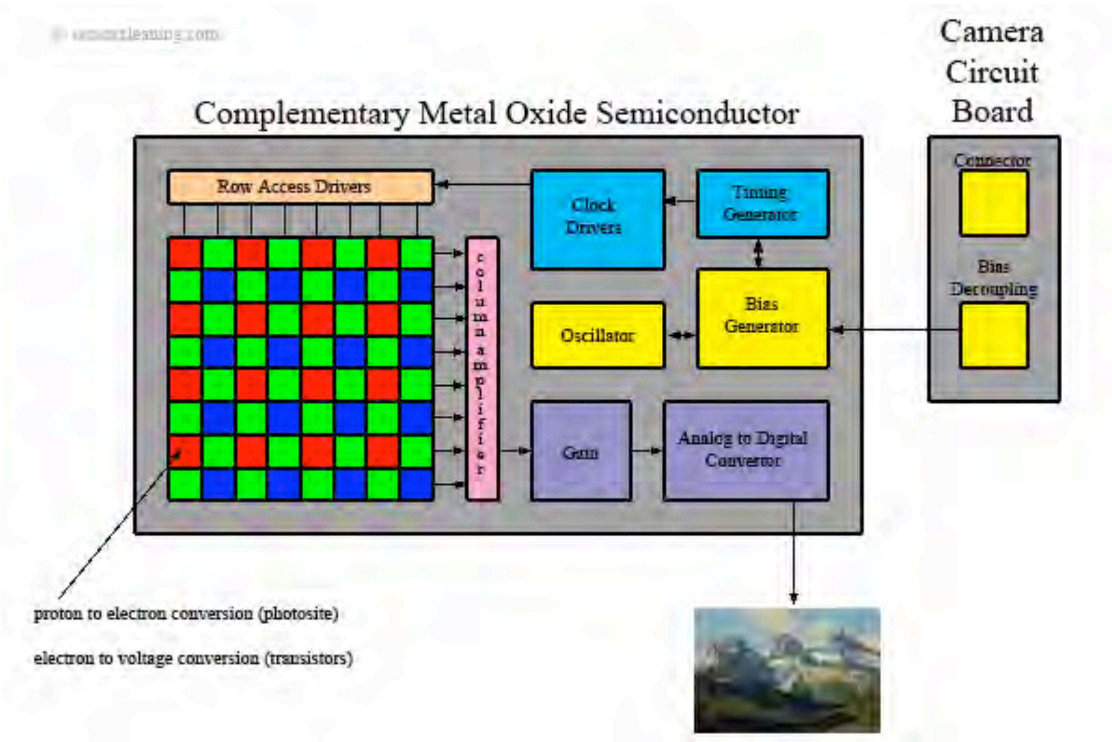


Figure 9. *CMOS chip diagram.* The CMOS chip has lower resolutions, but it addresses color spectrum issues better than the CCD version. http://www.sensorcleaning.com/pics/CMOS_sensor_diagram.jpg

It utilizes pixel-specific circuitry, which measures and amplifies the pixel's signal, all in parallel for every pixel in the array. The resulting pixel values are then carried to their destinations. An advantage of CMOS technology is that the same production lines that create microchips can produce CMOS chips at low cost. Additionally, the CMOS chip is simpler and operates at 1/100 the power level of alternative chips, which is a valuable asset in a power scarce AMR. However, the CMOS chip has disadvantages compared to other vision chips. Since there is additional circuitry on the CMOS chip compared to other chips, less photodiodes are available to absorb light, making the CMOS less sensitive. Expensive alternatives address this issue by utilizing color specific chips, resulting in higher resolutions. The CMOS technology is currently younger, which makes its best chip resolutions inferior to the best CCD chips available (Siegwart, Nourbakhsh, 2004).

3.2 Vision Systems

A vision technique developed by Kelly, Nagy, Stager, and Unnikrishnan (2007) utilizes image mosaicking techniques to generate a large-scale visual record of the floor. The technique first breaks down the point disclosures and scratches from the texture score of the original floor image. It then analyzes and decides where the scores should fit into the final mosaic. The combined image serves as the navigational map. **Figure 10** provides a visual representation of this technique.

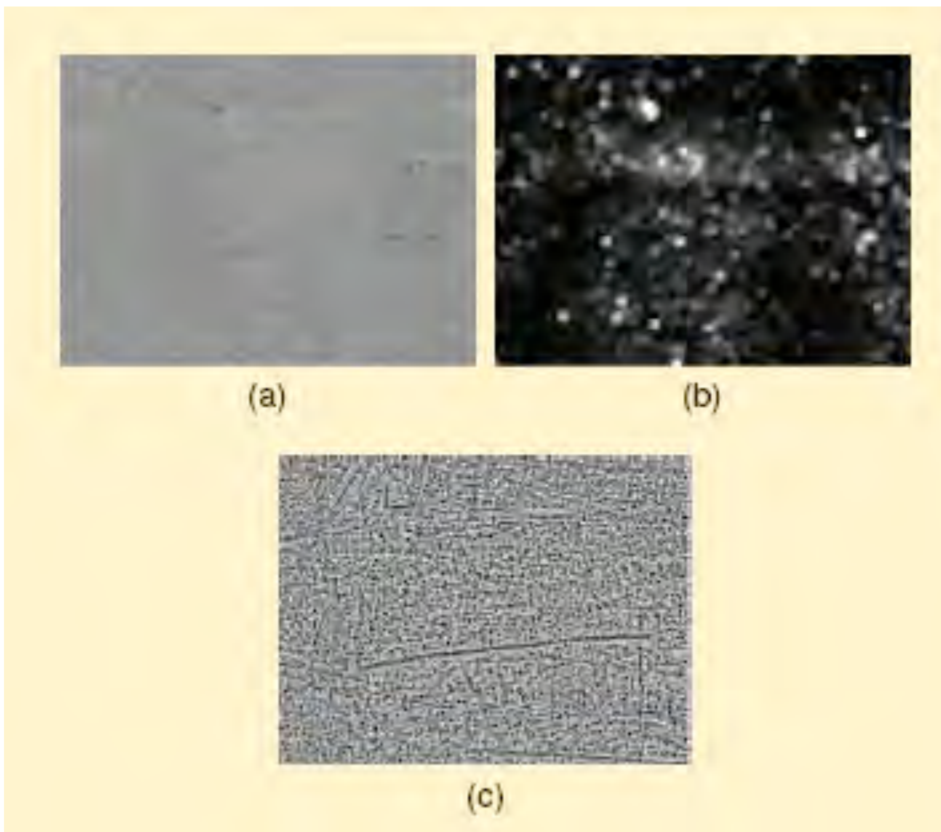


Figure 10. *A typical image of the shop floor (A), the texture scores of the image (B), and a normalized version of the input mosaic image (C).* The original picture is taken in (A), and then the texture scores are broken down in (B). "The point discolorations and scratches have high scores but linear features do not. These scores are used to decide which places in the images should be matched to the mosaic." Part (C) represents the image that is added to the composite navigation image. (Kelly et al., 2007).

The pictures are taken by a camera surrounded by an LED array underneath the AMR and the combined image becomes the navigational map in the vision tracker. The reason that this was successful is because the floor texture is rich in landmarks. Factory floors are inconsistent at the millimeter scale, making each image unique. Adequate storage for this map is easily affordable, as 1 GB can store detailed uncompressed imagery of a guide path that is 6.25km long and 1m wide (Kelly et al., 2007). Kelly et al. (2007) have improved many basic vision guiding systems that rely on topological maps that require an operator to inform the robot of the names of relevant locations (Bischoff, Graefe, 1998).

AMRs can come in the same designs as AGVs, and are suitable for any distributing or manufacturing environment. They have clear advantages over AGVS because:

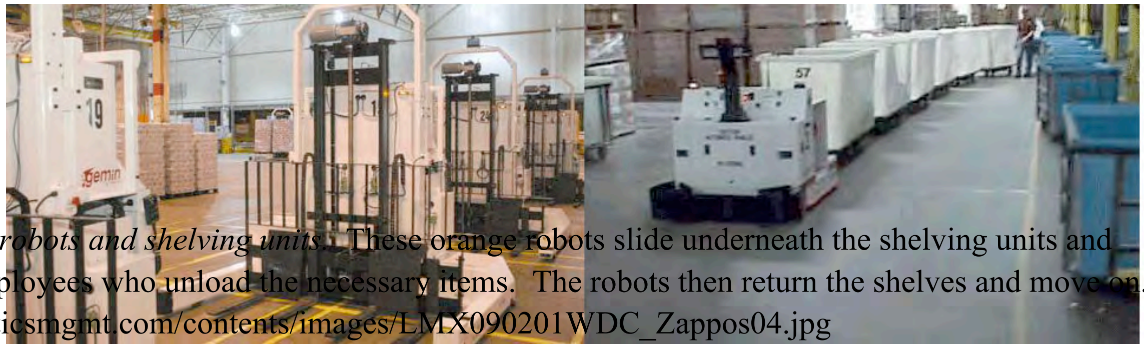
- AMRs do not require guide paths
- AMRs store the layout of the facility
- AMRs can be assigned tasks similarly to AGV
- AMRs can be effective in small numbers
- AMRs with manipulator arms can perform virtually any task

4. Cost-Benefit Analyses

Deciding what types of material handling systems to utilize is an important step in creating an effective manufacturing or production system. Possible material handling systems include: industrial trucks, conveyors, AGVS, cranes, AMRs, and stationary robots. The **Fuzzy Multi-Attribute Material Handling Equipment Selection** (FUMAHES) developed by Kulak (2005) is an example of one of these decision support systems. Please refer to the **Appendix** to see the configuration of the FUMAHES model. It contains a knowledge base of 142 rules that were acquired from manufacturing experts. If AGVs or AMRs are indeed the ideal solution to a company's material handling needs, the cost of either solution must be further analyzed.

4.1 Manufacturers and Case Studies

Egemin Automation is an AGV manufacturer that has many different types of models: tug vehicles, fork lift vehicles, unit load vehicles, and trailer loading vehicles. Some Egemin AGVs can be seen in **Figure 11.** Additionally, Egemin creates custom AGVs if necessary. The customizability and in-house software makes Egemin a successful AGVS manufacturer. A company purchasing an AGVS from Egemin can expect to pay roughly $100,000 per AGV unit with an additional $25,000 in labor per unit to setup and debug the laser guiding system (Eegemin Automation, 2009).



re 12. *Kiva robots and shelving units.* These orange robots slide underneath the shelving units and them to employees who unload the necessary items. The robots then return the shelves and move on. /www.logisticsmgmt.com/contents/images/LMX090201WDC_Zappos04.jpg

Figure 11. *Egemin Automation Dual Fork AGV (left) and Tugger AGV (right).* These AGVs operate by using a laser guided system. http://www.egeminusa.com/

A breakthrough AGVS manufacturer is **Kiva Systems**. A Kiva AGVS is much different than traditional systems, but its applications are fitted towards distribution. A Kiva AGVS utilizes hundreds of small robots that slide under shelves, lift them and bring them to workers. Inventory is scanned and recorded to shelves, allowing the system to coordinate the maneuvers of hundreds of robots. A typical Kiva robot and shelving system can be seen in **Figure 12**. The robots receive instructions from the clusters of servers and navigate using optical sensors that recognize the floor. The Kiva System is very effective but a basic system of 30 robots and 300 shelves for a 20,000 square-foot warehouse costs about $1,000,000. And it costs between $4,000,000 and $6,000,000 to equip a 100,000 square-foot warehouse (Overfelt, 2006).

Since labor picking is such a high cost in warehousing, Kiva's AGVS is a sensible solution for distribution. Gap, Zappos, Walgreens, and Staples have implemented this system in their distribution centers. Zappos vice-president Craig Adkins says, "It's exceeded all of our expectations, doubling the productivity of our pickers and cutting our energy costs in half (Scanlon, 2009)." Companies that implement a Kiva AGVS in their distribution centers gain an immense competitive advantage by speeding up the picking process and reducing labor costs.

The Kiva system is very flexible; robots and shelves can be easily added or moved to another facility if needed. The downside to the Kiva system is that it used primarily for distribution and it has not been implemented in manufacturing environments and large items cannot be moved using this system.

Seegrid, an AMR manufacturer, currently has 2 types of AMRs available: a tug model and a pallet truck model. The GT3 tugger is capable of pulling carts up to 3,000 pounds. The GT8 pallet truck, seen in **Figure 13**, is capable of moving pallets up to 8,000 pounds. These AMRs cost between at $54,000 and $65,000 respectively (Seegrid, 2009).

Seegrid's revolutionary **Industrial Mobile Robotics** (IMR) technology allows the robots to store a 3D map of the facility. The IMR includes the robot's artificial intelligence, image processing, and learning methods (Jeppsson, 2008). Seegrid's AMRs can store up to 15 miles of delivery paths and unlimited unique paths, which can be in completely different areas of the facility. These AMRs learn paths by being walked along each route by an operator. The AMRs can then be programmed to move material to different locations. Another upside is that these robots are dual-use; they can be used as manual operated pallet trucks or tug vehicles.

Figure 13. *Seegrid G8 pallet truck moving a pallet.* This AMR is capable of moving 8,000 pounds. http://www.seegrid.com/index.php

According to Donnie Dixon, supervisor of material control at Daimler Trucks, "We didn't want the wire guides, magnets, or lasers that come with an AGV; we needed flexibility to be able to change the routes easily and frequently, and the GT3 does that for us." The results of the GT3 implementation at Daimler Trucks were exceptional. Over 3 operating shifts, the GT3 reduced waiting time for parts by 22%; the transportation time of parts to line was reduced from almost 1 hour to 20-30 minutes. The GT3 reduced the need of unnecessary inventory by two-thirds and reduced inventory deficits by 98% (Seegrid, 2009). Seegrid's AMRs have better manufacturing capabilities to the Kiva or Egemin systems. The GT3 can be take parts to the line, and take finished goods or waste from the line. Additionally, the pallet truck GT8 model is capable of lifting 8,000 pounds, giving it a distinct advantage to large item distributors (Seegrid, 2009).

4.2 Possible Cost Savings

To fully understand the potential benefits of implementing an AGVS or AMR system, one must be able to measure the areas they are looking to improve. Some areas that tend to need improvement are (Berman, Schectman, Edan, 2008):

- **Throughput time**
    - Period required for a material, part, or subassembly to pass through the manufacturing process
- **Manufacturing lead time**
    - Total time required to manufacture an item, including order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time
- **Work in process**
    - Partially completed goods, parts, or subassemblies that are no longer part of the raw materials inventory and not yet part of the finished products inventory

Improving these areas can greatly reduce production costs. Automation can also reduce unnecessary labor hours and the costs associated with safety concerns.

Automated material handling can also reduce workplace injuries by limiting the number of potential incidents. According to the US Department of Labor, in 2007:

- Manufacturing industries experienced 187,200 injuries with days away from work
- Injuries occurred with an incident rate of 133 per 10,000 workers
- The median number of days missed per incident was 7 days

The cost of a lost work day to a company is a full day's worth of salary and benefits, not including the decrease in productivity. Company insurance costs cover the medical costs in most cases.

4.3 Injury Reduction Analysis

For simplicity, assume a laborer receives $20 an hour in salary and benefits, each lost day of work would cost a company at least $160 per day. Using the median number of work days lost, each incident, depending on the severity, would cost a company around $1120. If a large manufacturer had 1,000 material handling employees across all facilities, it could expect about 13 incidents per year making the cost of work related injuries around $14,560 per year. If an automated system, AGVS or AMR, will reduce work related injuries by 20%, that company can expect to save $2,912 per year. Larger companies can expect to save even more. Reduced work related injuries may even help reduce company insurance costs.

4.4 AMR Cost Analysis

A typical human operated electric fork truck can range from $18,000 to $25,000 plus $1,000 to $5,000 for a battery and charger (Buyerzone.com, 2009). A human operated electric power tug can cost about $2,500 (Globalindustrial.com, 2009). The completely automated Seegrid GT3 tug vehicle costs $54,000 and the GT8 pallet truck costs $65,000. Assuming an average wage of $20, across 3 shifts with 260 work days, the labor cost for the human operated vehicles would cost $124,800 per year per vehicle. If the labor is being done across 1 or 2 shifts, they would cost $41,600 and $83,200 per year respectively. Please refer to **Figure 14** for the potential savings using AMRs during 2 shift operations. Both of these AMRs would pay for themselves in less than a year. The low cost of ownership of a Seegrid AMR is ideal for small companies that are looking for long term productivity on a small investment.

Cost Analysis (1 Year)	Electric Forklift	Seegrid G8 Forklift AMR	Electric Power Tug	Seegrid G3 Tug AMR
Purchase Cost	$30,000.00	$65,000.00	$2,500.00	$54,000.00
Labor Cost (8 hr operation for 1 year)	$83,200.00	$0.00	$83,200.00	$0.00
Total Cost	$113,200.00	$65,000.00	$85,700.00	$54,000.00
Net Difference Saved		**$48,200.00**		**$31,700.00**

Figure 14. *AMRs cost savings table.* Using a Seegrid AMR could save a company running 2 shift operations up to $48,200 per year, assuming a wage of $20.

4.5 AGVS Cost Analysis

Le-Anh and Koster (2006) outline the requirements for setting up a successful AGVS program. Determining the guide path layout and required number of AGVs are the most important criteria for setting up an AGVS. For simplicity, this paper will analyze a system that uses 10 AGVs. Using Egemin's numbers, this system would cost $1,250,000. The Egemin Automation CEO, Jerry Dekker, commented in a personal email that this type of automation would require a 24 hour per day operation to pay for itself (Egemin Automation, 2009). If this type of AGVS could reduce the labor force by 6, it would take less than 2 years for the system to pay for itself. Additionally, the AGVS will result in greater productivity. Refer to **Figure 15** below for a visual representation of these calculations.

AGVS Costs		**Possible Savings**	
10 Machines @ $100,000	$1,000,000.00	Reduction in Labor Force	6
Installation -10 @ $25,000	$250,000.00	Yearly wages at $20 per hour	$41,600.00
Total Cost	$1,250,000.00	Number of Shifts	3
		Total Savings per year	$748,800.00
Years to Return AGVS Investment:		**1.7**	

Figure 15. *Cost savings analysis for AGVS.* This model is very basic, as it does not account for net present values or inflation.

Reducing jobs is a harsh way to look at the benefits of automation. However, it is the easiest way to perform a cost analysis because labor is the largest production cost. Automation reduces manufacturing lead time and increases throughput, which can be verified by using simulation. A company should run many simulations to understand the long term improvements in productivity, lead time, etc. Due to the scope of this project, this paper will not analyze simulations, but it recommends using them before investing in any type of material handling system.

4.5 Additional Applications

Automation can help implement business strategies, such as **Just-In-Time** (JIT) manufacturing. JIT is a business strategy that aims to reduce inventory by using only what is need when it is needed. As with the case of Daimler Trucks, who implemented JIT, automation speeds up material handling and reduces inventory carrying costs, by providing constant flow of materials to necessary areas or workstations.

AMRs and AGVs can also be used in **Flexible Manufacturing Systems** (FMS), where the materials being used or produced can be quickly changed (Murphy, Arkin, 1988). AMRs are more beneficial than AGVs to FMS because they can quickly retrieve different materials and bring them directly to work cells without being restrained by the guide path.

Even though autonomous mobile robots provide greater versatility than AGVS, they have not been dominating the market share as one would expect (Holland, 2004). This may be because companies have already invested large amounts of money into AGVS, and they do not want to reinvest in a similar technology. Outsourcing manufacturing processes to developing nations may be another factor; labor in developing countries is far cheaper than in developed countries. If manufacturing trends return to the United States, autonomous mobile robots may begin to replace AGVS as the standard material handling system.

5. Conclusions and Recommendations

Material handling is an expensive non-value adding activity can account for 30-75% of a product's manufacturing cost. A typical manufacturing company dedicates 25% of its employees, 55% of its factory space, and 87% of its production time to material handling (Gamberi, Manzini, Regattieri, 2009).

AGVS can be used in many different areas including: assembly systems, material handling in production systems, material handling in warehouses and storages, and storage and handling systems that use AGVs. There are three main types of AGVs, which can be customized by a manufacturer.

- AGVS use guide paths with control systems to carry out material handling tasks. Today's laser guided paths are much more flexible than the previous wire paths. AGVS are expensive, costing around $125,000 including installation cost per vehicle. These types of systems tend to pay for themselves in 24 hours operations.

- AMRs have a distinct advantage over AGVs because they do not rely on a guide path. AMRs see the world using computer-based vision technology and perform tasks without being restrained to a certain area.

- Most vision systems use CMOS based cameras to memorize the area. Vision technology can be applied to AMRs with manipulator arms to pickup items and bring them to other workstations. Two AMRs developed by Seegrid cost $54,000 and $65,000 and are significantly cheaper than their AGV counterparts.

- The Seegrid AMRs have demonstrated a low cost investment with high returns, making them ideal for companies with less capital to invest.

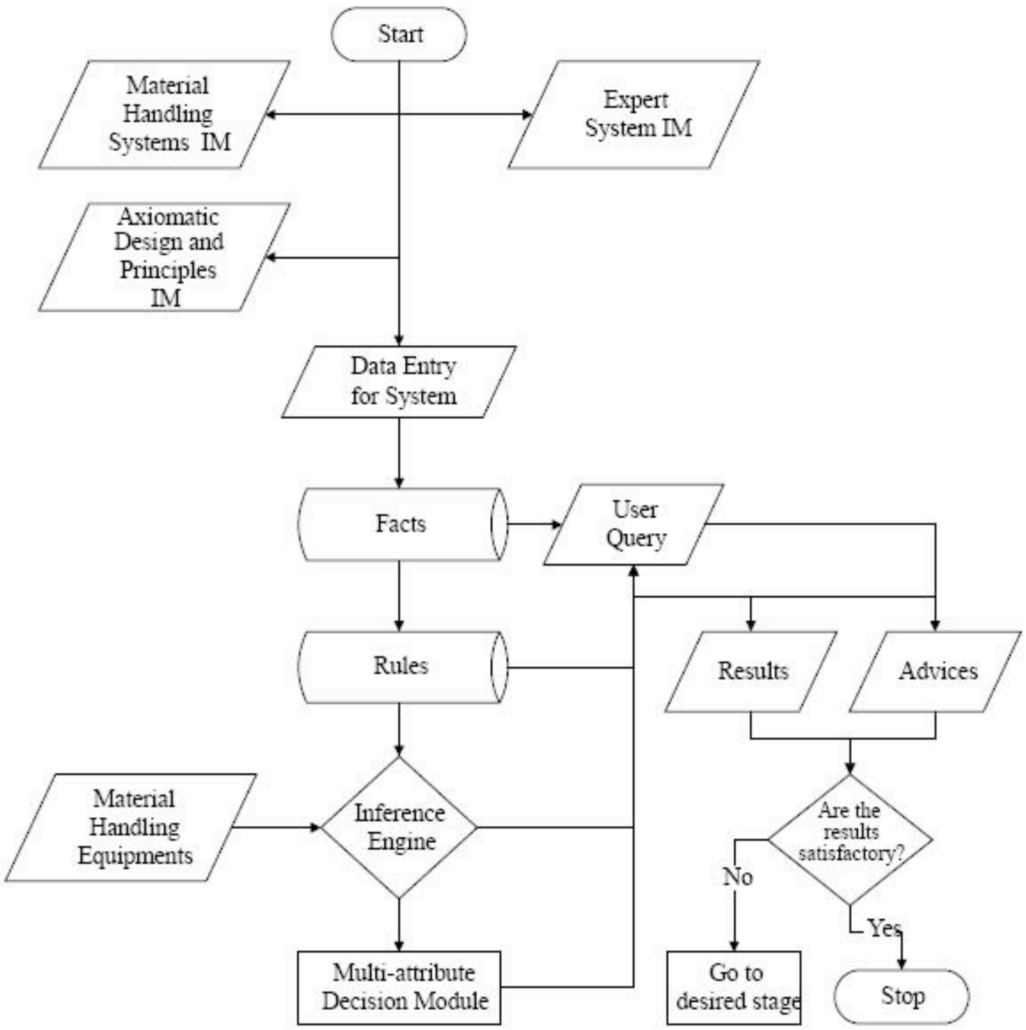
Idle time and labor are the highest costs associated with manufacturing and distributing. AGVS or AMRs can significantly reduce production costs.

- Reducing a labor force by 1 person per shift, a company can save between $41,600 and $124,800.
- Additional measures such as throughput time, lead time, and work in progress can be improved with AGVS or AMRs. Simulation can be used to estimate cost savings based on improved performance measures, such as throughput time and manufacturing lead time. This paper did not perform any analyses based on simulation, but it recommends using simulations to estimate these improvements before investing in any type of material handling system.

AMRs have not dominated the material handling industry, but that may be because manufacturing operations have been outsourced for lower labor costs eliminating the need for expensive AMRs. AMRs are very flexible for any manufacturing or distributing environment, and they are the material handling solution for the future.

6. Appendix

Fuzzy multi-attribute material handling equipment selection (FUMAHES)**:**



This is a typical type of decision system that companies should utilize before making material handling equipment decisions. It contains 142 rules in its knowledge base that were acquired from manufacturing systems experts and the literature about material handling equipments. Please refer to the cited source for more information. (Kulak, 2005)

http://www.sciencedirect.com/science/article/B6V03-4G243Y7-5/2/7d7d2fa6fae7e6e5e4647fb4be978080

7. Glossary

Automatic Guided Vehicles (AGVs): Vehicles that handle material and move with the help of a guide path and an Automatic Guided Vehicle System.

Automatic Guided Vehicle Systems (AGVS): The encompassing material handling system that operates utilized Automatic Guided Vehicles. An AGVS includes guide paths and control systems.

Autonomous Mobile Robots (AMRs): Mobile robots capable of making decisions and navigating through an environment, such as a manufacturing or distributing facility. Computer-based vision techniques allow AMRs to memorize the plant layout and perform tasks.

Centralized control system: A type of AGVS control system that requires less track cutting and communication wiring, and allows better communication between AGVs. It is simpler; however, it is more effective when there is a large layout with lower material flows and few AGVs.

Complementary metal oxide semiconductor chip (CMOS): A chip used in computer-aided vision techniques that has an array of pixels that accumulate charge. Utilizing pixel-specific circuitry that measures and amplifies the pixel's signal, the accumulated pixel charge values are carried to their destinations. A CMOS chip can operate at 1/100 the power of a CCD chip.

Decentralized control system: An AGVS control system that has better AGV position detection and fault finding capabilities, and can allow for more AGVs in the system. It is more effective with higher material flows, many AGVs, and complex layouts.

Egemin Automation: An AGVS manufacturer based out of Michigan. Egemin Automation is a world-wide competitor and offers many different types of AGVs, including custom models.

Flexible Manufacturing Systems (FMS): A manufacturing system in which the materials being used or produced can be quickly changed. Automation in FMS reduces labor costs and increases productivity.

Fuzzy Multi-Attribute Material Handling Equipment Selection (FUMAHES): A material handling decision system used to decide what types of material handling solutions to utilize. It contains a large knowledge base. FUMAHES is recommended before investing in AGVS or AMRs.

Just-In-Time (JIT) **Manufacturing**: Inventory reduction strategy that focuses on reducing in-process inventory by utilizing only what is needed when it is needed.

Kiva Systems: An AGVS manufacturer that has developed a revolutionary distribution system. Kiva's system utilizes hundreds of tiny robots that lift shelving pods and bring them to workers. The workers then pick the items off the shelving, the robot returns the pods, and the process repeats.

Manufacturing lead time: Total time required to manufacture an item, including order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time.

Throughput time: Period required for a material, part, or subassembly to pass through the manufacturing process.

Work in process: Partially completed goods, parts, or subassemblies that are no longer part of the raw materials inventory and not yet part of the finished products inventory.

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