National Center for Supply Chain Automation
RESOURCES FOR EDUCATION & INDUSTRY

E-MATE
E-books and Mobile Apps for Technician Education

Introduction to the Automated Warehouse

Second Edition

Preface

Through this exciting, interactive e-textbook, you will discover the Supply Chain Technician occupation, a high-wage job that is also sometimes referred to as Industrial Machinery Technician, Industrial Maintenance Mechanic and Electro-Mechanical Technician. Supply Chain Technician refers to a person who installs, operates, supports, upgrades or maintains the automated material handling equipment and systems that support the supply chain. The work involves a broad field of expertise that encompasses electrical and mechanical skills, robotics, optics, sensors, networks and complex conveyor systems. If you enjoy working with your hands, the Supply Chain Technician occupation is for you!

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Forward

The National Center for Supply Chain Automation brought together technicians working in automated warehouses across the country to find out what a Supply Chain Technician does on a daily basis. What we discovered is that a Supply Chain Technician installs, operates, supports, upgrades or maintains the automated material handling equipment and systems that support the supply chain. With this new information, the Center created model curriculum and searched for a textbook to use in schools and colleges across the nation. This is where a gap between what existed and what was needed was found.

There are plenty of textbooks on electronics, welding, safety, material handling and the other topics covered in the “Introduction to Automated Warehousing” course; but none include all the topics in one comprehensive book. Plus, none are interactive, electronic, always up to date, and FREE! It was because of this gap that the National Center for Supply Chain Automation (SCA) decided to create this interactive, electronic book.

This e-book is the first of its kind as no single textbook existed that could be used in an introductory Supply Chain Technology course. This book integrates content with visual models to give students a comprehensive overview of the skills and abilities they will need to become well trained supply chain technicians. The language was written to provide students with the most up to date information possible. It is current. It is relevant. It is fun.

The first edition of Introduction to Automated Warehousing was created by E-MATE using content provided by SCA. Both organizations are funded by the National Science Foundations’ Advanced Technological Education

Program, which made it all possible. The goal of SCA is to increase the number of qualified supply chain technicians to meet the growing national need across the private and public supply chains.

The authors of Introduction to Automated Warehousing are all supply chain technicians who are in the field on a daily basis. They represent companies that want to hire you. They are industry associations that value the importance of emerging technologies which support the supply chain. There is a growing supply chain industry out there looking for talented technicians, and this e-book provides you with the foundational knowledge and skills you will need to be successful.

We know you'll enjoy using it, learning from it, and sharing it with others.

Feel free to share your thoughts and comments with us at infor@supplychainautomation.com.

Valorie Piper

Principal Investigator, SCA

Preface to the Second Edition of *Introduction to the Automated Warehouse*

Much of what guided the NCSCA's initiatives to update the recommended model program and consequently this text can be found in the Manufacturing Skill Standards Council's (MSSC) newest training and certification system, the Certified Technician-Supply Chain Automation (CT-SCA). It was released publicly in August 2020 during the MSSC Virtual Summit. Building upon the solid foundation of the work of the first edition, the second edition has changes and additions with the following new features:

New organization integrating introductory chapters to make information about principles of the automated warehouse careers better connected for easier access

- New and updated information about the MSSC CT-SCA certification in Chapter 1
- New Chapter 4 offering insight into robotics and their use in the automated warehouse including AGV
- New and updated information in Chapter 5 about sensors, maintenance processes, prioritization and recordkeeping
- New Chapter 10 with information about the basics of networking and current internet use
- New Chapter 11 about cybersecurity

- New organization integrating introductory chapters to make information about principles of the automated warehouse careers better connected for easier access

These new features are the result of contributions by instructors, supply chain professionals and experts in the fields of automation and technology. The increasing need for supply chain technicians ensures access to exciting career opportunities in the future. From AI to blockchain to mechatronics, Supply Chain Automation is a growing field where certification programs, technical degree programs, and continuing education training ensure employees keep up with the pace of technology to prepare the next generation of the supply chain workforce.

Robert Sompolski

Acknowledgements

Thank you to the National Science Foundation's Advanced Technological Education Program, the National Center for Supply Chain Automation, and E-MATE for making the creation of this eTextbook possible.

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Introduction

It’s an exciting time to be a supply chain technician! Logistics companies across the country continue to invest millions of dollars into new high tech distribution centers and to add new automation technology to optimize their capital investment in their supply chains. Automation technology in warehousing is advancing at a faster rate because the buying trends of today’s consumers are changing. Warehouses must be able to identify, locate and ship product instantaneously and with 100% accuracy. Without automation, this would be impossible. Labor costs are expensive and many companies struggle to hire enough workers to keep up with their needs. Automation enables companies to get more work done with equivalent or fewer operators, so even small companies are beginning to invest in systems with advanced technologies that were once only found in manufacturing sites or very large companies.

As these new engineered systems become more complex, the need to keep the equipment well maintained and fully functional becomes even greater. Supply chain technicians play critical roles in supply chain success, and there are ever-increasing demands for highly skilled workers that can learn new equipment and software. New systems offer exciting opportunities to work with the most cutting edge technologies in the market today, such as robotics, automated guided vehicles (AGVs), and automated storage and retrieval systems.

A supply chain technician has to be versatile and knowledgeable about all of the equipment inside their facility. It is not uncommon for technicians to routinely work on any and all of the equipment that their companies own and use. Ongoing education and continuous learning is essential to keep up with the fast-paced

march of automation innovation. The more of these systems you understand, the more value you add to the facility.

This textbook introduces you to the career of a supply chain technician and the skills you will need to be successful. You will learn about warehousing and how it fits into a supply chain. You will have the opportunity to see firsthand the technology in use in an automated warehouse. You will meet experienced supply chain technicians and hear about the career from them directly. Finally, you will have the opportunity to read papers written by industry experts, of whom many contributed to the writing of this textbook.

This textbook is divided into 14 chapters. The first part of the book focuses on the career awareness, industry certifications and the principles of the supply chain. You will learn the terminology of the industry and hopefully spend a good deal of time reflecting and asking simple questions related to the supply chain. The middle section of the book focuses on the skills you will need to learn to be successful. Although this course will not teach you these skills, you will know what these skills are, why you'll need to master them, and most importantly, which classes you'll need to take and where to find them. The last part of the book focuses on the importance of workplace communication and the need for technicians to clearly articulate their intentions as they work with others.

In the next chapter you will learn about the career of a supply chain technician. The chapter includes several videos, quizzes, and interactivity with technology. As you progress through this course you will have an opportunity to explore the industry on your own. The internet is a wonderful tool and should be used to fulfill your curiosity. Good luck and I hope you find the world of automation interesting and exciting.

Instructor's Manual An instructor's manual is available to assist in planning and organizing courses that use this E-text. The manual includes learning objectives, case studies appropriate for classroom discussions or homework assignments, additional supplemental exercises, sample syllabi and all E-text Review exercise solutions. To obtain a copy of the instructor's manual, please request it from Bob Sompolski at somplski@oakton.edu.

Chapter 1

Introduction to the Field

In this chapter, you will learn what a supply chain technician is, what she/he does, and the education and training needed to be prepared for this exciting new career. You will learn also about current material handling certifications and some of the technical terms used in the industry standards underpinning them. In addition, you will be given an overview of the supply chain, how the many components of the chain work together, and an opportunity to review several case studies to help you better understand our nation's supply chain.



Section 1

Career Awareness

The career of a supply chain technician can be extremely rewarding. The successful technician will enjoy problem solving, learning new technology and taking responsibility. This section will introduce you to the career, outline the skills needed to be successful and show you all the resources you need to get started supporting our nation's supply chain as a highly skilled supply chain technician (SCT). This section will also give you insight into the day to day responsibilities of an SCT.

Many in the industry would describe this career as an industrial maintenance mechanic with expertise in the technologies and systems used in the 21st century's automated warehouses. That description is true. The Industry Leadership Team, providing guidance to the National Center for Supply Chain Automation, uses the following definition:

"A person who installs, operates, supports, upgrades or maintains the software, hardware, automated equipment and systems that support the supply chain."

As you read through this section you will have the opportunity to watch several videos, read relevant white papers, test your knowledge of the supply chain and create a list of resources you can use to plan your education.

Before you get started ask yourself these simple questions:

- How did the shoes that you are wearing get from the shoe manufacturer to your feet?
- How do you order something online right now knowing that it will get delivered to your home tomorrow?
- How many different types of soda are available for purchase?

Take a few minutes and write down the best answer you can. Think of all the steps necessary. How many people are involved? Why do consumers have so many choices? How far does a product have to travel? Where is it manufactured? The list of questions is infinite.

Now that you have thought about the scope of the supply chain, take a few minutes and watch this short video.

Movie 1.1 Material Handling as a Career



Tap to view a video

Now that you have a better idea of the technology used in the automated distribution center, who is going to keep this automated equipment operating?

Movie 1.2 What is a Supply Chain Technician?



Tap to view a video

We have spent time researching the role of an SCT and you may be wondering why warehouses have become so advanced in recent years. To help you understand why so much automation is being added to warehouses, think for a moment about what is driving the need for this technology.

Here are three examples. You may have several more.

1. E-commerce
2. Accuracy & efficiency
3. Massive amount of available products

That's right! We are purchasing products online more and more every day. Businesses have to track your order from the moment you place the order to the time the delivery driver drops the package at your door.

Take a few minutes and read this paper written by industry expert Steve Harrington.

Interactive 1.1 Factors Driving the Adoption of Automation in the 21st Century Warehouse PDF



Tap to view PDF.

Now that you understand why we need supply chain technicians, you may be wondering what type of education you need to become successful. The National Center for Supply Chain Automation has put together an occupation profile that will help you get started. The occupation profile will help you answer the following questions:

- What do you need to know?
- What do you need to do?
- What skills do you need to have?
- How much money are you going to make?

Interactive 1.2 Occupation Profile PDF



Tap to view PDF.

The final topic of the career awareness section focuses on what types of classes will you need to take to prepare yourself for this career. The Industry Leadership Team advising the National Center for Supply Chain Automation has agreed on a program of study that will meet the hiring criteria of most automated warehouses. Some locations have specific needs and put an emphasis on one skill over another. Some companies utilize specialists while other companies prefer someone with a more well-rounded skill set. In general, the skill sets listed in the sample program of study will prepare you for a career as an SCT.

Now that you have spent time learning about the role of an SCT, it's time to get started supporting our nation's supply chain as a highly skilled supply chain technician (SCT). Call or visit your local community college and ask them about the programs they have for this exciting field!

Interactive 1.3 Model Program of Study



Tap to view program.



Section 2

Industry Certification

The authors of this e-book believe industry recognized certification plays an important role in the success of our students.

The Manufacturing Skill Standards Council (MSSC) is a nonprofit education and testing organization offering certificates which recognize core skills and knowledge. The MSSC System, based upon industry and federally recognized standards, offers workers at all levels the opportunity to demonstrate that they have acquired necessary skills. MSSC has three certifications:

Certified Production Technician (CPT)

The CPT Certification addresses the core technical competencies of higher skilled production workers in all sectors of manufacturing. MSSC certifies individuals who pass any of its production modules: Safety, Quality Practices and Measurement, Manufacturing Processes and Production, Maintenance Awareness, and Green Production. A full Certified Production Technician (CPT) Certification is awarded to those who pass all of the first four modules listed above. (NOTE: At this time, Green is not a requirement for full CPT certification.)

MSSC's Certified Production Technician (CPT) is the only manufacturing certification that is accredited by the American National Standards Institute under

International Organization for Standardization (ISO) Standard 17024. ISO is the authoritative quality standard used by industry globally.

Certified Logistics Technician (MSSC CLT)

A certified logistics technician is an essential member of the supply chain automation team. Competent certified logistics technicians are in demand across many industries by companies that need skilled front-line workers to extend their national and global reach by linking factories, suppliers, and customers.

Logistics technicians work in fulfillment centers, warehouses, distribution centers, and factories, and are involved in receiving, packing, shipping, tracking, and processing orders. They work with management and team members on daily operations of logistics systems, warehousing, distribution, and ensuring freight is processed efficiently to maximize product service levels.

The MSSC Certified Logistics Technician (CLT) certification program recognizes mastery of the core competencies of material handling needed from entry-level positions to front-line supervisor through successful completion of the certification assessments.

The industry-recognized, nationally accepted CLA and CLT credentials help prepare individuals for careers in the rapidly growing and changing world of global supply chain logistics.

The MSSC CLT program consists of two parts:

- Foundational-Level Certified Logistics Associate (CLA) Certificate
- Mid-Level Technical CLT Certification (Candidates must have a CLA Certificate before attempting the CLT certificate assessment.)

The Certified Logistics Technician program covers a wide range of necessary skills:

- Global supply chain logistics
- Logistics environment
- Material handling equipment
- Safety principles
- Safe material handling and equipment operation
- Quality control principles
- Work communication
- Teamwork and good workplace conduct to solve problems
- Computer use
- Product receiving

- Product storage
- Order processing
- Packaging and shipment
- Inventory control
- Safe handling of hazardous materials
- Transportation mode evaluation
- Dispatch and trucking operations
- Measurement and metric conversions
- Industry 4.0 emerging technologies

Certified Technician Supply Chain Automation (MSSC CT-SCA)

The purpose of the MSSC Certified Technician-Supply Chain Automation (CT-SCA) program is to prepare technicians who install, operate, support, upgrade, and maintain the automated material handling equipment and systems which support the supply chain. Technicians will work with and test hands-on skills by use of a hands-on training and assessment system known as Skill Boss-Logistics.

The CT-SCA is comprised of three prestigious separate certificates:

- Certification in Equipment Maintenance
- Certification in Equipment Repair
- Certification in Network Repair

The Certified Technician-Supply Chain Automation program covers a detailed range of skills necessary for technicians to be successful in today's automated supply chain environment:

Certification in Equipment Maintenance:

- Implementation and removal of equipment/system safety protocols
- Identification and operation major automated equipment/ systems
- Monitor machine/system operation
- Availability of key parts and components are available in inventory
- Implementation of preventive maintenance
- Performance of preventive maintenance
- Establishment of monitoring and maintenance schedule for equipment/lubricant condition
- Safe use of hand tools to maintain equipment

- Communication with co-workers to promote productivity
- Performance of technical and administrative duties

Certification in Equipment Repair:

- Troubleshooting machine-mechanical/electrical/hydraulic/ pneumatic system failure
- Preparation for repair
- Repair of machine-mechanical/electrical/hydraulic/pneumatic system failure
- Installation, move or removal of equipment

Certification in Network Repair:

- Installation and maintenance of PLCs and PLC modules
- Troubleshooting and repair of PLCs with discrete I/O PLC modules
- Modification, troubleshooting or manipulation of standard PLC operating programs and test/verification for correct operation
- Installation, maintenance and troubleshooting of PLC systems with variable frequency AC drives
- Operation and tests of equipment network system, scanners and running of system applications

CT-SCA certificate candidates are required to use Skill Boss-Logistics for any MSSC CT-SCA Certification. The Skill Boss-Logistics system uses hands-on training and assessment for several situations students may encounter. Devised by Amatrol, Skill Boss-Logistics is based on 100 skills from MSSC's list of industry and nationally recognized CT-SCA standards.

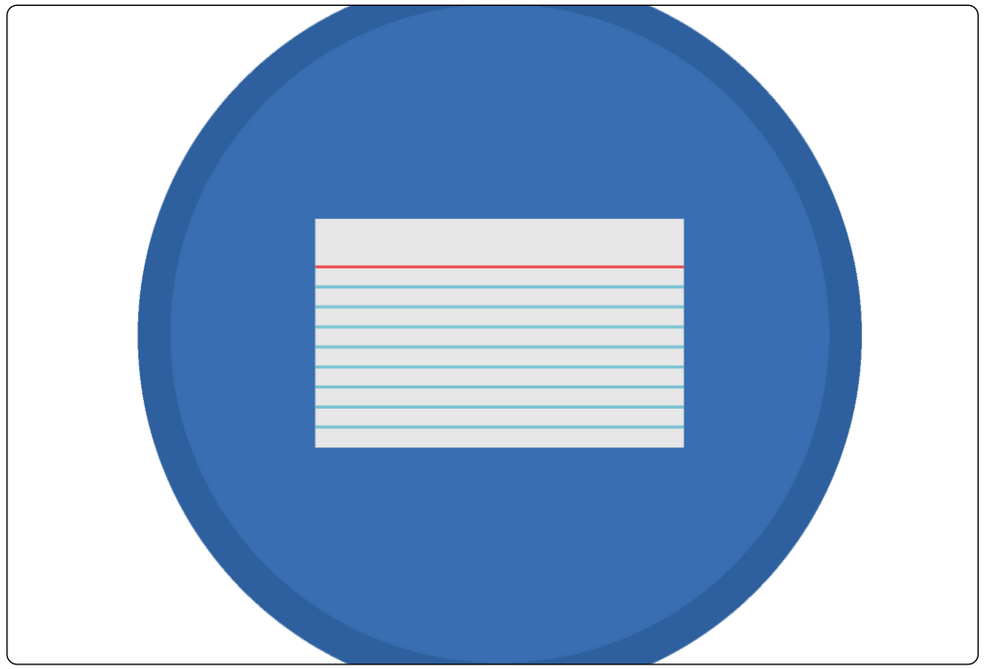
NOTE: Students seeking more information about these and other certificates should contact info@msscusa.org for complete information.

Review 1.1 Question Is . . . Round 1 (CLA-1)



Tap to test your knowledge.

Review 1.2 Flash Cards 1 (CLA-2)



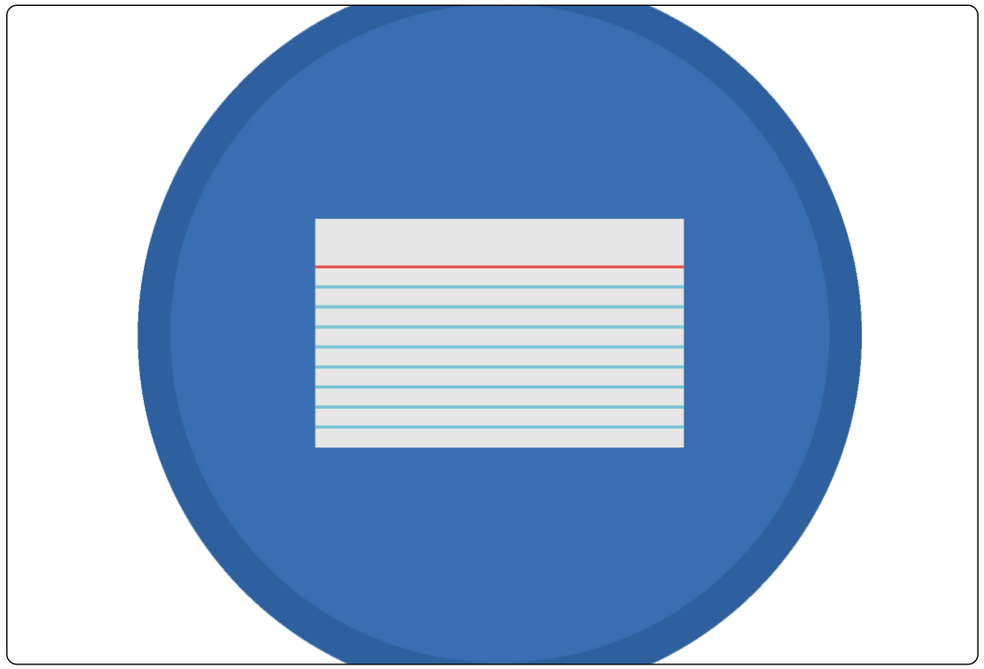
Tap to test your knowledge.

Review 1.3 Question Is . . . Round 2 (CLA-3)



Tap to test your knowledge.

Review 1.4 Flash Cards 2 (CLA-4)



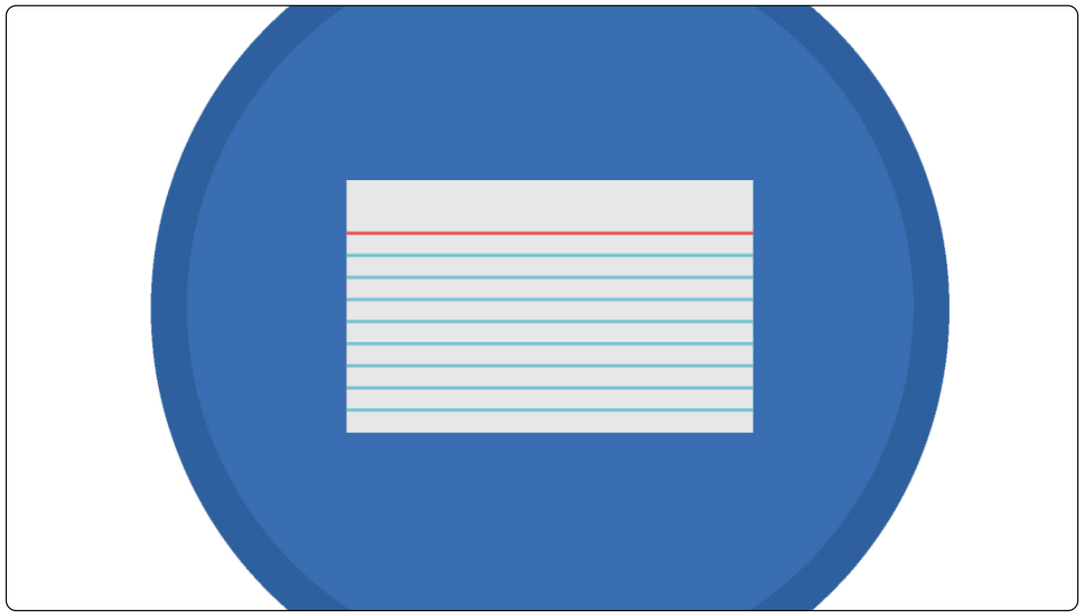
Tap to test your knowledge.

Review 1.5 Question Is . . . Round 3 (CLA-5)



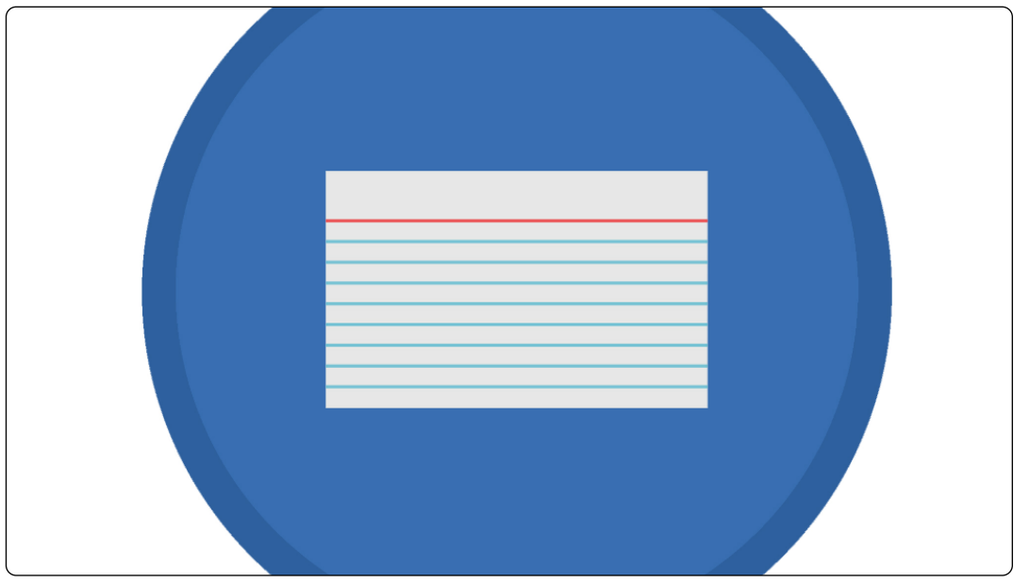
Tap to test your knowledge.

Review 1.6 Flash Cards 3 (CLA-6)



Tap to test your knowledge.

Review 1.8 Flash Cards 4 (CLA-8)



Tap to test your knowledge.

Review 1.7 Question Is . . . Round 4 (CLA-7)



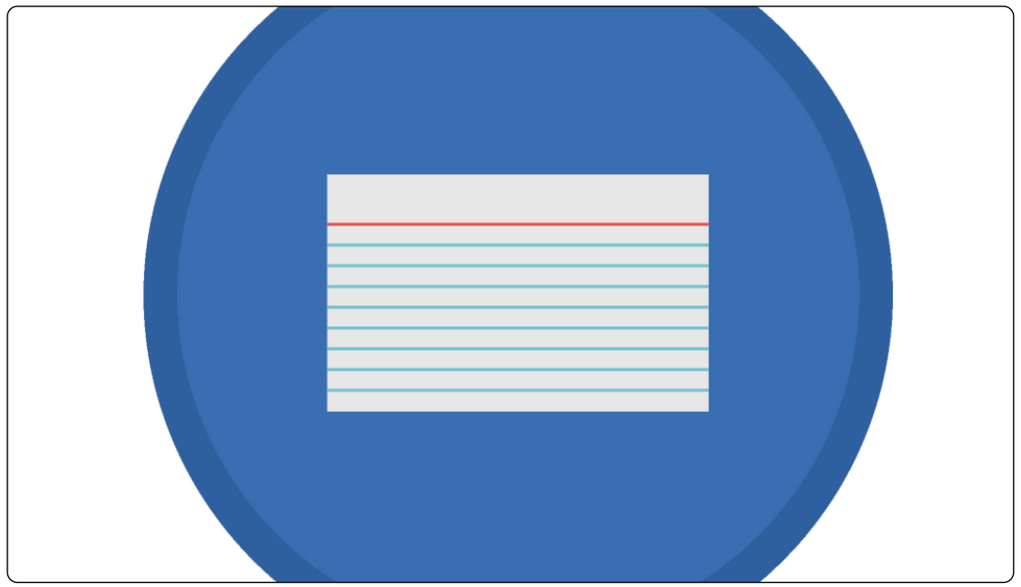
Tap to test your knowledge.

Review 1.9 Question Is . . . Round 5 (CLA-9)



Tap to test your knowledge.

Review 1.10 Flash Cards 5 (CLT-2)



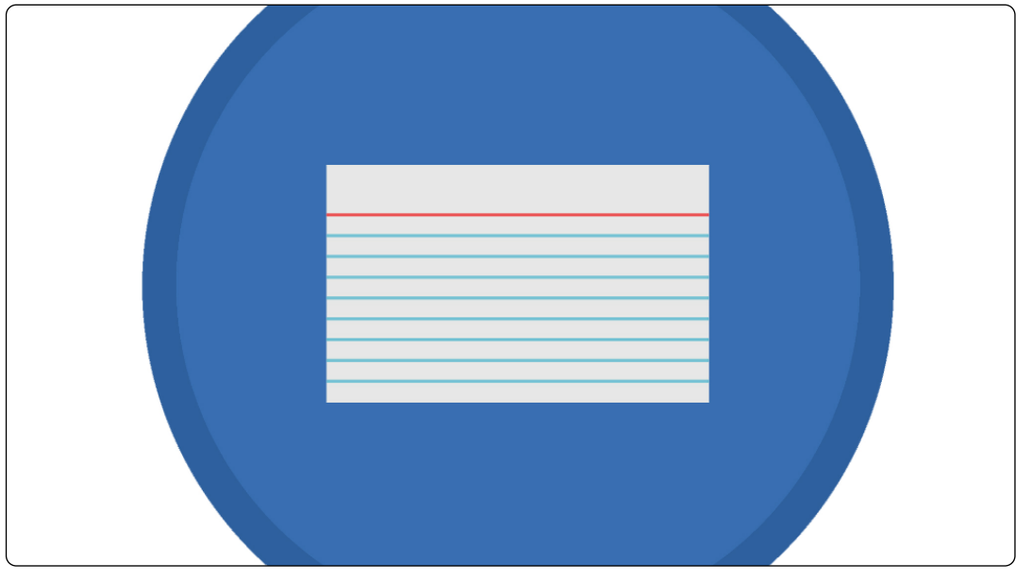
Tap to test your knowledge.

Review 1.11 Question Is . . . Round 6
(CLT-Comprehensive Final Round)



Tap to test your knowledge.

Review 1.12 Flash Cards 6 (CLT-4)



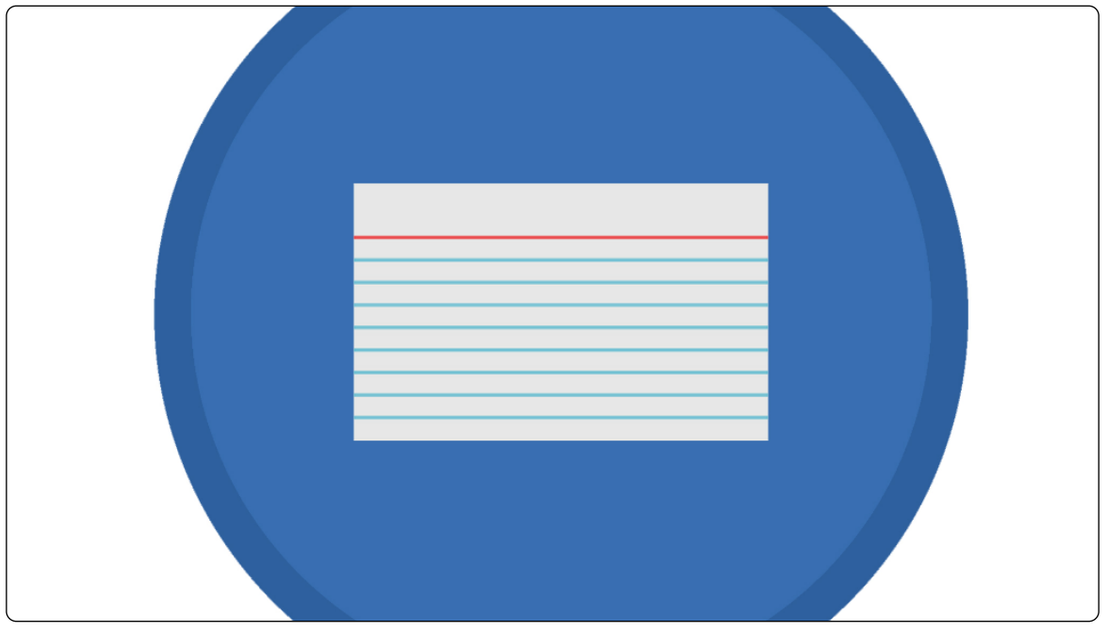
Tap to test your knowledge.

Review 1.13 Question Is . . . Round 7
(CLT-Comprehensive Round 1)



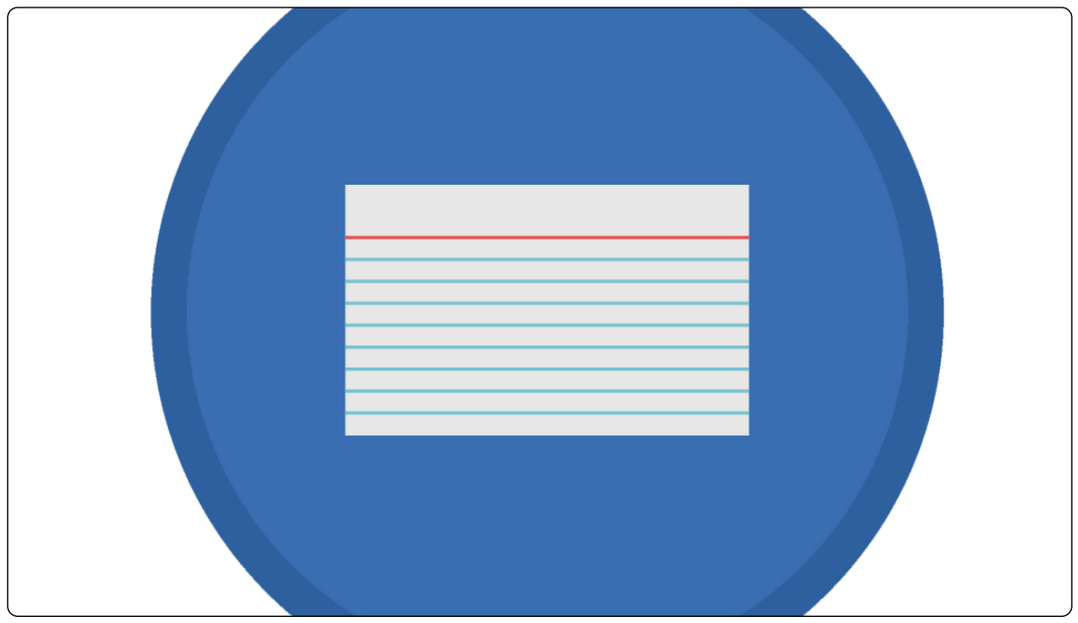
Tap to test your knowledge.

Review 1.14 Flash Cards 7 (CLT-6)



Tap to test your knowledge.

Review 1.15 Flash Cards 8 (CLT-8)



Tap to test your knowledge.



Section 3

Supply Chain Principles

What is a Supply Chain?

One definition for Supply Chain is a network of manufactures, retailers, distributors, transporters, storage facilities, and suppliers that participate in the production, delivery, and sale of a product to the consumer. It is typically made up of multiple companies who coordinate activities to set themselves apart from the competition. Take a few minutes and think about the supply chain needed to sell new automobiles. Now consider the supply chain needed to sell every model by a single automobile manufacturer. Now think about every new car sold! The concept of a supply chain is simple; however, the complexity to make it efficient can be daunting.

What are some examples of a Supply Chain or companies that you know which have a Supply Chain?

Some supply chains are quite small. Think of the local farmer who grows tomatoes and sells them at the Farmers' Market in town. In this example, the Supply Chain goes directly from Grower/Producer to Customer and there isn't a "middle man" in between. However, some supply chains are large, global, complex, and a differentiating factor for organizations. Think of Target and the Supply Chain that is required to keep thousands of stores in stock with the right product at the right time.

Interactive 1.4 What is Supply Chain Management?



Tap the image to open web page. Study the slides to learn what is supply chain management. View the various positions available for employees within the chain.

The supply chain has four major components.

Purchasing of supplies focuses on the raw materials supplied to manufacturing, including how, when, and from what location.

- What are some examples of raw materials? Wood, plastics, leather, cotton, steel, milk, eggs, flour

Manufacturing and operations focus on converting these raw materials into finished products.

- What are some examples of Manufacturing? Bakery, facility where cars are made or goods are produced, newspaper printing facility

Transportation focuses on the movement of raw materials and finished products using different modes of transportation within the supply chain.

- What are some of the examples of the methods of transportation? Trucks, aircraft, railroads, pipelines or ships

Warehousing and distribution focuses on ensuring these products reach the consumers through an organized network of distributors, warehouses, and retailers.

- What are some examples of Companies that have Distribution Centers nationwide? Wal-Mart, Target, Amazon, Barnes and Noble, Home Depot

While often applied to manufacturing and consumer products, a supply chain can also be used to show how several processes supply one another. The definition in this sense can apply to Internet technology, finance, and many other industries. Take a few minutes and try to identify a process that isn't needed in some supply chain.

History of Supply Chain

In ancient times, transportation technology was basic and the cost of moving goods was an important determinant of the production and distribution of a product. Thus, goods were put together close to the source of raw materials. Then, these products made their way in a largely linear chain to their end consumer.

Ancient trade routes like the Silk Road through Central Asia and the Spice Route over the Indian Ocean were mostly linear chains that took a finished product to its ultimate destination. Moreover, given the high costs, long-distance trade was limited to high-value items such as spices, weapons and luxury goods.

It was only in the 18th century that shipping technology improved enough to allow the large-scale functioning of an international production network. Interestingly, the first product to be put together with a truly global supply network was rum. Slave labor was imported from West Africa to the Caribbean in order to grow sugarcane (a plant originally from India). Sugarcane molasses was then shipped to New England where distilleries in Massachusetts, Rhode Island and Staten Island turned it into rum.

All of these changes were complimented by improvements in ship design and, by the mid-19th century, the introduction of steamships. As a result of all of these innovations, a global supply network emerged that involved shipping cotton grown in the southern United States to the cotton mills in England. The finished cloth was then shipped out to the rest of the world.

Over the next century, transportation technology witnessed major breakthroughs that included the railways, trams, bicycles and the Suez Canal. By the time of World War I, we also had the Panama Canal, automobiles and even early airplanes. As a result, the cost of transporting goods dropped sharply. Ocean freight rates, for instance, fell 70% between 1840 and 1910.

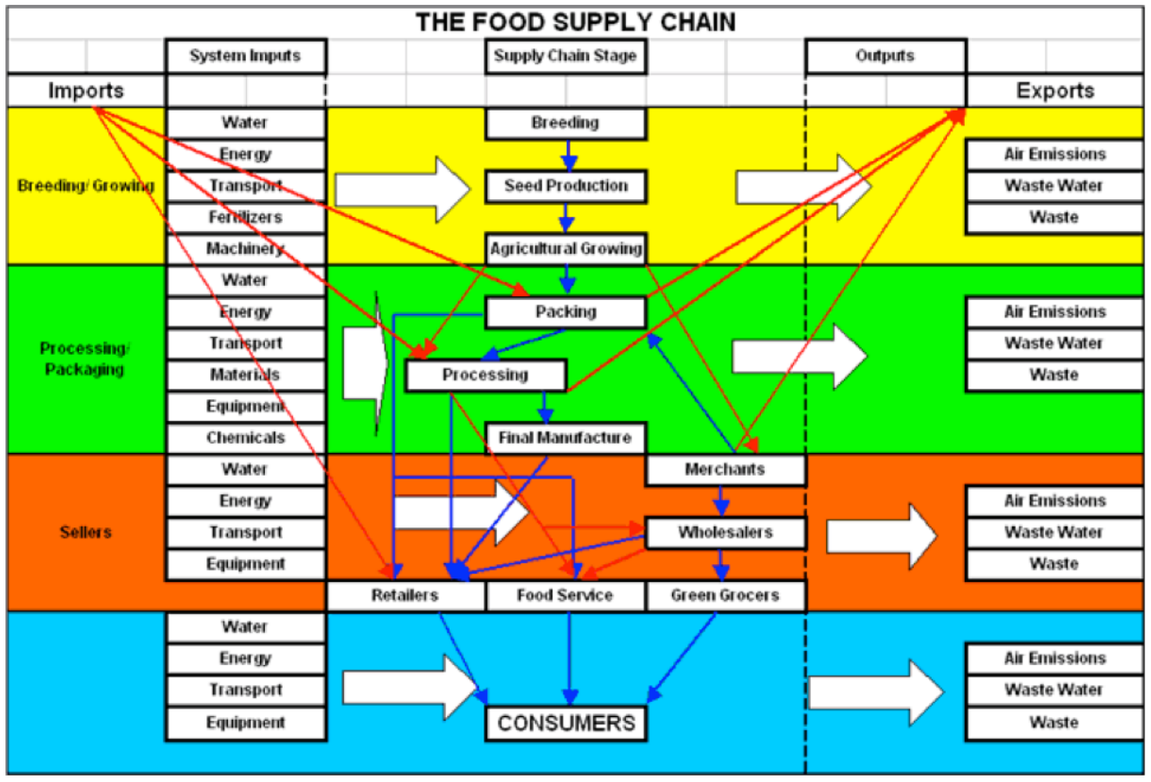
The Second World War witnessed the pinnacle of the Fordist production system. By 1950s, a new generation of technological changes began to alter the structure of global supply networks.

The combination of containerization (the loading of goods into Ocean Containers for transport) and telephones (and related technologies like the fax) caused the next shift in supply networks. Improved communications meant that it was possible to exactly specify components and products. Containerization meant that these components could be transported cheaply and be delivered “just-in-time (JIT).”

Meanwhile, the efficiency gains of "just-in-time" and lean production were making their way downstream and being applied to distribution networks. One of the results of this change was the rise of hyper-markets like Walmart and Carrefour. By leveraging scale, logistics and lean inventories, they were able to bring down retail prices as well as provide consumers with unprecedented

choice. It is very clear that the supply chain has become increasingly complex over the years. Think about today's supermarkets and unwind the retail progression. Before we had supermarkets we had standalone bakeries, meat markets, produce stands, bread trucks and milk men that delivered dairy products to your door. Now think about Super Target and Super

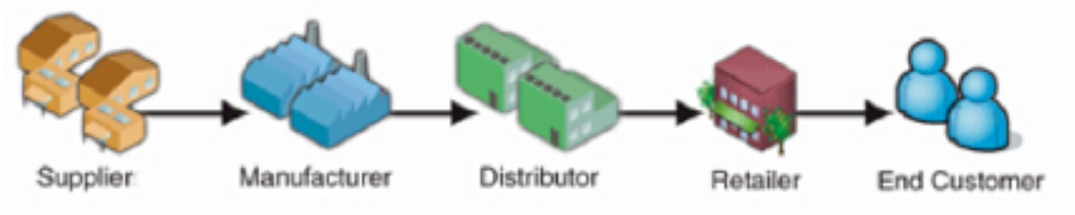
Complex Supply Chain Example



Tap to zoom.

Walmart and try to understand the retail progression that is taking place today. What's next?

Simple Supply Chain Example



Distribution Center

Has anyone toured, worked in or known anyone who works in a Distribution Center?

A distribution center for a set of products is a warehouse or other specialized building which is stocked with products (goods) to be redistributed to retailers, to wholesalers, or directly to consumers. Depending on the type of business or what part of a company's supply chain a warehouse is utilized in, you may encounter different types of warehouses. These different types of warehouses will be differentiated from each other based on these factors:

- The role they serve in the supply chain (raw materials, sub-assemblies, finished goods, etc.)
- The geographical region they service
- The processes and equipment used to bring goods into the warehouse, store goods, and ship goods out of the warehouse
- The particular storage requirements of the goods to be stored (climate controlled, secured, etc.)

Movie 1.3 Amazon Distribution Center



Tap to view a video

At a basic level, all warehouses receive goods in, store goods, and then ship goods out.

A distribution center is a principal part, the order processing element, of the entire order fulfillment process. Distribution centers are usually thought of as being demand-driven. In addition to being a warehouse, a distribution center can also be called a DC, a fulfillment center, a cross-dock facility, a bulk break center, and a package handling center. The name by which the distribution center is known is commonly based on the purpose of the operation. For example a "retail distribution center" normally distributes goods to retail stores, an "order fulfillment center" commonly distributes goods directly to consumers, and a

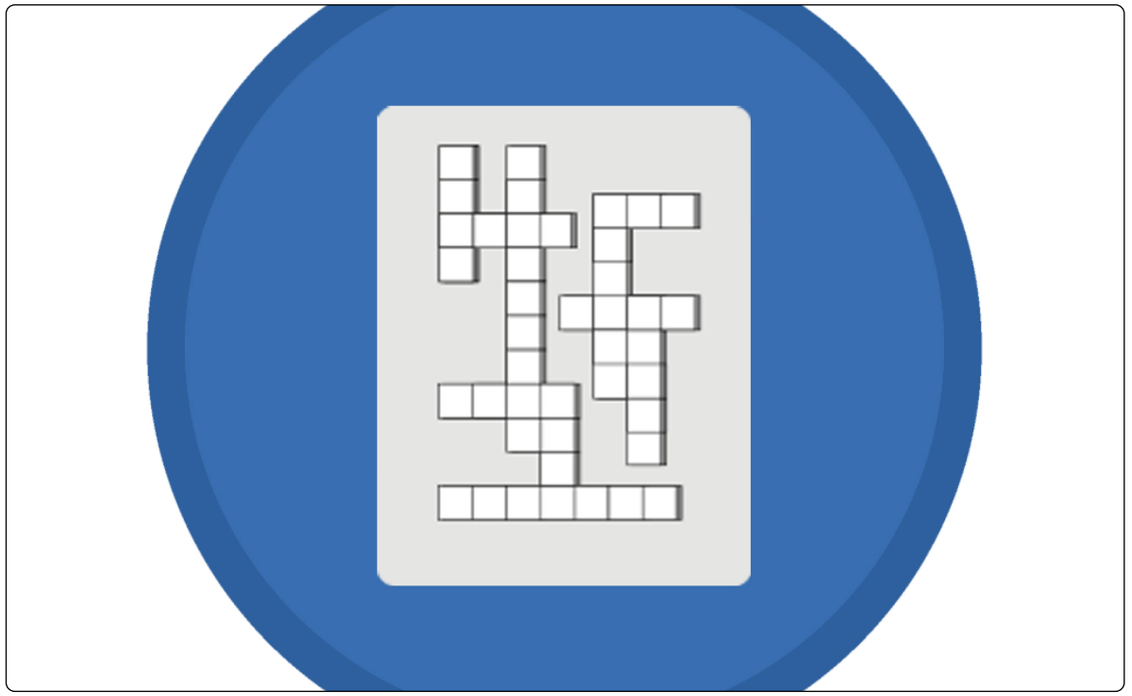
crossdock facility stores little or no product, but distributes goods to other destinations.

Distribution centers are the foundation of a supply network, as they allow a single location to stock a vast number of products. Some organizations operate both retail distribution and direct-to-consumer out of a single facility, sharing space, equipment, labor resources, and inventory as applicable.

A typical retail distribution network operates with centers set up throughout a commercial market, with each center serving a number of stores. Large distribution centers for companies such as Wal-Mart serve 50–125 stores. Suppliers ship truckloads of products to the distribution center. The distribution center stores the product until needed by the retail location, then ships the proper quantity.

Since a large retailer might sell tens of thousands of products from thousands of vendors, it would be impossibly inefficient to ship each product directly from each vendor to each store. Many retailers own and run their own distribution networks, while smaller retailers may outsource this function to dedicated logistics firms that coordinate the distribution of products for a number of companies. A distribution center can be co-located at a logistics center.

Review 1.16 Supply Chain Principles Crossword Puzzle



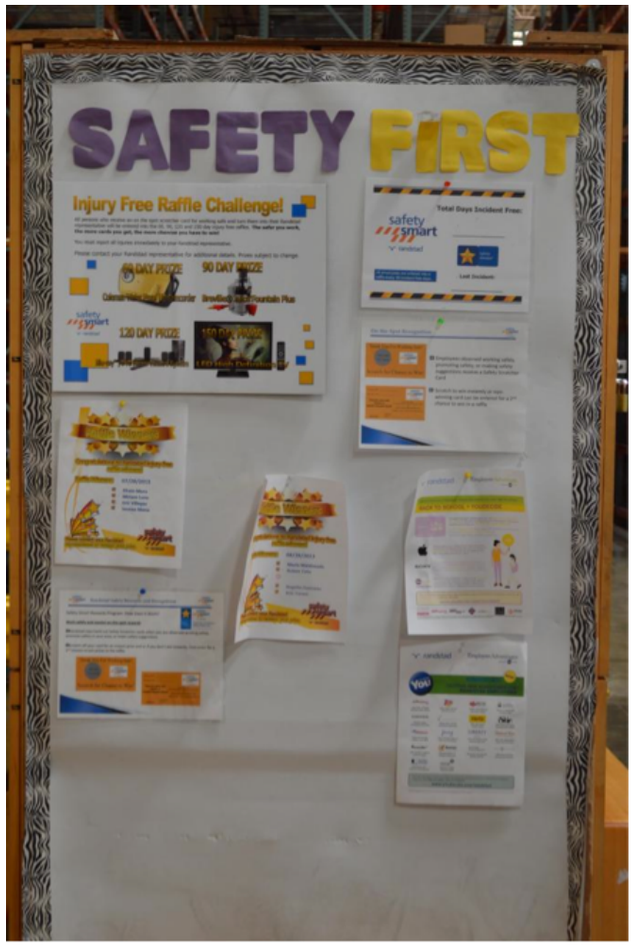
Tap to complete a crossword puzzle about supply chain principles.

Chapter 2

Safety

This chapter will explain the importance of safety in the automated warehouse and give you an opportunity to test your knowledge of safety best practices.

Safety Planning, Accountability and Reporting



A safety poster keeps safety on the mind of all employees in a distribution center. The constant reminder is a proven method of controlling accidents.

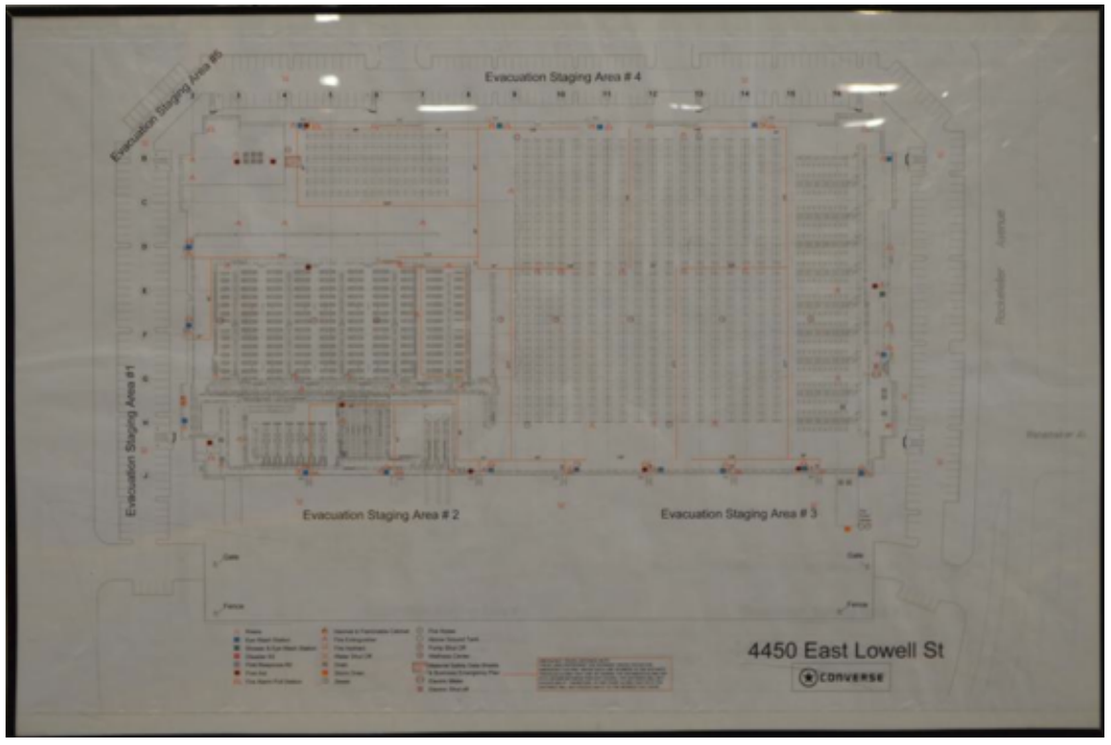
Working safely is the most important aspect of the working environment. Knowing the hazards and concerns of the workplace are a major part of all operations and tasks. Planning the task and identifying the hazards prior to the start of a project will minimize risk and make for a more efficient job completion. Documentation of the safety processes and activities are required for all employees and standardized forms need to be used. The complete and timely reporting of concerns is very important to expedite correction and eliminate future concerns.

Emergency Plan

Natural disasters and problems within the facility have to be planned for and practiced to make sure measures are taken to protect personnel and facilities. The overall crisis management plan must contain areas of responsibility, staging areas, personnel teams, and communication with inside and outside contacts and in most cases, security departments.

Evacuation Plan

The written evacuation plan is a document that is posted so all employees have access to the information and understand where to go to exit the facility in a quick and safe manner. Included will be staging areas and people responsible for each group of people exiting the facility.



Evacuation plan that is posted on the wall at the entrance to a distribution center. It shows the current location and the escape route.

Injury Plan and Report Form

Recordkeeping is very important to create documentation of any injuries that take place during an incident. Procedures and common forms are used to create consistency in the process and to verify that all required information has been included. Input from everyone involved is also very important so interviews and fact finding will be done. This process needs to be completed as soon as it is practical.

Serial no.

State date of resumption of work Year Month Day

Name of injured person	Date of birth
Address of injured person	Postal code

Please send to the address overleaf

OCCUPATIONAL ACCIDENT REPORT

Serial no.

Injured Person

Name	Date of birth	☐
Address	Postal code / Nationality	☐
Occupation	Time of accident Year Month Day Hour	☐ Self-employed ☐ Trainee ☐ Family Member

Employer Information

Name of business	Company registration No.	
Address	Postal code	Number of staff
Economic Activity	Length of service Years Months	
If the accident did not occur at the enterprise address state where / Address		Postal code

Type of work and work environment

What type of work was the injured person doing at the time of the accident? (e.g. iron founding, harvesting, slaughtering)
Where was the injured person at the time of the accident? (Inside buildings, underground, etc.)

Circumstances of the accident

Describe what the injured person was doing at the time of the accident and what item (tool, machine, etc.) was associated with the activity
Describe the action of deviation from normal including the item (tool, machine, etc.) associated with the deviation
Describe the action leading to injury including the agent (tool, machine, etc.) that caused the injury

Consequences of the accident

Type of injury		Injured part of the body	
☐ Contrusion, bruise	☐ Asphyxiation, gassing, drowning	☐ Head except eyes	☐ Hand
☐ Concussion and internal injuries	☐ Poisoning	☐ Eyes	☐ Fingers, one or more
☐ Open wound	☐ Heat injury or frostbite	☐ Neck	☐ Hip joint, thigh, knee cap
☐ Amputation	☐ Chemical burns	☐ Back, spine	☐ Knee joint, lower leg, anide area
☐ Open fracture	☐ Effect of radiation	☐ Chest	☐ Foot
☐ Closed fracture	☐ Electric shock	☐ Abdomen	☐ Toes, one or more
☐ Luxation, dislocation	☐ Injury not ascertained	☐ Shoulder, upper arm, elbow	☐ Large parts of the body
☐ Distortion, sprain, torn ligaments	☐ Other	☐ Lower arm, wrist	☐ Other injury

Describe fully the nature of the injury and the injured part of the body

Consequences of the accident

☐ No absence/absence less than 1 day ☐ Absence 1-3 days ☐ Absence 4-14 days ☐ Absence expected to exceed 14 days ☐ Permanent disability ☐ Death

Date _____ Signature of person reporting the claim _____

Occupational accident report form that is used to account for and standardize the collected information.

Incident Reporting

Incident Reporting is the overall collection of information on an incident that has an effect on personnel, equipment or deliverables. The process includes accident reporting, statement forms, equipment review forms and property damage reports. This documentation allows for fact finding and planning for changes to operational processes to eliminate the problems in the future.

Accident /Incident Report and Investigation Form

Directions: Complete sections 1, 2, and 3 for all accidents and incidents. Accidents or incidents that require medical attention or lost or restricted work require the signature of the Divisional Vice President. Attach additional sheets as necessary. Send competed forms to the Director Of Human Resources.

1. EMPLOYEE INFORMATION

Name: _____ **Social Security #** ___-___-___
First MI Last

Dept.: _____ **Job Title:** _____

Full Time ☐ **Part Time** ☐ **Student worker** ☐ **Other** ☐ _____

2. ACCIDENT/ INCIDENT INFORMATION

Date of incident: ___/___/___ **Location:**_____

Time of incident_____**AM/PM** **Time Employee began work** _____**AM/PM**
☐ Check if time cannot be determined

Types of incident (check all that apply) ☐ **Accident** ☐ **Injury** ☐ **Illness** ☐ **Other** _____

What was the employee doing just before the incident occurred? Describe the activity as well as the tools, equipment or materials the employee was using just before the incident.

_____

_____

What happened? Describe the incident. _____

_____

_____

_____

_____

_____

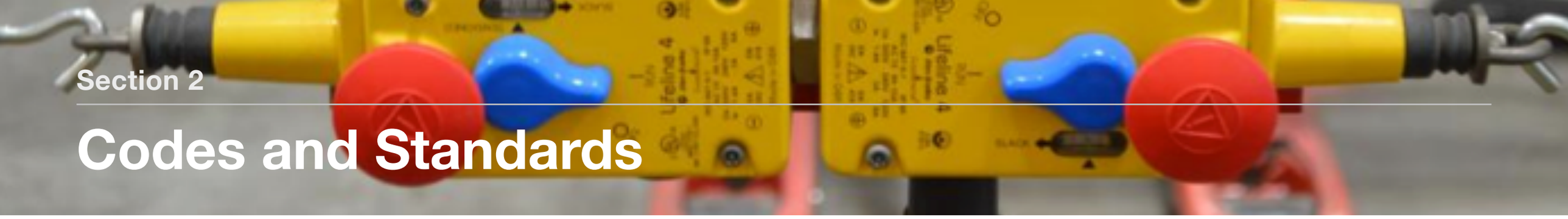
_____

_____

_____

_____

Accident/Incident report and investigation report form is used for the collection of information from an incident that may be for equipment or process failures. They can also be a follow up to an injury report.



Section 2

Codes and Standards

Safety is the concern of all employees and maintenance technicians working within a distribution center. The best way to establish a safe working environment is to create codes and standards that can be applied and documented for consistent approaches in the workplace. These standards and codes can be local and apply to a single facility and established by the company or they may be established by national, state or local organizations of which all companies must comply. Most employers will use a combination of codes and standards that are both local and specific to a facility and yet meet the federal and state requirements.

Occupational Safety and Health Administration (OSHA)

OSHA website and logo

The Occupational Safety and Health Administration is the most comprehensive and recognized federal agency that deals with all aspects of workplace safety. The regulations they provide are the standards and codes that are the most widespread in use and most other regulatory organizations must abide by their requirements. They are the minimum standards

established for all safety concerns and apply to all areas of industry workplaces. State and local agencies can require more complete and comprehensive standards.

American National Standards Institute (ANSI)

The American National Standards Institute is an organization that is a clearinghouse for guidelines to create conformity to enhance the competitiveness and safety within the global markets for US companies. Technical organizations create and recommend the standards which are then approved and co-published for use by all related industries. This allows for consistency and compatibility between products and guarantees quality. The American National Standards Institute is also the organization that represents US interests in the International Organization for Standardization that does the same work internationally.

ANSI logo

US Department of Transportation (USDOT)

The Department of Transportation has the responsibility of creating and enforcing the transportation regulations that are used to establish and improve the transportation system as it applies to health and safety. The application to distribution centers is that all goods are moved to and from the center by ship, rail, or truck, all of which must meet or exceed DOT standards. These standards produce a safe and healthy environment for everyone and consistency in requirements nationally.

US Department of Transportation (USDOT) logo



Section 3

Emergency Shut Off Devices

Electrical and mechanical devices in the distribution center will all have some sort of emergency shut off device. They range from electrical controls for panels to mechanical/electrical emergency stops on equipment. Some of the stops are automated using sensors to automatically stop operations. These stops are required and are located so as to provide direct access for employees.

Interactive 2.1 Emergency Shut Off Devices



Tap to view multiple images.



Section 4

Personal Protection Equipment

Personal Protection Equipment (PPE) is required whenever a working environment cannot be developed in such a way that creates a safe working condition for employees. These issues include any time an employee is put at personal risk of injury because of a situation requiring clothing, helmets, shoes, hearing, eyes, falling or hand and arm protection above normal dress and conditions. Some applications can also include chemical and electrical hazards that require specialty PPE.



Personal protection equipment used for battery service on lift trucks in a distribution center

Eye and Face

Safety Glasses

Safety glasses are the most common safety device used extensively in the working environment. They protect the eyes from liquid, particulate and impact damage. They are normally clear and made of a plastic lens and frame. Tinted lenses are used for outdoor use or in a light emitting area. In extreme applications such as chemical exposure, goggles may be required. Designs differ, but regulations dictate the protection in each type of application.

Face Shields

Face shields are required for both protection and comfort when the environment is more hazardous and safety glasses will not be adequate. They are normally a plastic lens mounted to a head band that covers the entire face and neck to protect the user from impact and particulate intrusion. They can be tinted for use when bright light is a concern. They can also be used with safety glasses to improve facial comfort and protection. Eye wash stations must be in all areas where specific risks such as chemicals are present.

Interactive 2.2 Personal Protection Equipment



Tap image to learn more about personal protection equipment.

Respiration Protection

Inhalation of hazardous gases or particles is especially damaging. The use of a respirator when at risk is a requirement. Respirators vary based on the materials and conditions under which the concern exists. They are worn to eliminate dust, liquid particulates, airborne chemicals and gases. The selection process for the type of device and the cartridges used is critical to a safe application.

Head Protection

Head protection (hard hat) is worn where a possibility of falling objects, electrical shock, flying items or bumping of the head puts the worker at risk for injury. Hard Hats are normally made of a plastic or composite material with suspension liners that distribute the impact so injury doesn't occur. Different classifications exist for determining the correct protection for the work environment. Another known value for requiring the use of head protection is that most workers see a commitment to safety by the employer and safety becomes a normal part of their job.

Hearing Protection

Hearing protection prevents initial occupational hearing loss, preserves and protects remaining hearing, and equips workers with the knowledge and hearing protection devices necessary to safeguard themselves. Employers are required to measure noise levels, monitor employees' hearing, and provide hearing protection and training. Research indicates that workplaces with appropriate and effective hearing protection programs have higher levels of worker productivity and a lower incidence of absenteeism.

Feet

Protecting feet during the performance of a task will require a level of footwear that is appropriate to the activity. Impact protection, slip resistance, foot support, chemical resistance and comfort are all part of the selection process. The most common requirement for safety shoes is for protection from impact or falling items. Working in an area of heavy materials and potential dropping or displacement of items requires a steel or composite toed shoe or boot for this type of protection.

Hands

Hand protection is usually in the form of gloves. Protection can be for chemicals, cuts, abrasions, heat, electricity and many additional risks. The selection of the proper gloves for the task is critical for the safety of the employee and may be influenced by the need for dexterity and protection.

Section 5

Hazardous Materials

Handling of hazardous materials in the workplace is the responsibility of employees and management. All authorized, qualified and competent people need to be trained in the laws, procedures and processes for the safe handling of materials to minimize accidents. The discarding of materials is controlled and monitored to address the issues within the environment.



Hazardous materials must be isolated, identified and contained. Secondary containment is normally provided to be sure no leakage is possible.

Hazardous Material Identification System (HMIS)

The Hazardous Material Identification System is a numerical rating that incorporates the use of labels with color-coded diamonds to define the type of hazard that is present and the degree of risk; the higher the number, the greater the risk. The four bars are used as symbols to identify different hazards: blue for health issues, red for flammability or fire issues, orange for physical hazards and white for personal protection. Each area includes a number system, ranging from 0-4, to identify the degree of risk.



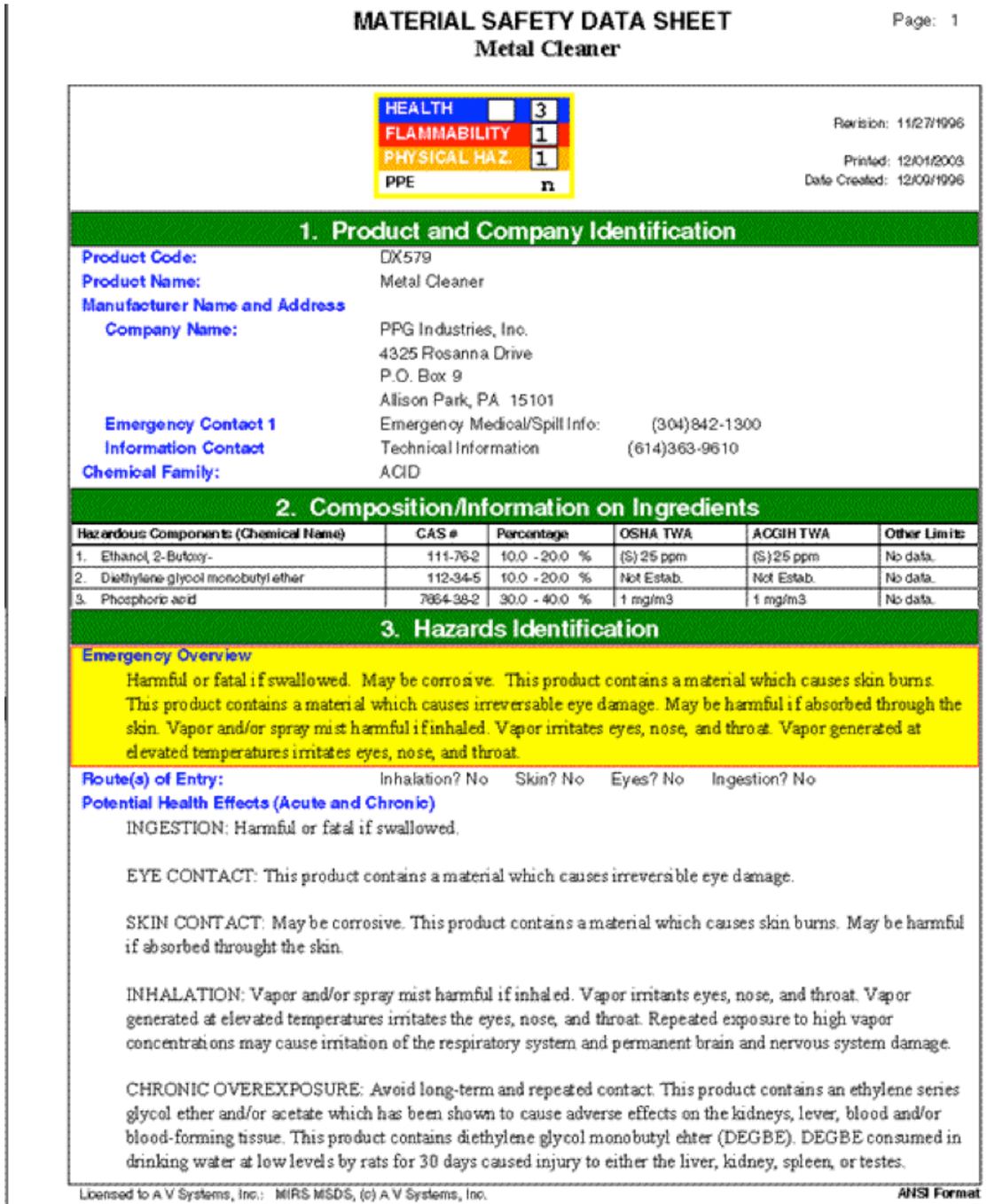
Hazardous Material Identification System poster identifies the type of hazardous material so appropriate precautions can be taken. All materials must be identified. www.nfpa.org

Material Safety Data Sheets

All hazardous materials must be properly labeled, and information about each material must be posted on a Material Safety Data Sheet (MSDS). The sheet must include identification, and all chemical and physical properties, protective handling, explosive/fire hazard, incompatibility issues, health and medical issues, handling guidelines and spill/leak procedures. The sheets must be available at an easily accessed location for employees, safety officials and fire departments.



Material Safety Data Sheets are available for employee and public access for emergency responders and are normally kept in a binder for easy updating and changing.



MATERIAL SAFETY DATA SHEET
Metal Cleaner

Page: 1

HEALTH 3
FLAMMABILITY 1
PHYSICAL HAZ. 1
PPE n

Revision: 11/27/1996
Printed: 12/01/2003
Date Created: 12/09/1996

1. Product and Company Identification

Product Code: DX579
Product Name: Metal Cleaner
Manufacturer Name and Address
Company Name: PPG Industries, Inc.
4325 Rosanna Drive
P.O. Box 9
Allison Park, PA 15101
Emergency Contact 1: Emergency Medical/Spill Info: (304)842-1300
Information Contact: Technical Information (614)363-9610
Chemical Family: ACID

2. Composition/Information on Ingredients

Hazardous Components (Chemical Name)	CAS #	Percentage	OSHA TWA	ACGIH TWA	Other Limits
1. Ethanol, 2-Butoxy-	111-76-2	10.0 - 20.0 %	(S) 25 ppm	(S) 25 ppm	No data.
2. Diethylene glycol monobutyl ether	112-34-5	10.0 - 20.0 %	Not Estab.	Not Estab.	No data.
3. Phosphoric acid	7664-38-2	30.0 - 40.0 %	1 mg/m3	1 mg/m3	No data.

3. Hazards Identification

Emergency Overview

Harmful or fatal if swallowed. May be corrosive. This product contains a material which causes skin burns. This product contains a material which causes irreversable eye damage. May be harmful if absorbed through the skin. Vapor and/or spray mist harmful if inhaled. Vapor irritates eyes, nose, and throat. Vapor generated at elevated temperatures irritates eyes, nose, and throat.

Route(s) of Entry: Inhalation? No Skin? No Eyes? No Ingestion? No

Potential Health Effects (Acute and Chronic)

INGESTION: Harmful or fatal if swallowed.

EYE CONTACT: This product contains a material which causes irreversible eye damage.

SKIN CONTACT: May be corrosive. This product contains a material which causes skin burns. May be harmful if absorbed throught the skin.

INHALATION: Vapor and/or spray mist harmful if inhaled. Vapor irritants eyes, nose, and throat. Vapor generated at elevated temperatures irritates the eyes, nose, and throat. Repeated exposure to high vapor concentrations may cause irritation of the respiratory system and permanent brain and nervous system damage.

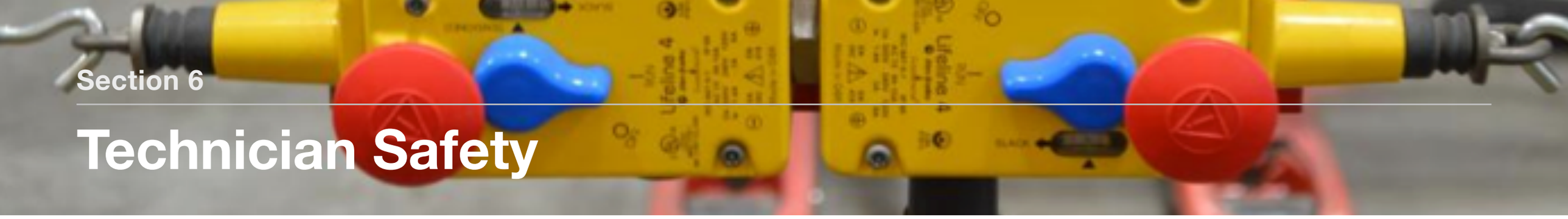
CHRONIC OVEREXPOSURE: Avoid long-term and repeated contact. This product contains an ethylene series glycol ether and/or acetate which has been shown to cause adverse effects on the kidneys, lever, blood and/or blood-forming tissue. This product contains diethylene glycol monobutyl ehter (DEGBE). DEGBE consumed in drinking water at low levels by rats for 30 days caused injury to either the liver, kidney, spleen, or testes.

Licensed to A V Systems, Inc.: MIRS MSDS, (c) A V Systems, Inc. ANSI Format

Individual MSDSs include standardized information that is important to employee health, risks and emergency responders handling accidents or applying procedures.

Handling and Disposal

Proper handling and disposal of hazardous materials is the responsibility of all employees. Handling guidelines or regulations should be in place and everyone should abide by the processes. In many situations, outside venders are used for the disposal process since they are normally licensed, insured and better informed of the proper handling processes.



Section 6

Technician Safety

Lockouts and Tagouts

Lockouts and tagouts are a technique used to prevent operation or access to an area while maintenance or repairs are being done on facilities or equipment. Lockout is the placement of a lock or control device or can mean physically disconnecting the source of power. Tagout is the placement of a tag that informs people that the area or equipment is not to be activated, but it is not a physical barrier to use. Normally, the person activating the lockout/tagout should be the only person to remove the lock or tag and place the area or equipment back in service.

Fall Protection

Falls are among the most common causes of serious work related injuries and deaths. Employers must set up the work place to prevent employees from falling off of overhead platforms, elevated work stations or into holes in the floor and walls. OSHA requires that fall protection be provided at elevations of four feet or greater in general industry workplaces. In addition, OSHA requires that fall protection be provided when working over dangerous equipment and machinery, regardless of the fall distance.

Fall Arrest Systems

A personal fall arrest system is one option of protection that OSHA requires for workers in sites who are exposed to vertical drops of 6 feet or more. These systems can include lanyards, deceleration devices, harnesses and anchorage points. The systems vary with application, but all accomplish the same task of controlling a personal fall. In the distribution center, workers picking materials on lift equipment will be using harnesses and deceleration devices.

Guardrails

At any point with a drop of three feet or more, a guardrail is required. They are used as a safety device to stop a person from falling off a platform, steps or walkways. They are 42 inches in height depending on the application and must be solidly fastened to the base.

Interactive 2.3 Technician Safety Images



Tap to view images.



Section 7

Fire Safety and Prevention

Fire safety is the primary concern of most safety managers in the industrial setting. The development of fire safety training and a comprehensive plan is the responsibility of all employees and must be followed. Steps must be taken to prevent an environment where fire can start and propagate throughout a facility. An organized plan with good housekeeping at the forefront will minimize the possibility of a loss.

www.osha.gov/SLTC/firesafety/



Fire hoses are positioned around the distribution center to fight a fire if needed.

National Fire Protection Association (NFPA)

The National Fire Protection Association creates and distributes codes and standards to help minimize the risks of fire. Building materials, sprinkler systems, wall coverings, accessibility and item storage are a few areas addressed in the guidelines.

www.nfpa.org

Fire Types

The four types of fires are listed below:

1. Class A, general combustibles
2. Class B, flammable liquids
3. Class C, electrical fires
4. Class D, flammable metals (magnesium, aluminum oxide, sodium)

Types of Extinguishers

The three basic types are listed below:

1. Water, used on class A fires
2. Carbon Dioxide, used on all types but best on class B and C
3. Dry Chemical, used on A, B and C fires

Fire Safety Plan

The implementation of a Fire Safety Plan helps to assure effective utilization of life safety features in a building, to protect people from fire. The required Fire Safety Plan should be designed to suit the resources of each individual building or complex of buildings. Fire Safety Plans are intended to assist the facility with the basic essentials for the safety of all occupants, to ensure an orderly evacuation at the time of an emergency and to provide a maximum degree of flexibility to achieve the necessary fire safety for the building. The fire safety plan shall be reviewed as often as necessary, but at intervals not greater than 12 months, to ensure that it takes into account changes in the use and other characteristics of the building.



Dry chemical fire extinguisher for use on A, B or C fires. An employee may not use a fire extinguisher unless trained on its proper use by the employing company.

First Aid



Wall-mounted first aid kits are located throughout the distribution center.

First Aid and Emergency Medical Procedures

First aid is the providing of emergency care to an injured person to stabilize the injury before professional help arrives. A first aid plan or an emergency plan should be established and published so every employee knows the plan and how to implement it. Training and retraining are an important part of the plan and should be done on a regularly scheduled basis. It is a requirement of OSHA that employees be given a safe and healthy workplace that is reasonably free of occupational hazards. However, it is unrealistic to expect accidents not to happen. Therefore, employers are required to provide medical and first aid personnel and supplies commensurate with the hazards of the workplace. The details of a workplace medical and first aid program are dependent on the circumstances of each workplace and employer.

First Aid Kit Locations

Materials needed to provide first aid are normally in kits that would be distributed throughout the facility to allow for quick and easy access by employees. The medical supplies would be based on the needs for the types of activities that take place in the facility and can be simple or comprehensive. The kits are purchased from approved venders to meet local requirements and special needs in the facility. Kits must be refilled if supplies are used.

Chapter 3

Material Handling Equipment

Material handling equipment is the cornerstone of the automated warehouse. This chapter will introduce you to the wide variety of equipment used to move product.



Section 1

Introduction to Material Handling

Material handling equipment (MHE) is equipment related to the movement, storage, control and protection of materials, goods and products throughout the processes of manufacturing, distribution, consumption and disposal. MHE is divided into the following areas within the supply chain:

Storage and Handling Equipment

Storage and handling equipment is usually non-automated storage equipment. Products such as pallet racking, shelving and carts belong to storage and handling.



Pallet Racking

Engineered Systems

Engineered systems are typically custom engineered material handling systems. Conveyors, robots, AS/RS, AGV and most other automated material handling systems are examples. Engineered systems are often a combination of products integrated into one system with common software. Many distribution centers optimize operations by using engineered systems such as pick modules and sortation systems.

Interactive 3.1 Engineered Systems Examples



Tap to view images.

Industrial trucks

Industrial trucks usually refer to operator driven motorized warehouse vehicles, powered manually, by gasoline, propane or electricity. Industrial trucks assist the material handling system with versatility; they can go where engineered systems cannot. Forklifts are the most common example of industrial trucks, but aren't the only examples. Their greatest advantage lies in the wide range of attachments available; these increase the trucks' ability to handle various types and shapes of material. OSHA requires industrial truck drivers be trained on them by the company by which they are employed.



Forklifts are the most common type of industrial truck.

Bulk Material Handling

Bulk material handling equipment is used to move and store bulk materials such as ore, liquids, and cereals. This equipment is often seen on farms, mines, shipyards and refineries. This type of equipment is associated with supply chain movement of products, however is not found inside supply chain facilities.



Cranes for maritime shipping containers

Movie 3.1 Nike Logistics Center



Tap to view the video.



Section 2

Industrial Trucks

A Distribution Center's (DC) purpose is the efficient handling of cartons, either for temporary storage or to trans-load freight from vendors to outbound trucks headed to stores or direct to customers. Similar cartons are frequently palletized for storage and handling, creating loads that are too heavy for lifting without machines, so DCs use forklifts. Different types of lifts are used to accomplish specific functions in the warehouse, such as lifting, transporting, or case picking. A typical DC might have dozens to more than a hundred forklifts, depending on the size of the facility. Even when the DC utilizes a complex automation system for pallet or case storage and handling, forklifts are typically used on the receiving and shipping docks for unloading and loading of pallets. Many DCs still use inexpensive high bay racking and forklifts to store pallets of freight when not needed for shipment.

Electrical Lifts

Electrically-powered lifts are predominantly used within distribution centers. They are quiet, maintain air quality without gas fumes, and can be powered by plug-in recharging. Forklifts are offered in both electrical AC and DC powered drives. They utilize large low voltage, lead acid batteries to provide power, as well as counter-balance the lifts to allow heavy weights on the forks. Characteristics of electrical motors also allow for efficient braking ("plugging") by reversing motor direction. Electrical forklifts are generally only used inside a building and are generally not designed to operate in inclement weather.

Interactive 3.2 Electrical Lifts



Tap to view images.

The batteries of electrical lifts discharge power during operation, requiring periodic replacement or recharging. In larger, multi-shift warehouses, a battery changer permits the storage and recharging of extra batteries, allowing operators to come in through the day and swap batteries. In lower usage facilities, the lift may be plugged in at end of shift to be ready for the next day.

Interactive 3.3 Electrical Lift Batteries



Tap to view images.



Standup forklift in use



Standup forklift



A specialty clamp attachment for grabbing a heavy load by the sides

Forklifts

Electric forklifts are the workhorses of the distribution center. They permit quiet, fume-less heavy lifting and moving of pallets within the warehouse. If there was just one type of lift in the warehouse, this would be it. Although they cannot perform all of the necessary functions within the building, they are the most versatile, offering a variety of functions that are used to offload trailers on receiving docks and load trailers at shipping doors. Most trucks can lift individual or stacked pallets by counter-balancing the fork weight with the weight of their electrical batteries. They can be made more versatile with attachments that can clamp cases or pick up slip sheets to efficiently build pallets or layers for efficient storage in the warehouse.



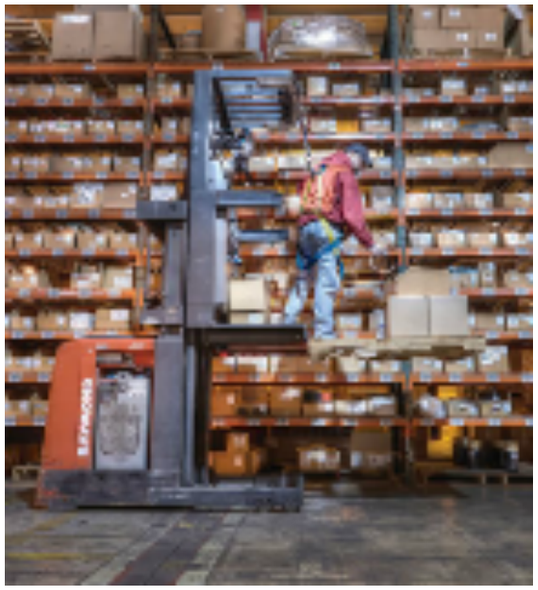
Reach truck in use



Three views of reach truck operation



Order picker



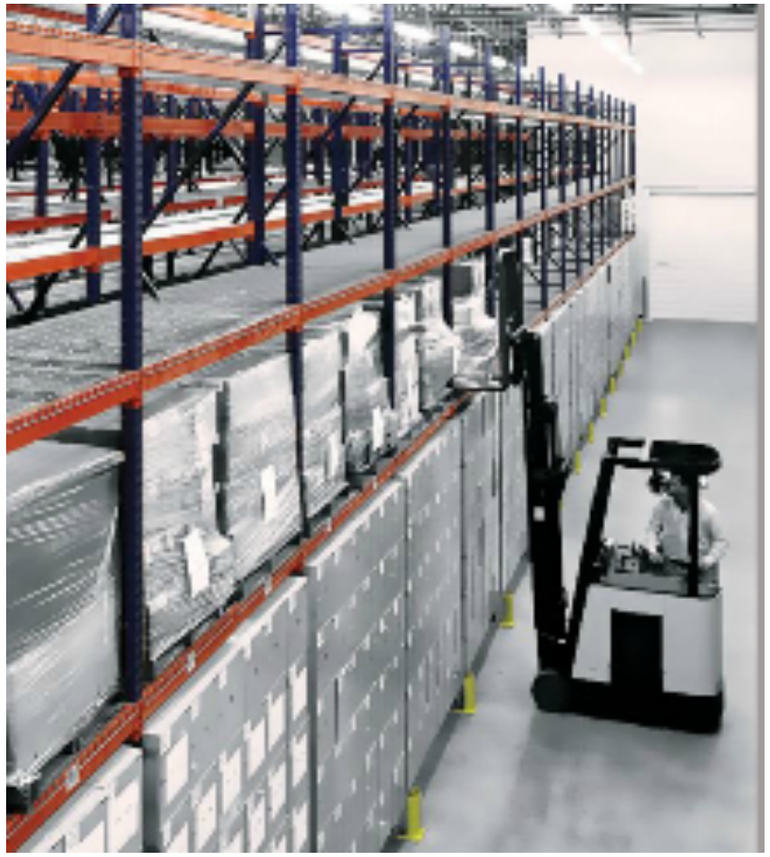
Order picker



Operating the order picker

Reach Trucks

Reach trucks are forklifts with multi-stage masts that lift and lower heavy pallets into high bay storage racking above 30 feet in height. The operator remains at ground level in the compartment, raising the pallet on the forks up into the air above the lift. The operator uses a multi-function handle to extend the forks into the racking, shift the pallet horizontally to position it, or tilt the pallet to place pallet runners on rack beams. Reach trucks allow storage rack heights that allow efficient use of vertical space within the warehouse.



Reach truck



Turret/swing-reach truck

Order Pickers

An order picker is a powered lift that raises the operator in a compartment up to the level of pallets in high bay racking storage so that they can remove individual cases to fulfill less-than-pallet quantity orders. Individual cases are placed on pallets or carts that rest on forks at the back of the operator compartment. Operators can vary their height repeatedly through a rack aisle to pick numerous orders. Operators can individually steer the lift, or engage wire guidance systems in the floor (frequently used in very narrow aisle configurations).



Receiver using pallet jack

Turret/Swing-Reach Trucks

Turret trucks are hybrid lifts that combine characteristics of reach and order picker lifts, and put away or pick pallets inside very narrow aisle storage racking. The operator raises himself (in a compartment) and the pallet into the air to the desired put-away level. They swing the forks 90 degrees from direction of travel, and extend the pallet into the racking. Turret trucks allow rack aisles of smaller width by reducing pivot radii for the lifts. This allows denser utilization within rack storage areas. Turret trucks are very large and heavy, and take multiple batteries to provide necessary weight to counterbalance the heavier weights placed on the mast sections.



Tugger with flat carts



Train of cage carts

Pallet Trucks/Jacks



Forklift outdoor use

Powered pallet jacks (also known as electric pallet trucks, “walkies,” or single/double/triple pallet riders are lifts that move individual or stacked pallets between different areas in a distribution center. The operator drives the forks into slots inside the pallets, raises the forks off the ground, and moves the pallet to a desired drop-off point. Pallet trucks are less costly than forklifts, and capable of more efficiently moving heavy pallet loads between receiving docks, storage areas, and shipping doors.



Forklift operator (gas powered)



Propane forklift in use

Transfer Tugs

Tuggers are the simplest types of powered lifts. They are used to tow “trains” of cage or flat carts for cost-efficient transportation of individual cases between areas within the warehouse. They can be used to pick individual orders at ground level, but are more frequently used to gather and move carts used by order pickers to fulfill numerous individual orders.



Articulating boom lift in use

Gas Powered Lifts

Forklifts that need to be used both inside and outside the DC are usually powered by fuels such as natural gas, diesel, or propane. Propane powered forklifts are the most common, due to low operating costs, easy change-out of cylinders, easy storage of replacement cylinders, and lower emissions than gas or diesel lifts. Careful maintenance is required to reduce emissions of carbon monoxide, making gas-powered lifts less desirable for frequent use within a restricted inside area. Gas powered lifts are also frequently used in smaller facilities because they do not require investment in multiple batteries, battery chargers, and other related infrastructure and labor costs associated with electrical forklifts.

Specialty Equipment

Distribution centers also frequently have a variety of specialty pieces of rolling stock so that maintenance teams can perform various specialty functions that cannot be done well by conventional lifts. These may include:

Articulating Boom Lifts

Boom lifts are usually combination drives of electrical and propane. The battery power is quiet and has no emissions, and the propane power allows outside workability and redundancy.

The multiple “joints” in the articulating booms give almost unlimited ability to stand-off and maneuver the work platform to where the base cannot move. They allow technicians to access very high or difficult to access areas where they cannot use ladders or scissor lifts to change lights or access roofs or other elevated systems.

Scissor Lifts

Scissor lifts allow individual or groups of technicians to raise heavy drives or parts to elevated or ceiling-suspended conveyors, and then provide a stable work platform to do maintenance functions. They come in many different sizes of varying width and maximum elevation to best suit the work environment.

They are an excellent choice when workers or materials need to be raised above ground level, without the obstructions caused by overhead cranes or machinery that lift the item from its side (such as forklifts). With a scissor lift, the entire lifting mechanism is contained beneath the lift platform or table, providing lifting capability with minimal footprint.

Safety with a scissor lift is very important. When the lift table is raised, there is a very high center of gravity, which can pose a tip-over hazard, if the lift is bumped. It is also important to look carefully all around and above when the lift table is raised because there are many different obstructions like pipes and cables and joists near roofs.



Scissor lift in use

Cleaning Equipment

Distribution Centers become dirty over time, accumulating large quantities of wood debris and nails from pallets and cardboard dust from boxes. DCs may use propane-powered cleaning machines such as sweepers or scrubbers to keep the floors clean and reduce wear on rolling stock equipment.

Rider Sweepers

Sweepers use rotating brushes and vacuum suction to pick up debris. Different brushes and tires enable the sweepers to work either inside or outside, as needed.



Rider sweeper



Rider sweeper diagram

Industrial Scrubbers

Scrubbers lay down a combination of soap and water to clean the floors, and vacuum suction to pick up the solution.



Industrial scrubber in use



Schematic of scrubbing tank



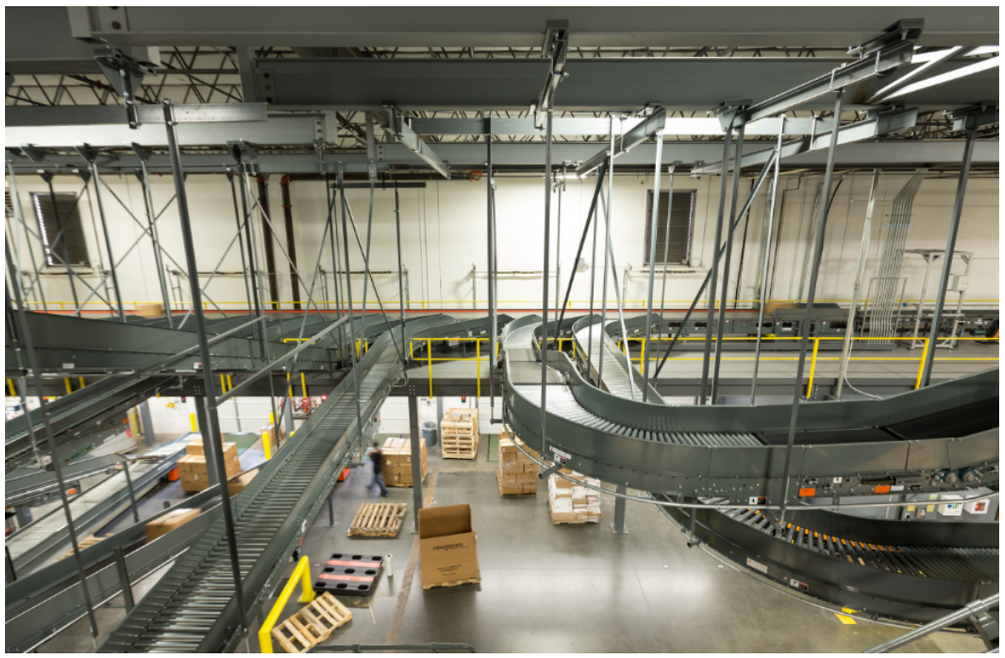
Section 3

Engineered Systems

Automated material handling systems (conveyors, sorters, AS/RS) are extensively used in DCs for a variety of reasons:

- Conveyor and sortation systems usually are less expensive over time on a cost per carton basis than manual handling because fewer operators are needed to process large volumes of freight.
- Automation can handle very high volumes of throughput that are not manageable with forklifts alone.
- Automation permits very dense storage options that efficiently utilize the entire vertical space of a DC (cubic footage), enabling greater storage capacity than high bay racking. Automated Storage/Retrieval Systems (AS/RS) cranes allow vertical storage heights in excess of 100 feet, allowing the use of smaller amounts of real estate for the needed capacity.
- Automation can handle freight in freezers or other conditions in which it would be difficult for people to work.
- Specialty automation such as shrink-wrappers and label printers are much more efficient than manual handling.

- Warehouse Control System (WCS) Software in modern material handling systems permit detailed control of freight flows (“waving”) that correctly time sequence freight to shipping doors for scheduled pick-ups.
- WCS software combines and integrates different types of automation technology to work together.
- Sequential use of integrated automation can efficiently handle virtually every aspect of handling and storage in a warehouse, with little human intervention.



An engineered system with conveyor and a sorter

As examples, the video below shows the associated automation used in a food distribution center by complex, specialized engineered systems used by several different grocers in the US and Canada.

Movie 3.2 SSI Schaefer Food Warehouse Video Showing Robots and Palletizing



Tap to view the video.

Belt Conveyors

Belt Conveyors are the most commonly used unit handling conveyor because they are usually the least expensive and simplest option to move a unit load from one point to another. They typically require the least amount of maintenance effort of any type of driven conveyor. They are used to convey unit loads in varying sizes, shapes, and weights. Since the conveying medium is a flat belt, these conveyors are capable of moving everything from well-formed boxes, cartons and totes to very flimsy bags and bundles.

Typically, belt conveyors are used to carry unit loads over long distances with a single drive motor, or to safely move them from one elevation to another. These are often referred to as incline belt conveyors when going from a lower elevation to a higher elevation, and as decline belt conveyors when going from a higher elevation to a lower elevation.

Belts must be correctly tensioned to turn correctly. The belting is typically centered on the rollers or slider beds underneath, but can be tracked more to a specific side to help position cartons better for subsequent turns or diverts to change carton direction of travel.

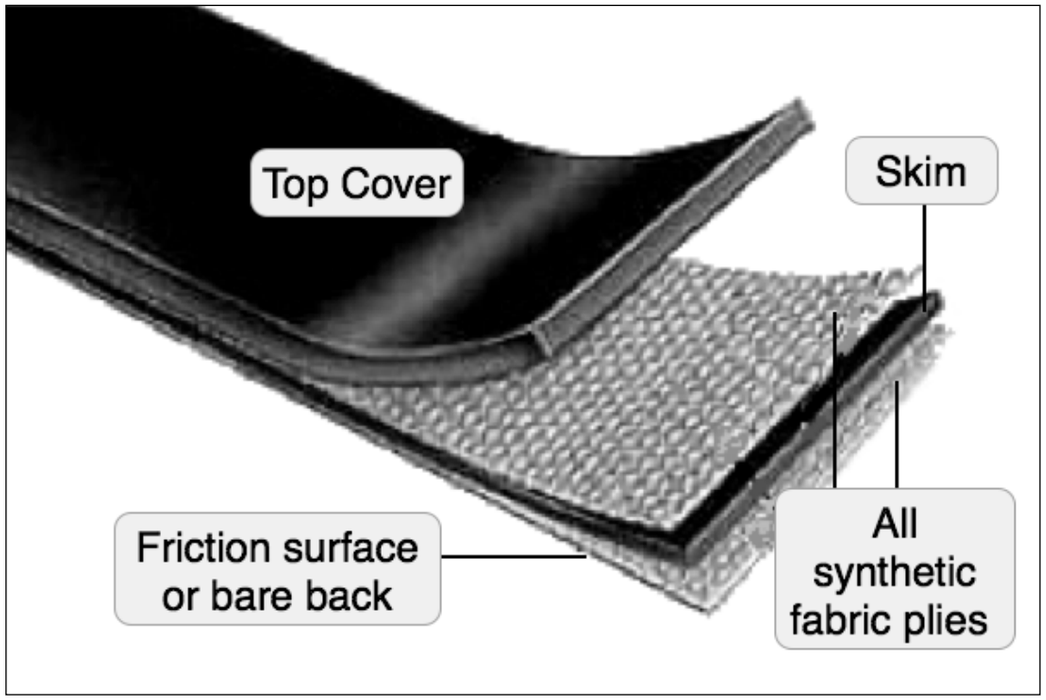
Belt Conveyors use the following components:

Belt Medium

The belt consists of one or more layers of material. They can be made out of rubber. Many belts in general material handling have two layers.

- An under layer of material, called a carcass, provides linear strength and shape. The carcass is often a woven fabric having a warp and weft. The most common carcass materials are polyester, nylon and cotton.

Interactive 3.4 Multi-Layer Belt Schematic



Tap label to zoom; tap label, home, or image to return.



Rough-top belting

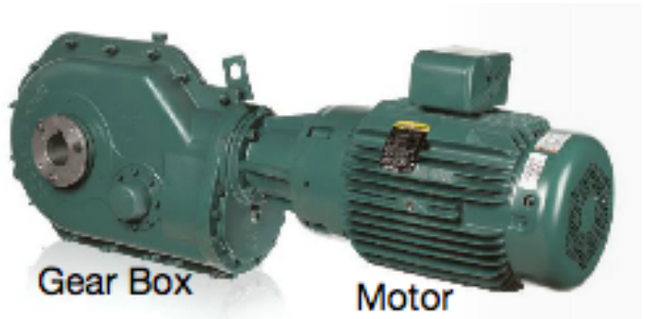


Standard belting

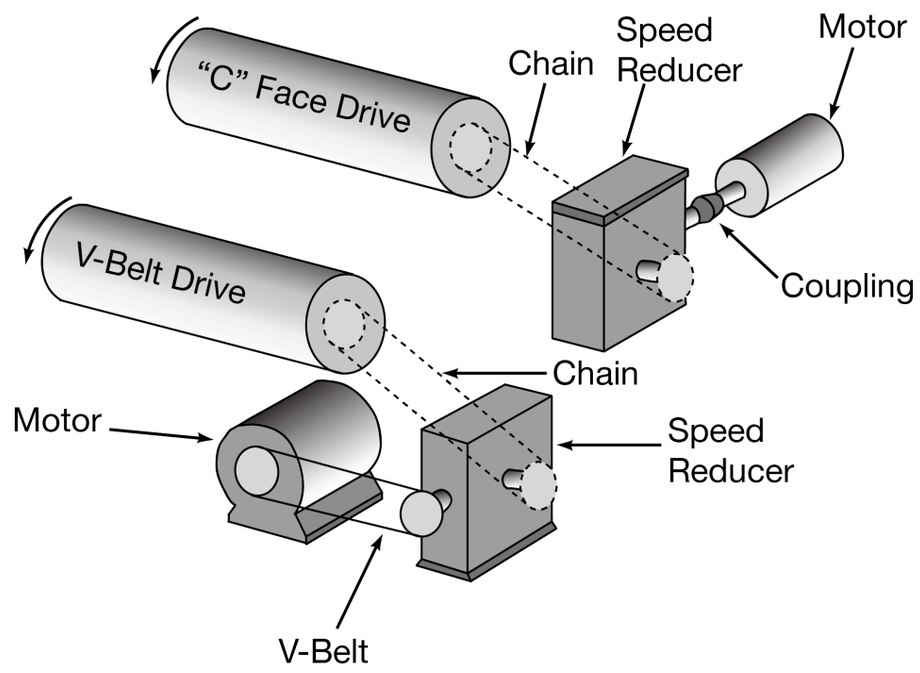
- An over layer is called the cover, and provides the desired surface to contact the conveyed material. The cover is often various rubber or plastic compounds specified by the use of the belt.

Drive (Gear Box and Motor)

Belt conveyors use a drive to provide power to the pulley. A drive is composed of both a motor and a gear box. Motors are typically 480 volt, three-phase powered.



Connected drive assembly

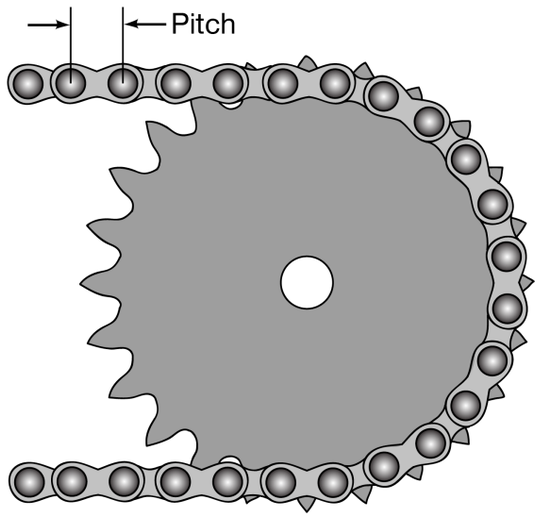


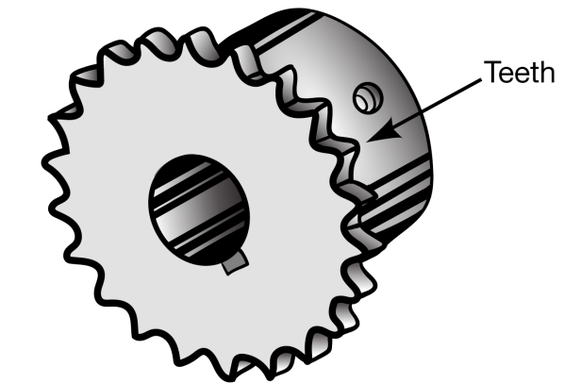
Schematic of two different ways motors and drives can connect to a drive pulley

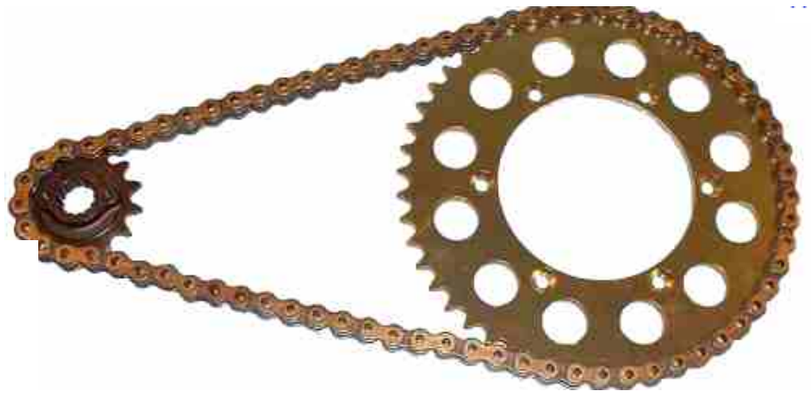
Because a motor turns much faster than the belt can move, a gear box (speed reducer) is added between the motor and the drive pulley to step down the speed. That is done inside the gear box by intermeshed metal gears of different diameters, similar to a car transmission. Lubricant oil inside the gear box ensures that the gears connect without metal to metal wear.

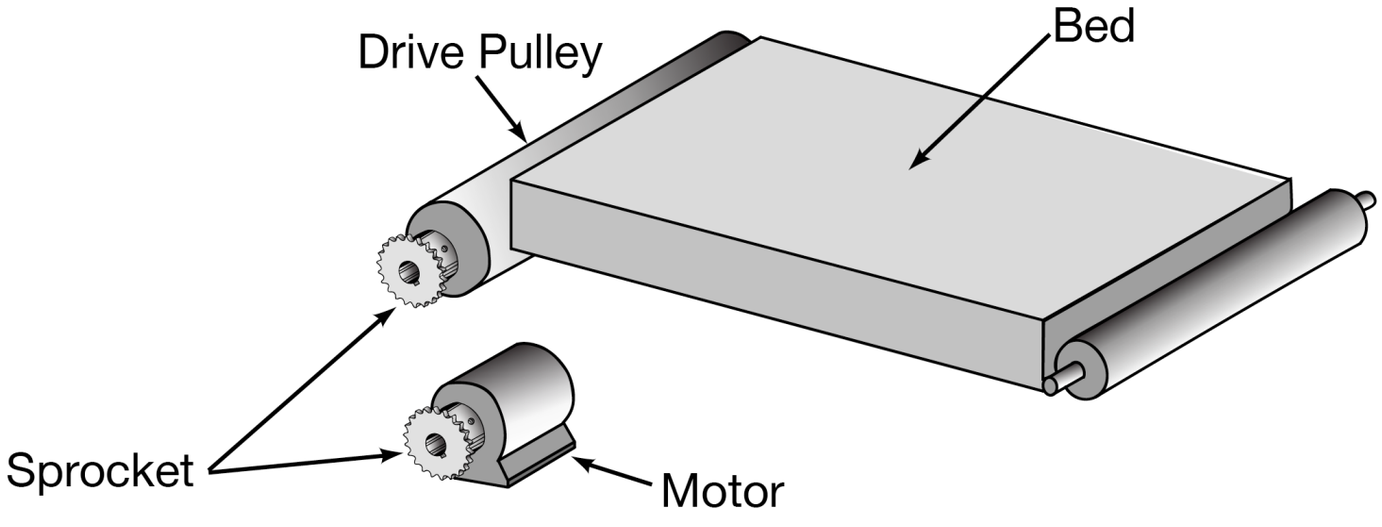
Sprockets

A sprocket is a metal “wheel” with “teeth” on the outside. The links of a chain ride over the teeth on the sprocket to turn the chain in the correct direction. When connected to the shaft on a pulley and a drive, a chain can be used to efficiently transmit torque to the pulley from the motor and drive.









Pulleys

Conveyor pulleys are the main elements providing the transmission of torque from the drive and ensuring that belts remain taut. Typical pulleys include:

Drive Pulleys

Drive pulleys (connected by chain and sprocket to the drive) are located at the end of the direction of travel of the belt or underneath in the center. Drive pulleys are typically “lagged,” or covered with vulcanized rubber to maintain friction and prevent the belt from slipping freely on the roller. A drive pulley is also frequently “crowned,” or slightly larger in the center than the ends to keep the belt tracked to the center instead of “walking” towards the sides.

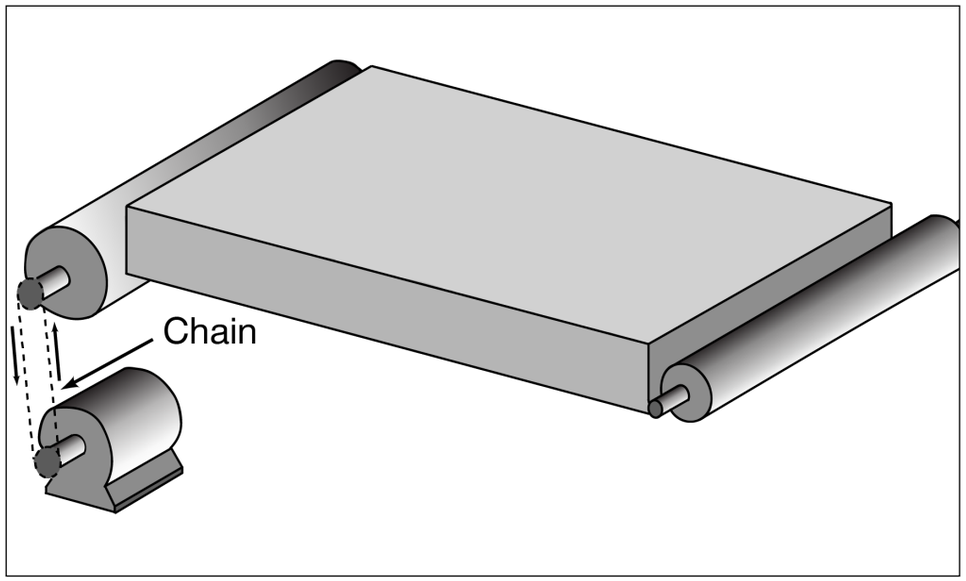
Tail Pulleys

Tail pulleys (typically un-driven) are located at the starting end of the conveyor, or at both ends of a center-drive. A tail pulley turns freely, and is adjustable to take-up belt stretch.

Take-Up Pulleys

Take-up pulleys maintain correct tension or bend the direction of belt travel for routing. Take-up pulleys are adjustable by screws to apply tension against the belting.

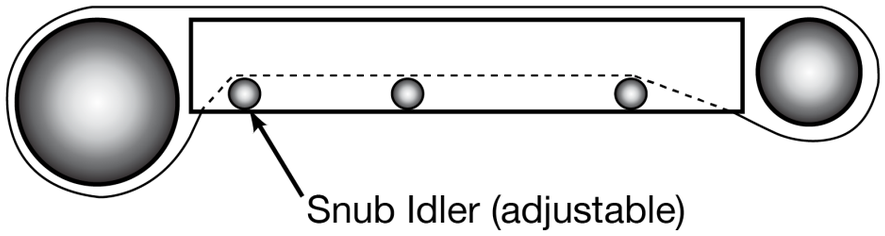
Interactive 3.5 Pulleys

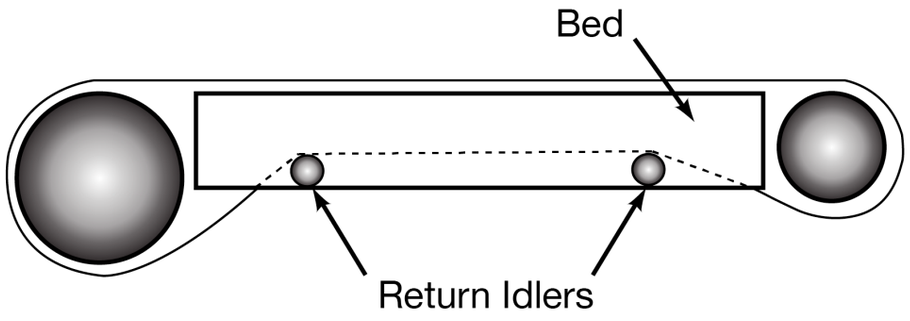


Tap to view pulley graphics and images.

Snub Idler Rollers

A snub idler roller is located closer to a drive pulley to make the belt hug more of the drive pulley surface, increasing the drive efficiency. Regular idlers are simple un-driven rollers that the belts ride across to eliminate the danger of a hanging belt underneath the conveyor bed.

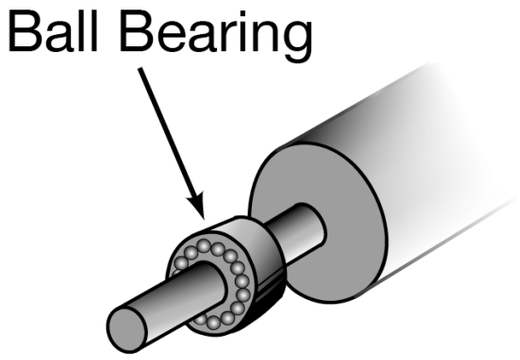




Bearings

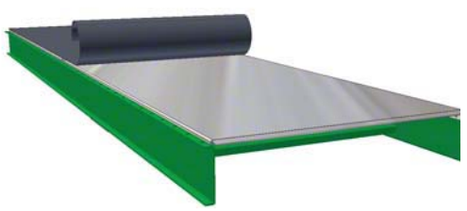


When two pieces of metal touch each other, they cannot turn quickly and easily without bearings. Bearings are little steel balls that sit in a raceway to keep the pulley shaft and the conveyor bed from rubbing together. This allows the pulley's metal shaft to turn freely, but stay fixed in the same location.



Flat Belts

There are two typical types of flat belt conveyors: slider beds and belt on roller conveyors. A straight belt (frequently of rubber composition) rides on a series of rollers set at fixed intervals. Power comes from a motor and drive attached to a pulley at either the end or middle of the conveyor section.



Slider Bed Belt Conveyor



Belt on roller

The belt is connected together by:

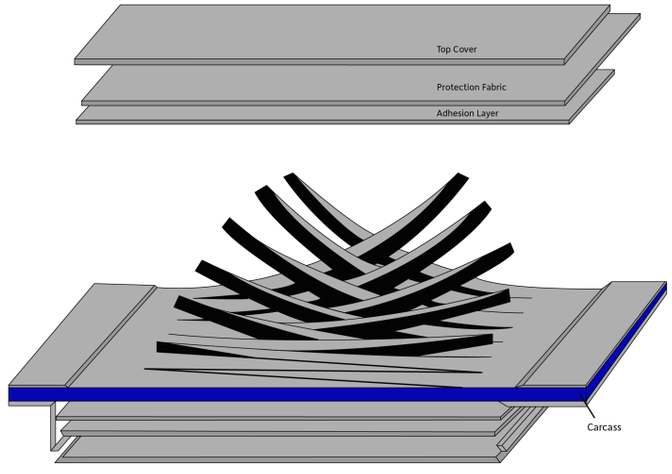
- A vulcanized heating process to fuse the ends
- Steel clipper lacing and pins to hold the two sections together.

To keep the belt tracked true, it is essential that the belt sections are cut perfectly perpendicular to the length so the two ends mate up correctly.

Flat belts tend to wear out or become separated over time. The belts are generally easily replaced with a comparable length of new belt, or in the case of a temporary repair, a small intermediate section (or “Dutchman”) can be spliced into the existing belt to replace a damaged section quickly.



Clipper lacing on belt



Schematic of vulcanized belt splicing

Interactive 3.6 Belt on Roller Conveyor



Tap to read about belt on roller conveyors.

Interactive 3.7 Brake Meter Belts



Tap to read about brake meter belts used for carton gapping.

Curved Belts

A curved belt conveyor permits change of direction for carton flow. They handle the same types of loads as a flat belt, and ensure that speed tracking and gapping is maintained throughout the curve by matching the speed of surrounding belted conveyors. Curved belts are used on spiral conveyors to move cartons between different levels over a short horizontal distance without cartons tumbling end over end.

Interactive 3.8 Curved Belts



Tap then swipe to view images.

Most curved belts use slider beds with low friction surfaces, although in special situations of heavy loads, a combination of roller and slider beds may be used. Belts on curved belt conveyors are precisely dimensioned and cut from the factory to turn smoothly without bowing or tearing apart from the twisting motion. The primary drive types available on belt curves are the friction drive, pinch drive and chain drive. The most frequently used configuration in DCs has a friction drive with guiding elements composed of a series of bearings on a guide bead.

Interactive 3.9 Roller Conveyors



Tap then swipe to view images.

Roller Conveyors

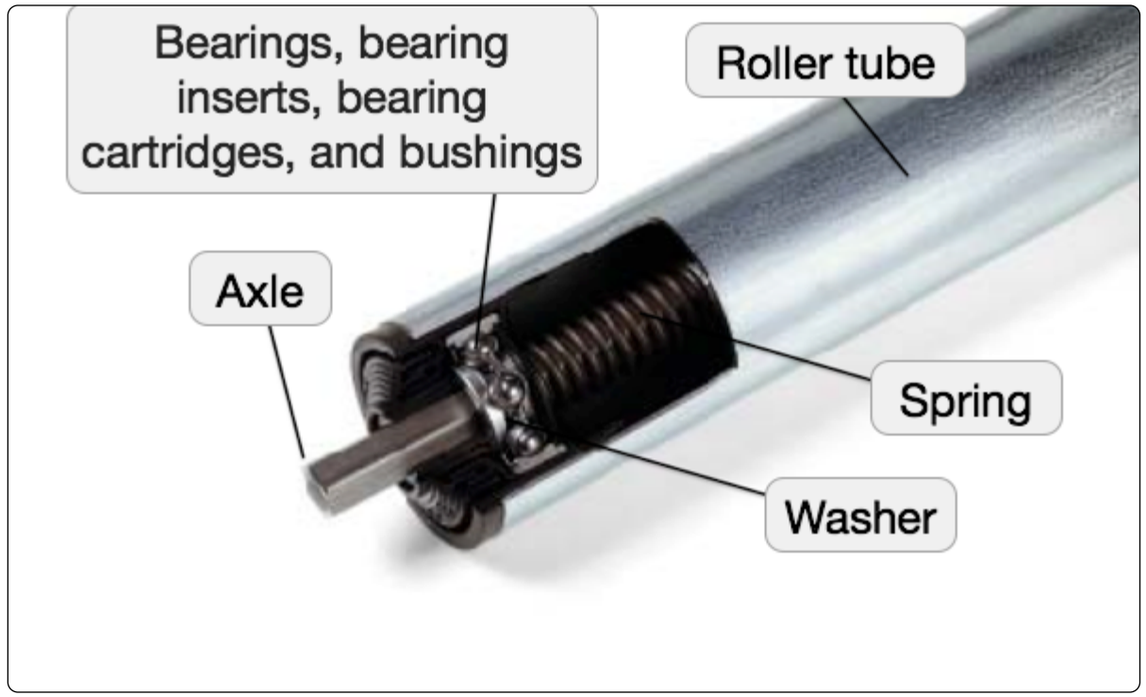
Some of the most prevalent conveyor types in distribution centers utilize many variants of rollers.

- **Heavy duty** rollers are used to slowly move wood or plastic system pallets. Speed is typically limited by the need to keep taller loads stable as they move on the conveyor.

- **Lighter duty** rollers are used to handle individual cases or containers (totes or trays), and are capable of handling tens of thousands of cartons per hour. Because individual cases or containers are considerably more stable, lighter duty rollers can run much faster, and designers can adjust speeds for specific control purposes.

Rollers are the most prevalent means of conveyor system in most facilities because they allow accumulation of lots of product throughout the entire system. Accumulation conveyors are used to temporarily stop, hold, and release material. This type of product flow management makes sure that boxes are transported as close as possible on the system. It allows efficiencies throughout the system by regulating flow for maximum utilization of downstream sortation. It allows flexibility to react to changing product volume in different areas of the facility without adversely reducing throughput or making people slow down or stop because of congestion.

Interactive 3.10 Roller Cross-Section Showing Components



In all roller conveyor variants, the rollers are composed of the parts detailed in the image above.

Different types of driven roller conveyors vary based on the drive mechanisms used to turn the rollers. Vendors use poly-vinyl driver pads, or various types of belts underneath the rollers, to engage specific sections of the conveyors to turn the rollers and to move product. Rollers can be skewed inside the side beds to move cartons from one side of the rollers to the other to set up subsequent changes in direction. Electro-mechanical controls activate sections of the conveyors as individual or grouped zones. Controls are also used to activate pneumatic systems, since air pressure is frequently used to selectively engage drive mechanisms and rollers.

System designers suit the component materials listed above to the types of freight to be conveyed. Roller tubes are typically steel or aluminum, of varying thicknesses based on the weight of the cartons or pallets. Plastic is sometimes used for food handling involving wash-downs. Rollers can be coated with rubber or poly-urethane for better grip and to provide more friction and control for a carton, especially in curves or after divert sorters.

The types of shafts and springs are suited to how rollers will connect with conveyor side rails. To work on drives, belts or chains used to turn the rollers, side rails must be notched to lift out the rollers, or the roller shafts must be spring-loaded on one or both sides so the rollers can be easily added or removed.



Bearings or bushings allow the shaft to stay fixed in the side rail while the roller turns. ABEC 1 precision bearings are most frequently used for carton handling rollers because they turn quickly and are quiet. Since individual rollers are relatively inexpensive, they are typically replaced when they wear or are damaged.



Drive belt on plastic sheaves

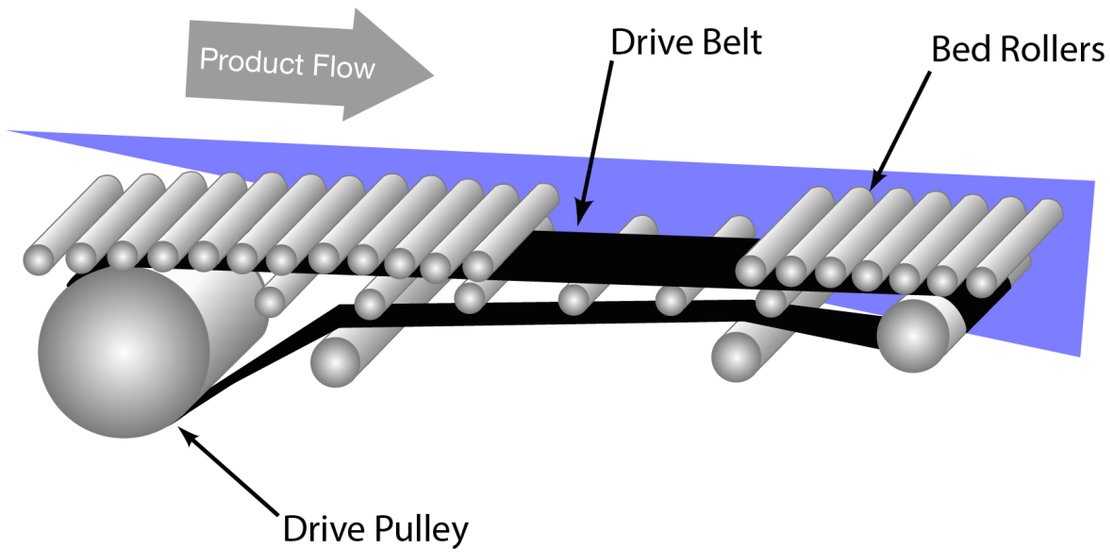
Belt-Driven Roller Conveyor

The belt-driven roller conveyor is driven by a narrow belt that runs beneath the roller bed, perpendicular to the rollers. As a motor drives the belt, the belt turns the rollers. The belt-driven roller is a good accumulator because it's easy to create zones. You can lower the belt away from the roller in any zone by reducing pneumatic pressure to create accumulation.

Movie 3.3 Belt Driven Roller NBC Accumulation Conveyor



Tap to view the video; the video has no sound.



Pallet-Handling Roller Conveyor

The Pallet-handling roller conveyor looks like the roller conveyor used for handling packages, but the rollers are wider and thicker to handle the additional weight. Most pallet-handling roller conveyors are chain-driven because the drive method (sprockets and chain links) provide the best torque without slippage. The heaviest pallets may incorporate roller guides to make sure the pallets are centered on the conveyor system.



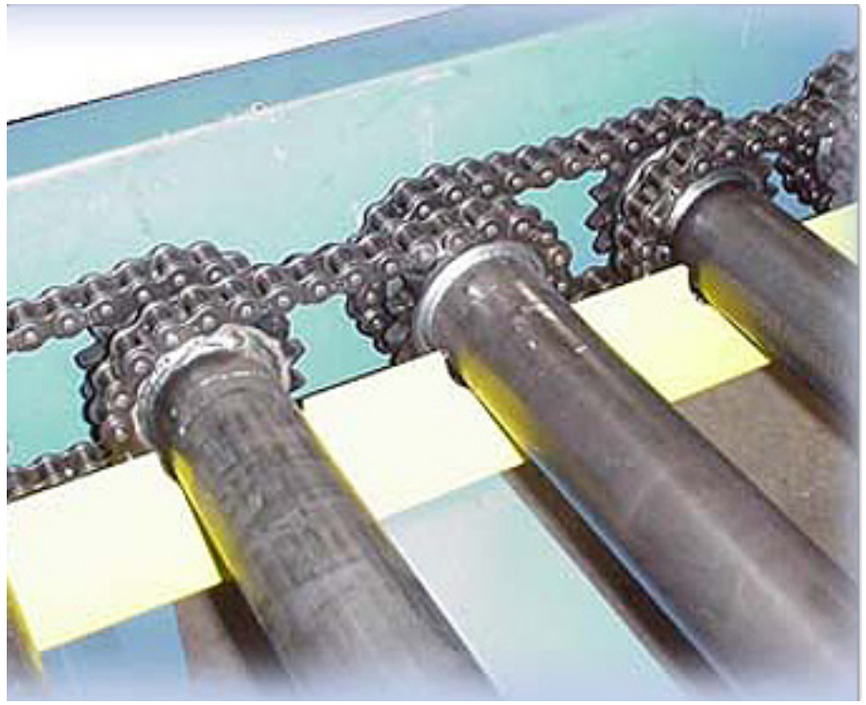
Pallet conveyor



Pallet conveyors

Chain-Driven Pallet Conveyor

The chain-driven pallet conveyor works differently from the chain-driven package conveyor. Instead of running beneath the rollers, the chain runs along one side of the roller bed. Each roller is connected to the chain with a sprocket. The conveyor is divided into small segments, and each segment has its own AC induction motor. This segmentation allows for better control and allows some accumulation of pallets.



Chain-driven rollers coupler



Chain-driven rollers

Motorized Driven Roller Conveyor

Forms of conventional roller conveyors date back over a hundred years. The biggest change to conveyor technology in recent years has been the advent of motorized rollers. The innovative ways that they can be incorporated into new designs are making a big difference in enabling new technology in material handling.

The motorized roller is also known as internal motor or motor-driven roller (MDR) conveyor. The MDR conveyor, there is not an external powered motor and drive.



MDR Drive Roller Cross-section

A section of motorized roller conveyor is divided into small zones. At least one roller in each zone has an internal motor that turns the roller. The rollers in each zone are connected to each other by rubber O-rings so that the turning of the motorized roller turns all the rollers in that zone. Additionally, belts can go over the zones instead of O-rings, yielding the product handling benefits of a belted conveyor with the precise control of roller sections.



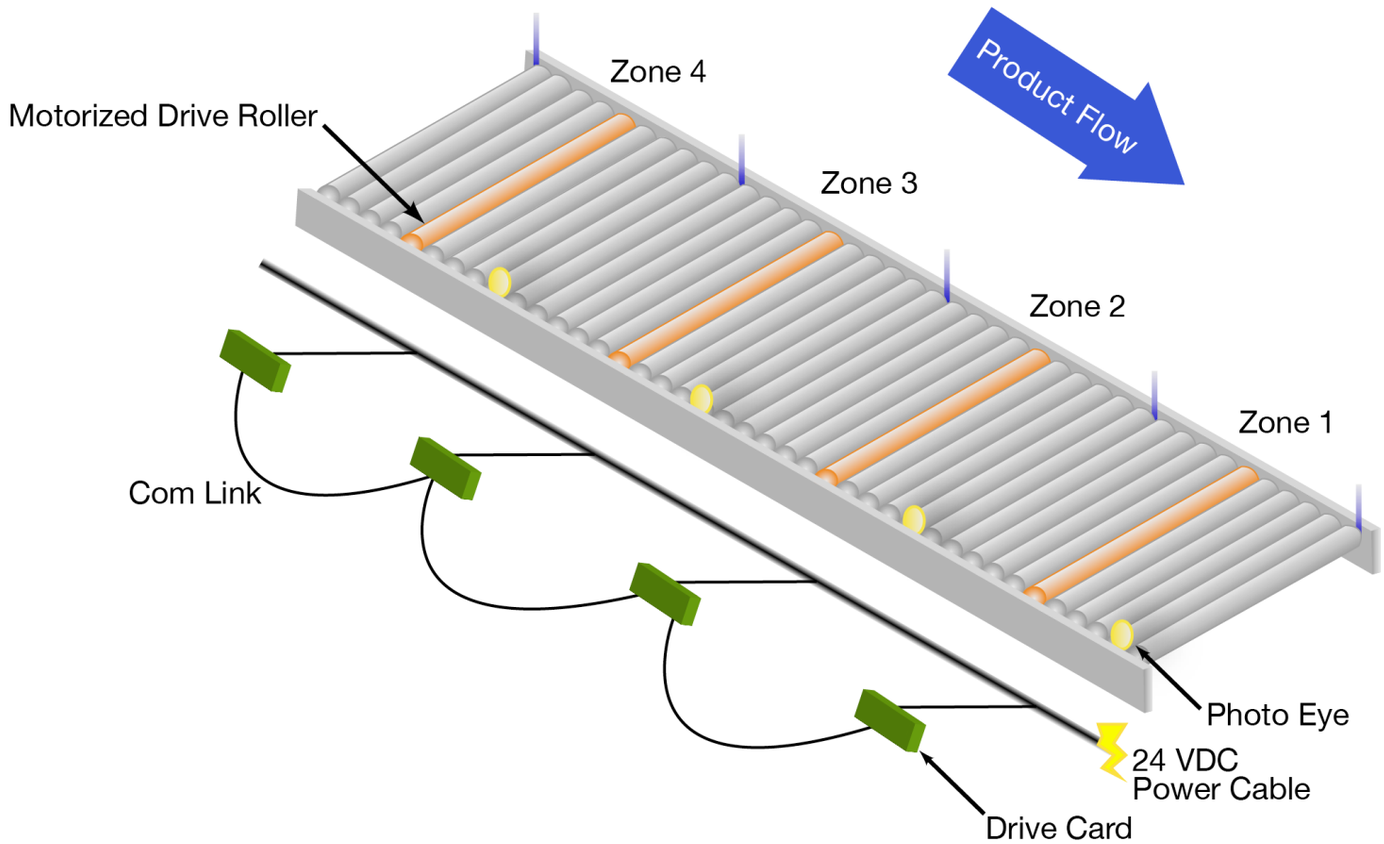
MDR conveyors provide good product control

The motors used in the motorized roller are usually 24-volt DC motors. These motors use less energy than the motors used to drive other forms of roller conveyors and they provide less torque, making them safer, too.

Because each zone of rollers is powered independently, the zones can be configured to run only when a package is present. This on-demand feature increases energy savings even further and decreases noise—both are important factors when the end user is addressing economics and ergonomics.

The motorized roller doesn't move as fast as the other forms of roller conveyor, because it's smaller, low-voltage DC configuration is designed to power only one zone, but it offers better product control and is easier to maintain.

With any roller conveyor, there's a basic rule of thumb: You want three rollers under your product at all times. Two rollers might create a wobble when the product hits a gap, but keeping the front, middle and back of a product supported will provide a smooth ride.



MDR conveyor with accumulation

Tapered Roller Curved Conveyor

A roller conveyor can be used to gently change the direction of carton flow by using sections with a degree of bend, usually in set turns like 45, 90, or 180 degrees. These conveyor sections use tapered rollers for use in a curve with end and intermediate diameter proportional to their distance from the center of curve. In cases where location and direction of orientation of the carton is important to maintain through the curve, the rollers can be lagged. The rollers are usually driven by v-belts or chains.



A lagged tapered roller



A tapered roller conveyor

Vertical Reciprocating Conveyors (VRCs)

Vertical Reciprocating Conveyors are used in factories, warehouses, DCs or industrial plants where products or supplies need to move from one level to another. They are sometimes used with multi-shuttle systems to quickly and efficiently bring cartons or trays up to rack levels without having to use numerous incline and decline conveyors that require lots of space.

Vertical Reciprocating Conveyors are not elevators. In fact, they have their own national code (ASME B20.1) and are specifically exempt from the national elevator code. Whereas elevators are highly regulated and most DCs outsource elevator maintenance to companies that specialize in elevators, maintenance technicians do frequently maintain and repair VRCs.



Inside a VRC for raising cartons to different rack levels



A VRC moving pallets between floor and mezzanine

Vertical Reciprocating Conveyors provide fast, efficient, convenient and safe access to/from mezzanines, balconies, basements, and between levels in multiple story buildings. They can be installed in through-floor, interior or exterior applications. The principal components of Vertical Reciprocating Conveyors include guide columns, a carriage and a mechanical or hydraulic actuating mechanism.

Directional Sortation

To separate and route items—such as parcels, boxes, cartons or parts—within a facility, you typically use a sortation system. The sorter merges, identifies, inducts and conveys products to specific destinations. Working in conjunction with fixed conveyors and automatic identification systems and controls, sortation systems transfer items off main conveyor lines to spur tracks. Sortation moves large volumes of material rapidly through a facility, allowing companies to ship or receive higher volumes with smaller storage space and lower labor costs. Typical sortation



Sorter

applications include the routing of cases, totes or palletized loads to and from static or automated storage systems, or from a picking area to packaging for shipping.



Sortation line

Movie 3.4 Abel Womack, Inc. Sortation Video



Tap to view the video.

Chutes

Chutes are used as an inexpensive way to move products without drive or control. Chutes are often referred to as “gravity chutes” or “slides” because gravity provides the force to carry the load down the chute. Many different materials have been used for the surface of the chute to provide as little friction as possible, but cost and wear characteristics have driven most suppliers to steel or fiberglass.

Chutes are frequently used as a transition section from a powered sorter to a decline conveyor. In cases where a significant vertical decline must be done over a limited horizontal distance, a spiral chute may be used.



Gravity chute example



Spiral chute example

Sliding Shoe Sorter

A sliding shoe sorter is a continuous series of slats or tubes, on which rides a rubber block (or “shoe”). An electrical divert sends the shoe across the slat, making contact with the side of a carton. Multiple shoes can be actuated to match the length of the carton, gently pushing the carton at an angle into a chute, or onto another conveyor.

Shoe sorters are generally chain driven, but can also be driven by linear actuator motors along the length of the sorter that drive the slats by electrically induced magnetism. Oiler systems on chain driven systems are very important to reduce chain stretch and wear at very high speeds of potentially more than 600 feet per minute.

Sliding shoe sortation systems provide a very soft, positive divert (accurate) at high speed rates. Shoe sorters can be used where there are a wide variety of product sizes, shapes and weights being sorted. It is an excellent sortation choice when the product is fragile or easily damaged and requires a smooth and gentle movement from the sorter to the takeaway lane. Single and dual diverts are available and can be customized based on a particular conveyor system’s design.

Interactive 3.11 Sliding Shoe Sorters



Tap then swipe to view images.

Movie 3.5 Intelligrated Shoe Sorter Video



Tap to view the video; the video has no sound.

Movie 3.6 FKI Logistex Shoe Sorter Video



Tap to view the video.

Tilt Tray Sorter

A tilt-tray sorter is a high-speed, continuous-loop sortation conveyor that uses a technique of tilting a tray at a chute to slide the object into the chute. Tilt tray sorters are highly reliable, and when equipped with linear motor (LM) technology, very energy efficient and quiet. They are primarily used for sorting cartons, are frequently found in general merchandise DCs, and allow the highest throughputs in cartons per minute of any sortation type.

The continuous loop is composed of a “train” of interconnected carts that ride along a track. When the cart arrives at the sort location, controls activate an electrical solenoid that tips the tray over at an angle that allows the parcel to slide off into a chute. At various points along the rail, the trays are righted back to their horizontal position to receive a new parcel.

Older tilt tray sorters were driven by trains, but newer generation sorters frequently use linear motor technology, propelling the cart train by electrically induced magnetism.

Interactive 3.12 Tilt Tray Sorters



Tap then swipe to view images.

Movie 3.7 Intelligrated Tilt Tray Sorter Video



Tap to view the video; video does not have sound

Cross Belt Sorter

Cross Belt sorters are used to sort parcels, mail, apparel (in poly bags), and very small items, at high speed, that are difficult to sort, such as fragile or high friction items that would not easily slide off a tray or slat. Advantages of a cross belt sorter include tight divert centers for after-sort lanes that are close together or very narrow, and sortation rates in excess of 500 cartons per minute.

Cross belt sorters are used heavily in internet fulfillment centers.

In a cross belt sorter, each section (or tray) of the sorter has a motorized belt that runs perpendicular to the direction of the sorter. When the item comes to its correct destination, the motor turns on and runs the item off the side into the new direction of travel.

Movie 3.8 Bastian Solutions Cross Belt Sortation Video



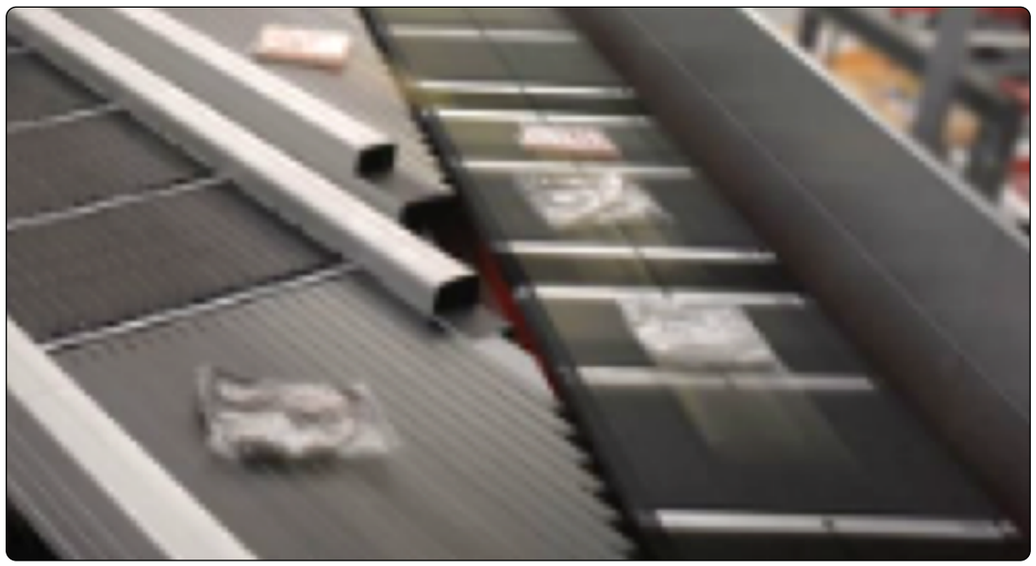
Tap to view the video. This video has no audio.

Interactive 3.13 Pop-up Roller



Tap to read about overhead view of a pop-up roller sorter that just diverted a tote.

Interactive 3.14 Cross Belt Sorters



Tap then swipe to view images.

Pop-up/Skewed Wheel Sorter

A pop-up skewed wheel sorter is an in-line diverter conveyor that has wheels that pop up between the rollers of a powered roller conveyor or between belt conveyor segments and direct sorted items onto a powered take-away line. The take away line usually runs at a faster speed, and is sometimes equipped with rubber-lagged rollers to quickly take the carton away from its original direction of travel. These sorters are used most frequently to change a carton from one line to another within a warehouse.



A pop-up wheel sorter with raised wheel section to turn the direction of box travel



Section 4

AS/RS Systems

Automated Storage and Retrieval Systems, known as AS/RS are computer-controlled systems that put away, store and retrieve product in warehouses, distribution centers and manufacturing facilities. Retrieval of items is accomplished by specifying the item type and quantity to be retrieved. The computer determines where in the storage area the item can be retrieved from and schedules the retrieval. It directs the proper automated storage and retrieval machine (SRM) to the location where the item is stored and directs the machine to deposit the item at a location where it is to be picked up.

AS/RS systems usually fall in several categories: unit load cranes, miniload cranes, vertical lift modules and carousels, and multi-shuttles. AS/RS have several benefits, including controlled access to valuable inventory, increased accuracy and productivity, and reduced labor costs and risk to workers. For example, these systems are useful in freezers and other harsh environments that can be hazardous to people.

Storage Retrieval Machine (SRM) Cranes

Regardless of size, most AS/RS have the same configuration: Two rows of metal racks face each other with a narrow aisle in between. Down the center of the aisle is a raised metal rail. A tall mast travels through the aisle along the rail. When the mast reaches a designated storage location, a carriage travels up or down the mast to the level of the location. A load-handler mounted on the carriage then reaches into the storage location to put away or retrieve a load.

The mast, carriage and load-handler collectively are known as a Storage and Retrieval Machine (SRM), or crane. SRMs may have single or double masts. With a single-mast machine, the carriage is attached to the front of the mast. With a double-mast machine, the carriage rides between two masts, adding stability in very tall AS/RS or in systems that handle heavy loads.

Interactive 3.15 Storage Retrieval Machine (SRM) Cranes



Tap then swipe to view images.

Unit Load (Pallet) SRMs

Unit-load AS/RS cranes are designed to store large loads of 1,000 pounds or more, typically stored on pallets. They are large and slow to safely handle their loads. Unit load systems are extensively used for temperature controlled food storage. When used to store food in freezers with temperatures well below zero, special modifications to the equipment must be made.

While a unit-load AS/RS can reach 100 feet in height, a typical system is less than 40 feet high. A standard unit load AS/RS stores loads on rails designed specifically for automated systems. The rails run perpendicular to the rack aisles. (Standard pallet racks store loads on cross beams that run parallel to the aisles.) AS/RS racks can be configured single-deep, double-deep or as deep-lane racks with several pallets and stored one behind the other.

The load-handler for a unit-load AS/RS is usually a telescoping device, called a shuttle, that reaches into the storage location, slides under the pallet, then pulls it onto the carriage.

Movie 3.9 Swisslog Vectura SRM Video



Tap to view the video.

Interactive 3.16 Unit Load (Pallet) SRMs



Tap to view images.

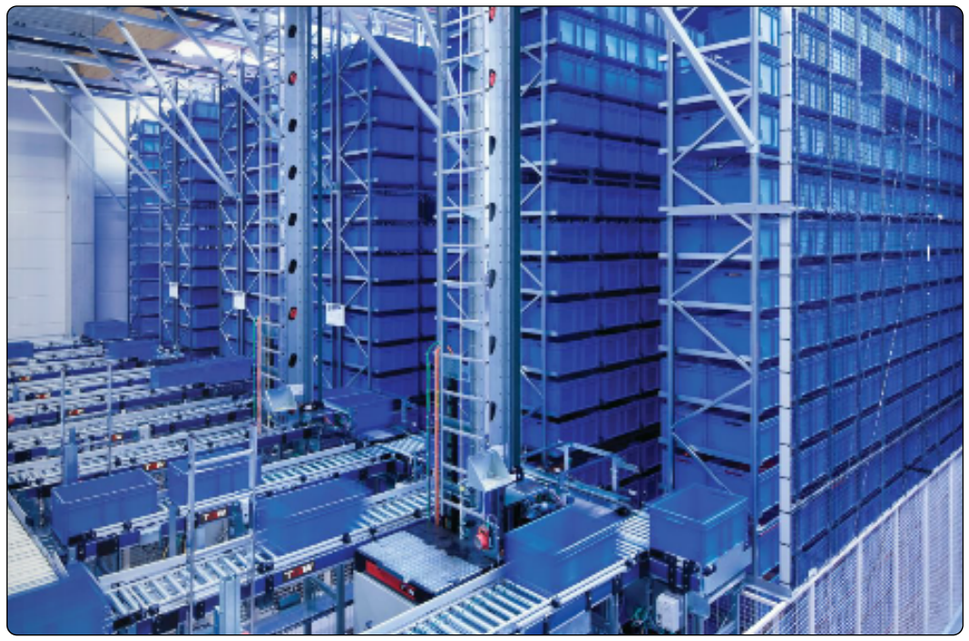
Miniload SRMs

Miniload AS/RS handle lighter loads, usually less than 1,000 pounds, in containers such as trays, totes or cartons. Rack systems usually reach up to the ceiling, and storage is extremely dense, with only a few inches between individual levels.

Most miniload AS/RS look similar to unit-load systems with drive carriages, masts, and load handlers. Instead of using shuttles to pick up and retrieve loads, they use different load-handling devices, including extractors to grasp/pull handles on metal or plastic trays, vacuums to attach to corrugated cases, and robotic arms to grip plastic totes. Cartons and trays are frequently stored double deep, so miniload cranes can usually pick more than one load at once.

A typical mini-load stands between 10 and 40 feet tall. Because they do not carry heavy loads, miniload cranes can move extremely quickly. Many miniload AS/RS are used for small items and order fulfillment, replacing many order picker forklifts.

Interactive 3.17 Miniload SRMs



Tap to view images.

Movie 3.10 Daifuku Miniload Video



Tap to view the video.

Carousels and Vertical Lift Modules

Other storage technologies such as horizontal carousels, vertical carousels and vertical lift modules (VLMs) are also variants of AS/RS.

Horizontal carousels are like the equipment used by a dry cleaner, but instead of clothes hanging from the top rail, wire carriers are suspended from the rail. These carriers typically hold plastic bins containing small-sized products. They are often paired with pick-to-light and voice technology picking systems.

Vertical carousels are similar to a Ferris wheel. This technology uses shelves that rotate up and down inside a metal cabinet. The shelves can hold metal trays or plastic bins. When an operator requests a part from its computer system, the carousel rotates to deliver the correct shelf to an access window at the proper ergonomic level. Vertical carousels work well in situations where the inventory changes, but the product profile remains the same.

Vertical lift modules are a combination of vertical carousel and traditional AS/RS technology. While the outside looks like a vertical carousel, the inside stores trays located on both sides of a column. An extractor mechanism travels up and down the column, retrieves the trays and delivers them to the operator at an ergonomic work counter. VLMs are flexible, can change with operation's changing requirements and optimize space tray density.

Interactive 3.18 Carousel and Vertical Lift Module Images



Tap to view images.

Multi-shuttles

Multi-shuttles are a newer version of AS/RS, sometimes replacing miniload-type SRM cranes. In an AS/RS that uses a single crane per aisle, throughput is driven by the speed of the crane as it performs movements back and forth within the aisle. When a crane is unavailable due to maintenance, you are unable to access the items inside the aisle. Multi-shuttle systems have evolved to address these shortcomings and increase throughput capability.

Multi-shuttles have smaller shuttles or “bots” on each level of an aisle, permitting simultaneous picking on all levels of an aisle at the same time. A vertical lift or a fixed miniload SRM mast raises and lowers cartons or totes to the different levels. Some multi-shuttle systems can move bots between aisles, or even change levels, increasing flexibility further.

Computer software controls the shuttles or bots, communicating wirelessly. A larger system can include dozens, or even hundreds of individual shuttles or bots. If a shuttle or bot breaks down, it can usually be easily removed from the racks for maintenance, allowing the system to continue to keep on working with little disruption.

Specialized rails are mounted on either side of the racks within the aisle, allowing the shuttles or bots to move quickly up and down the aisle. When the shuttle or bot comes to a stop, onboard load handlers reach into the racking to grab the cartons or totes, or put them away. Individual shuttles or bots can be powered by capacitive charging, receiving quick bursts of charge when they pick up or drop off their load, allowing the shuttle or bot to do its next assignment until it returns for a new charge.

Interactive 3.19 Multi-shuttle Images



Tap then swipe to view images.

Autonomous Bots

Autonomous bots are new versions of “goods to persons” systems, allow a system to pick goods and bring them to a person located at a fixed work station. Individual, or multiple bots working together, move along fixed routes (“ant trails”) or raised grids in the storage area, controlled wirelessly by a computer, grabbing totes or even entire shelves and transporting them to workstations along the periphery.

Similar to multi-shuttles, individual bots rapidly charge at stations along the edge, holding their charge in onboard low voltage batteries. Autonomous bots are very new to the material handling world, but show promise for rapid order fulfillment inside direct-to-customer fulfillment centers, due to their simple, scalable setups that fit in virtually any warehouse floor space.



Swisslog bots grab individual totes inside storage stacks



KIVA bot moving an entire shelf of items

Chapter 4

Material Handling Equipment - Robotics

In recent sections, you've been introduced to automation in material handling. Until recent decades, robots and robotics were concentrated in automotive factories. As the technology continued to develop, although it spread to more and different industries, it was still most often used in manufacturing environments.



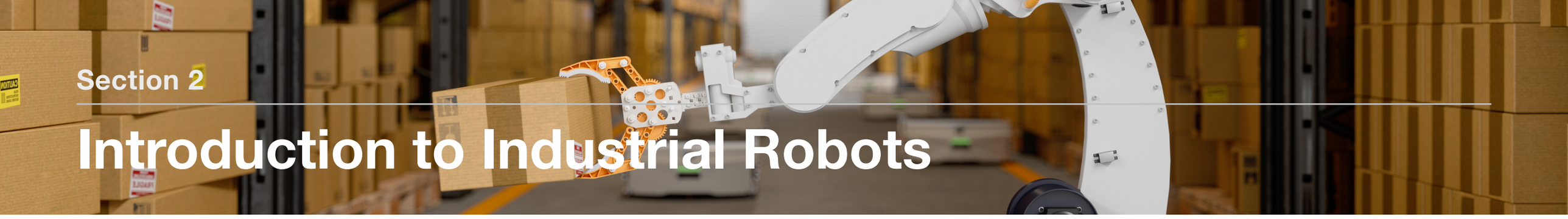
Section 1

Introduction

With the introduction of Automated Guided Vehicles (AGVs), robotics began to appear more and more in the warehouse environment. The design of various industrial trucks began to feel the influence of robotics, including forklifts, order pickers, and pallet transports.

The AGV was succeeded by the Autonomous Mobile Robot (AMR). AGVs are still in widespread use, and AMRs are growing rapidly. While there is some disagreement over the use of terms, generally the distinction between the two is in the degree of autonomy the robot has in determining the best pathway to travel. AGVs usually cannot navigate around obstacles in their path, whereas AMRs can.

In the sections that follow, we will explore these robots in more detail.



Section 2

Introduction to Industrial Robots



Custom Pallet Building Robot



Robotic depalletizer singulating cases

Many material handling functions are tedious, dull and time-consuming for human workers. Several of them may require heavy or repetitive lifting that can cause injuries. These applications, once done only by people, are now being automated with robotic systems to increase production speed and safety levels. As robot costs progressively become more affordable, and programming becomes easier and more intuitive, it is likely that robots will become more prevalent in supply chain warehouses, and maintenance technicians will need to be familiar with how to repair and maintain robots.

A robot utilizes an end effector tool or End of Arm Tooling (EOAT) attachment to hold and manipulate items. A computer program controls the specific repeated movements and functions. A technician can also manually control the robot with an attachable control pendant.

There are many different functions that material handling robots can perform, but the most common function in supply chain facilities is palletizing and depalletizing.

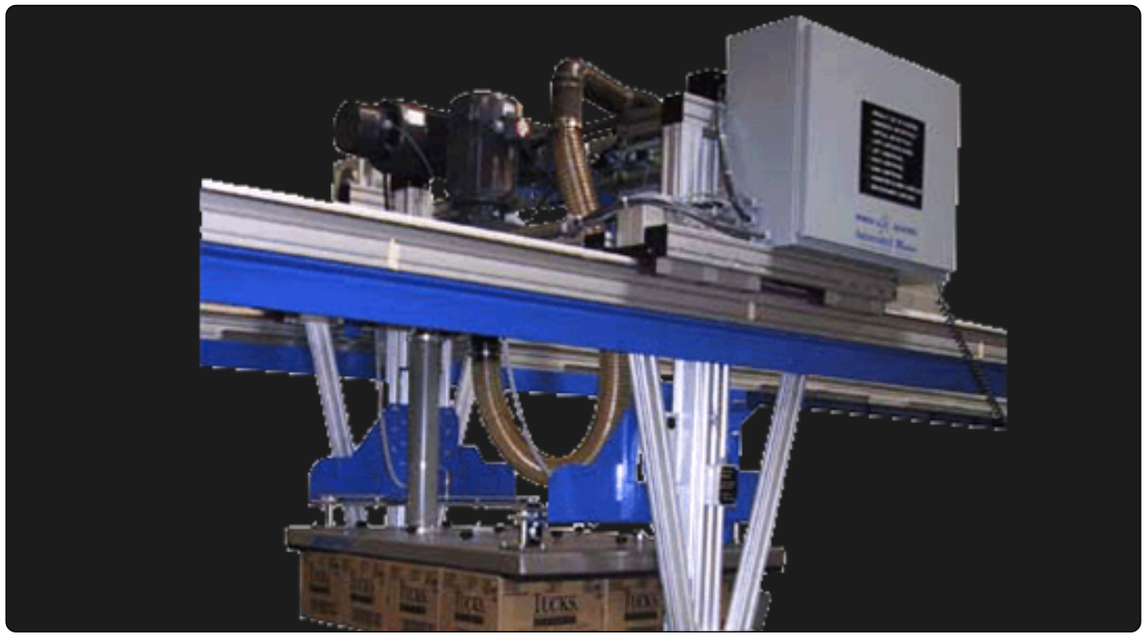
Palletizing/Depalletizing

Industrial robots load cartons or other packaged items onto a pallet in a defined pattern. Palletizing robots can stack cases layers higher and faster than a human can safely do at a sustained pace. Robotic palletizers are usually mounted either at a fixed position, or hanging from an overhead gantry (moving along an overhead rail). Special tooling interfaces with the individual load components, building simple to complex layer patterns on top of a pallet to maximize the load's stability during transport. There are three primary types of palletizing:

- Inline (layer forming)
- Depalletizing (unloading)
- Mixed case.

Robots can also do the process in reverse (delayering). Robots use specialized grippers (end effectors) to delayer tall pallets into individual layers or cases for dense storage or for individual case handling on conveyors.

Interactive 4.1 Palletizing/Depalletizing Images



Tap to view images.

Introduction to Robotics

Definition

According to the Merriam-Webster dictionary, “robotics” is a technology dealing with the design, construction, and operation of robots in automation. “Robot” is defined as a machine that looks like a human being and performs various complex acts, such as walking or talking. It is also defined as a device that automatically performs complicated and often repetitive tasks.

Robotics originated in a short story titled “Runaround”, written by Isaac Asimov, published in 1942. The word "robot" was popularized in 1920 when Karel Capek wrote the utopian stage play entitled "Rossum’s Universal Robots" in Prague. This gave the word "robot" popularity. The drama was almost an anticipation of modern science fiction: The robots seize power, kill nearly all humans, and destroy the secret of their construction. Only with the re-awakening of human feelings is life afforded a new chance.

The designation "robot" has its root in the German word "robat". This has survived in Polish and Czech as "robota" meaning "drudgery" or “servitude” and as ”robotnik” meaning “peasant” or “serf”.

A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. The robot is a computer-controlled device that combines the technology of digital computers with the technology of servo control of articulated chains. It should be easily reprogrammed to perform a variety of tasks, and must have sensors that enable it to react and adapt to changing conditions. A robot is a device that sometimes resembles a human being and is capable of performing a variety of often-complex human tasks on command or by being programmed in advance.

The three fundamental characteristics of a robot are:

- Possess some form of mobility
- Able to be programmed to accomplish a large variety of tasks
- Operate automatically after being programmed

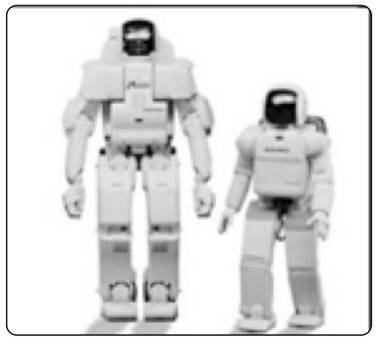
What Can Robots Do?

Robotics has been of interest to mankind for over one hundred years. However, our perception of what robots can do has been influenced by the movies and largely the media. A robot’s characteristics, as well as the way it looks, change depending on the environment it operates in.

According to the magazine of Melbourne PC User Group, some of these applications include:

- Outer Space – Manipulative arms that are controlled by a human are used to unload the docking bay of space shuttles to launch satellites or to construct a space station.
- The Intelligent Home – Automated systems can monitor home security, environmental conditions, and energy usage. Doors and windows can be opened automatically and features such as lighting and air conditioning can be pre-programmed to activate. This assists occupants regardless of their state of mobility.
- Exploration – Robots can visit environments that are harmful to humans. An example is monitoring the environment inside a volcano or exploring our deepest oceans. NASA has used robotic probes for planetary exploration since the early 1960s.
- Military Robots – Airborne robot drones are used for surveillance in today's modern army. In the future, automated aircraft and vehicles could be used to carry fuel and ammunition or clear minefields.

Interactive 4.2
Honda Humanoid Robots



Tap to read about Honda Humanoid Robots.

- Farms – Automated harvesters can cut and gather crops. Robotic dairies allow operators to feed and milk their cows remotely.
- Automotive Industry – Robotic arms that are able to perform multiple tasks are used in the car manufacturing industry. They perform tasks such as welding, cutting, lifting, sorting, bending, and assembly.
- Food Processing – Similar to the automotive industry but on a smaller scale, several applications are used for the food processing industry for the trimming, cutting, and processing of various meats such as fish, lamb, and beef.
- Hospitals – Under development is a robotic suit that will enable nurses to lift patients without damaging their backs. Scientists in Japan have developed a power-assisted suit which will give nurses the extra muscle they need to lift their patients and avoid back injuries.
- Disaster Areas – Surveillance robots fitted with advanced sensing and imaging equipment can operate in hazardous environments such as areas damaged by earthquakes by scanning walls, floors, and ceilings for structural integrity.
- Entertainment – Interactive robots exhibit behaviors and learning ability. SONY has one such robot which moves freely, plays with a ball, and can respond to verbal instructions.

History

Considering the technical progress in the course of the millennia, it could be said that this is due to the endeavors of mankind to find ways and means of reducing work. The wish to hand over arduous or repetitive actions to machines or devices dates back a considerable time. As far back as 2,000 years ago, procedures such as "set in motion" and "vary quantities" were achieved by means of mechanically controlled or adjustable appliances.

In approximately 230 B.C., Philon of Byzantium constructed an oil container which replaced the tedious refilling of lamps with oil by automatic topping up. Another impressive example is the automatic closing of temple doors achieved by Heron of Alexandria around 110 A.D. After lighting a sacrificial fire on top of a hollow altar, the temple doors shut themselves on their own. This made skillful use of the pneumatic effect from the temperature difference.

However, it was the ultimate dream of mankind to create something akin to man: an "android" (literally: "human like") which had to serve him. From sagas and literature, we know of many attempts to build androids such as Olympia the doll, Homunculus, and Frankenstein.

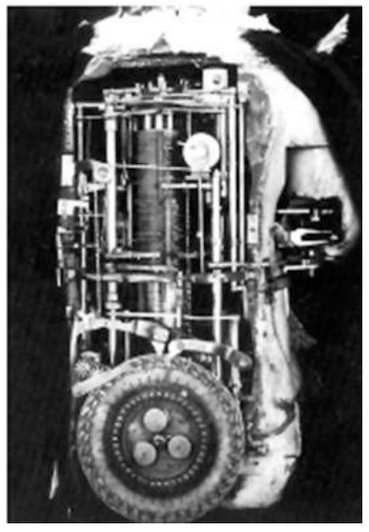
So-Called Robots

But even working appliances of humanoid shape were built. At the end of the 18th century, the watchmakers' craft achieved particular distinction in western Switzerland. Due to the mastery of precision mechanics achieved at the time, the art of watch making still evokes high levels of respect. Pierre Jaquet-Droz built three "androids" around the year 1770 in Neuenburg. These were dolls capable of putting entire sentences on paper by means of writing quills. By changing an internal metal disk, other sentences could be written, so the device was considered to be "reprogrammable". Contemporaries expressed surprise and admiration for his work.

Aside from attempts to gain attraction at fairgrounds and popular festivals, there were also pure deceptions, such as an automatic chess player by Herr von Kempelen in 1783 which, in reality, concealed a dwarf who moved the pieces.



Writing doll by Pierre Jaquet-Droz, from the 18th century



Inside view of doll

The First Industrial Robots

The International Organization for Standardization (ISO) defines “industrial robot” as an automatically controlled, reprogrammable, multi-purpose, manipulative machine with several degrees of freedom which may be either fixed in place or mobile for use in industrial automation applications.



"Unimax", one of the first industrial robots of the 1960s

The first industrial use of robots came in the form of automated machinery. In 1801 Joseph Jacquard invented a textile machine which was operated by punch cards. In 1892 Seward Babbitt designed a motorized crane with a gripper to remove ingots from a furnace. In 1946 George Devol patented a magnetic process recorder which allowed for general purpose playback control of machines.

The mid-1960s introduced the first industrial robots when the American company, Unimation, launched "Unimax". This device was capable of executing simple motion sequences such as picking up workpieces with a tong-like device and rotating them. In addition, rotary movements around one horizontal and one vertical axis were possible. One of the first robots of this type was put to work in a Swedish foundry. Its task was to pick-up casting molds from which poisonous fumes were escaping and place them into a cooling station.

Although human-like appearance is not a criterion for the design and application of robots, there were often repeated attempts to create robots in human image. At the end of the 1920s, a robot called "Televox" was created in the U.S.A. It supervised water containers; switched a pump, light, and ventilator; and opened and shut doors and windows.

Honda was successful in creating two humanoid robots. The research for developing an “intelligent and mobile robot” started with the concept that the robot "should coexist and cooperate with human beings, by doing what a person cannot do and by cultivating a new dimension in mobility to ultimately benefit society." This provided a guideline for developing a new type of robot that would be used in daily life, rather than a robot purpose-built for special operations.

This is, however, not necessary, as any possible or desired complex movement can be divided into rotations and translations (longitudinal displacements) and thus be carried out by means of much simpler constructional arrangements.

Rationalization

Every type of industrial production is subject to the same requirements – the parts or products must be manufactured quickly, economically, and with uniform quality.

This initially brings to mind the revolutionary flow-line conveyor introduced by the Ford Motor Company early 1900s. However, in this instance only one among many operations was automated, the transport of the cars on a conveyor belt during the construction process. The workers had to carry out the same basic manual operations, at the preset pace of the conveyor belt.

With increasing mechanization, other possibilities were also pursued. Individual operations were carried out by appliances and workers could limit their intervention to the placement and removal of parts. Automation should encompass conveying as well as processing/machining. The idea envisioned a factory hall devoid of human beings – definitely no longer a utopia these days!

Economy

When serially manufacturing a certain component, production costs are to be reduced by various factors, including:

- Large batch quantity and short cycle times
- High reliability of the manufacturing process
- Constant high quality of the product

Wage costs form a very important component of the analysis for economic viability. In addition, worker satisfaction must be considered for workers who carry out monotonous and constantly repetitive operations. Even overlooking these two factors, a machine controlled manufacturing process merely supervised by humans is still most likely to provide the best solution to the three requirements specified.

Automation

Automation is a technology concerned with the application of mechanical, electronic, and computer-based systems to operate and control production with little or no human interaction. The word “automation” comes from the Greek word “automatos”, which means “self-acting”.

An automated system consists of three basic elements:

- Power to accomplish the process and operate the system
- A program of instructions to direct the process
- A control system to actuate the instructions

The decision to automate a new or existing production facility depends on the:

- Type of product to be manufactured
- Quantity and rate of production required

- Particular phase of the manufacturing operation to be automated
- Level of skill in the available work force
- Reliability and maintenance problems associated with automated systems
- Economics (labor cost versus equipment cost)

Some of the reasons used to justify automation are to:

- Increase labor productivity
- Improve quality
- Reduce lead time
- Reduce labor costs
- Mitigate the effects of labor shortages
- Reduce/eliminate routine manual and clerical tasks
- Improve safety
- Avoid the high cost of not automating

The application of automation offers various advantages:

- *Technical*: Uniform quality, constant and higher working speed
- *Economical*: Higher productivity, replacement of increasingly expensive human labor by machines
- *Social*: Relieving mankind of the burden of dirty, monotonous, difficult, or dangerous activities

Movie 4.1 Automatic Order-Picking System



Tap to view the video.

Types of Automation

Automation can be classified into three categories based on the level of automation and ease of making changes in the system:

- *Fixed* Automation*:* The sequence of processing steps is fixed by the equipment configuration.
- *Programmable* Automation*:* The production equipment is designed with the capability to change the sequence of

operations in order to accommodate different product configurations. The operations are controlled by a program, which can be changed as product configuration changes.

- *Flexible* Automation*:* This is an extension of programmable automation, which is capable of producing a variety of products with virtually no time lost for changeovers. Computer numerically controlled machine tools, industrial robots, and programmable logic controllers are included in this category.

Robotic Safety

Safety around robots is particularly important. Robotic arms are extremely powerful and can quickly move heavy loads around. They do not sense the presence of surrounding objects, potentially causing injuries to surrounding people. Safety regulations call for controlled access robotic cells with safety fencing to prevent people from walking into the range of motion when the robot is in automatic mode. Maintenance technicians can only enter in the cells when the robot's energy source is removed (locked-out), or the robot is under individual manual control with a control pendant that permits them to emergency stop movement.



Robot safety cell with fencing



Robot control pendant with e-stop

Movie 4.2 Material Handling Robots Video



Tap to view the video.

Movie 4.3 KUKU Robot Video



Tap to view the video.

Cobots

A rising trend in fixed robotics is collaborative robots or cobot arms, which are designed for interaction with people. They have special sensors that detect the presence of humans or other objects and embedded systems that enable them to take safe actions. The actions might be to swerve, slow down, or stop, to avoid collisions.

Compared with industrial robots, collaborative robots are smaller, slower, and lighter, making them safer to operate around humans without caged work cells. Thanks to versatile grippers and modern programming, cobot arms also offer greater flexibility for high-variability production and pick-and-place processes.

Movie 4.4 Cobots Video



Tap to view the video.



Section 3

Autonomous Guided Vehicles (AGVs)

An automated guided vehicle or automatic guided vehicle (AGV) is an unmanned mobile robot that follows markers or wires in or on the floor, or uses vision system camera technology or lasers to self-locate and move along a programmed route. Sometimes they are composed of regular forklifts equipped with add-on sensors and controls.

AGVs excel in applications with the following characteristics:

- Repetitive movement of materials over a distance
- Regular delivery of stable loads
- Medium throughput/volume
- When on-time delivery is critical and late deliveries are causing inefficiency
- Operations with at least two shifts
- Processes where tracking material is important

AGVs are one of the most exciting developments in the world of powered lifts, and new types of AGVs are regularly being introduced to potentially assume many of the functions previously done by manned forklifts. They are especially popular in food distribution centers.

They are most often used to move product around a warehouse. They can be used to reduce labor requirements in a DC that are normally done using operators on forklifts. When AGVs are integrated with other automated material handling applications using Warehouse Management Systems (WMS) and Warehouse Control System (WCS) software, the system can automatically move the AGVs on pick routes through pallet rack aisles and stop automatically where product is located. A light can shine on the desired pallet, and a display will tell a human picker how many boxes to grab and load on the AGV.

Safety around unmanned AGVs is extremely important, and AGVs are typically equipped with numerous, redundant safety sensors to automatically stop the equipment if the AGV senses an object or person in its direction of travel or the AGV loses its location or path.

Movie 4.5 AGV Video



Tap to view the video.

Movie 4.6 Tugger AGV Video



Tap to view the video.



A pallet truck AGV used for product picking



Several AGVs moving pallets



Section 4

Autonomous Mobile Robots (AMRs)

Introduction

An autonomous mobile robot (AMR) can be broadly defined as any robot that can understand and move through its environment to achieve a goal without being overseen directly by an operator or having a fixed path defined. AMRs have an array of sophisticated sensors that enable them to interpret their environment, efficiently perform their task and navigate around stationary (pallets, racks, workstations, etc.) and moving (people, lift trucks, etc.) obstructions.

Though similar in many ways to autonomous mobile robots mentioned in previous chapters, AMRs differ in several important ways: AGVs must follow much more rigid, preset routes while AMRs can find the most efficient route and dynamically navigate around obstacles. Additionally, AMRs are designed to work collaboratively with operators in work such as picking and sorting operations, whereas AGVs typically stop moving when people are detected nearby or blocking their path.

Recent surveys indicate a high percentage of warehouses and distribution centers plan to invest in additional automation, and AMRs consistently produce dramatic improvements in productivity. A doubling in productivity is common, and many case studies show even much higher improvements.

There is no doubt that AMRs have been transformed from a laboratory curiosity into becoming an increasingly common and readily accepted part of the toolkit of the modern distribution center.

According to the market intelligence firm Tactica, nearly a million warehousing and logistics robots will be shipped annually by the year 2022, almost a fivefold increase over 2018.

AMRs are Collaborative Robots

The autonomous mobile robot falls under a broader designation called the collaborative robot. The idea is a robot that is intended to work alongside, or in conjunction with, human associates.

This has not historically been the case. As shown in previous sections, large, powerful, and fast robot arms have been used in automobile manufacturing for decades. These robot arms are used for welding and assembly, for example. They are not equipped with sensors or software that enables them to detect the presence of human beings. Get in the way--and you could be gravely injured or even killed. Consequently, such robots are fenced off within a manufacturing environment to protect people from them.

Collaborative robots are designed for interaction with people. AMRs have special sensors that detect the presence of humans or other objects. Embedded systems enable them to take safe actions. The actions might be to swerve, slow down, or stop, to avoid collisions. Or, in the case of a robotic arm, the speed and force might be limited, and it may stop or reverse direction if it detects a bump against another object.

It is clear the future will involve close collaboration between humans and robots.

What defines an AMR?

So, what makes up AMRs, and how and why are they used in the automated warehouse?

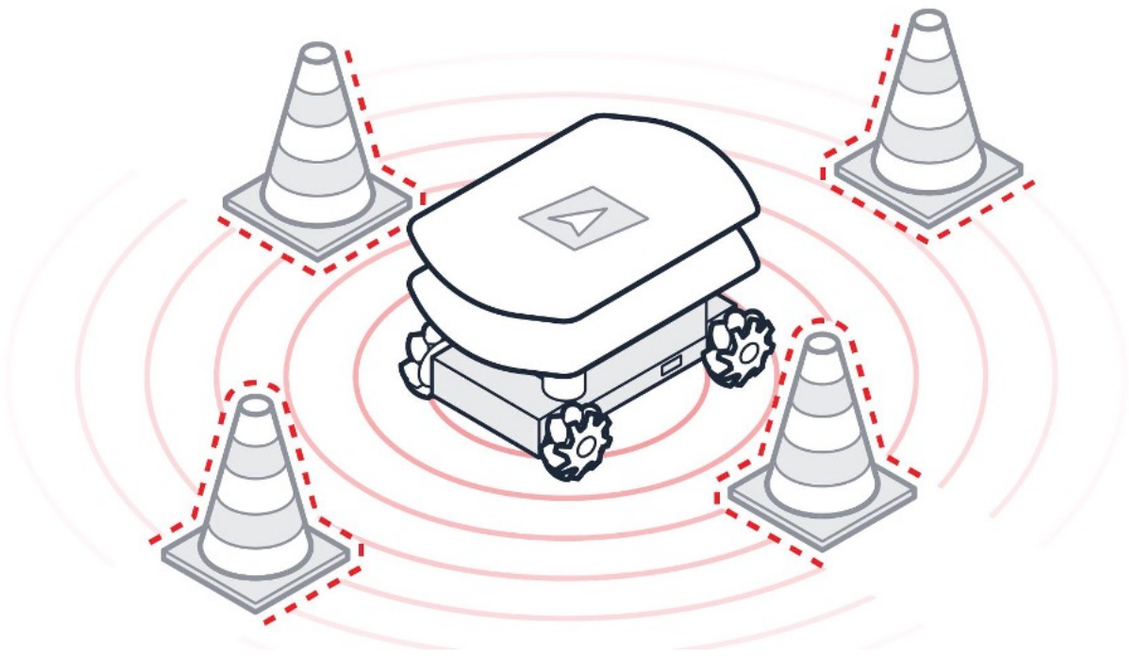
Broadly, the components of an AMR are **perception, decision, navigation, actuation, communication and self power**. An AMR must be able to

- **perceive** its surroundings. This includes permanent objects like walls, moveable objects like doors, pallets, and shelving units, and moving objects including people, forklifts, and other AMRs. This is necessary not only for safety, but also to be able to autonomously navigate around obstacles and find its way to its destination.
- **decide** autonomously what is the best route to take, whether to slow down or speed up, and whether to start, stop or swerve.
- **navigate** based on its decisions, which means it needs motors or other actuators, depending on the application.

- **communicate** with devices and software systems like PLCs, Warehouse Management System (WMS), Warehouse Control System (WCS), and with other command and control tools or systems.
- **carry** its own **power**, supplied by rechargeable batteries.

Below we consider these elements in more detail.

AMR Component: Perception



AMR & perception

An autonomous mobile robot perceives its surrounding with sensors. AMRs will often have an assortment of different sensors, and each one has capabilities that fill a need that the other sensors can't. In the most general terms, sensors need to do at least one of two things -- Object Detection and Object Avoidance (ODOA) or localization of the robot within the facility.

The modern distribution center is a beehive of activity. Various kinds of industrial vehicles move about, people are constantly on the move, and products are continuously transported. In addition, lighting conditions will change, clutter can block aisles, doors open and close, and entire shelving units can be relocated. In this dynamic environment, an AMR must have multiple and different kinds of sensors to be able to safely and autonomously navigate around the building.

Here are a few types of sensors that are often used in industrial AMRs.

Common Proximity Sensors

2D LiDAR Sensors

Light Detection and Ranging is similar to RADAR, except that it employs eye-safe, infrared laser light instead of radio frequencies. From within the LiDAR sensor, a pulse of light is sent from a laser emitter, and it bounces off of obstacles in the environment; a light detector is also built into the LiDAR sensor, and it detects the returning light. The distance to an object can be determined by measuring the time of flight (ToF) required for the light to make the round-trip from the emitter to the detector. LiDAR measurements are relatively accurate and reliable because the speed of light

doesn't change with environmental conditions. ToF sensors can therefore be more accurate than other sensors.

AMRs use a type of LiDAR sensor that is often referred to as a "laser scanner" because the emitter/detector pair described above is rotated at high speeds, and distance measurements can be taken at fractions of a degree as it rotates. When combined, all these measurements will create a 2D map of obstacles that are in the same plane as the scanner and near the AMR at that moment in time.

Limitations of 2D LiDAR:

- 2D LiDAR sensors only detect what's in the plane of the laser beam; they can't sense anything above or below the scanning plane.
- The color and material type of the surface reflecting the light can affect the quality of the measurement.
- Direct sunlight can saturate the light receiver and effectively blind the sensor (although they are much more resilient to this than other sensors).
- The angular resolution of the 2D map decreases with distance (think of spokes on a wheel, which are close together at the hub, but far apart at the rim, and then imagine a wheel with a 40-meter diameter).
- LiDAR sensors can be delicate, relative to other industrial devices.
- Dirt, dust, debris, oils, fingerprints, and many other substances can end up on the lens of the sensor, and that can cause errors.

Fun fact: LiDAR was invented in the 1960s as part of the Apollo space program. One of its earliest uses was to measure the distance between the earth and the moon.

3D LiDAR

LiDAR is commonly used for distance measurement. For example, laser "tape measures" are increasingly popular, and are used in commercial and residential construction. This could be described as one dimensional or 1D LiDAR; another term for this type of sensor is a "point ranger."

As described above, a 2D LiDAR scanner is a point ranging LiDAR that is rotated to measure the distances to everything around it. Sometimes the emitter/detector pair is rotated, and sometimes a mirror is used to reflect the light beam while the laser and detector remain stationary.

Regardless of the angle through which the laser is scanned, since the light beam remains confined to a plane of operation, this mode of LiDAR is called two dimensional, or 2D.

In a 3D LiDAR sensor, the laser beams are scanned horizontally like the 2D sensor, but they are also scanned vertically, providing

a third dimension to the measurement. Each measurement can be considered as a point in space, relative to the sensor; that point has a distance, a horizontal angle, and a vertical angle from the sensor's reference position. Each time the sensor makes a rotation, depending on the sensor, it might generate millions of these points and all together they are called a Point Cloud.

3D LiDAR sensors come in many configurations. Some sensors have multiple emitter-detector pairs in a vertical array, which are rotated, giving a multiplane point cloud. As the sensor moves through the environment, the planes are in a slightly different location each time and results in a point cloud that includes measurements of the entire three-dimensional space. The more the sensor is moved, the more the point cloud is filled in, and all of those measurements together start to build a three-dimensional model of the space the sensor is in.

Another 3D LiDAR configuration is an emitter/detector pair that is reflected off a rotating mirror that also pivots up and down. This will return a set of measurements that looks like a sine wave for each rotation, but each subsequent rotation is slightly out of phase with the previous one. Imagine drawing a wavy line across a piece of paper and then drawing another wavy line exactly like the previous one but shifted slightly to the side of the first one, and then another line shifted slightly, then another, and another. Soon your single wavy line will turn into a solid band across the piece of paper. Now roll that piece of paper into a cylinder and stand it on end. The band is like the coverage pattern of a 3D LiDAR sensor that scans the walls of a room. As you can see, a sensor of this type doesn't need to move through the room to be able to completely build a point cloud of the area around it.

360 Degree vs. Restricted

Some LiDAR systems employ lasers mounted on a spinning apparatus (or a mirror that rotates) which gives the AMR 360-degree visibility. It can detect the presence of external objects in front of the AMR, as well as behind and on all sides. This might be in 2D or 3D. Other configurations give the AMR a more restricted view by confining the scanning of the laser beams such that the AMR can only "see" objects directly in front of it, or possibly in front and a certain angular displacement away from dead-center front. Separate LiDAR sensors might be used on the sides of the AMR or the back. These are all design choices, and different manufacturers will make distinct choices.

Depth Cameras

Another kind of sensor is a depth camera. Some depth cameras use LiDAR-based technology, and others use vision-based technology. A depth camera that utilizes LiDAR is still an emitter/detector pair, but often it will have one very large emitter, or many small emitters, that all fire at once like a miniature jumbotron. The detector is often one large detector that is comprised of many small detectors like a digital camera sensor. However, whereas in a normal digital imaging camera, each pixel measures the intensity or amplitude of the light; with LiDAR, the measurement is

the time of flight of light as previously discussed. Each pixel is measuring the ToF of light rather than intensity, and this is how a depth "image" is created. Some LiDAR sensors can detect both intensity and ToF, and this can yield impressively detailed grayscale images that appear to be "painted" onto the point clouds.

Another kind of depth camera uses a vision-based approach, which is to use electro-optical (EO) cameras to measure depth. One way to use vision is called a stereo camera, which uses two EO cameras that are separated by a precise, known distance called an optical baseline. When the images from each camera are compared, the difference between the locations of each environmental object on the EO cameras' sensors can be measured. When combined with the optical baseline, a calculation can be made to determine the distance the objects in the environment.

Yet another vision approach is called structured light, which uses a light pattern emitter in combination with an EO or infrared (IR) camera sensor. The light pattern can be a grid of lines projected onto a surface or a set of dots that are projected in a grid; in either case, the geometry of the pattern is known. When the pattern is seen by the camera, the distortion of the pattern can be measured, and the distance to all objects in view can be calculated. Since an EO camera is typically involved in a vision approach, it is typical to be able to get not just depth information, but also a color image that can be "skinned" onto the high-density point cloud that is generated by the depth camera. Vision-based depth cameras can, therefore, generate full color 3D models in real time.

Limitations of Depth Cameras:

- LiDAR-based depth cameras can be solid state, but they have a limited field of view (FOV). For example, a LiDAR depth camera might have a 90-degree FOV whereas a scanning 3D LiDAR sensor might have a FOV of up to 360 degrees.
- Vision-based depth cameras are extremely easy to be blinded by too much light or too little light. And like the LiDAR-based cameras, they also have a limited FOV.
- Even though vision-based depth cameras can be inexpensive, they often require a powerful computer with a GPU to create useful data output from the sensor(s). And the more sensors you need, the more computers you need, so the total cost can often be higher than a 3D LiDAR scanner.

Fun Fact: The Stereo Camera works similar to the way human vision works with two eyes.

Machine Vision

Machine vision is a general term for the practice of using EO cameras for obstacle detection. As previously discussed, stereo cameras can be used for depth perception. But there are additional vision strategies that use interesting lenses, reflectors,

or algorithms to detect and measure obstacles. One of the most powerful and prolific methods is called Monocular SLAM. As the name implies, a single EO camera is used to do simultaneous location and mapping, but the algorithm that makes it possible is generally categorized as Structure from Motion (SfM). The SfM method takes advantage of the fact that obstacles that are closer to the camera move faster and farther across the FOV of the EO camera or get larger faster than objects that are farther away. Using a single EO camera to detect obstacles is attractive for its simplicity and low cost, but there are tradeoffs, of course.

Limitations of Machine Vision:

- Machine vision systems can be very sensitive to lighting conditions; their accuracy is tied to the quality and consistency of available lighting.
- Machine vision is easily blinded by too much light or too little light.
- There's a tradeoff between the FOV of a machine vision system and the resolution of the sensor -- the wider the FOV, the lower the resolution.
- Machine vision cameras can be inexpensive, but they often require a powerful computer with a GPU to create useful data output from the sensor(s).

Ultrasound

These sensors send out sound waves at frequencies higher than those audible to the human ear. The waves are bounced off of obstacles nearby and then received by the sensor. Distances to objects can be determined by measuring the time required for the sound to make the round trip.

Fun fact: Ultrasound echolocation is how bats, dolphins and whales navigate.

Other Types of Sensors

Wheel Encoders

Wheel encoders are used to measure the distance that a wheel has traveled by counting pulses that are generated as the wheel turns. In addition to distance, speed and acceleration can be calculated by measuring the time between pulses. These pulses are typically generated by an emitter-detector pair. Often the emitter is an LED, the detector is a phototransistor, and the pulses are created by passing an object between the emitter and the detector to break the light beam. The object is usually a "paddle" type object that is attached to the shaft, like the blades on a fan. The more precision required, the more blades on the fan. As the number of blades increases, the size of the blades must decrease to make room for all of them. In an encoder, the "fan" is called an encoder wheel, and it is generally made by cutting slits into a flat disk. High resolution encoders can have thousands of slits so that many pulses are generated per degree the shaft turns.

Another type of encoder is magnetic. The concept of operation is the same as the light-based encoders, where pulses are generated by an emitter-detector pair as the shaft turns. But with a magnetic encoder, the emitter is a magnet mounted to the shaft and the detector is a hall effect sensor mounted to a fixed structure. Increasing resolution is accomplished by increasing the number of magnets. In practice, a magnetic encoder wheel is a disc made of magnetic material and adjacent parts of the disc magnetized with alternating polarity.

Limitations of Wheel Encoders:

- Shaft position can be measured precisely, but measuring the distance travelled by the wheel depends on everything between the encoder shaft and the ground. Factors that can reduce the accuracy of the measurement: traction between the wheel and the floor, backlash in the gear train, or flexing in the mechanical system.

Inertial Measurement Unit (IMU)

Inertial measurement units or IMUs are the sensors that allow robots to have the same kind of perception that people have, which allows someone to know that they are spinning in an office chair, even if they are blindfolded. IMUs can measure position, angular acceleration, and linear acceleration, which allow the relative position and orientation of the robot to be measured.

Limitations of IMUs:

- IMUs suffer from a condition called drift, which is what happens when an IMU at rest will report that it is moving. This happens because of the type and quality of the construction of the devices and materials used.
- Temperature fluctuations can change the measurements reported by the IMU.
- Vibration can increase the noise in the IMU measurements.
- Even in the highest quality, most sophisticated IMUs which can be very large and cost millions of dollars, the rotation of the earth can affect the measurements.

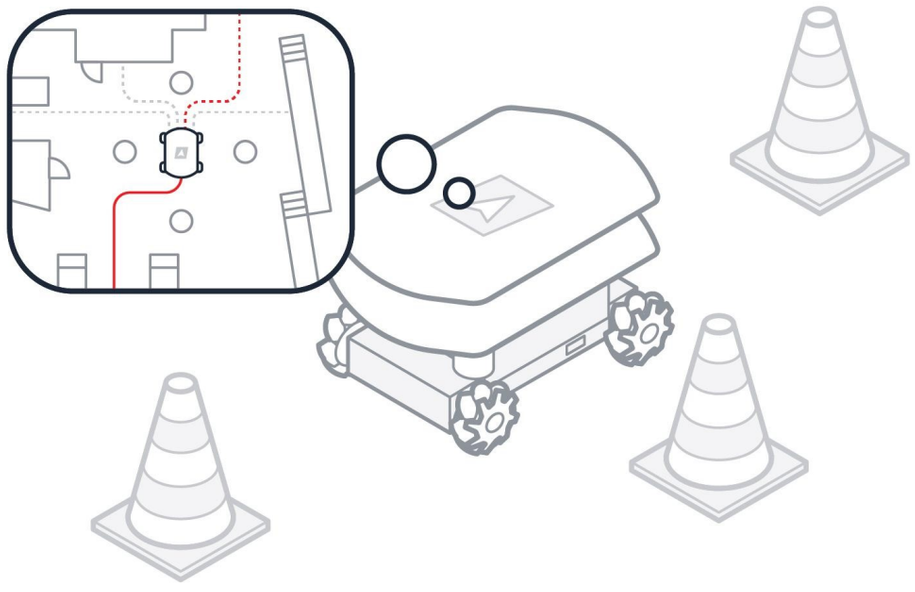
Sensor Fusion

Sensor fusion combines data from multiple sensors and multiple types of sensors to produce higher quality information so that autonomous systems can make better, safer decisions. Sensor fusion is also known as data fusion, filtering, or target tracking. When designing an AMR, it's important to have a set of sensors that have strengths and weaknesses that offset each other and complement each other, since no sensor is perfect. Sensor fusion is the glue that turns many sensors with many different strengths and weaknesses into a single robust sensing system.

AMR Component: Decision

Every AMR will have onboard electronics, employing a microprocessor with software that enables it to make decisions. This is in contrast, for example, with an Automated Guided

Vehicle (AGV) which does not require much in the way of onboard computing power. An AGV travels along a set course, guided by strips of magnetic tape placed onto or perhaps embedded into the floor along the pathway. Alternatively, optical markers or painted lines can be employed for this purpose. Guided by these marks on the floor, the AGV always travels the same route with no deviation. Therefore, it has very few decisions to make and, consequently, requires little in the way of onboard computing power. All it needs are proximity sensors which tell it to stop if there is something in the way; an AGV has no ability to navigate around an obstacle in its path.



AMRs on the other hand, can independently calculate the most efficient route from their current position to their assigned destination. They know the floor plan of the warehouse and do not need to only take prescribed routes. They can autonomously navigate around obstacles, including moving objects, along the way. Therefore, they need considerable onboard computing power to make these decisions and calculations.

ROS

The Robot Operating System (ROS) is an open-source programming environment. Its goal is to make creating robots easier and faster, by making available a library of open-source software. The design is modular, which means the user can use as many or as few of the available resources as needed.

Invented in the labs of Stanford University, it has rapidly become widely used as a common, standard tool among robotics researchers and industrial engineers since its initial release in 2013. Many but not all the AMRs available today have ROS-based designs.

SLAM

How does an AMR obtain the map of a warehouse? A floor plan can be downloaded directly to the AMR. It is possible to have the robot create its own map.

SLAM (Simultaneous Localization And Mapping) is a method used for autonomous vehicles that enables a robot operator to build a map and localize the vehicle in that map at the same time. SLAM algorithms allow an AMR to map out unknown environments. Operators use the map information to program the

robot to carry out tasks such as path planning and obstacle avoidance.

As a household example, some high-end robot vacuum cleaners can perform SLAM. While lower cost units randomly wander about the space, changing direction when they bounce off an object (and given enough time, eventually cover the entire floor), higher end autonomous vacuums use SLAM algorithms to make a map of the floor plan of the house and use that for their cleaning assignments.

Movie 4.7 Making a map with an AMR



Tap to view the video.

The process of creating a map of a facility depends on the robot manufacturer's design. The procedure described here is intended to give an idea of a typical AMR.

After unboxing the AMR, the user can use a joystick or similar remote control to drive the AMR around the space where the AMR is intended for use. The AMR's sensors and scanners detect and measure its surroundings, and these readings are fed into the SLAM algorithm.

In order to stay within the range of the remote-control device, the user will typically walk behind the AMR as it is driven around the warehouse. The created map can be viewed by the user, using a tablet or other portable device, as it is formed. This serves to inform the user of parts of the floor plan that need to be filled in.

After this process has been completed, a bit of clean-up is usually needed. There will be certain objects the AMR has detected, such as chairs or trucks, which are frequently moved, and should not be included in the map. The user can interact with the AMR-created map, deleting such objects on the displayed floor plan.

"No go" zones can be defined to ensure the robot doesn't try to plan a path or navigate through those areas.

Using this method, the AMR can be "taught" the floor plan of a warehouse, without complex computer coding.

With some AMRs, the learned map can be transferred from one AMR to another, so the process need not be repeated for each device.

Hierarchy of Authority

In addition to the decision making built into AMRs, an important safety feature involves building in different levels of authority and reaction time to the decision-making function of an AMR.

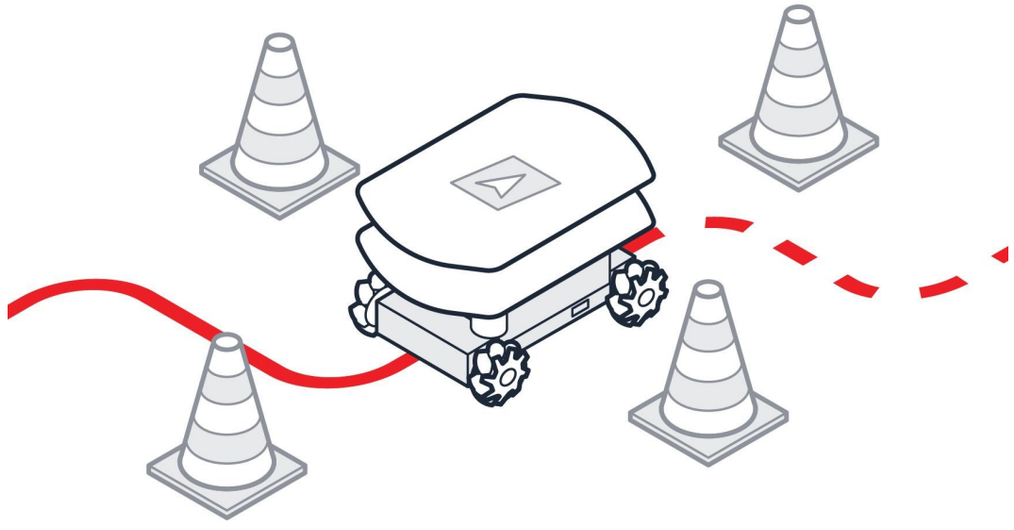
For humans, our brain makes most of the decisions. However, there are times when a decision is made within the human body that doesn't require a cognitive process.

Cognition involves making higher level decisions, about where we want to walk, or what our agenda is for the day, for example. This level of decision making is sometimes described as executive, denoting that these decisions are more complex and require high-level planning.

But sometimes our biology supersedes our brains, and our bodies react to things before our brains even know what's happening. These reflexive behaviors, like eyelids closing faster than a flying piece of debris or withdrawing your hand from a hot surface, operate more rapidly and without the need for executive decisions. These reflexes involve a faster reaction time for the purpose of protecting our bodies and are usually involuntary. We don't have to think about it; it just happens.

Autonomous robots can have similar decision-making structures. The "brain" of a robot may be a PC-type computer and make executive decisions based on what its mission is, and what information it receives along the way, but lower-level control may take place in dedicated hardware, such as embedded microcontrollers or programmable Logic controllers (PLCs), to provide immediate and reliable response akin to reflexes in humans. Control of motors or safety related functions are typical examples of subsystems that get their own dedicated computation hardware and generally operate at higher frequency and authority than the computer that is executing a mission plan and parsing data. This allows, for example, a robot to immediately stop if it notices an obstacle in its way, if it detects a problem with itself, or if its emergency-stop button is pressed.

AMR Component: Actuation



Actuation

Electric Motors

Almost all modern AMRs use electric motors as their actuators. Electric motors come in all shapes and sizes from the very tiny to the very large and powerful.

The most common type of electric motor found in AMRs is the direct-current (DC) motor. Because batteries operate on direct current, it's quite convenient to use DC motors and rechargeable batteries.

Rotational Movement

For the typical AMR in today's warehouses, electric motors will be connected with the wheels that move the robot around. A four-wheeled robot can drive about and steer using technology similar to that used in today's electric cars.

Most AMRs will have some sort of feedback from their wheels to determine their speed, distance travelled, or even to gauge and compensate for the "slipperiness" of the floor. That feedback is typically provided by wheel encoders, as previously described.

Drive Trains

The drive train contains drive shafts, wheels, electric motors, and gear heads. These components move and steer the vehicle. Direction of the vehicle is typically controlled through synchronized or independent rotation of its wheels. It's worth noting some of the common drive trains employed in AMRs.

Tricycle Drive consists of one drive wheel and two non-driven wheels in a triangular configuration. The sole front drive wheel is used to both steer and move the vehicle. One gear motor is necessary to rotate the drive wheel, and another motor is necessary to steer.

Differential Drive steers the vehicle using differential speed and direction of the two drive wheels. These include two motors for the drive wheels. This generally has increased maneuverability over a tricycle drive; it can rotate around the center of the vehicle, but angular positioning is less precise.

Mecanum Drive

The Mecanum drive and wheel design moves in an omnidirectional or holonomic fashion. The wheels feature multiple small rollers diagonally installed within the perimeter of the wheel that enables a vehicle to rotate 360 degrees while otherwise remaining in one location and move directly sideways without requiring the wheels to change their direction or orientation. These wheels employ multiple small rollers diagonally installed within the perimeter of the wheel.

Using Mecanum wheels, a vehicle can move in any direction and in any orientation merely by controlling the direction of each wheel's rotation forward or backward, and the relative speeds of rotation.

Movie 4.8 Vector 3D HD Maneuverability



Tap to view the video.

The advantages to Mecanum wheels include allowing the vehicle to precisely navigate to waypoints, reach precise waypoints faster, and maneuver in tighter spaces than would be possible for vehicles not using such wheels. And with a mobile manipulator, Mecanum wheels are essential to being able to quickly, precisely locate the AMR and the attached robot arm. Moreover, because Mecanum wheel robots can move in any orientation, the mobile manipulator can move sideways from one picking location to the next.

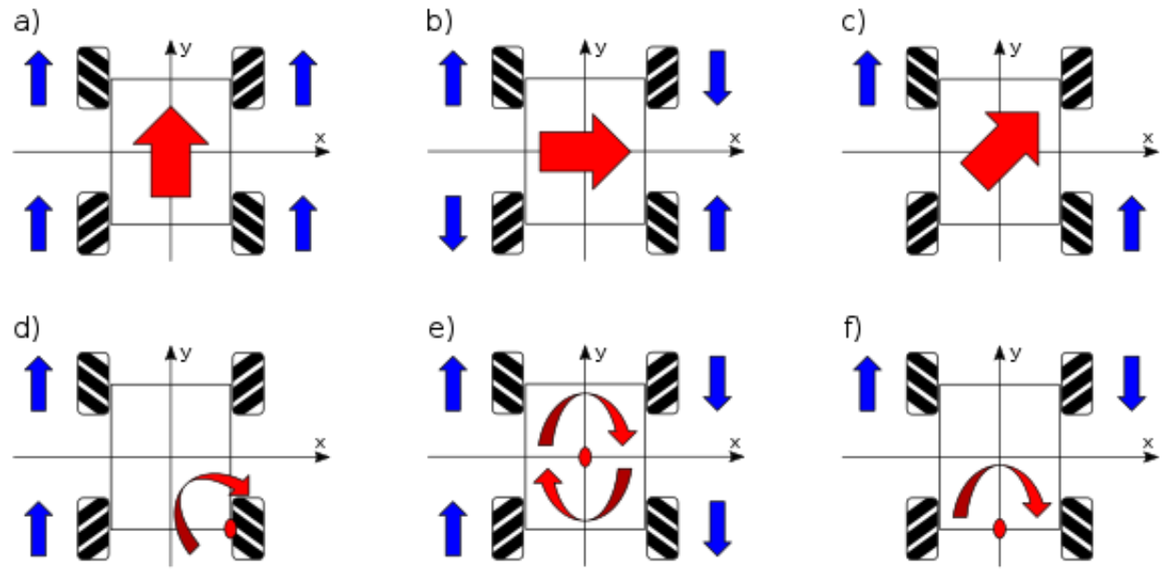


Illustration of Mecanum wheel control

AMR Component: Navigation

Movie 4.9 Touch Screen with Buttons



Tap to view the video.

Once an AMR has made a map using SLAM or other technology described above, AMRs can make their way around a warehouse, and independently and dynamically determine the best route to travel to a destination. For some AMRs, this is done via an onboard, stored map of the facilities. Consequently, even if the Wi-Fi of a warehouse were to become disabled, the AMR could still navigate.

For some AMRs, the assignment of where to go next is done by a dedicated command and control system. For example, a touch-screen with buttons displaying different destinations within the warehouse can be employed so that a user merely needs to touch one of the buttons, and the AMR will be sent on its way. Conversely, a “come here” button can summon an AMR.

Alternatively, a WMS (Warehouse Management System) or WCS (Warehouse Control System) can control a whole fleet of AMRs.

Some AMRs are highly dependent on their fleet management system for instructions and for traffic control between the individual robots within the fleet. One of the many trade-offs that must be considered when a company is choosing an AMR, is how much dependence on Wi-Fi networks or internet connections it is willing to tolerate as a risk of failure.

AMR Component: Communication

A full treatment of networking is left to another chapter in this textbook. Below we review a few basic computer communication concepts as they relate to Autonomous Mobile Robots.

Wi-Fi

Introduction

Wi-Fi is a familiar part of modern life; however, as with much of modern technology, not that many people understand the details of how it works. Regardless, most people use their laptops, PCs, smart phones, tablets, and other devices to connect to the internet via Wi-Fi at home, and many at the office too. Wi-Fi also gives people the ability to share peripherals like scanners and printers. Increasingly, the Internet-of-Things (IoT) involves connecting household appliances like refrigerators and washing machines via Wi-Fi.

One could say AMRs are a kind of peripheral--although of a special, very powerful kind. They can communicate with the Warehouse Management System (WMS) and other command and control systems.

Many AMRs communicate with warehouse systems and can be controlled by those systems via Wi-Fi. However, other technologies can be used also.

Factors Affecting Wi-Fi Performance

The Wi-Fi configuration in an automated warehouse is a considerably more complex question than for households or offices. The warehouse contains many more objects that can block or weaken the radio frequency (RF) signal upon which Wi-Fi relies. Metal objects in general can disrupt Wi-Fi signals. Examples in a warehouse include metal racks, conveyor systems, and tanks, to name a few. In addition, large amounts of liquid can block RF signals, and this can also be a factor in a warehouse. Add to the picture fork-lifts and other industrial trucks--it becomes quite a challenge for those designing a warehouse Wi-Fi network. AMR robots that require a constant external connection may experience problems if adequate Wi-Fi coverage is not put into place.

Access Points

An access point is a device that creates a wireless local area network, or WLAN, usually in an office or large building. An access point connects to a wired router, switch, or hub via an Ethernet cable, and projects a Wi-Fi signal to a designated area. In the warehouse environment, wireless access points are often ceiling mounted, and distributed throughout the space to provide strong signals in all locations.

Access points (AP) are an important consideration with AMRs because not all access points can hand off communication quickly from one to another. Since AMRs are always moving from one area to another, they need to be able to rapidly connect to the next AP. For this reason, it's important to understand that if constant Wi-Fi connections are required, then high quality fast-switching APs are required. Alternatively, selecting an AMR that can work without constant Wi-Fi connectivity is a good solution.

Digital I/O

Digital I/O or General Purpose Input Output (GPIO) is a generic term, and it stands for Digital Input and Output. The term governs almost any kind of digital communication between a microprocessor and peripheral devices such as doors, elevators, lights, sensors, and many others in a modern warehouse.

Digital Input: A digital input detects if a voltage is above/below a specific threshold. If the voltage is higher than some value, the computer will detect the digital input as a logical value of one. If the voltage is lower than some value, the computer will detect the digital input as a logical value of zero.

Digital Output: A digital output allows you to control a device with a computer. Most industrial GPIO devices will use a relay for a digital output, but there are also signal only digital outputs that use opto-isolated output signals. Either one of these approaches will allow the GPIO device to interface with or control an industrial device.

GPIO is often used on AMRs to communicate with or control a device (also a "payload" or "top module") that is installed on the AMR. It allows the AMR to turn the device on or off, or provide

feedback to the device, and vice-versa. Additionally, when combined with some type of wireless communication, GPIO that is offboard the AMR can be used to control or communicate with devices that are in the environment with AMR. Examples of offboard devices an AMR might need to interface with are automatic doors, elevators, conveyors, etc.

PLC

A programmable logic controller (PLC) or programmable controller is an industrial digital computer. PLCs are adapted for the control of manufacturing processes, such as assembly lines, conveyor belts, robotic devices, or any activity that requires high reliability and real-time response.

The PLC is specifically designed for automation processes and optimized to respond within a predictable amount of time to changes in the environment. This consistent and real time response makes it ideal for industrial applications.

Since PLCs are often found in the warehouse and manufacturing environments, it is important that AMRs be able to communicate with them.

Modbus TCP Servers

Modbus is a data communication protocol that is popular in industrial environments because it is openly published and royalty free. It was developed in 1979 to communicate with Programmable Logic Controllers (see below). Modbus allows communication to and from multiple devices connected to the same cable or Ethernet network. For example, there can be a device that measures proximity and another device measuring temperature connected to the same cable. It is in this sense that it is a “bus.”

TCP/IP

Transmission Control Protocol/Internet Protocol is the basic communication protocol of the internet and similar private networks. Most Wi-Fi devices use TCP/IP.

Websocket interface

WebSocket is a data communication protocol that is full duplex (allows for simultaneous two-way communication). It is designed for efficient communication, minimizing the amount of overhead. These qualities make it attractive for use in an automation environment.

The kind of connection you make when you use a browser on your computer is HTTP (Hypertext Transfer Protocol) is uni-directional. You send a request, and the server sends a response.

AMRs often use a Websocket interface as a method of communicating with warehouse management systems (WMS), manufacturing resource planning systems (MRP), or similar software systems.

AMR Component: Human-Machine Interface (HMI)

A Human-Machine Interface is a user interface that enables a person to interact with a machine, system, or device. It is sometimes referred to as Man-Machine Interface (MMI), Operator Interface Terminal (OIT), Local Operator Interface (LOI) or Operator Terminal (OT).

HMI and Graphical User Interface (GUI) are similar terms, but not the same; GUIs are utilized for visualization, but an HMI need not be graphical.

Movie 4.10 Waypoint HMI



Tap to view the video.

Touchscreen

Some AMRs have a touch screen as part of the HMI, and often the touch screen is the user interface for an onboard computer in the form of a tablet. This GUI can be used to display product information to an operative whose job it is to take a product off a shelf and place it into a bin onboard the AMR, for example.

In another example, an onboard HMI can be used to send the AMR to a location within the warehouse --“go to shipping” for example. This might involve a touch screen, or discrete buttons.

Another possible configuration is to have a touch screen/tablet wall-mounted in one or several locations. The operator can tap a button on the HMI to summon the AMR, or a different button to send the AMR to a predetermined waypoint, like the shipping dock, or laboratory, or whatever designations were assigned during the setup process. This kind of interaction with the AMR is analogous to using an elevator.

Movie 4.11 Waypoint Whistle - Common Sense Robot Control



Tap to view the video.

Movie 4.12 Waypoint AMR Hands On: Controller



Tap to view the video.

A remote HMI can control the AMR with a “joystick” type of interface. Such a remote controller can be used to program the AMR as it is “driven” around a space; the operator can indicate destination points, for example. See the video for an illustration.

Another typical user interface (UI) is via a desktop computer. Sometimes the UI involves dedicated standalone software which needs to be installed. In other cases, the UI is accomplished via a web-based interface using a browser to connect to a server.

Status Indicators

AMRs generally come with onboard LED indicators, showing the battery charge and various other relevant conditions like direction of travel, etc.

Barcode & QR Code Readers

When AMRs are used in eCommerce for picking, a barcode scanner will sometimes be built-in to the HMI of the robot. Alternatively, wireless handheld barcode scanners can be used that communicate with the AMR. Usually, a person will pick an item out of a bin, based on a picture and description shown on the AMR’s onboard display, scan the item to confirm it is correct, and then place the item into a bin on the AMR.

AMR Component: Power

Improvements in battery technology have played an important role in the rise of AMRs. Without long-lasting, quick-charging batteries, it would be difficult to design a usable AMR for the warehouse. A dramatic reduction in cost has been an additional

feature of the revolution in battery technology in the last decade. The most common type of battery currently used in AMRs is lithium-based because of its power density and energy density--the robots can run longer on batteries that are smaller.

Naturally, AMRs need to recharge their batteries. Most AMRs incorporate the ability to detect if their batteries are low and can automatically and autonomously navigate to a charging station when needed.

Additionally, there is “opportunity charging.” An AMR can decide, if it doesn’t have any other assignment at the moment and it’s near a charging station, to take advantage of that opportunity and charge up.

Conductive Charging

Conductive charging is the type of charger most of us are used to -- a charger has a connector at the end, which plugs into, or otherwise makes physical contact with charging contacts on the AMR. The advantages of conductive charging are that it's inexpensive and relatively straightforward. The disadvantages are that the contacts get dirty, they wear out, and they are often susceptible to losing connection when the AMR becomes misaligned with its charging dock. Additionally, there's a safety risk with conductive charging because conductive material (like a screw or piece of foil) can work its way into the charging contacts on the AMR while it is driving around, and when the AMR docks and power is turned on to charge, the debris can cause a short circuit, which can lead to dangerous conditions. The risk of this type of situation is relatively small, but it's extremely important to be aware of the risk, so that as AMR operators, we can all keep an eye out for conditions that might lead to dangerous situations.

Wireless Charging

Wireless charging has multiple advantages over charging that requires a physical, wired connection. It can establish a charging connection to the AMR even with misalignment in the vertical, horizontal, or angular directions without a decrease in power transfer. It also is possible for multiple robots to share a single charging station, even if the different AMRs use batteries with various chemistry or voltage ratings.

Movie 4.13 EnZone Wireless Charging Video



Tap to view the video.

There are currently few AMRs using wireless charging at the time of this writing. One example of a wireless system on the market employs RF-Resonant Wireless Charging technology because it's robust, reliable, and efficient over a wide envelope of distances and alignment variations.

Because of the inherent advantages of wireless technology, it is hoped that an industry standard will be achieved so different manufacturers can share the same charging station.

Benefits of AMRs

The rise of autonomous mobile robots promises to revolutionize life in many ways. In the warehouse environment, AMRs are already bringing multiple and significant benefits.

Relief from Undesirable Work

AMRs can relieve humans from the requirement to do tasks that are uninteresting or physically demanding. By freeing people to do work which is more interesting and enjoyable, AMRs can improve the workplace for everyone.

Mankind has been inventing machines to remove the need for physical labor for hundreds of years. One man with a tractor can do the work of fifty men without one. Imagine planting a field by scattering seed by hand, in comparison with riding a tractor that precisely measures the amount of seed placed into the furrows. With a tractor, you can do the job better in a fraction of the time. Imagine trying to build a large suspension bridge without the aid of large earth-moving equipment and heavy lifting cranes. It would be more difficult, labor-intensive, and dangerous than the use of modern construction equipment.

Thus, we can see that AMRs are simply the latest in a long line of labor-saving machines. These machines are different because of the degree to which they can operate more independently. But ultimately, they are an evolutionary outgrowth of a long-standing process in mankind’s history.

Efficiency

Studies show that people in warehouses (lacking the use of AMRs) spend 50% to 75% of their time walking. This can be exhausting and excludes otherwise healthy people with some minor health conditions from doing those jobs. Time spent walking also adds no value to the process - it’s basically wasted time. By using AMRs to reduce the time spent walking, dramatic improvements in productivity and efficiency are realized and workers can avoid the repetitive, harmful physical parts of the job.

When AMRs are implemented in a picking capacity, especially using the goods-to-person or the robot-to-goods models, productivity improvements of two times or more are common.

Customer Satisfaction and Making Possible the On-Demand Economy

Amazon pioneered the guarantee of two-day delivery in 2005. At first, this was available only for relatively few items. Over the

years since then, Amazon has expanded its program, so that now tens of millions of items can be delivered within two days. Prior to this, people expected to wait seven to ten business days for an item to arrive that they'd ordered online. Amazon has changed people's expectations forever.

Now, same day delivery and two-hour delivery are options, especially, but not only, for perishable items.

Robotics are a big part of the story in creating this logistical revolution. In 2012, Amazon purchased Kiva Systems, a pioneering company in warehouse robotics, renamed it Amazon Robotics and proceeded to deploy its mobile robot technology throughout warehouse and fulfillment centers worldwide.

According to Amazon robotics chief technologist, Tye Brady, "The efficiencies we gain from our associates and robotics working together harmoniously--what I like to call a symphony of humans and machines working together--allows us to pass along a lower cost to our customer."

Safety

Safety in the workplace is an extremely important issue. According to the U.S. Department of Labor statistics in 2019 (the most recent year for which statistics are available at the time of this writing), the three top sources of warehouse injuries in the United States are

- slip and fall accidents;
- injury from lifting, pushing, pulling, and reaching;
- material handling/forklift accidents.

In 2019, there were 213,100 workplace injuries in the Transportation and Warehousing sector.

These numbers have been steadily falling for the last 15 years, no doubt due in part to increasing adoption of robotics over that period.

By using robotics to do the heavy lifting, pushing, pulling, and reaching, muscle strains can be avoided. By reducing the amount of walking required, slip-and-fall accidents are diminished. In addition, by using the advanced sensing and navigation capabilities of AMRs, long, monotonous pallet moving tasks, forklift accidents and other industrial truck collisions can be avoided; and the human forklift drivers can concentrate on more difficult, interesting, and rewarding work.

Accuracy

Human beings can become tired, bored, or distracted; when that happens, mistakes are more often made. By relieving some of the tedium of the job, robots improve overall accuracy in warehousing processes. This, in turn, improves customer satisfaction.

Flexibility

Compared to Automated Guided Vehicles (AGVs), the previous “state-of-the-art” in warehouse transportation robotics, AMRs offer many advantages, especially in the realm of flexibility.

AGVs are fixed path vehicles that are guided by some type of external device, whether it is RF wires or magnetic milestones embedded in the floor, magnetic tape or 2D barcodes installed on top of the warehouse floor, RF beacons or IR reflectors mounted to walls and storage racks. This requires surveying and installation of these navigation guides, sometimes requiring substantial facility renovation. Altering AGV operating paths or destinations often require a lengthy and disruptive deployment process. The result is a system with limited flexibility to adapt to a changing environment or changing workflow.

An AMR, on the other hand, is self-sufficient in that it contains sensors onboard to identify its surroundings and can dynamically plan its own shortest path to a location based on current conditions and requirements. If the work or the environment changes from one day to the next, the AMR’s route will change with it.

While AGVs sometimes have a lower capital cost per robot than AMRs, there are significant costs associated with set up, deployment, reconfiguration, and operation. Installing the physical guides to allow the AGV to navigate and locate itself in its surroundings is expensive and disruptive to operations. All these facility modifications mean hours lost to renovation, plus the cost of the actual work.

Once the physical environment has been prepared, the AGV must be deployed with a predetermined path that is based on the work being done at the time. The AGV will run on a set course, unable to move around unexpected obstacles that get in its way. Oftentimes, the AGV will stop completely until the path is fully cleared. If the environment changes or the work changes, additional costs are incurred to reconfigure the system and repeat the deployment process.

In contrast, an AMR requires no alterations to the facility and can autonomously navigate through manufacturing and warehouse spaces. It learns its environment, remembers its location, and dynamically plans its own path from one destination to another. If its path is blocked, an AMR can reroute itself with no assistance.

The sensors an AMR uses to navigate ensure that it can operate safely in a dynamic environment alongside humans and material handling equipment. Because an AMR is not a permanent structure in the facility, it can be moved and re-deployed with minimal cost as a business grows and changes over time. In fact, an AMR can work in one part of the facility in the morning and be deployed for a completely different task later in the day.

AGVs vs. AMRs: Understanding robotics in the age of Industry 4.0

Function	AGVs Automated Guided Vehicle	AMRs Autonomous Mobile Robot
Navigation	Guided by immovable magnetic strips or wiring installed on or under a warehouse floor	Autonomously navigates using advanced technologies that can sense surroundings, avoid obstacles and park at waypoints throughout a facility
Deployment	Requires installation of navigation guides, which sometimes calls for substantial facility renovation	Minimal facility changes mean faster deployment. Some AMRs like Waypoint's vector can be unboxed and put to work in any setting in 15 minutes
Flexibility	(Operational): Altering AGV operating patterns requires repeating the entire deployment process	On board sensors reroutes robots to avoid obstacles and instantly change paths at any time
Responsiveness	Limited flexibility to adapt to changing environment	AMRs will automatically sense obstacles and blocked paths to find the best path to its next waypoint
Cost	Often requires Infrastructure updates to a facility, costing time and money or renovations.	No additional costs or facility updates requires for operation
Accessibility	Complex operating systems require expert training to set up and operate	Built for the workforce, Waypoint AMRs are the easiest to use mobile robots and require no advanced degrees or extensive training

Source: Waypoint Robotics

Resistance to Adoption of AMRs

Although precise figures are difficult to come by, estimates are that at the time of this writing, less than 15% of the 300,000 large warehouses in the U.S. have adopted robotics. Projections are that this number will grow 11% annually. The impressive growth numbers signal the market's realization that AMRs make sense.

But with so many benefits to AMRs, what has taken so long and why haven't they been adopted sooner? What are some of the factors that prevent adoption of robotics technology in the warehouse environment?

Expense

Investing in robots in the past has involved a substantial capital expenditure. In the case of AGVs, for example, it was difficult to start small, since AGVs required the installation of external guidance devices to enable pathways. This, in turn, often required at least a partial redesign of the layout of the warehouse, an expensive proposition. Therefore, adopting AGVs was more of an “all-or-nothing” proposition.

AMRs have dramatically changed this picture because an AMR can work with existing warehouse layouts, and starting small by purchasing a limited number of units to begin is quite feasible. Once the benefits are demonstrated, it is easy to purchase additional units, scale up the automation, and extend it to other areas.

Resistance to Change

There is a certain natural resistance to any change because it brings about uncertainty, and that often gives rise to anxiety and fear. This is exacerbated by minimal communication between management and workers. By including workers early on in the automation process and communicating openly about current and future plans, uncertainty is reduced, and fear can be mitigated. Early and open communication with workers also sets the stage for identifying existing employees who might be interested in working with the AMRs and configuring, reconfiguring, or maintaining them.

Experts and Outsiders

When outside experts are brought in, such as roboticists, resentment can arise. Outsiders are frequently viewed with suspicion. Apart from a simple prejudice against strangers, it is true that outsiders will not know the people, the unique processes, or the specific layout of a building.

Fortunately, there are some AMRs on the market that are so flexible and adaptable that it is not generally necessary to bring in outside robotics experts. In-house personnel can unbox and deploy the robots on their own; this helps to reduce the resistance to outsiders. If the robots are easy enough to use, those workers with the valuable experience and insider knowledge will be able to do a better job than an outsider when

configuring and reconfiguring the AMRs to meet the specific needs of that organization.

Involving workers early and keeping them engaged in the adoption of any new technology, soliciting, and considering their feedback, is the best way to lower the barriers.

Job Security

Do an internet search for robots and jobs, and you'll find hundreds of articles that proclaim the future is bleak because robots are stealing our jobs. There are dozens, if not hundreds, of movies and videos on the theme that robots will take over the world.

While it is true people in the lowest skilled jobs are vulnerable to being displaced, in general it's always been true that new technologies have created more jobs than they've replaced. For example, the rise of the computer displaced many jobs including telephone operators, secretaries, and bookkeepers. McKinsey and Company conducted a study published in 2017 entitled, "Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation." This study reported since 1950, 3.5 million jobs were destroyed by the introduction of computers.

However, over that same period, 19.3 million jobs were created by the computer industry in a wide range of occupations and industries. Entirely new jobs that never before existed sprang into being. Network engineers, help desk specialists, computer trainers and programmers, and hundreds of other, entirely new jobs were created.

We are already seeing this in robotics as new jobs are created like "robot wrangler," people who set up, monitor, reconfigure, and maintain the robots.

Naturally, continuous education and job retraining are an ongoing need for any technologically progressive society, so that people in the lowest skilled jobs can upgrade their skills. Indeed, it is a hallmark of an advancing society that its members are constantly learning new things and achieving higher levels of education and training.

In addition, a great and relatively new trend in robotics is the creation of robots and robot technology which are accessible to the workers who are on the job already. Well-designed tools would ideally not require retraining to use, and the robotics community is putting that idea in action.

Types of AMRs in the Warehouse

Now we turn our attention to the question of the various kinds of AMRs one finds in the modern automated warehouse, as well as some that are just on the horizon.

Picking

The process of "picking" is analogous to shopping at the grocery store or pharmacy. You have a list of items you want, and you

walk the aisles picking the ones you want and placing them one-by-one into a tote you carry or a cart you push.

The process of picking in a warehouse environment is mission critical. According to a study done by Georgia Tech, 63% of operating costs in a warehouse can be attributed to order picking!

First, let's take a look at how picking is done without an AMR.

Pick to cart from static shelving (with no AMR)

Orders come in from customers; and in a traditional warehouse, the items must be picked from the shelves and then packed up and shipped out.

Pick to order is the simplest order picking method and goes by many names, including "discrete order picking" and "picking by SKU." SKU stands for Stock Keeping Unit, and it is an identification code for each product on the shelves. An employee receives a list of orders and walks the warehouse to pick the products before packing and shipping them. Usually, in this method, one order is completed before another is begun.

For seasonal fluctuations, a business can hire more people to handle the increased volume during peak periods. However, once the volume of orders or SKUs begins to grow, this method becomes problematic. The picker ends up wasting a lot of time walking the aisles.

Optimization of Manual Processes

There are ways to optimize this process. For example, by carefully arranging the layout of the warehouse and then sorting the items within a customer order according to where the items are kept, the amount of walking can be substantially reduced.

A Warehouse Management System (WMS) can help support this kind of optimization.

AMRs Used in Picking

Beyond improving picking using manual methods, the use of Autonomous Mobile Robots is revolutionizing the methods of order picking and fulfillment.

Below we describe some of the different ways AMRs are being used to help in the process of picking.

Lead-me or person-to-goods

Movie 4.14 6 Rivers "Chuck" Video



Tap to view the video.

This type of picking involves the use of an AMR cart to lead a human from one item location to the next. The person walks behind the robotic cart, and the user interface on the AMR displays which item is to be picked and its quantity. When all the items have been picked, the AMR proceeds autonomously to a packing station.

This strategy requires the AMR to be in communication with the Warehouse Management System (WMS) and to be controlled by it. The WMS decides “what’s next” based on the shortest distance to travel.

Zone Picking

The zone strategy involves human pickers who “own” an aisle or two in the warehouse--a zone. They are responsible for all of the picking in their zone. AMRs, controlled by the WMS, come into their zone and position themselves next to an item’s location. A picture, description and quantity of the item to be picked might be shown by the robot on its display. Or perhaps the associate might receive this information via a voice pick headset or “heads up” display smart glasses.

Once the item is picked, the person scans the barcode of the item, perhaps using a hand-held scanner or a built-in scanner on board the AMR, and drops the item into a bin onboard the AMR cart. The AMR then proceeds autonomously to the next pick location in this zone or another, as directed by the WMS.

This method employs many robots that can be in a zone at any particular time, and the person responsible for that zone does all the picking.

Movie 4.15 Locus Robotics Video



Tap to view the video.

Hybrid Picking Models

Some systems are a combination of person-to-goods and zone picking where the Warehouse Management System (WMS) optimizes the picking functionality by independently directing both people and AMRs with carts to specific picking locations for them to load the carts. When the cart is full, it is directed to the pack area.

Because the people are decoupled from the cart and also decoupled from a particular part of the facility, their task assignments can be fully optimized. Likewise, since the AMR's

activities are decoupled from the person and any particular part of the facility, it can be maximally optimized. With this total flexibility, there might be more than one picker who is loading a single cart at any given time; or there might be one picker who is loading three different carts in one area. The any-to-any and many-to-many capability of the hybrid model is extremely efficient.

This case study video shows how an e-commerce facility tripled order picking capacity and doubled their overall output using this methodology.

Movie 4.16 Waypoint Robotics E-Commerce Case Study Video



Tap to view the video.

Goods-to-person or Shelves-to-Pickers

Movie 4.17 Amazon Robotics Video



Tap to view the video.

Kiva Systems, which was acquired and became Amazon Robotics, re-imagined the warehouse to reduce worker walking by implementing a goods-to-person model. Amazon has deployed AMRs on a massive scale that brings shelving units to picking stations by people. The Amazon robots shown in the accompanying video are AGVs. They are only able to travel on a predefined grid marked by coded tags affixed to the floor. The path they take through the grid is rigidly defined by the WMS, and the robots themselves have very few sensing capabilities and almost no intelligence on board. Because of the simplistic nature of the robots, they are kept separate by fencing from the people who are picking and packing orders.

Amazon warehouse robots are low profile devices that are designed to move underneath shelving units. Once positioned appropriately, the robot lifts the shelf from below using its linear actuator, and then carries the shelf to a picking station where a human being picks the items out of the shelf for an order.

Once the items for an order have been picked and that shelf for the moment is no longer needed, the robot transports the shelf from the picking station to a storage location until another order requires items from that shelf.

All of this is coordinated and directed by a Warehouse Management System (WMS).

Automated Picking

With automated picking, an AMR “mobile manipulator” is used to travel throughout the warehouse, find the item to be picked, take it off the shelf, and put it into an onboard bin, and then bring the picked order to the packaging area, all without human assistance.

A mobile manipulator is an AMR equipped with a robotic arm, an end of arm tooling and a vision system. The End of Arm Tooling (EoAT) enables the arm to grasp an object. The type of EoAT depends on the SKU to be picked; it may be based on the use of vacuum force, with a suction cup tip or tips, or it could be a two or multi-pronged gripping device for picking up boxes of various sizes.

Batch Processing & Sorting

A good application for AMRs is in the sorting of outgoing packages. The packages need to be sorted to go into different over-the-road trucks. The trucks will have different destinations--perhaps different cities or different stores in a drugstore chain, for example.

Movie 4.18 Geek + Sorting System



Tap to view the video.

In one example of AMRs being used for such batch processing and sorting, the AMRs are equipped with a tilting tray mounted on top. A swarm of AMRs operates on a mezzanine level--perhaps a floor or two above ground level. Each AMR moves to a pickup station where a machine or a human associate places a package into the tilt tray on top of the AMR. As the AMR carries the package away from the pickup station, it automatically scans a barcode or QR code on a package label that tells it where the

package needs to go. The AMR then proceeds autonomously to the appropriate hole that leads to a chute in the floor. When the AMR reaches the correct destination (in this example, a hole in the floor), the tray tilts up on one end, sliding the package into the hole. The chute carries the package into a pile intended for a particular outbound truck. The AMR then returns to the pickup station for the next package.

Using this method, thousands of packages can be sorted per hour with no errors.

Material Transport

There are many workflows in a modern warehouse requiring material transport.

Types of AMRs in Material Transport

Here are some different form factors and types of AMRs used in materials transport.

Unit Load Robot

A unit load robot is a small footprint AMR with a passive payload deck slightly larger than the payload. Often used to transport pallets, the unit load AMR can be manually loaded in a part picking application, or an entire pallet may be loaded or unloaded from its deck by a forklift.

Movie 4.19 Waypoint MAV3K video



Tap to view the video.

Tugger Robot

The AMR has a trailer hitch which can connect to a train of up to 4 trailers for point-to-point batch transport. It pulls the trailers behind it, like a train, car with a boat trailer, or like a tugboat. The trailers are equipped with 4-wheel steering so that they will follow along in the same tire tracks as the tuggers for maximum agility.

Movie 4.20 Automated tugger train with Still LiftRunner®



Tap to view the video.

Movie 4.21 AutoGuide MAX-N Tugger Video



Tap to view the video.

Tunneling Robot

A low-profile mobile robot can travel underneath a cart and mates up with a connector that is fastened underneath the cart. Oftentimes these devices are not fully autonomous and require guidance to navigate. The cart has its own wheels which support the payload weight. The AGV is underneath the cart as it drives the unit to its destination.

Movie 4.22 Toyota Mouse Tunnelling



Tap to view the video.

Conveyor Deck Robot

The AMR has a small section of a powered roller or other powered conveyor system on its top. The conveyor deck AMR can dock to a line side conveyor section to automatically load or unload a payload.

Movie 4.23 Waypoint Robotics Conveyor



Tap to view the video.

Movie 4.24 MiR Conveyor Top Module Video



Tap to view the video.

Lift Deck Robot

This type of AMR will drive underneath a shelving unit or pallet fixture. In this type of application, such shelving units or pallets typically do not have wheels. In the case of a shelving unit, the AMR often has enough of a low profile that it is able to slide underneath the shelf. The AMR then lifts the shelf using a linear actuator of some kind, and carries it to the destination, where it is lowered back down onto the shelving unit's own legs.

Movie 4.25 Vector with Kingpin Lift & Hitch Top Module: Load/Unload & Connect to a Variety of Carts



Tap to view the video.

When the application calls for transporting pallets, there will frequently be some kind of docking station in which the pallet is suspended a foot or two above the floor, so that the AMR can slide underneath and lift up the pallet for conveyance. A similar

docking station will exist at the destination so the pallet can be deposited.

Autonomous Forklift



Autonomous forklift with pallets

An autonomous forklift can pick up pallets and moving them from location to location without a driver. Some autonomous forklifts are AGVs, and others are AMRs. As the name suggests, such a truck is equipped with special blades that protrude from the front and slide into mating channels or spaces designed into the pallet.

The autonomous lift truck will be equipped with special sensors and software that allow it to automatically remove, store and stack pallets. For example, special sensors are installed at the tip of the “forks” that slide into the channels in the pallet so that the autonomous forklift can automatically pick up pallets.

Some autonomous forklift trucks look similar to ordinary trucks, with a seat for a human operator and a full set of controls that would allow manual control. These trucks can, therefore, be operated in a fully manual, semi-autonomous, or fully autonomous manner.

Others are very low-profile devices with minimal user interface controls--they are only designed to be operated in an autonomous mode. They might lift the pallet only a few inches above the floor while it is being transported.

Palletizing Robots

At the time of this writing, palletizing robots are often large, powerful, robotic arms, fixed to the floor that can pick up cases of goods, and stack them onto pallets.

Sometimes palletizing machines have a complex series of operations, involving specialized equipment for sorting, conveying, and boxing products. One piece of equipment might push goods into alignment; another might wrap that aligned grouping of products into a box. Yet another kind of machine might be used to assemble boxes onto a pallet as the boxes are conveyed to it.

Such equipment can also be used to remove cases of material from pallets; this is called de-palletizing.

This kind of equipment could not be called an AMR because it is fixed to one spot.

However, AMRs are increasingly being used as part of the palletizing process. AMRs can assist in palletizing and de-palletizing in a variety of ways.

Here are a few examples:

- AMRs can bring boxes of goods to the palletizing robot or equipment.
- AMRs can transport pallets of goods away from multiple palletizing stations equipment and bring them to a shared stretch wrapping machine.
- A robotic arm can be installed on top of an AMR forming a large-scale mobile manipulator which can be used to pick up boxes and stack them onto a pallet on the AMR deck. Such a combination of a robotic arm and an AMR can also be used to de-palletize. In either case, flexibility is gained by enabling the palletizing process to occur in different locations within the warehouse.

Inventory Management Robots

"Taking inventory" is an expensive, slow, and difficult process in a warehouse or distribution center. It requires many man-hours and often involves climbing up on ladders, or using lift trucks to elevate people up to the level where they can see labels and quantities of stock. Some of the hours spent on inventory can be reduced in warehouses that use radio-frequency (RFID) tags to track the assets in the facility. The workload can be further reduced if robots are used to read and locate the RFID tags.

Autonomous mobile Robots for Inventory Management

Because RFID tags can be read by an appropriate scanner at distances up to 300 feet, depending on the technology employed, a robot that traverses the floor of a warehouse or distribution center can read even the tags on items placed on high shelves.

Movie 4.26 Fetch Robotics AMR - TagSurveyor (wheeled AMR for inventory assessment)



Tap to view the video.

Aerial Drones for Inventory Management

An emerging kind of robot for inventory management is the unmanned aerial vehicle (UAV). The advantage to using autonomous airborne drones for this task is that they can fly up to whatever height the products are stacked.

By employing UAVs equipped with barcode or RFID scanners, a slow, labor-intensive process can be automated and done faster. But UAVs are limited on runtime, and indoor flight can be extremely difficult to do safely and reliably with cost-effective hardware.

Movie 4.27 FlytWare, Warehouse Drone Solution, Scans Inventory at IAG Cargo's Madrid Facility



Tap to view the video.

Movie 4.28 Indoor Drones for Warehouse Inventory and Facility Inspection



Tap to view the video.

Movie 4.29 Automating cycle counting with warehouse drones at CEVA Logistics



Tap to view the video.

Chapter 5

Other Sensors and Applications

As discussed previously, there are many types of sensors. Optics and sensors provide the information to identify where the product is located in the automated warehouse and assist in preventative and machinery maintenance. This chapter gives you an in-depth look at different types of sensors that are used and what types of signals they are sending. The installation, maintenance and repair of these sensors and other equipment are a major task for supply chain technicians who require experience in troubleshooting, electronic signals and networking processes.





Section 1

Sensor Overview

Automated delivery systems require the use of sophisticated data input that is provided by different types of scanning devices. The use of barcodes and optical scanners has become the standard method used in today's distribution centers. Radio frequency identification is the wireless use of radio waves to transfer data so automatic tracking and identification of objects can be accomplished. This technology is growing in use and is being integrated into the supply chain system to promote better speed and accuracy. As the price declines, it will become more prevalent in distribution centers. Used for counting, weighing, sizing, identifying or positioning, these devices are the basis for all processes within a distribution center.



Section 2

Optical Sensors (Light)

Optical sensors in a distribution center are electronic sensors that convert a light beam, or a change in a light beam, into an electronic signal. They are used in many industrial and consumer applications. Light used can be red light, infrared light or laser light depending on the application. The sensor measures the physical quantity of light and then converts it into a form that is readable as an input to a controlling computer system. An optical sensor is generally made of multiple components that integrate a source of light, a measuring device and the optical sensor. The sensor signal reacts to the change in the light signal within the light sensor. An optical sensor can measure the changes in one or several light beams. When a change occurs, the light sensor operates as a photoelectric switch which is used to create an on or off signal. An optical switch enables circuits to be switched selectively from one circuit to another without physically contacting the product.

Barcode Readers

Barcode readers or barcode scanners are an electronic device for reading printed barcode labels. They consist of a light source, a lens and a light sensor translating the light changes of the white and black bars into digital signals for identification. They normally use a laser as their light source to increase accuracy and dependability. Additionally, nearly all barcode readers contain circuitry analyzing the barcode's image data provided by the sensor and sending the bar code's

content to the scanner's output port for use throughout the control system. Laser scanners use a laser beam as a light source and typically employ either a reciprocating mirror or a rotating prism to scan the laser beam back and forth across the bar code.

Interactive 5.1 Barcode Readers



Tap to view images of barcode readers.

Hand Held Barcode Readers

Hand held barcode readers as the name implies are portable and consist of a light source and photodiode that are placed next to each other on the tip of the device. To read the barcode, the person holding the reader must move the tip of it across the bars at a relatively uniform speed. The photodiode measures the intensity of the light reflected back from the light source as the tip crosses each bar and space in the printed code. The photodiode generates a waveform that is used to measure the widths of the bars and spaces in the bar code. Dark bars in the bar code absorb light and white spaces reflect light so that the voltage waveform generated by the photo diode is a representation of the bar and space pattern in the bar code. This waveform is decoded by the scanner in a manner similar to the way Morse code dots and dashes are decoded.

Interactive 5.2 Hand Held Barcode Readers



Tap to view images of hand held barcode readers.

Omni-Directional Scanners

Omni-directional scanners are most familiar to us as they are horizontal scanners in supermarkets, where packages are slid over a glass window. There is a range of different omnidirectional units available which can be used for differing scanning applications ranging from retail type applications with the barcodes read only a few inches away from the scanner to distribution center conveyor which can scan where the unit can be from a few inches to ten feet away from the barcode label. Omnidirectional scanners are also better at reading poorly printed, wrinkled, or even torn barcodes.

Charge Coupled Devices

Charge coupled device (CCD) readers can be used in hand held or permanent mounts and use an array of hundreds of tiny light sensors lined up in a row in the head of the reader. Each sensor measures the intensity of the light immediately in front of it. Each individual light sensor in the CCD reader is extremely small and because there are hundreds of sensors lined up in a row, a voltage pattern identical to the pattern in a bar code is generated. The important difference between a CCD reader and the other bar code readers is that the CCD reader is measuring emitted ambient light from the bar code whereas other scanners are measuring reflected light.



CCD scanners are very fast so they read barcodes at any speed.

Position or Displacement Sensors

Photo sensors are used to respond to light or to a source of light which is part of the same circuit or system. They are normally used by allowing or blocking a light source to create an on/off switch which is used as an input for establishing presence of a box on a distribution system conveyer to control motion of the product. Photo sensors are also used to determine dimensions for the sizing of boxes as they are input into the distribution center during receiving operations. In most cases, the light source is simply blocked by whatever item is being controlled to create a signal. The computer management system can then make

decisions about the operation of the system. Safety controls and automatic safety shut offs may be controlled by photo sensors. An example would be if a person's hand or arm enters a dangerous area and blocks the light sensor. The system would stop in order to minimize risk to the operator.



Observe the sensors on each side of the conveyor system. The sensor could count, position or determine the speed of moving products.

Speed and Count Sensors

Optics can be used for measuring the speed of an operation by using photo sensors. The Warehouse Management System (WMS) can read the input information from the sensors and determine the speed or count the number of units during operation. This information is then used to manage the speed and delivery of product throughout the system. Observe the sensors on each side of the conveyor system. The sensor could count, position or determine the speed of moving products.

Interactive 5.3 Speed and Count Sensors



Tap to view images of speed and count sensors.

Hall Effect Sensors (Magnetism)

A Hall Effect sensor is a device that varies its output voltage in response to a magnetic field. Hall Effect sensors are used for proximity, switching, positioning, speed detection, and current sensing applications. Hall Effect technology did not begin to gain acceptance until the 1980s. This was because the voltage potential across the Hall element is minuscule and may easily be influenced by outside forces, such as temperature and stresses. More recent devices incorporate advances in the ability to amplify

the signal, which has allowed Hall Effect sensing technology to be employed even under extreme environmental conditions such as applications in distribution centers. Furthermore, the "non-contacting" operation of Hall Effect sensors gives the user a nearly infinite life and reliability with regard to actuation and switching. Most Hall Effect sensors are combined with circuitry that allows the device to act as a digital (on/off) signal as an output and may be referred to as a switch. The concept of operation is to create a signal when magnetism is present and remove the signal when the magnetism is removed. The sensors are very versatile, and they can be used as position, speed or level controls.

Hall Effect proximity sensors are able to detect the presence of nearby objects without any physical contact. Proximity sensors emit electromagnetism or a beam of electromagnetic radiation (infrared, as an example), and look for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target. Some types of sensors use capacitive sensing, including sensors to detect and measure proximity, position, size or movement. This is done by the volume of the product changing or interrupting the magnetic field being produced by the sensor.

Electricity carried through a conductor will produce a magnetic field that varies with current, and a Hall Effect sensor (current probe) can be used to measure the current without interrupting the circuit. This application is used for motor control electrical loads and data information for maintenance. Typically, the sensor is integrated with a wound core or permanent magnet that surrounds the conductor to be measured. These are commonly seen in distribution centers as speed controls for motors to control conveyor speed. They are also used in consumer equipment such as automotive speedometers and position inputs for conveyor systems.

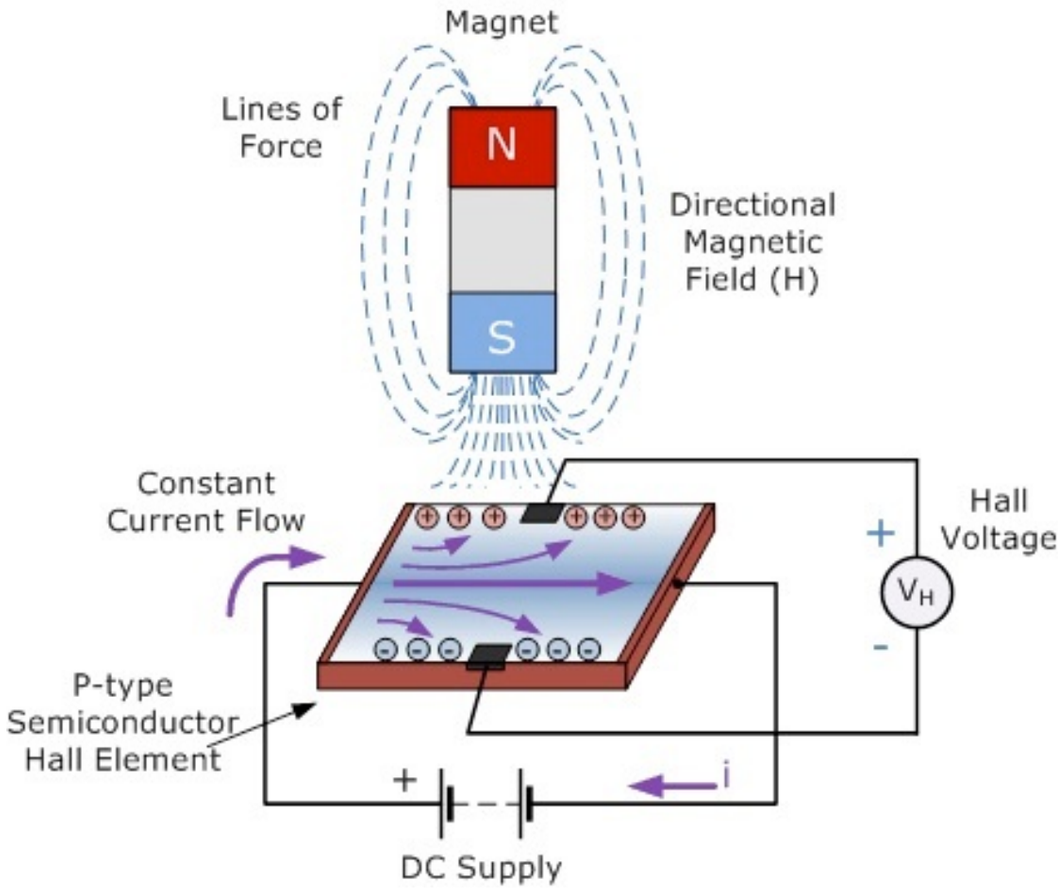
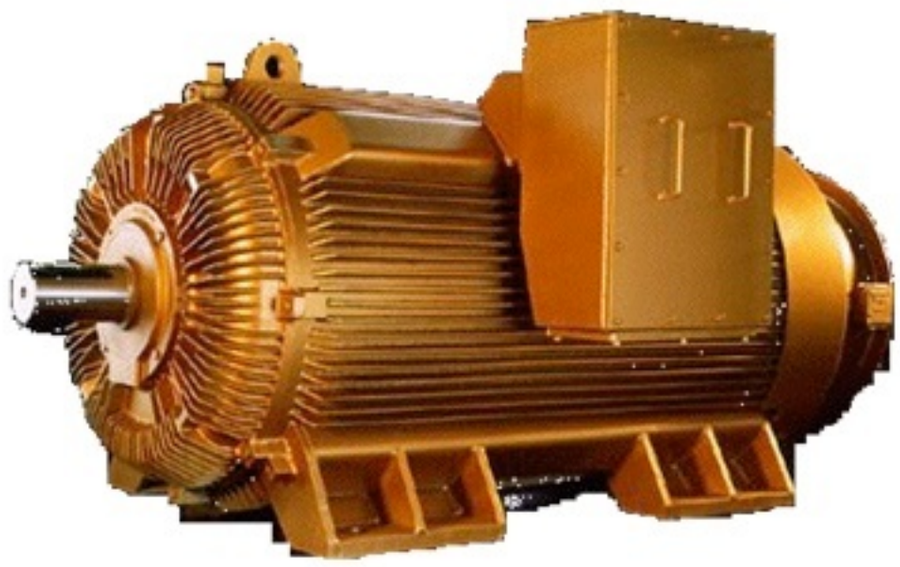


Diagram of the theory of a Hall Effect sensor. Magnetism allows a small voltage to flow through the plate.

Radio-frequency identification (RFID)

RFID systems use wireless radio signals to transfer data for the purposes of automatically identifying and tracking tags that are attached to boxes or individual items. The tags contain electronically stored information that will identify and track items as they flow through the distribution center. Some tags are powered by and read at short ranges (3 to 6 inches) via electromagnetic signals, and then act as a signal generator to give off radio waves at high frequencies. Others use a local power source such as a battery, and may operate at hundreds of feet away. Unlike a bar code, the tag does not necessarily need to be within line of sight of the reader, and may be embedded in the tracked object.



Drive motor with a speed control box and start-up capacitor attached in the square box

RFID Tags

RFID tags can be passive, active or battery-assisted passive. An active tag has a small battery and periodically transmits an ID signal. A battery-assisted passive tag has a small battery on board and is activated when in the presence of an RFID reader. A passive tag is cheaper and smaller because it has no battery. However, to start operation of passive tags, they must be activated with a power level roughly three times stronger than for signal transmission. Tags may either be read-only, having a factory-assigned serial number that is used as a key into a database, or may be read/write, where object-specific data can be written into the tag by the user. Field programmable tags may be write-once, read-multiple. Blank tags may be written with an electronic product code by the user. A tag with no inherent identity is always vulnerable to manipulation.

An RFID reader transmits a radio signal to the tag. The RFID tag receives the message and then responds with its identification and any other information that it contains. This may be only a unique tag serial number, or may be product-related information such as a stock number, lot or batch number, production date, or other specific information.



An RFID chip that is compared in size to a grain of rice. The chip is embedded into a label and then attached to a product for identification.

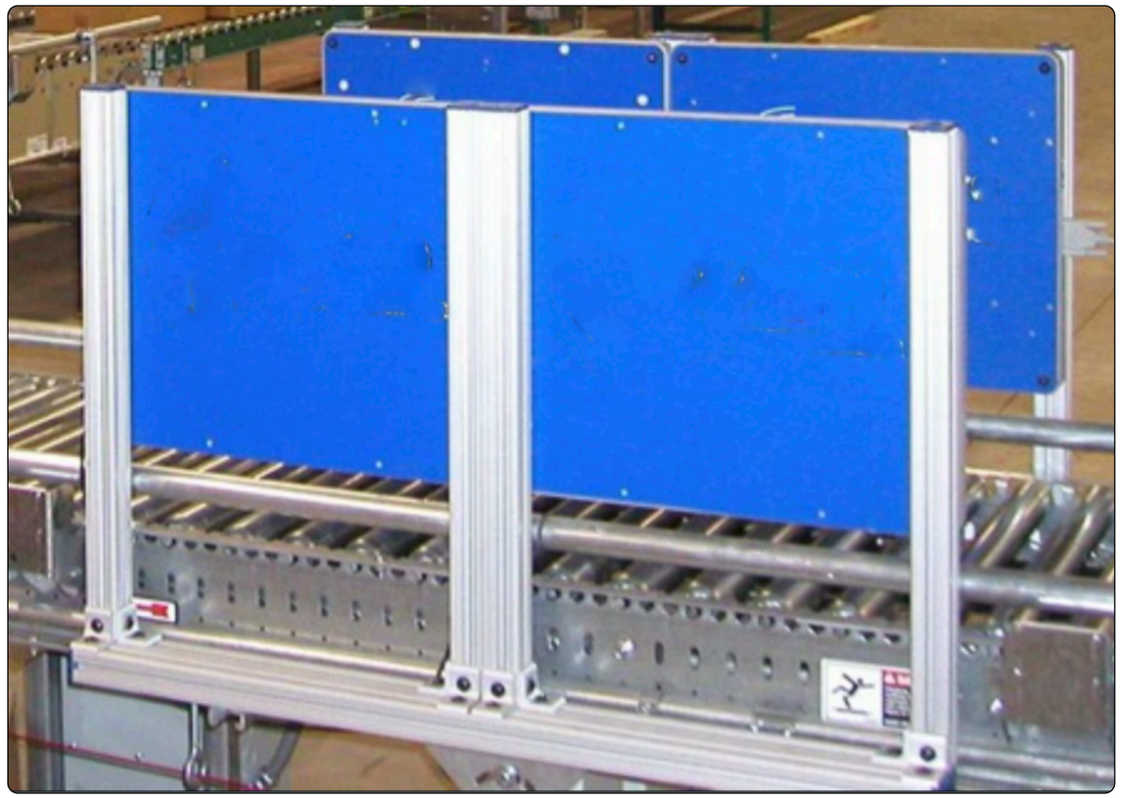
RFID Readers

RRFID readers can be classified by the type of tag they read. A passive system has a passive reader which only receives radio signals from tags that are periodically active. The reception range is up to 2,000 feet, allowing flexibility in applications such as theft protection and location of product. An active system has an active reader, which transmits interrogator signals and also receives authentication replies from passive tags which are read periodically. An active reader system uses active tags initialized with an interrogator signal from the active reader, which allows the tag to be dormant until requested to activate. A variation of this system could also use a battery-assisted tag which acts like a passive tag, but has a small battery to power the tag's return reporting signal.

Fixed readers are set up to create a specific zone, which can be tightly controlled, to actively read the tags. This allows a highly defined reading area for when tags go in and out of the controlled zone. Mobile readers may be hand-held or mounted on carts or vehicles.

RFID is used in a small number of distribution centers to control product where extreme accuracy and accountability is needed. Health care, pharmacy and high value-items are a good application for RFID. Personal identification in keys and badges is a more common application for RFID in most distribution centers for area restrictions or access and security. They are very versatile and replace barcodes or magnetic strips. The biggest negative for general RFID use is the cost. The tags cost between $.50 and $25 each, making it difficult to compete with the inexpensive use of barcode labels. RFID readers are also substantially more expensive. As their use increases and technology improves, they may become more widely used.

Interactive 5.4 RFID Readers



Tap to view images of RFID readers.

Piezoelectric

A piezoelectric sensor is a device that uses the piezoelectric effect to measure changes in pressure, acceleration, strain or force by producing a small electrical charge. Piezo refers to the production of small electrical signal as a result of compression or force on a material that is capable of giving off such signals. This process is normally used to weigh boxes or product. As the box or product is in place above the scale the compression on the piezoelectric material will give off an electrical signal based on the weight or stress on the material, which is then converted to a conventional weight. An advantage is that the scale doesn't move or deflect very far during the process so making the scale part of the conveyor or movement system is easier.



Vibration sensor using piezoelectric technology

Vibration sensors use the same technology and can be used to monitor possible failures or deterioration of equipment by converting the vibration into an electrical signal produced by a Piezo electric sensor input that can be monitored by a maintenance system. This process can inform distribution center technicians that maintenance is required.

Sensor Troubleshooting

Troubleshooting techniques for sensors requires the ability to isolate which component has failed. The use of a DVOM will allow the technician to isolate the cause of failure by determining if the sensor has input power, if required, and is producing output signals that are normal. If the input is good, but the output is not, then a quick replacement of the sensor may save a lot of time and

control the loss of productivity. If this is happening, then alignment of the optics or placement evaluation of the magnetic sensors will be required. If these conditions are normal, then establishing conduction of electricity in the wiring will follow. This level of repair will require a diagnosis of the system with a scan tool that can monitor the parameters. The key to this is, once again, to isolate the failure to a hard part or to a software control issue. In the next section, we'll discuss preventive and predictive techniques that can help us avoid troubleshooting.

Interactive 5.5 Troubleshooting



Tap to view troubleshooting images.



Section 3

Maintenance Overview

Prioritizing maintenance is a critical part of a technician's role. Equipment downtime in supply chain warehouses can quickly impede business production and can be far more costly than repairing a broken machine part. Maintenance processes reduce costs and time spent for the technician and company.

Prioritizing maintenance requires the technician to estimate the time necessary to perform the repair, assess the impact to production, and inform leadership of the plan and progress. To do this, the technician needs to have a deep understanding of the business to determine which repair best supports that business. This frequently involves the following:

- Collaborating with other technicians to maximize speed of effort
- Choosing the repair that ensures that business productions can resume
- Performing temporary repairs that allow the system to run

These types of repairs can weigh heavily on the technician, as the company will be relying on technicians to resolve the problems as fast as possible. Keeping a clear head, maintaining safety awareness, and having the capacity to adapt in challenging circumstances are imperative to a technician's job requirements. When problems arise and productions stop, technicians are invaluable.

Maintenance can be broken down into three categories:

Run to Fail (R2F) - R2F techniques involve running a piece of equipment to the point where a part fails and the machine is taken off-line in order to be repaired. This type is still employed infrequently today.

Preventative Maintenance (PM) - PM is basic scheduled maintenance that is run according to a variety of different factors. These factors are determined by the equipment being maintained. This type of maintenance is the most common type today and will likely be so for the foreseeable future.

Predictive Maintenance (PdM) - PdM is a type of preventative maintenance that is more data-driven than its predecessor. PdM techniques can change daily, depending on the amount of data being collected and analyzed.

Corrective Maintenance

Equipment sometimes breaks down or wears out, regardless of good preventive maintenance processes. Corrective maintenance is required when an item has failed or worn out, in order to restore it to operating condition. Corrective maintenance usually involves these tasks:

- Troubleshooting to identify the root cause of the equipment failure or malfunction
- Disassembly of components
- Replacement of failed components
- On-the-spot repairs of components
- Reassembly and restoration of service

Interactive 5.6 Scheduled/Preventive Maintenance Images



Tap to view images.



Section 4

Preventative Maintenance vs. Predictive Maintenance

An example of PM is a scheduled appointment for an annual oil change on a machine. This scheduled production extends the life of the machine. In contrast, PdM might consider the number of hours the machine has been used, oil quality data, the machine's location and environment, and the age of the machine to determine the most effective and efficient time to change the oil.

Predictive maintenance collects and analyzes data from digital data systems, then makes predictions on the quality of the equipment. Predictive maintenance assists a technician's role in that it can give the technician an idea of when a problem will arise, thus reducing unexpected repairs. This type of maintenance can take some of the pressures off of a technician by preparing technicians for future repairs. This approach is favored over PM, but is of limited use in many industries.

Preventive Maintenance

Scheduled preventive maintenance of equipment is an important part of keeping equipment available and extending the useful life of purchased equipment. In supply chain facilities, maximum use of equipment during scheduled production is critical to reduce company expenses, so quality maintenance programs focus on ways to avoid costly breakdowns. The value of lost productive time may substantially exceed the value of the equipment itself. Timely preventive maintenance reduces failures, unnecessary production loss, and safety issues.

Technicians frequently spend much of their time performing scheduled maintenance.

Equipment manufacturers develop maintenance procedures for each type of equipment with appropriate scheduled intervals, based on normal usage patterns. These are often put into Computerized Maintenance Management System (CMMS) software to help schedule when to perform maintenance and to document the work performed. Preventative Maintenance (PMs) may look like checklists, but may include schematics or prints for the technician's reference.

Routine maintenance that technicians perform when doing PMs typically include these:

- Removing dust, excessive grease, or debris
- Lubricating moving equipment, like chains or bearings
- Verifying the correct range of equipment motion and operational checks
- Checking tightness of connections
- Measuring or observing components or checking for excessive wear
- Checking chain stretch, belt tensions, and tracking
- Checking alignment of components
- Measuring voltage, current, or resistance
- Checking hydraulics, gauges, and pressures
- Checking sensors

Scheduled maintenance programs frequently include walkthrough/observation PMs. These involve watching equipment for non-standard behavior, finding broken or missing components, listening for unexpected sounds, smelling for burnt odors, and detecting unwanted heat. These observations subsequently become follow-up work orders for repairs. Many potential breakdowns can be identified and avoided before they turn into emergencies.

Preventative maintenance has been used for decades and is still employed today by many companies. This process has clear benefits and should be used to prevent equipment from failure.

In the future, more companies will use predictive maintenance alongside preventative maintenance. Technicians can use both approaches to ensure equipment operates at maximum efficiency.

Predictive Maintenance

Predictive maintenance (PdM) techniques help determine the condition of in-service equipment to predict when maintenance should be performed. This approach offers cost savings over routine or time-based preventive maintenance because tasks are

performed only when warranted. Predictive maintenance is highly valued due to its convenient scheduling practices of corrective maintenance and that it helps prevent unexpected equipment failures.

The core building blocks of predictive maintenance are sensor technology, failure prediction, and optimization techniques. Predictive maintenance is described as a state-of-the-art process that involves key steps, including data acquisition, data analysis, maintenance optimization, and asset management.

Data Acquisition

Data acquisition involves the use of sensors that monitor the condition of the parts of the machine. The sensor collects and stores data more accurately than a visual inspection from the human eye. Using specific sensing techniques on the condition of the parts allows a data-driven analysis of vibration (VA), sound, oil quality, and infrared thermography (IR). These techniques are nondestructive to the equipment. This step in the predictive maintenance process is still being researched and comes with its own set of challenges. These challenges include the high cost of implementing a sensor system, the need for knowledge about installing and maintaining sensor equipment, and the way to store and access the data.

Infrared (IR) Thermography

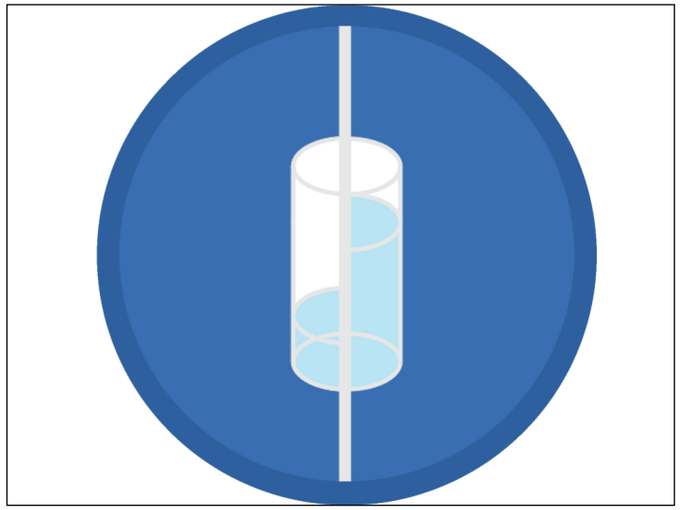
Thermal photography (thermography) technology utilizes radiation emitted in the infrared light spectrum to image and measure thermal problems that are normally undetectable to the human eye. Without shutting down equipment or interfering with production, IR cameras and sensors can detect problems in electrical panels, motor controllers, switchgear cabinets, breakers, fuses, transformers, terminations, and equipment control panels. These problems include overloaded hot circuits, low integrity or high resistance connections, overrated wiring, and many other defective electrical parts. If left unaddressed, these problems can result easily in electrical fires, mechanical breakdowns, or significant business interruption.

The two key components are the IR camera and software to interpret the data and prepare reports.



Technician using IR camera to photograph switchboard

Interactive 5.7 Infrared Thermography Comparison



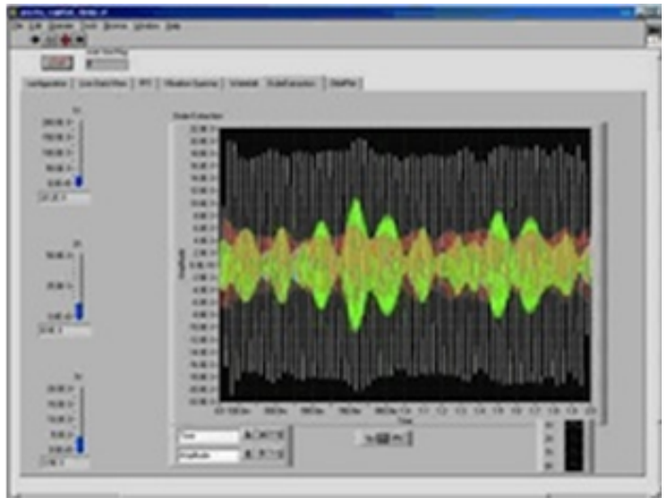
Tap to view a normal view of three-phased fuses and the IR view of the same fuses showing problem hot connection.

Vibration Analysis (VA)

Vibration sensors applied to high speed equipment monitor and transmit records of wave forms and measure degrees of equipment vibration. Software interprets excessive or irregular vibration that might indicate developing problems and allows for scheduled replacement instead of breakdown.



VA sensors.



VA software interprets vibration wave forms

Oil Analysis

Maintenance technicians take oil samples from equipment and send them to a lab to measure contaminants in the lubrication to assess mechanical wear. Labs will frequently recommend replacement of oil or recommend inspection of internal components for machines if there is evidence of excessive contaminants.



Observing an oil sample for contamination



Drawing an oil analysis sample for testing purposes

Data Analysis

Analyzing the data that the sensors collect allows technicians to monitor the data and make assumptions and predictions about the condition of the equipment. Data analysis increases the efficiency of predictions over time. This will lead to a safer and more efficient workplace. As more data becomes available, the accuracy of the predictions increases. Companies can hire a third party to collect and display the data. Some companies are moving towards artificial intelligence to collect and analyze the data.



Section 5

Maintenance Optimization

Most organizations have used preventive maintenance for years. This process maintains the equipment based on specific factors of the machine. Technicians schedule the maintenance based on the operation life of each part of the equipment. However, preventive maintenance can lead to technicians performing scheduled tasks too early in the lifespan of the equipment. Additionally, it may be difficult to anticipate a failure before it happens due to unforeseen circumstances.

Predictive maintenance differs in that the data collected gives the technician the freedom in choosing when the parts actually have to be fixed. This results in increased capacity to handle more urgent needs or unexpected circumstances. Predictive maintenance can save a company time and money by ensuring that maintenance is not being performed on fully functioning equipment.

Asset Management

To use predictive maintenance effectively, a company must have a system in place that tracks each machine and its parts. Asset management ensures that organizations are fully aware of each piece of equipment and their parts. For example, a library needs a system that tracks every single book that is loaned out or is on a shelf. In a rural library, a simple tracking system using pen and paper could suffice. However, a large city library with multiple branches would need a highly sophisticated software platform. Similarly, a large company or organization will need a highly intelligent system that tracks each part of each and every

machine. This allows technicians to have the materials or parts on hand when maintenance or repairs need to be done.

Predictive maintenance is a developing field in its infancy. Many companies and organizations are hesitant to take on the challenges that come with these processes. Predictive maintenance allows for an easier view of when items need repair or troubleshooting. With the use of nondestructive sensing technologies, corrective maintenance becomes more convenient for the maintenance technicians.

Record Keeping

Documentation and recordkeeping are routine parts of a technician's role. An industry standard practice is to assign work orders to all work performed by a technician. These work orders do the following:

- Assign a tracking number
- Describe the problem or issue
- Track parts issued for repairs
- Track time spent to perform the task
- Record the Problem, Cause, and Remedy (P/C/R).

These work orders often are printed out from Computerized Maintenance Management System (CMMS) software. Some companies use hand-held devices that allow the technician to digitally interact with the CMMS.

Typically, maintenance technicians fill out detailed time sheets accounting for their activities for a work shift. This allows maintenance managers to understand better how their staffing aligns with maintenance workload. Detailed and accurate documentation is a professional expectation of a maintenance technician. Although documentation can be time consuming and tedious, it is an essential part of maintenance best practice. A technician relies heavily on good documentation to look at equipment history and trends in order to make a good diagnosis during troubleshooting.

Work order and CMMS processes allow the maintenance team to manage and order spare parts inventory, track trends of equipment performance, and accurately schedule technician work. Preventive maintenance work orders typically have maintenance procedures and checklists to guide a technician through all the steps to perform a maintenance procedure. The data collected from the predictive maintenance approach is analyzed by the technician or through artificial intelligence. The analyst then generates the work order in the CMMS.

Documentation and recordkeeping are routine parts in a technician's role. Data collection, such as this, allows technicians to observe and analyze the equipment's history. It ensures equipment is being maintained properly, it allows technicians to

understand the root cause of the problems or repairs, and it upholds warranties of the machines.



Section 6

Looking Towards the Future

As technicians, you should always prepare for the next breakthrough in asset and equipment management. We know that as technology progresses, so do strategies of best maintenance practices. What comes next is, therefore, a valuable question to ask and investigate. In the future, companies are looking to use predictive maintenance alongside preventative maintenance. Technicians can use both approaches to ensure that the equipment operates at maximum efficiency. We can imagine a world where sensors not only monitor equipment and predict failures, but also help decide how to fix the issues. If the machines can make those decisions in real time and offer possible fixes, supply lines will become more efficient.

Chapter 6

Fundamentals of Mechanics

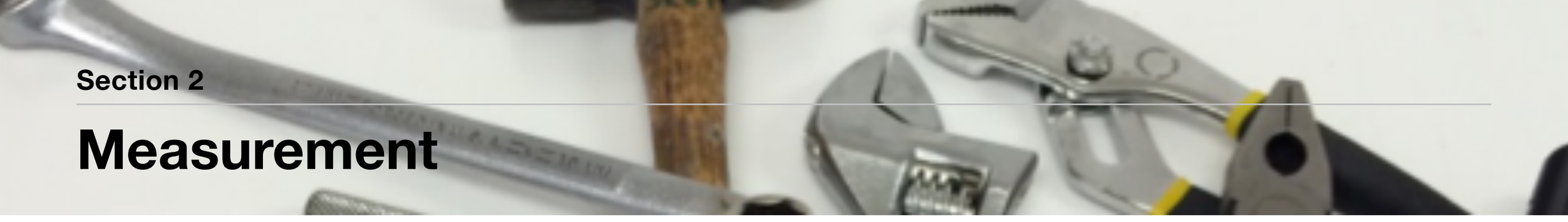
Having the ability to use the tools and equipment necessary to maintain the automated equipment is a mandatory skill for all supply chain technicians. This chapter will introduce you to the mechanical aspects of the automated warehouse.



Section 1

Overview

Mechanical systems drive the entire operation within the distribution center. The movement of product is done by robotics, conveyor systems, lifts, and controlled sorters which are all mechanical devices. The operation, maintenance and repair of this equipment is essential to reduce and prevent failure and maintain the efficiency of production.



Section 2

Measurement

Measurement of parts and components is required for operations to be accomplished by service technicians. Production, maintenance, construction and assembly all rely on measurement for consistent quality and control. The tools required are diverse and need to be organized and protected for maximum benefit and time savings. Quality measuring devices will last a lifetime if kept clean and protected from harsh treatment.

English/Metric Systems

The English (Society of Automotive Engineers, or SAE) system of measurement uses the basic units of inch and foot. This system is used almost exclusively in the United States. A foot is equal to 12 inches. Feet can be advanced into larger units which can be as long as a mile (5280 feet). Inches can be divided into smaller units that are represented as fractions of the whole; 1/2, 1/4, 1/8, 1/16, 1/32 or 1/64. The inch system can be presented as a fraction or as a decimal. The decimal is created by dividing the top fractional number by the bottom to arrive at a number that is a percentage of the inch system. This system is used extensively in precision measurement.

The metric system is based on the value of 10 and is the most common form of measurement in the world. The basic unit of the metric system is the meter (39.37 inches equals one meter). The meter is divided or multiplied by ten to increase or decrease the measurement size based on the unit needed. Prefixes are used to

define the size. A kilometer is one thousand meters (1000) and a millimeter is one thousandth (.001) of a meter. The metric system is used extensively for international manufacturing and trade to standardize production.

Rules and Tape Measures

Rules and tape measures are used for measuring linear distances. Small rules are normally 6 or 12 inches in length and are used for more precise measurement. Tape measures can be as long as 100 feet but are normally between 6 and 12 feet and are used for less precise measurement. Rules are incremented into vertical lines representing a whole or a fraction of the whole. Most small rules are incremented with marks representing 1/64 of an inch but most long tape measures use 1/8 or 1/16 as the most accurate denomination. Many rules and tapes are incremented in both English and metric since the use of both systems has become so common. Rules are placed across or between the distance to be measured and the increments then represent a common size that anyone can compare and understand.



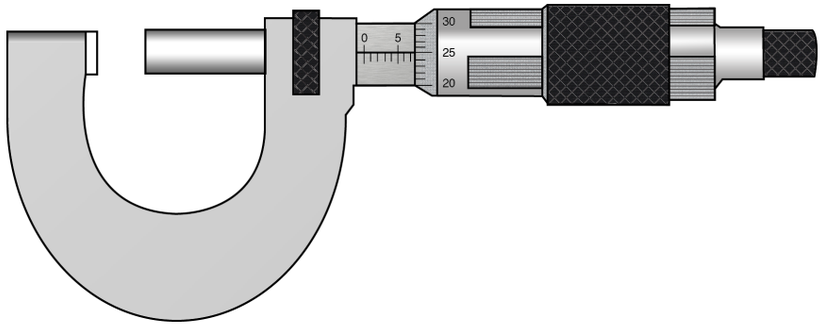
Tape measure and steel rules used for measuring

Precision Measurement

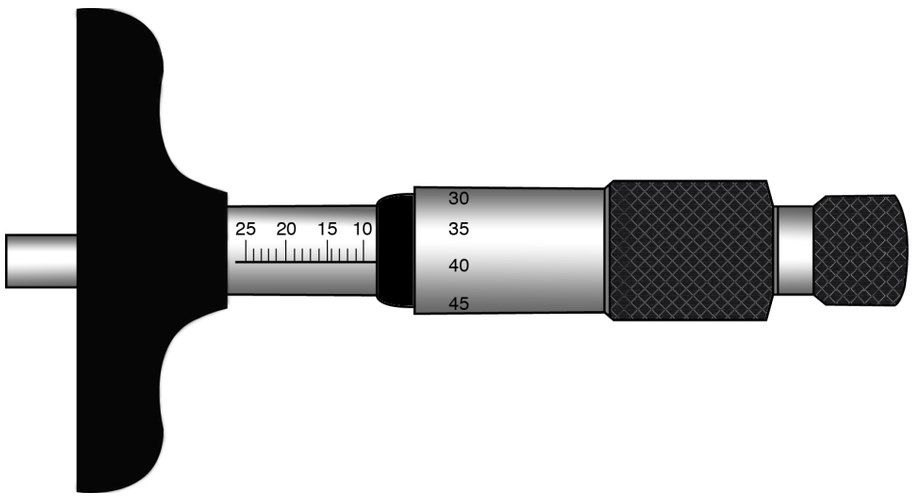
Precision measurement is critical when checking tolerances, verifying wear limits and selecting the proper parts for installation or repair. The accuracy on many components will determine if it is to operate effectively and reach an expected operating life. The tools and equipment needed for these measurements are very accurate and are designed to measure to one thousandths of an inch (.001) or one thousandths of a millimeter. Multiple tools will be needed to measure different configurations.

Micrometer

The micrometer is a hand tool used for accurate measurements. The standard micrometer will measure to one thousandth (.001) of an inch or, with the addition of a vernier, to one ten thousandths (.0001) of an inch. The tool is used for measuring thickness, diameter or any outside dimension. The micrometer head can also be adapted as a depth or inside measurement tool since the unit of measurement is the same. Micrometers are read by turning the thimble until the measuring points are snug on the device and reading the barrel increments to determine size. The numbered lines represent 100 thousandths (.100), the increments between represent 25 thousandths (.025) and the individual numbers on the thimble represent one thousandth (.001). The exposed markings are added to determine the total.



Outside micrometer used for precision measurement.



Depth micrometer used for precision measurement.

Dial Caliper

The dial caliper is a precision measuring tool that will measure inside, outside or depth linear measurements from 0 to 6 inches at an accuracy of one thousandths of an inch (.001).



Dial Calipers used for inside, outside and depth precision measurement.

The dial caliper has a sliding head that works with the main beam to be very versatile in what it can measure. The tool is quick and easy to read. The main beam is incremented in inches and tenths of inches and the dial in one thousandth. To read the tool, it is snugged on the part and read as an addition of inches and tens of inches as exposed on the beam and individual thousandths on the dial.

Protractors



Protractor for measuring angles.

The accurate measuring of angles is done with protractors. Protractors are normally a semicircle incremented in degrees with a moveable pivoting arm. The flat or bottom surface is placed along a plane and the pivoting arm is positioned so it duplicates the angle, which is then shown as the exposed incremented line. Protractors are usually made of steel when used as an industrial tool but can be plastic when used in a drafting or engineering situation.



Section 3

Tools and Applications

The proper use of tools is essential for the performance of mechanical tasks; without tools productivity stops. The proper tool for the right job is also paramount for safety and quality. The right tool must be chosen for the right job.

Hand Tools

Hand tools are the lifeblood of maintenance technicians. They are used for all aspects of repair, maintenance and installation of equipment. The versatility and applications are endless and without them the process will not function and productivity will fail.



Hand tool set for service technicians



Miscellaneous tools used by service technicians

Hammers

Hammers are hand held striking tools with a head attached to a handle to allow control, leverage and strength. Hammers range in size from very small to very large depending on the application and design. Hammers can be used for shaping, riveting and bending metal or can be used in conjunction with other devices like punches and chisels to cut or press materials. Sledge hammers can be used for demolition or for applying large force to move an object.



Assorted hammers for applying blunt force power

Wrenches

Wrenches are used to apply twisting force to a bolt, nut, pipe or any item that requires torque. Open end, box end and combination wrenches are used in close quarters where access is limited. Sockets and drive devices (ratchet handles) are tools used to speed up the process and allow reach not possible with conventional wrenches. Pipe wrenches are used for twisting round objects, such as those used in plumbing, but they do have a tendency to damage the surface of the application. Adjustable wrenches allow for infinite sizes but lack some strength in the jaw and are bulky in use.

Interactive 4.1 Assorted Wrenches and Sockets



Tap then swipe to view images.

Screwdrivers

Screwdrivers are used for applying a twisting force to small threaded fasteners. Most screwdrivers are of the flat, phillips or captured type tips and come in varying sizes. The standard or flat tip is the most commonly used for many applications. The phillips design tip has an advantage that it will not allow the tip to slid out of the screw, which is common in the blade type tip. The captured tip can be of varying types to include allen, torx, clutch or fluted and are normally used with power tools.

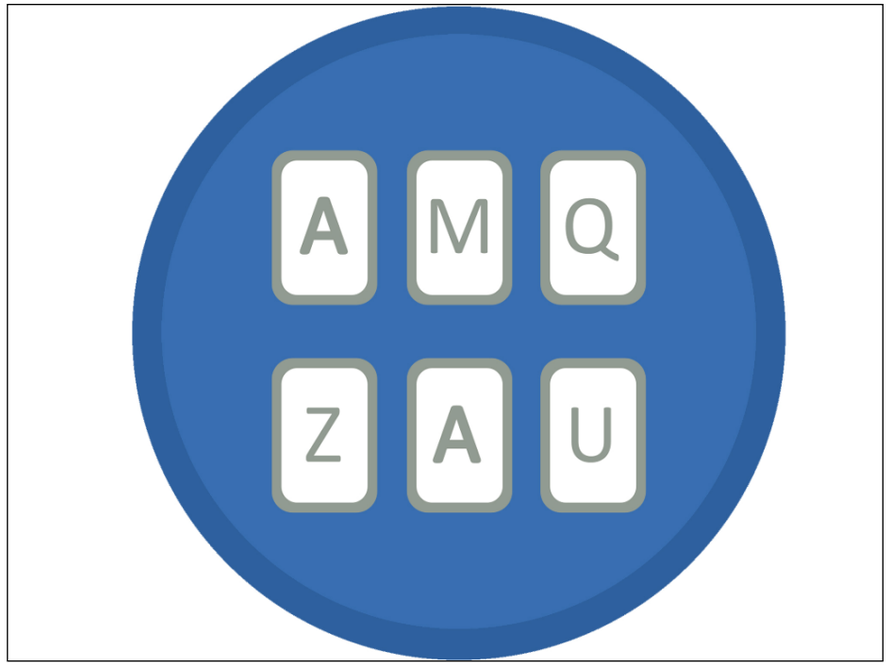


Slotted screwdriver as commonly used by service technicians



Screwdriver set to cover most types and sizes

Review 6.1 Screwdriver Driver Types



Tap then match screwdriver drive types. Tap trash can to clear and repeat activity.

Pliers

Pliers are gripping tools with opposing handles and jaws that increase the leverage of the user's grip. They come in many different configurations to accomplish different tasks. Some pliers are adjustable by slipping the grooved jaws to change the jaw opening. Some pliers are locking jaw and can be used to hold work together as another task is being accomplished. Extended reach pliers allow the user to reach into areas that are either not accessible or unsafe to reach into. Pliers can also be used as cutting devices for small wire pins or nails.



Assorted pliers to apply griping and cutting force to a project

Power Tools

Power tools, when used in the appropriate manner, will lessen the workload and accomplish tasks much quicker. The use of electrically powered tools increases strength and versatility for the worker.

Drills

A power drill is a power tool that provides rotary motion to accomplish many tasks. They can be driven by wall current or battery power. It is used primarily for drilling holes in metal, wood or plastic but can also be used for drilling concrete or brick if used with the proper bits. Size (1/4", 3 /8", 1/2") and RPM can vary depending on the application. Drills can be fitted with different kinds of attachments which allow for screwing, grinding or buffing.



110 VAC drill motor

Saws

Cutting of materials is accomplished by saws. Portable circular saws are commonly used to cut wood or plastic and can be fitted with abrasive blades to cut metal. Reciprocating hand saws are used extensively for cutting all types of materials. They are versatile and can be used with many types of blades to accomplish multiple tasks.



Portable power saw for cutting wood or metal

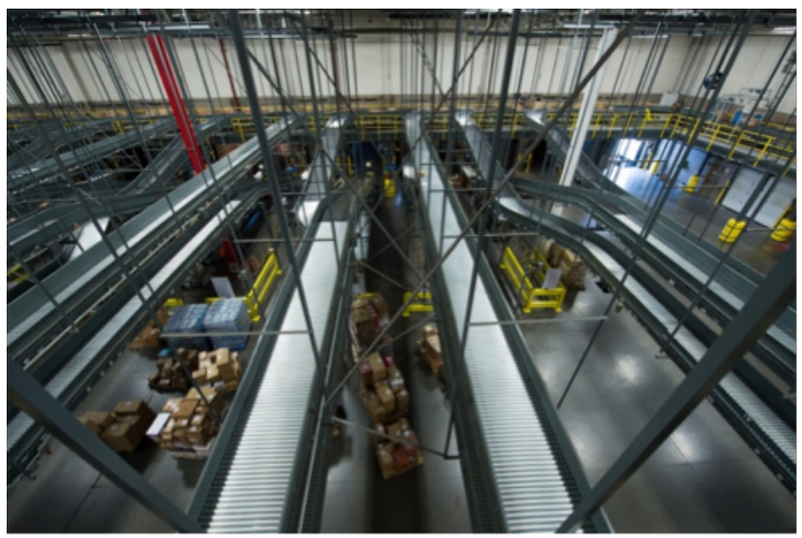
Tool Safety

Tool safety is the most important consideration when using tools. Proper tool choice for the job is always a must. Organization and access to the proper tool will minimize the risk of using the wrong tool. Personal Protection Equipment (PPE) is always a consideration when working with tools so the worker is not placed at risk. Replace damaged or worn tools and have a tool replacement and purchase plan. When working with power tools make sure you understand their operation and the potential risks from electricity, chip removal, or torque concerns. Be in control of the tool by positioning your work where it is safe and secure. Think before you do the process and know the end result.



Section 4

Physical Properties



Angled components shown in a distribution center storage system to increase strength and stability

Formulas and calculations are used to determine the quantities and volume of applications. Linear units, volume, sizes and weights all play a role in the design, installation and maintenance of a distribution center. These properties need to be understood and correctly applied.

Conversions and Formulas

Formulas are the use of combined numbers to determine a needed value. The grouping of these numbers and mathematical applications become equations to determine the values. Examples of common formulas are area, volume, rise and unknown dimensions.

Angles

Angles are formed by the intersection of any two planes, lines or sides. Angles are measured in degrees, minutes and seconds. Different angle types have differing applications and will be used when installing equipment or structures. Some types include right, adjacent, supplemental, and obtuse.

Area

Area is the number of square units that make a flat surface. The configuration dictates what formula will be used to mathematically figure the total. Area is expressed as square inches, feet or a metric denomination such as square meters

or millimeters. The applications of the formulas vary depending on shape and configuration.

Pressure

Pressure is the force created on a unit area. The inside of a tank or a pipe will contain pressure and its power is exerted against its sides. Pressure is expressed as atmospheric, gauge or absolute. Atmospheric pressure is outside air pressure which applies force to everything. Gauge pressure is internal to a system and is produced by a source. Absolute pressure is pressure above a perfect vacuum. Each has application but most of what will be used for a distribution center is gauge or enclosed pressure within a hydraulic or pneumatic system. This pressure is produced by compressors and pumps as a central system or as part of an individual piece of equipment.



Industrial air compressor with a refrigeration drier



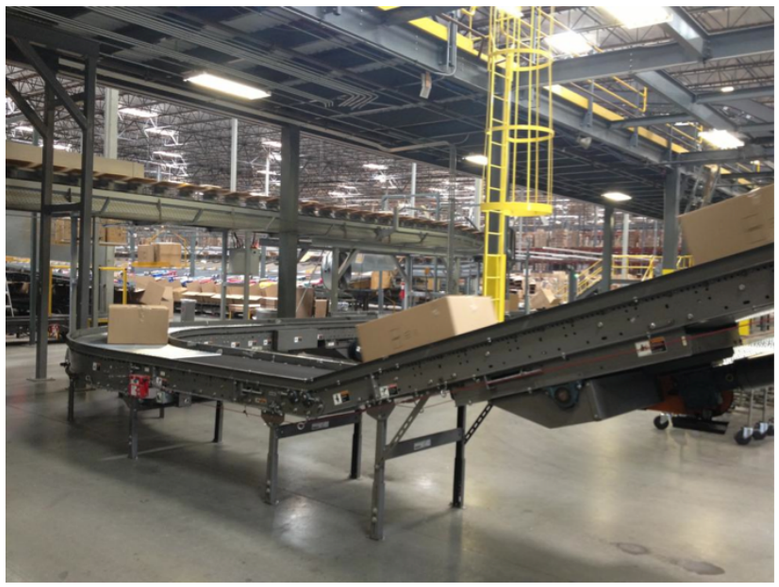
Pressure gauge indicated in PSI and metric systems (bar)



Section 5

Structures

The distribution center is made up entirely of structures. The distribution equipment from input to shipping is all supported by different structures that work together to allow flow and control of all items within the center. Maintenance and installation are part of the maintenance personnel's responsibility so an understanding of its function is important.



Distribution center structures

Stairways

Fixed industrial stairways are the standard for all distribution centers and must comply with the safety guidelines established by OSHA. Step design, width, hand rails and angles are part of the code, with all applications abiding by the guidelines.

Mezzanines

Industrial mezzanines are semi-permanent floor systems installed inside a building to create a secondary floor to increase floor space and expedite movement of materials.

The distribution center designs the system to increase productivity and volume and to maximize available space. Protection from falling product and personal safety concerns is part of the design. Most mezzanines are made of steel, supported by structural beams and anchored to the floor.



Ramps and mezzanines to increase floor space for better utilization

Racking

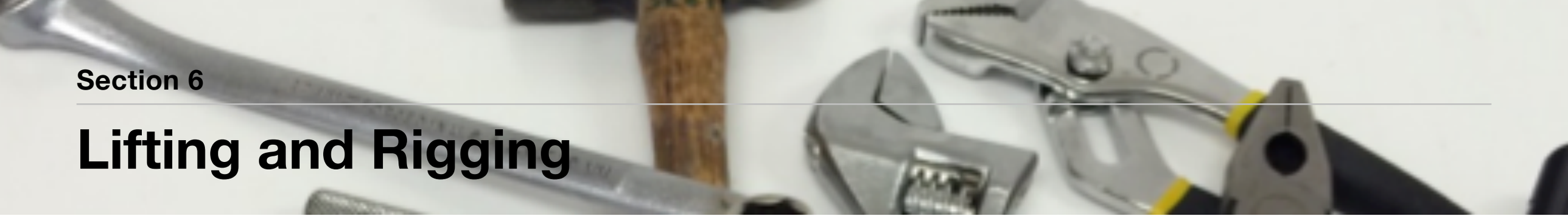
Distribution center racking is an extremely important part of the center. Efficiency is the primary issue in the design and application of racking systems. Racking can be as simple as pallet racks serviced by a lift truck or as complex as an automated storage and retrieval system. Volume and height are also a major part of the design so as to accommodate the merchandise that has to be distributed. Racks are built with cross supports to give structural rigidity and meet local building codes.



Storage racking

The distribution center conveyor system must progress to multiple elevations which is done by belt, rollers or lifts depending on the system design.

Most down movement is done by gravity on chutes or free rollers. The lifting of pallets during input and shipping is done by lift truck or moveable conveyors. The choice of processes depends on volume and cost effectiveness and if the center is designed to deal with pallets or individual items. Material lifting can be fully automated if the volume justifies the cost effectiveness of the initial expense. Automatic storage and recovery systems (AS/RS) are being used in most large distribution centers.



Section 6

Lifting and Rigging

Lifting and rigging is the safe movement of materials and equipment to a required height. Rigging is the securing of equipment for the preparation of lifting and the lifting is the use of hoists and cranes to accomplish the task. The needed equipment must be compliant and complete in order to accomplish the task in a safe and efficient manner. Straps, slings, hooks and cables are all used for different applications.

Rigging

The safe and effective process of lifting items during maintenance operations is critical to effective repair and replacement. Balance, security and strength all need to be evaluated effectively. A-frames or overhead hoists are a standard for lifting machinery and lifting jacks and platforms can be used when access and logistics allow.

Load Calculations

Estimating the weight of a load may be done by referring to the shipping weight of the replacement part or by using a material weight table. Large motors and gear boxes are some of the more difficult estimates to make without manufacturer specifications. The load also needs to be balanced, which requires the center of gravity to be considered when planning a lift.

Attachments

Attachments for rigging are normally steel hooks, shackles and lengths of chain or steel cable. The attachments can be gated or ungated and may use a swivel or a clevis to support the attachment. Shackles, as with all attachments, are of differing sizes to allow access to the rigging and to ensure appropriate strength for the load. Master links are also commonly used to allow multiple attachments to come together or to allow flexibility in the placement of the attachment.

Strapping/Slings

The choices of materials used for lifting range from rope to steel chain, and the options are dictated by the load. Rope is an inexpensive lifting tool that can be sized for a minimum weight or a very large weight. Webbing is also used and, as with rope, its strength is in relation to its width and thickness. The flexibility of webbing and its ability to grip on a component make it popular. Using steel rope or chain is common and again, its strength is dependent on the size.

Interactive 6.1 Lifts



Tap then swipe to view images.



Section 7

Mechanical Drives

The movement of distribution center items is done by a large, complex system of driven machinery. This power is delivered by mechanical drives. Gears, belts and direct electric motors provide torque and movement for all items. The supply chain technician is responsible for installation, service and maintenance of all moving equipment. Mechanical torque changes, speed changes and directional changes are all done by mechanical drives.

Energy Transfer

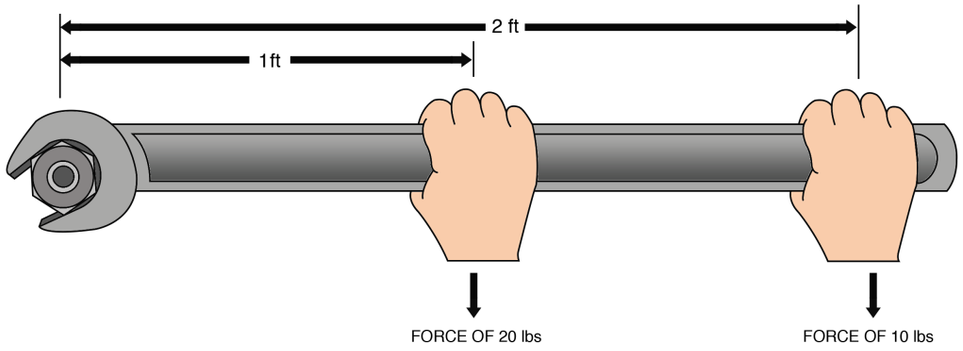
The transfer of energy is accomplished by mechanical means; this can be gear transfer or belts. The end product is the transfer, by a mechanical energy, from one source to a driven mechanism.



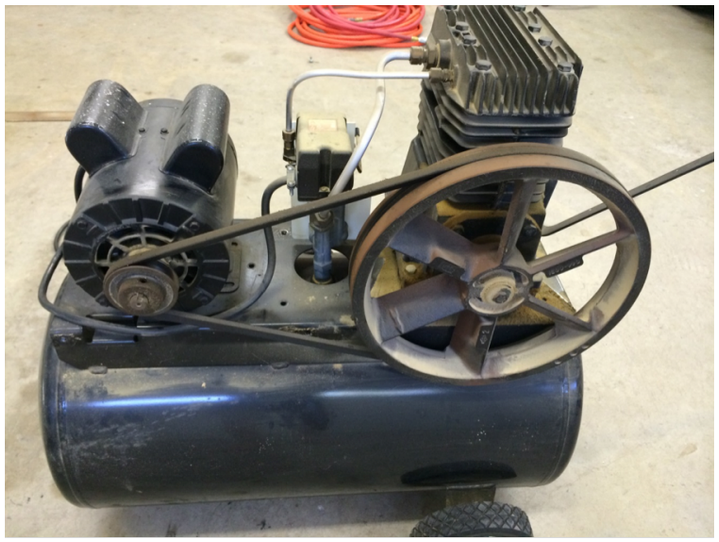
Gear set for changing torque and speed

Torque

Torque is the twisting force exerted on a shaft within a machine. Torque can be increased by going from a small drive device to a larger driven device. The multiplication of torque results in more power but less speed.



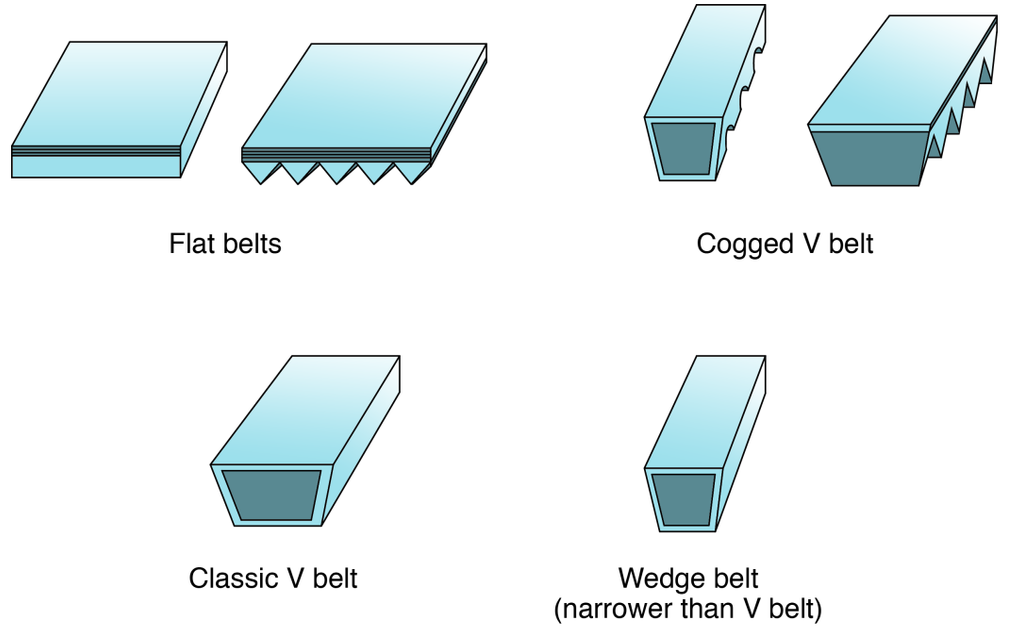
A wrench being used to multiply torque



Small sprocket driving a large sprocket to decrease speed and increase torque

Belt Drives/Pulleys

Belt driven systems use belts and pulleys to transfer power from a drive motor to a driven component. Belt drives create a convenient drive system that is quiet and forgiving. Belts normally have good useful life and can be easily maintained and serviced. They also have the advantage of not being a positive transfer, to minimize component breakage. Safety concerns are always present so make sure all guards are in place and the power is tagged off before work begins. Working around moving belts or pulleys should never be attempted.



Belt types

Flat Belts

Flat or serpentine belts are used when the belt or tension system changes direction to drive multiple loads from both sides of the belt. The flexibility allows for small pulleys to be used without damaging the belt.



Flat belt in operation

V-Belts

V-Belts are the most common drive belt system for industrial applications. The belt has a large surface area to contact the pulley and is self-centering. Replacement, service and tensioning are simple and the costs are low. Larger power systems will use multiple groove pulleys and multiple belts to transfer torque and speed.



V-belt application for driving multiple rollers on a conveyor system



Cogged belt drive

Cogged Belts

Cogged belts are used to transfer high torque energy but they also index or time the pulleys if needed. Cogged belts allow no slippage so the transfer of energy is more controlled.

Gear Drives

Gear drives are used in distribution centers to increase torque and determine speed for driving conveyors or belts. The gears are housed in a gear box that is normally self-contained with an electric motor and gear train with lubricant for the gears in the sealed package. They are used for high torque applications and can be used to drive chains or belts, but are normally attached to high load equipment.

Straight

Straight cut or spur gears have gear teeth that are parallel to the direction of rotation. The advantage of this gear arrangement is that no side loads are placed on the gears and they transfer torque in the same plane to a driven gear. These gears are the most commonly used in industrial applications but produce substantial noise during operation.

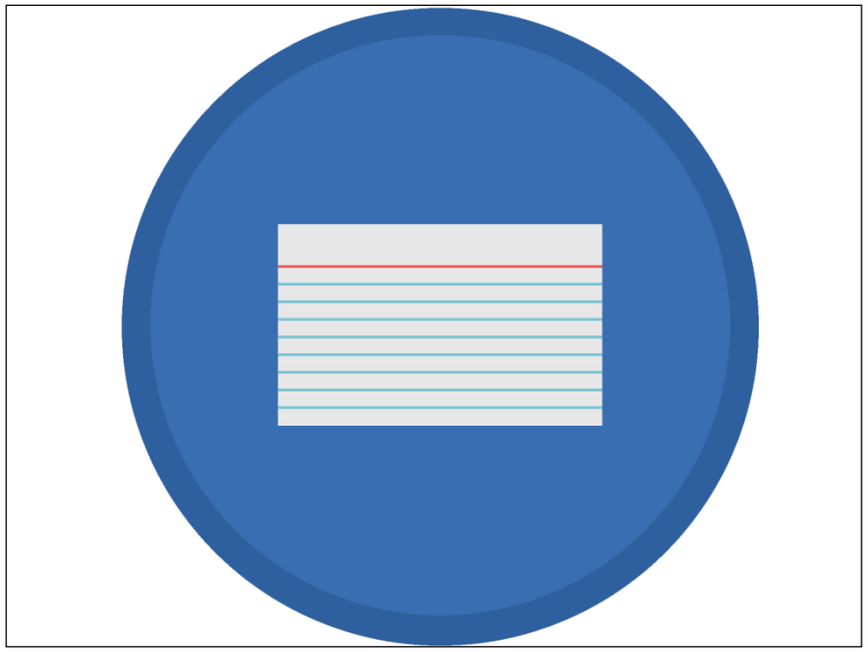
Bevel

Bevel gears are cone shaped so they can transfer torque and speed between shafts that are not in the same plane. Bevel gears produce heavy side thrusts on the gears so they must be used in a strong, well supported housing. They can be produced at different angles to provide additional applications. They can be produced with a spiral gear tooth to produce a quiet operation.

Worm

Worm gear sets are used for slow operation with high torque, speed reduction and a change in direction. The worm gear is on a shaft which drives a wheel gear in the perpendicular direction. Worm gear sets also lock the wheel gear in place when the drive worm gear is stationary.

Review 6.2 Different Types of Drive Gear Sets



Tap to test your knowledge of drive gear sets.

Chain Drives/Sprockets

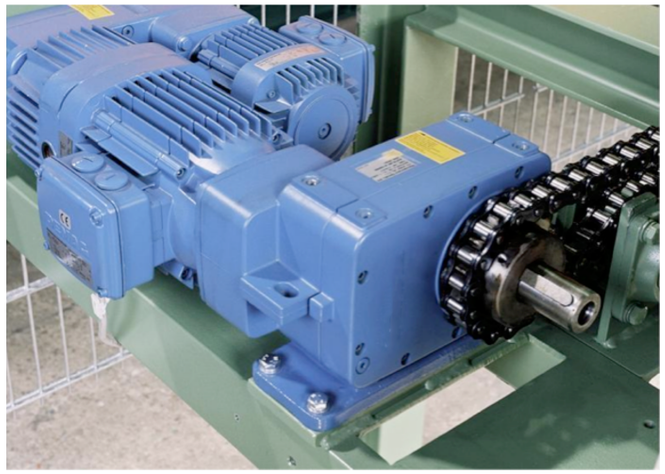
Chain drives transfer energy in a controlled application. The sprocket teeth are in contact with the chain links so no slip is allowed and timing is achieved. These drives can be used in high torque applications. The meshing of the sprocket and chain create a positive drive system that is self-guiding.



Chain driven rollers for heavy-duty applications

Roller Chains

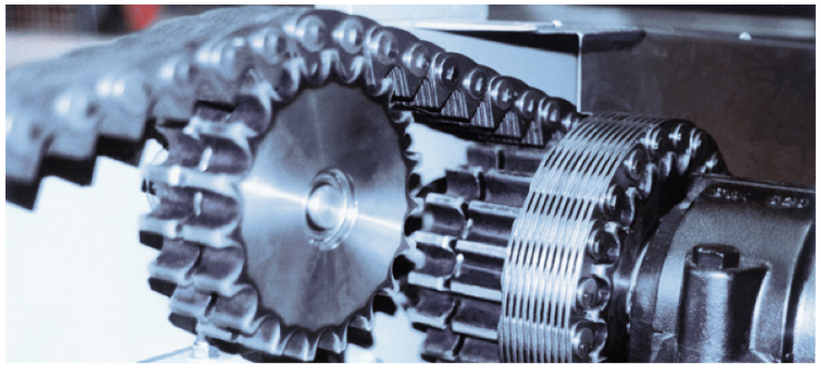
The roller chain contains a roller, pin and connecting links to make a flexible chain with internal lubrication. Roller chains come in different sizes based on torque requirements and function at moderate speeds with little or no lubrication.



Roller chain being driven by a gear box reduced drive motor

Silent Chain

The silent chain is made of a number of links pressed together on a pin which allows rotation. The edges or center link is not relieved so it will track on the sprocket. The advantage of the silent chain is less noise, longer operational life and greater efficiency.



Silent chain

Ladder Chain

Ladder chains are used to create meshed sprockets that turn at a very low speed. It is normally used for position changes and control functions. It doesn’t require lubrication and is inexpensive.



Ladder chain



Section 8

Fasteners

Most fabricated facilities today are held together with threaded fasteners. Threaded bolts and nuts are the most favored holding device since they are removable and can allow for easy maintenance and repair. Thread sizes differ based on application for size and strength. Bolts and nuts are rated for strength and can be produced with different drive types to fit individual needs. Wrenches and sockets are used to apply tightening force and automated power tools can be used to speed assembly or increase tension.



Nuts and bolts used for assembly processes

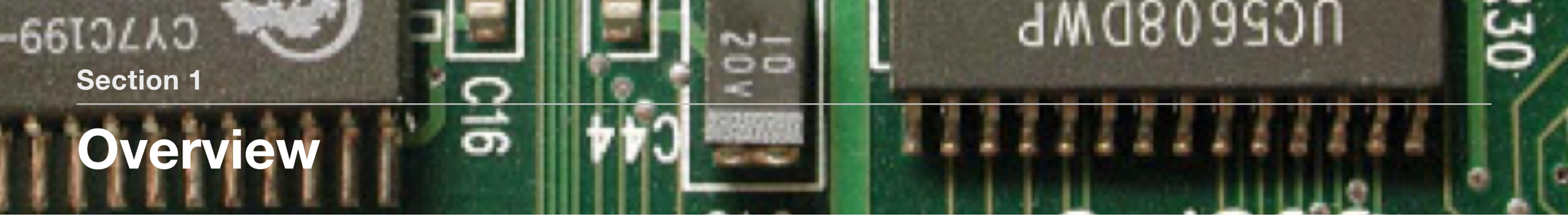
Anchoring

All equipment in a distribution center must be properly anchored to the floor or walls. This is done with anchor bolts and hammer drills that allow for future disassembly or repair. Permanent anchoring can be done during slab development but does away with the flexibility of anchor bolts.

Chapter 7

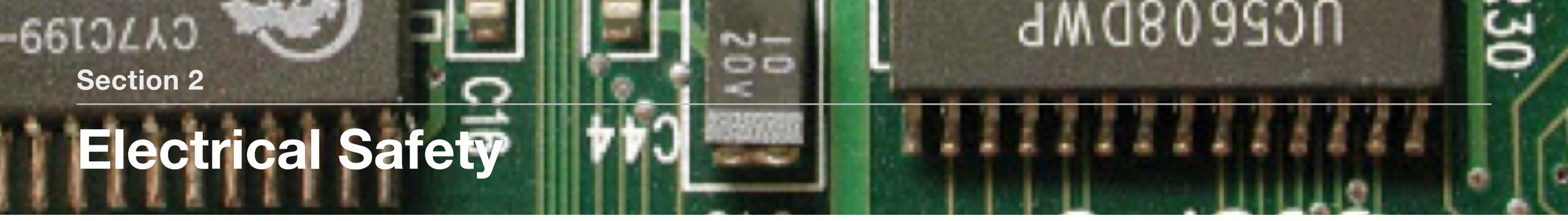
Electrical

Every supply chain technician will need to know basic electronics. This chapter will introduce you to electrical theory, safety and the tools we use to diagnose, troubleshoot and repair electrical problems.



Overview

Electricity is the movement of electrons from one atomic structure to another. The movement is accomplished by creating polarity changes in the atomic structure to force electrons to flow through a pathway made of conductive materials. The basic atomic structure is comprised of neutrons, protons and electrons. The neutrons and protons make up the core or nucleus with the protons being positively charged and the neutrons being neutral or having no charge. Electrons are free to orbit in shells around the nucleus and are negative in polarity and are held in position by opposing forces of centrifugal force and magnetic attraction. If the number of electrons and protons are the same in each atom the polarity is neutral and no movement of electrons is possible. If the number is different, the atomic structure can be of negative or positive polarity depending on which has the greater number. This is what forces electron movement or electrical energy and this movement of electrons is what does all work associated with electrical energy.



Section 2

Electrical Safety

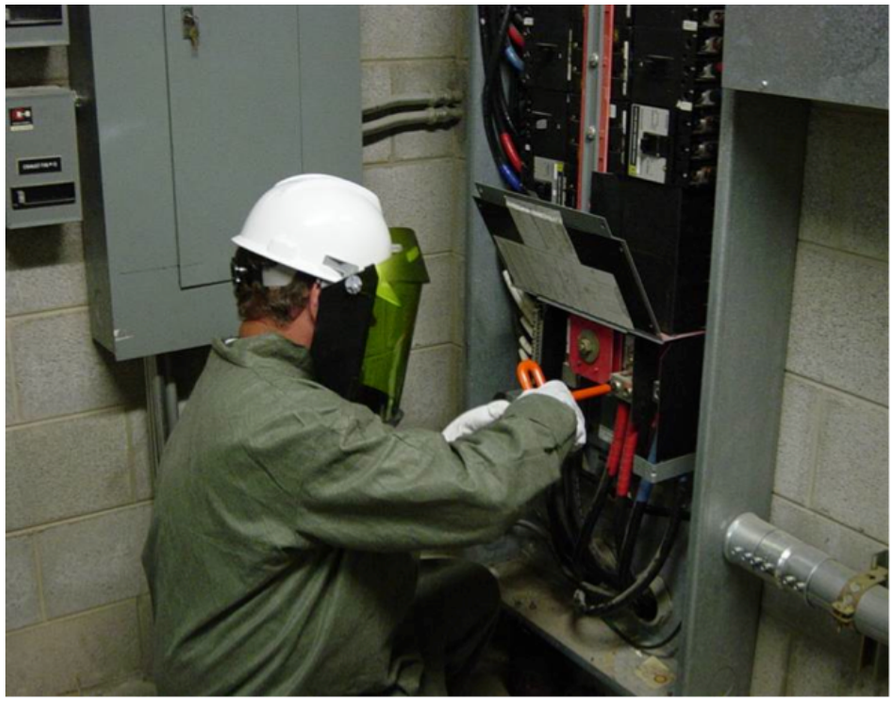
Safety Codes and Organizations

Safety codes are procedures to follow and implement when working on electrical applications to protect the technician from injury and death. Organizations developing and setting uniform safety practices include the National Electrical Code (NEC), National Fire Protection Agency (NFPA) and the Occupational Safety and Health Administration (OSHA). These organizations require strict guidelines to include lock out/tag out procedures on equipment for safety to the technician for all electrical installs, repairs or preventative maintenance.

Each company will have governing electrical procedures and safety codes, however all companies are governed by safety in all operations, including electrical, from the agencies listed above. In industry there have been unfortunate injuries and deaths to technicians who have circumvented the procedures in place to either complete the job quicker or believe that skipping some safety procedures is acceptable. All procedures for electrical safety are in place to be able to do the job safely and effectively and must be followed at all times.

Personal Protection Equipment

PPE or personnel protection equipment is required for working on electrical applications live, an energized circuit. The requirements are set by the NFPA as determined by the types and amount of voltages and currents. As the voltages increase the amount of protection must also increase.



Protective clothing worn during electrical testing on a live circuit

Meter Safety

Meter safety falls into two categories. First ensuring the meter is properly protected with internal fuses in case of an error for checking voltages with the correct meter setting. Second ensuring the meter has been calibrated annually and is operable for reading accurate voltages.

Most importantly for meter functionality, understanding what the settings are on the Digital Volt-Ohmmeter (DVOM) allows for a level of confidence in the readings. Knowing the processes and how to check the various measurements for Amps, Volts and Resistance will ensure effective troubleshooting with safe practices.

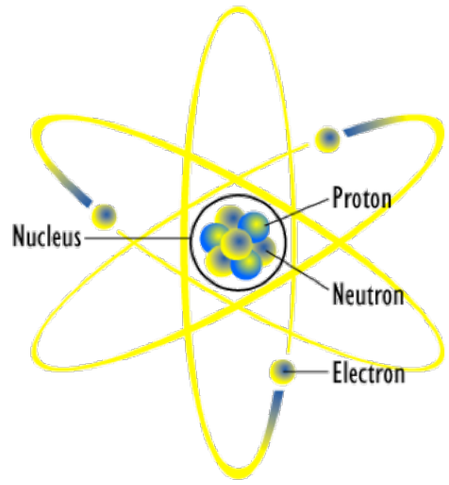
Overload Protection

The use of devices with fuses or circuit breakers provides protection that will open and deactivate the circuit if it is overloaded. This will protect devices or wiring within a circuit. Overload devices are important for protection during component errors such as a grounded hot wire, a malfunctioning component or overheating of a device. It is important never to bypass or use the incorrect rating of overload devices as this can lead to device damage and/or electrical fires.

Electrical Principles

Atomic Structure

The atom is a basic unit of matter that consists of a nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charged protons and electrically neutral neutrons (except in the case of hydrogen). The electrons of an atom are bound to the nucleus by both electromagnetic force and centrifugal force. Likewise, a group of atoms can remain bound to each other by chemical bonds based on the same force, forming a molecule. An atom containing an equal number of protons and electrons in each atom is electrically neutral; otherwise it is positively or negatively charged and is known as a positive or negative ion. A negative ion has more negative electrons than positive protons so it will attempt to give off the extra electrons to become neutral. A positive ion has more positive protons than negative electrons so it will attempt to attract electrons to become neutral. The movement of these electrons from one atomic structure to another is electricity that does work.



Atomic structure as the basis for electricity

Voltage, Amperage, Resistance

Voltage is the electrical difference between two points of a circuit, or the difference in electric potential energy between two points. Voltage is indicated in units of volts (V). Voltage is the force pushing electricity (electron movement) to do work. It can be compared to water pressure in a pipe. The pressure on the water creates the potential to do work but the flow of water actually does the work.

Amperage is the movement of electrons through a circuit expressed and measured in amperes (A). Amperes are the component that is based on the movement of electrons through a conductor. The movement of electrons is what does the work. This could be the lighting of a light or the turning of a motor. The greater the volume of current the more work can be done. Amperage or current can be compared to the gallons of water flowing through a water pipe which can be said as doing all the work.

Electrical resistance is the opposition to the movement of electrons in an electric current through a conductor. The opposite is electrical conductance, the ease at which an electric current passes electrons. The unit of electrical resistance is the ohm (Ω). Electrical resistance is the control for electron flow. It can be compared to a valve in a water system as a closed valve being high resistance (no flow) and an open valve being no resistance (high flow).

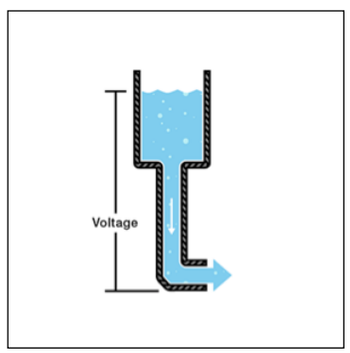
Understanding the relationship of Volts, Amperage and Resistance in an electrical circuit is vital to understanding circuit applications and to effective troubleshooting. Once the relationships and roles of these parts of an electrical circuit are understood, the technician goes beyond guessing at the fix, but systematically isolating and identifying issues within electrical malfunctions.

Movie 7.1 What is Electricity



Tap to view the video.

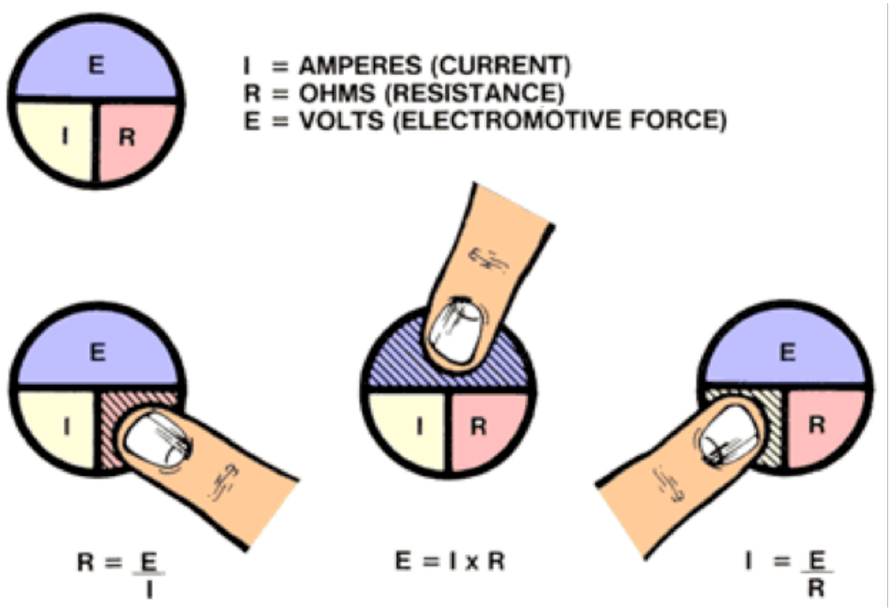
Interactive 7.1 Water flow demonstrating electrical properties



Tap image to view images of water flow demonstrating electrical properties.

Ohm’s Law

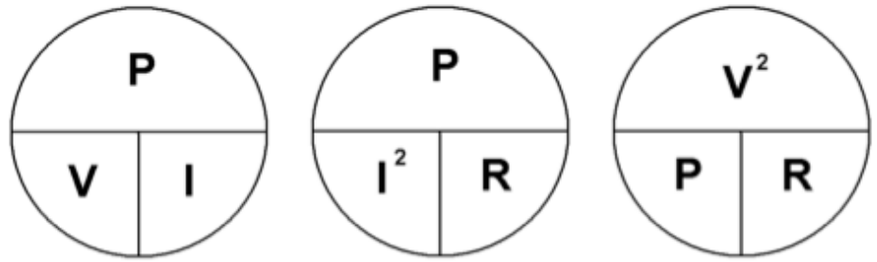
Ohm's law states that it requires 1 volt to push 1 ampere through 1 ohm of resistance. This is accomplished by the current through a conductor between two points being directly proportional to the potential difference across the two points. The mathematical formulas give order and understanding to the concepts of electricity. The most common method of applying the formula is called the ohms law pie where the unknown item is covered and it represents the formula for finding the unknown value.



Determining the unknown values by formulas for Ohm's Law

Power (wattage)

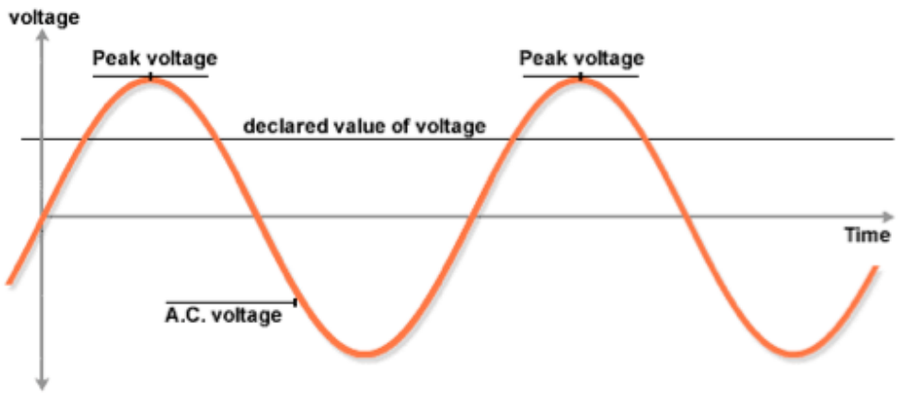
Power is the rate at which energy is transferred, used, or transformed. The unit of power is known as the watt (in honor of James Watt, the eighteenth-century developer of the steam engine). For example, the rate at which a light bulb transforms electrical energy into heat and light is measured in watts—the more wattage, the more power, or equivalently, the more electrical energy is used per unit time. The formulas for wattage are established by using the pie the same as the ohm’s law pie.



Power equation pie used to determine the amount of work that is being done and to help design a circuit so overloading doesn’t occur

AC/DC

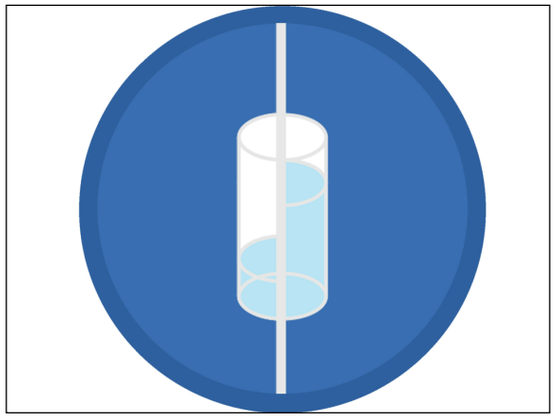
AC stands for “Alternating Current,” meaning voltage or current that changes polarity or direction over a given time. AC is the most common form of electrical energy used in industry because it is efficient to produce and transmit by suppliers over long distances. AC current is produced at a generating station and is then distributed to the automated warehouse. AC current can be used as single phase or three phase applications. Single phase at 120 or 220 volts is normally used on application below 5 horsepower and three phase 440 volts and above for larger energy applications.



Oscilloscope waveforms showing single phase AC

DC stands for “Direct Current,” meaning voltage or current that maintains constant polarity or direction. DC voltage is used to power sensors, lights and communication networks at a low voltage of normally 24 volts. In the automated warehouse, all DC is rectified or produced by changing existing AC to DC through the use of a rectifier. DC voltage is also used extensively in low voltage control circuits and to power LED indicator lights.

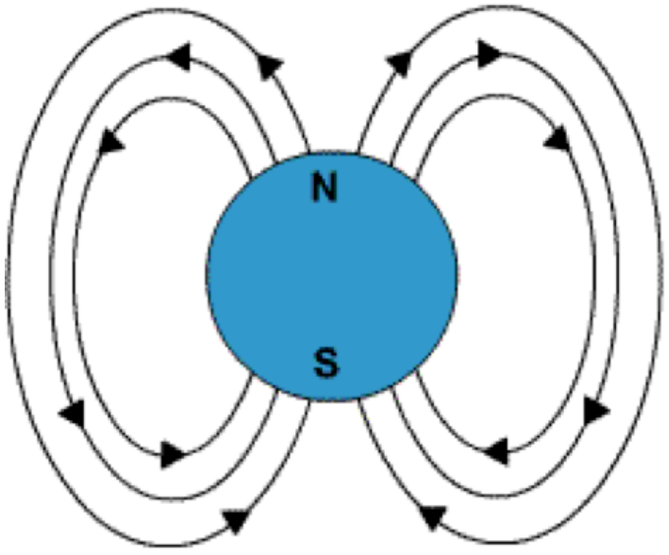
Interactive 7.2 Comparison of DC and AC oscilloscope waveforms.



Tap then slide bar to compare DC and AC oscilloscope waveforms .

Magnetism

A magnetic field consists of imaginary lines of flux coming from moving or spinning electrically charged particles. Examples include the spin of a proton and the motion of electrons through a wire in an electric circuit. What a magnetic field actually consists of is somewhat of a mystery, but we do know it is a special property of space. Magnetism is the property that propels motors, moves relays or any number of mechanical movements. Magnetic lines of flux move from north to south and “like” polarities will repel and “dislike” will attract. Most controllably, magnetism is produced by electricity since current flow will produce magnetism. Electricity is also produced by magnetism so the two interact to provide electricity and magnetism to do work. Some materials are permanently magnetic with constant polarity, some are magnetized by electrical current around them and some materials cannot be magnetized.



Magnetic field or lines of flux of a moving charged particle

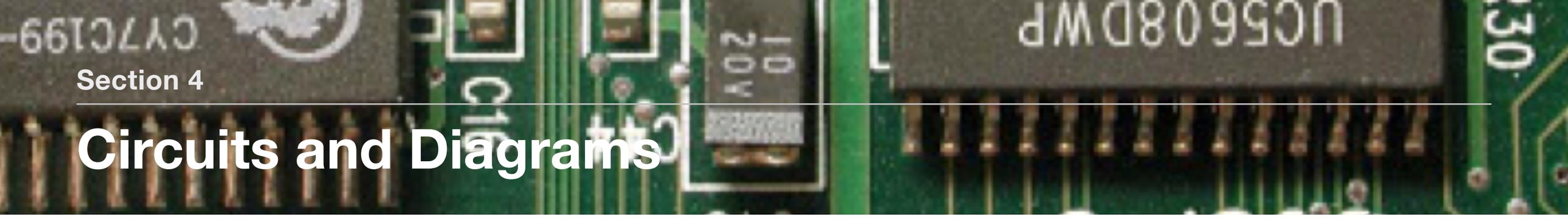


Electric motor powering a hydraulic pump

Motors

Electric motors are devices that convert electricity into magnetism and produce mechanical energy or motion. An electric motor is a type of prime mover for a mechanical system.

Typically when motors are thought of in an automated warehouse environment, a gear set, chain and sprocket or a belt are included as driven devices. This is true of most motor applications, which are the core of many industrial control applications. Motors are also classified by the input power being AC or DC and can be rated by horsepower or wattage.



Circuits and Diagrams

Series, Parallel, Combination

Components of an electrical circuit or electronic circuit can be connected in many different ways. The two simplest of these are called series and parallel circuits. Components connected in series are connected along a single path, so the same current flows through all of the components. Components connected in parallel are connected so the same voltage is applied to each component. Parallel circuits are the most common type of circuit used in a distribution center. A circuit composed solely of components connected in series is known as a series circuit; likewise, one connected completely in parallel is known as a parallel circuit.

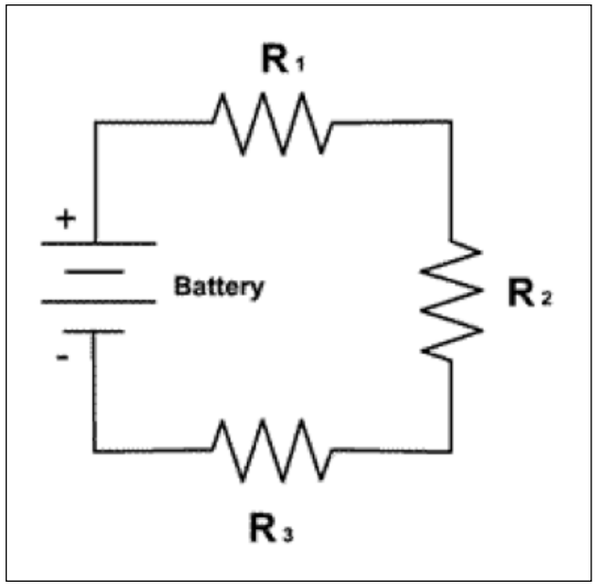
In a series circuit, the current through each of the components is the same, and the voltage across the circuit is the sum of the voltage drops (voltage used) across each component. In a parallel circuit, the voltage across each of the components is the same and the total current is the sum of the currents through each component. Some circuits are a combination of both and will have the characteristics of both.

Understanding series, parallel or combination circuits are the basics for circuit design. Some components of a designed circuit will need varying voltages with the same amperage while other parts of the circuit will need consistent voltages with varying amperages for the electronic components. The components may be diodes, capacitors, resistors, memory chips, motors, actuators, etc. A circuit with

these requirements would be designed as a series parallel circuit (combination).

For the technician, understanding the function, (voltages and amperages) of series–parallel circuits will give precise information when evaluating or troubleshooting a systems function by helping the technician know what to look for and why. These are skills needed to troubleshoot failures. The laws of circuits create a means for applying known values to find unknown values to troubleshoot a system. The basic laws are listed below.

Interactive 7.3 Series, Parallel, and Combination Circuits



Tap to view diagrams of series, parallel, and combination circuits.

Series Laws

1. Total resistance of the circuit is the sum of the individual resistances
2. Current is the same at any point of the circuit
3. Voltage drops must add to the total voltage

Parallel Laws

1. Total resistance must be less than the value of the smallest resistor
2. Voltage is the same on each branch of the circuit
3. Total current is the sum of the individual branch currents

Movie 7.2 Voltage, Current, and Resistance



Tap to view the video.

Circuit Faults

Faults within a circuit will result in a specific error or operational failure. In digital circuitry this could be a signal or command error. Circuit faults can be simple or complex depending on the application and function. For example, the light doesn't work when the switch is turned on. Could it be a bad bulb or incomplete circuit where current, pushed by voltage, for some reason is not making it to the light or completing the circuit? The reasons for circuit faults could be as simple as a loose wire or connection to a room light, or a capacitor gone bad on a circuit board that is not providing direction for a PLC to control the light operation. More complicated circuit faults can be connected to digital electronics where operations and functions of the circuits are moved by correct digital signals to input or output correct voltages for circuit operations. The idea for the technician is to understand the basics of circuit faults in order to isolate the problem and make a quick repair. The circuit board design does not need to be mastered, just understanding the flow of electricity in and out for circuit operation.

Opens

An open circuit is an incomplete pathway within the circuit. It can be an open protection device (fuse or breaker), broken wire, open switching device, separated terminal or any number of other faults. An open in a series circuit will affect the entire circuit but in a parallel circuit it will only affect the faulted pathway. Testing for opens is done with a meter by doing voltage drop tests or measuring for available voltage on an active circuit or resistance testing on a denergized and disconnected circuit. Open faults never affect the protection devices since no current is available.

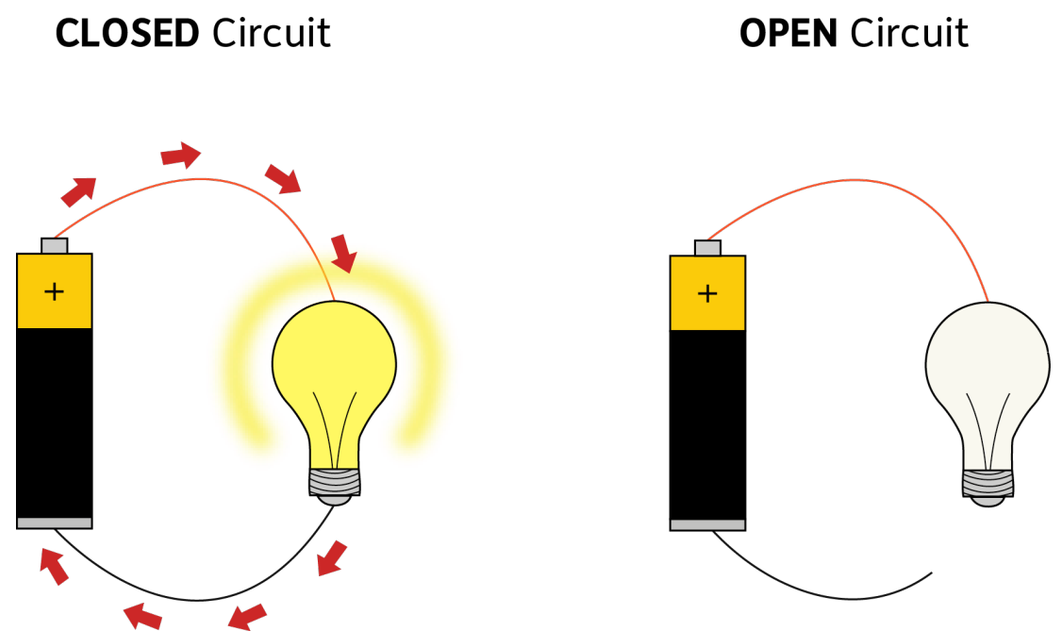


Diagram showing a closed or open circuit

Shorts

Shorts to Voltage

A short to voltage fault occurs when wires from one circuit are connected to power from another circuit. This failure will involve the power or supply side of the circuit. The circuit in question may be controlled by another circuit and in some cases can't be denergized easily. It may open the protection device depending on its position within the circuit and whether current is increased

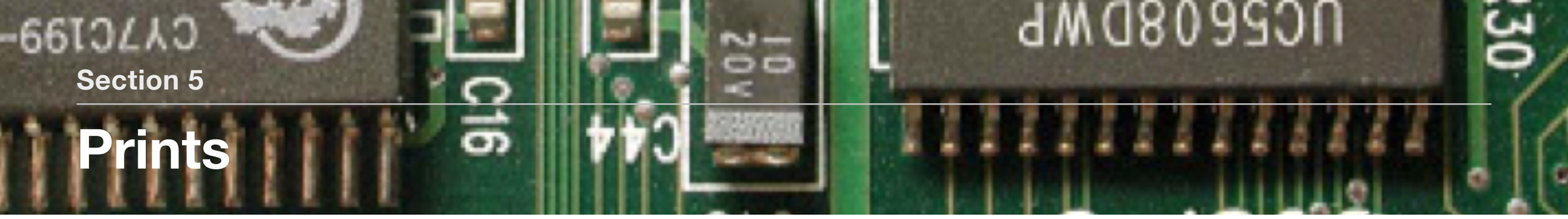
to a level of overload. Testing for this condition will normally require a meter and isolation of the wiring.

Shorts to Ground

A short to ground fault is when the current flow bypasses a load and goes directly to ground prior to the component. This fault will usually result in an open occurring at the protection device (fuse or breaker). This condition exists when a powered wire touches a ground or a component has an internal pathway to ground eliminating resistance. Testing can be done with a meter by doing voltage drops, voltage availability or a resistance check between the wiring and ground.

High Resistance

High resistance in a circuit is when the wiring or components are partially faulted, allowing less current to flow so less work is done. Examples of this fault could be dim lights, slower than normal motors, clicking of relays or solenoids or no operation of the circuit due to a lack of current. Corroded wiring and connections, undersized wiring during construction, loose connections or sockets are all examples of possible high resistance causes. High resistance can be tested with a meter to determine voltage drop across the fault or an ohmmeter in a circuit that is inactive.



Prints

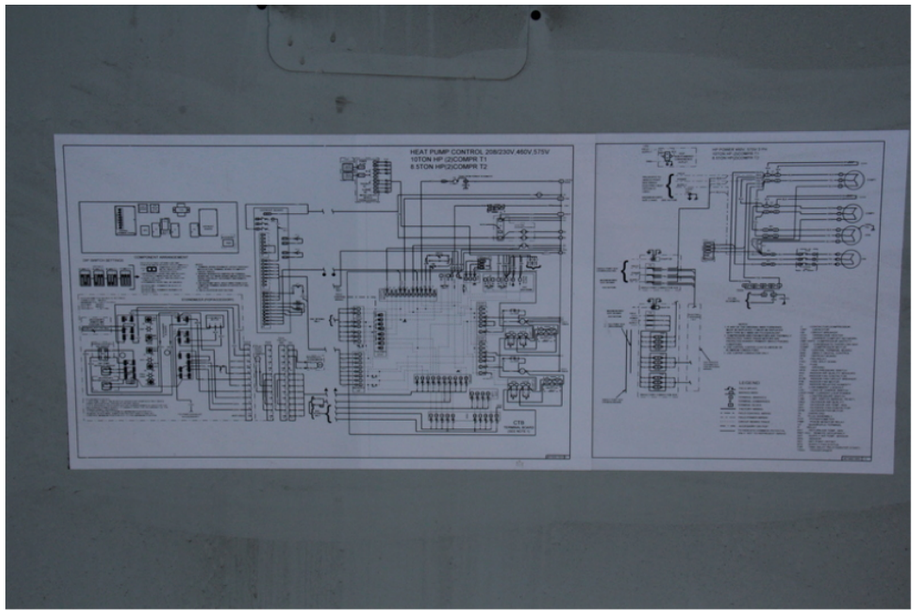
Diagrams

Diagrams are plans, sketches, drawings, or outlines designed to demonstrate or explain how something works or to clarify the relationship between the parts of an electrical system. Diagrams are maps for the installer or technician to use to see how components work together to function properly. Understanding diagrams can aid the technician in determining correct operation as well as noticing incorrect operations. Diagrams can offer physical locations for components to include wiring, safety interlocks, power and control inputs/outputs, internal connections and all extensions and associated devices connected to the equipment.

Schematics

Schematics show the main parts of an electrical circuit usually in the form of a simple drawing or diagram. Schematics are drawings on paper or through an electronic medium of a physical object. Electrical schematics show all the components, electrically, for a piece of equipment, to include all the connections for the power and control inputs for a device. This includes the start and stop switches, power transformers, fuse ratings of a circuit, wire connection points at the terminal boards, all digital interfaces for the equipment, etc. The benefit to a technician learning to read and interpret schematics is it gives the technician greater ability to understand the operation of devices. By understanding schematics, simply learning the flow of electricity through their equipment, the

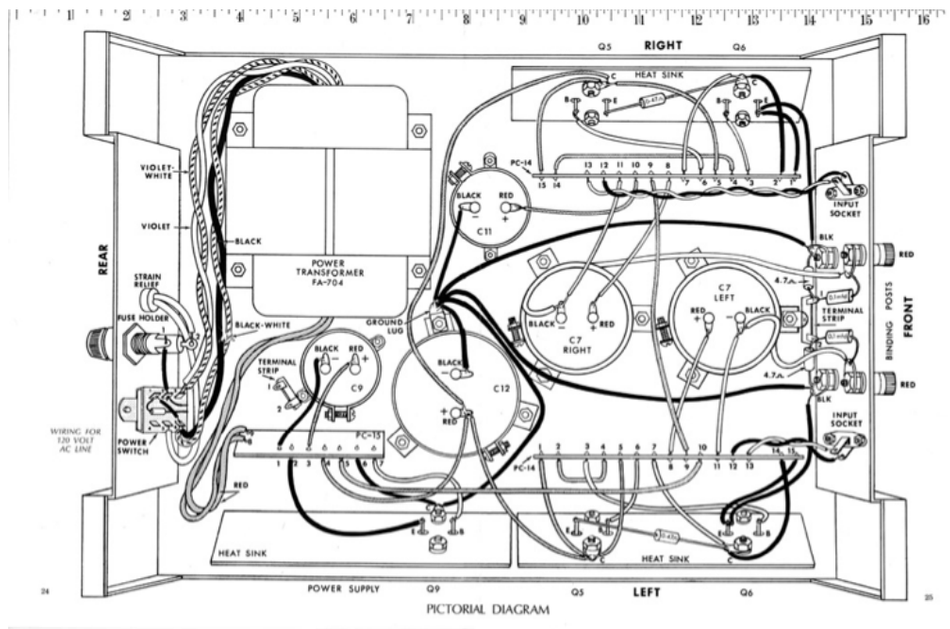
technician will be an effective troubleshooter. Reading schematics will be used with a meter (DVOM) giving measurement information to compare with the schematic data.



Electrical schematic for understanding of a system

Pictorial

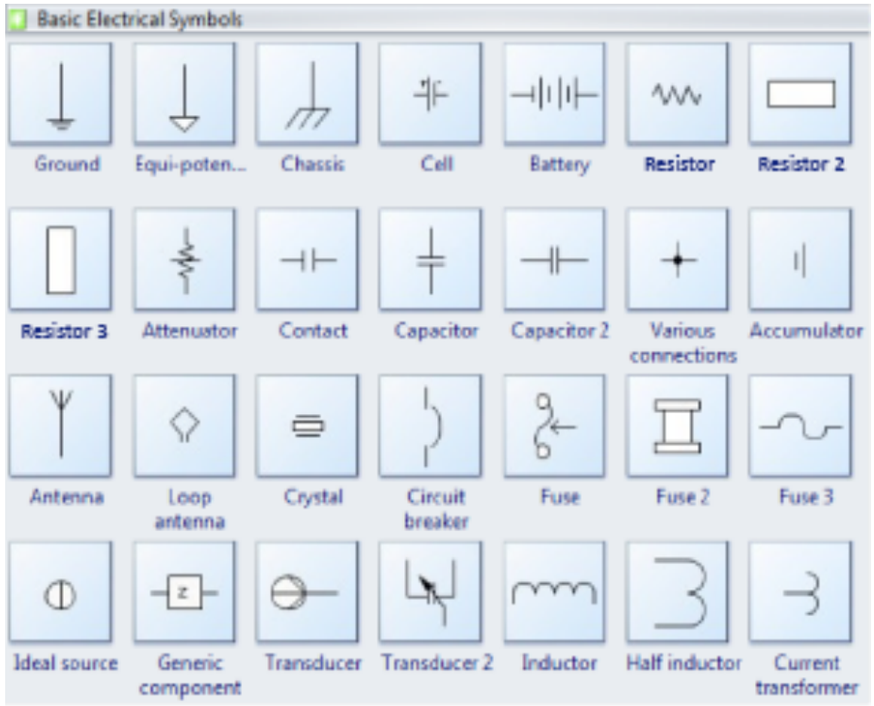
Pictorials are used for organizing the components of a system or component by using pictures. Pictorial diagrams can be useful in showing the location of a component, exactly what the component looks like and how it may be connected. Pictorials are not as accurate as wiring diagrams but are most important for identifying each component in a system and allowing a technician to find and isolate the component to allow repair.



Electrical pictorial used for identifying components and functions

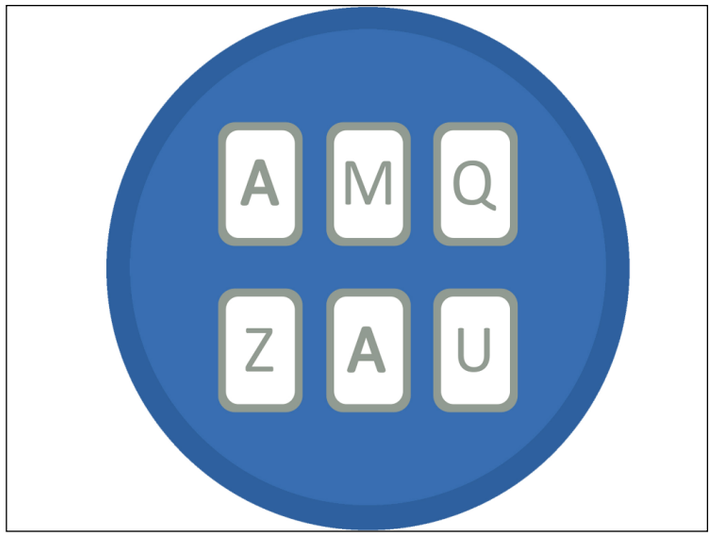
Symbols

Symbols are used to clarify or simplify a schematic or chart. In the world of electrical schematics, symbols are important to understand and interpret so the technician can understand quickly what the symbol or abbreviation stands for. All prints have a legend, which is a summary and description of the symbols, somewhere on the face of the drawing or as an attachment. The purpose of symbols is to use small objects to illustrate meanings or purposes of devices in a drawing. Writing the meaning of a symbol in the schematic may take up too much room and can vary from device to device and cause congestion within the prints.



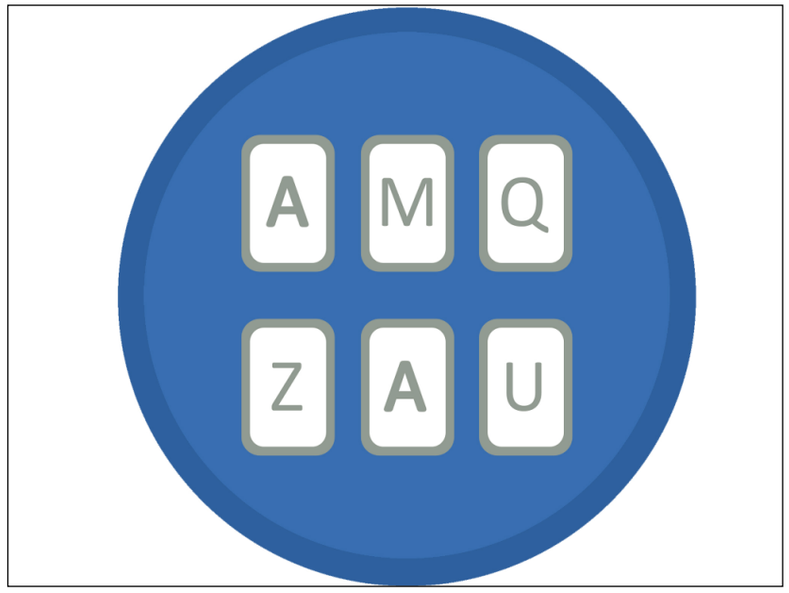
Symbols list used to identify parts on a schematic.

Review 7.1 Basic Electrical Symbols 1



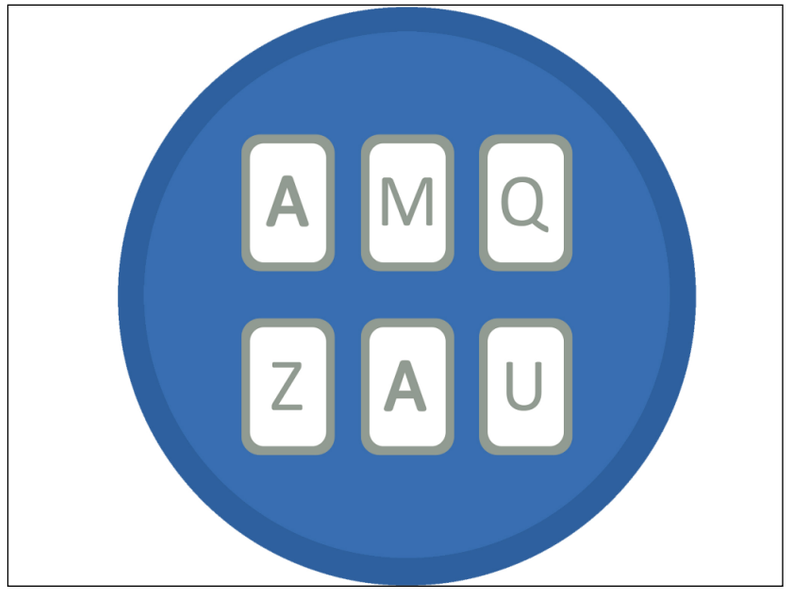
Tap image to begin pair matching activity. Tap symbol name and then the matching electrical symbol image.

Review 7.2 Basic Electrical Symbols 2



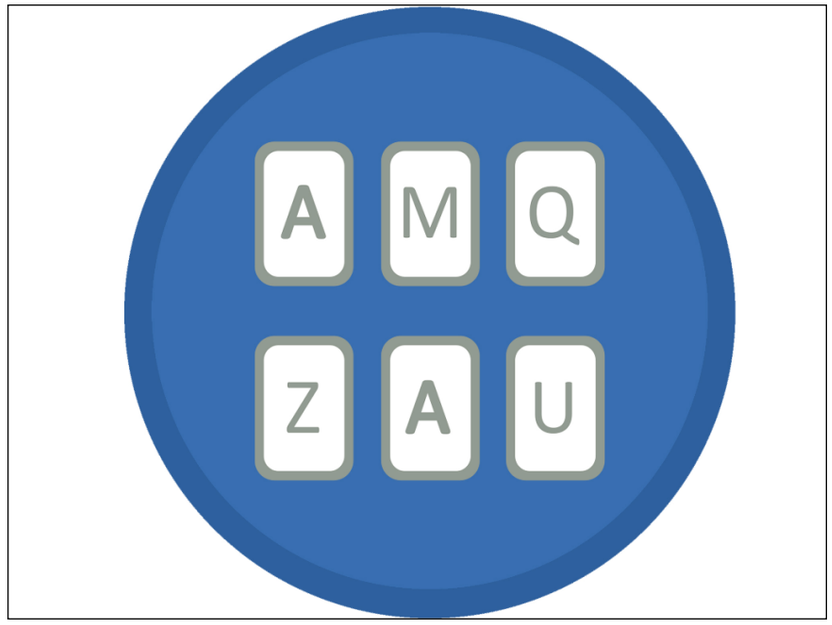
Tap image to begin pair matching activity. Tap symbol name and then the matching electrical symbol image.

Review 7.3 Basic Electrical Symbols 3

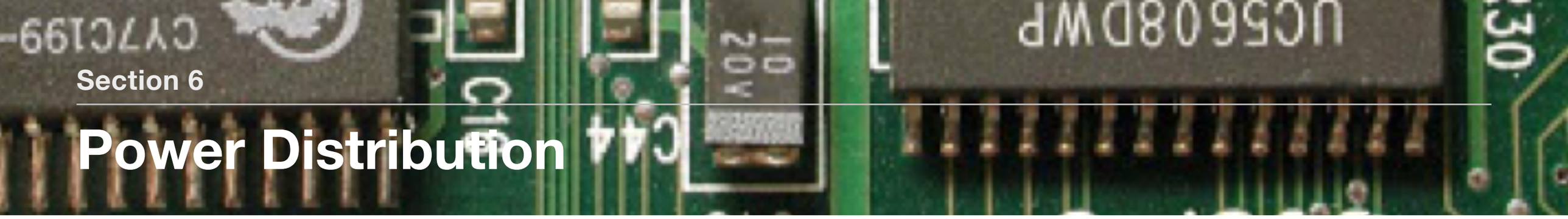


Tap image to begin pair matching activity. Tap symbol name and then the matching electrical symbol image.

Review 7.4 Basic Electrical Symbols 4



Tap image to begin pair matching activity. Tap symbol name and then the matching electrical symbol image.



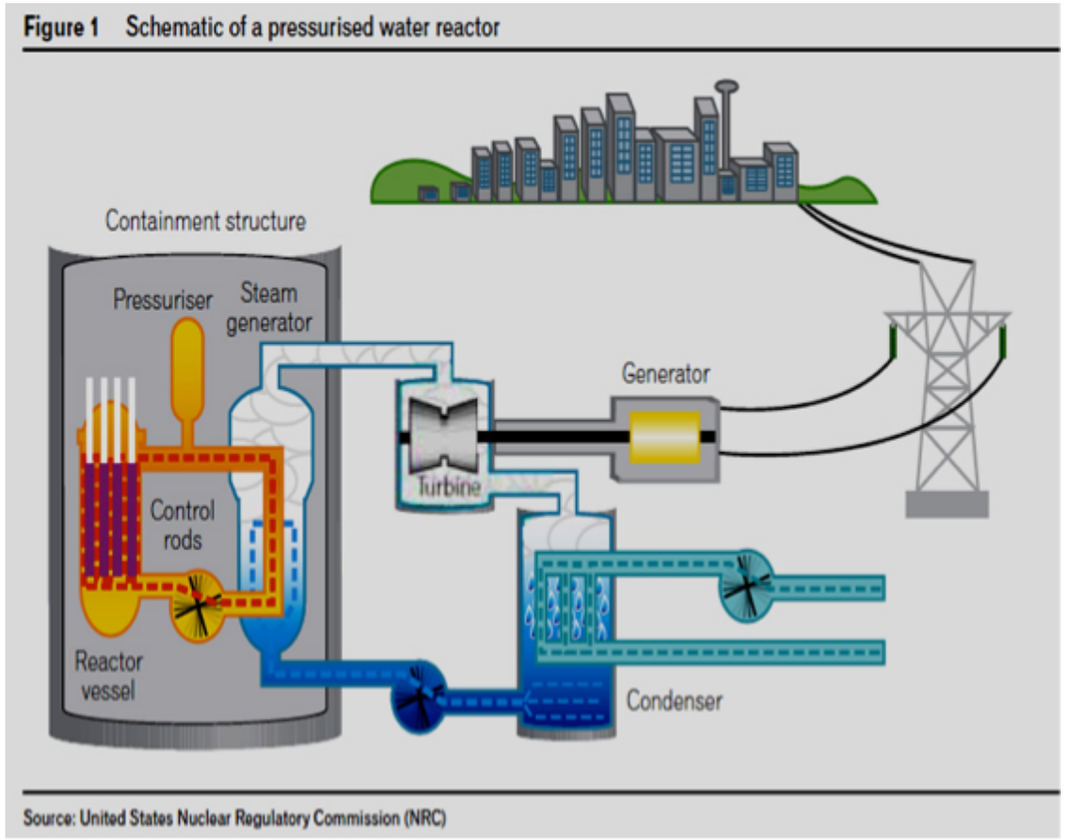
Section 6

Power Distribution

Power Generation

The production of electric power for industrial and residential use is described as power generation. Electric power generation generally comes from large-scale production of electric power at stationary plants designed for that purpose. The generating units in these plants convert energy from water flow (dams), coal, natural gas, oil, and nuclear fuels (heat production) to electric energy. Most electric generators are driven either by hydraulic turbines for conversion of water energy, or by steam or gas turbines for conversion of fossil fuel. Geothermal, wind and solar energy development is progressing in its various forms but these methods produce a small percentage of the total electrical energy that is produced and used.

Generating power is the key to providing electricity to everything in our lives. Power generation on a local level is regulated and provided by the utility companies and produced and distributed by them. It is important to understand the electrical energy that is supplying the distribution center to ensure proper safeguards are used during preventative maintenance, operations and troubleshooting. Different protections are required for different supply voltages. The technician must confirm that any equipment worked on is safe and the processes are understood, checked and verified.



Electricity generation by nuclear energy

Single and Three-Phase

Single-phase

A single-phase circuit is an alternating-current using only one sine wave current flow, a circuit that consists of three wires – live, neutral, and ground (earth). The main protection device in a single phase system is a single pole breaker, resembling the others in the panel and is rated at the required capacity.

Three-phase

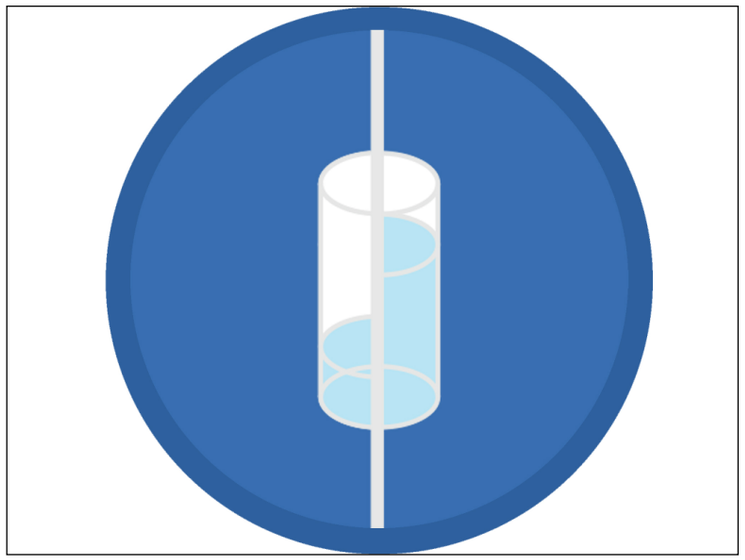
A three-phase circuit consists of three different sine wave current flows, different in phase by 120 degrees from each other. Three-phase is used for commercial applications and for demands for higher power. The main protection device is a double breaker at the rated capacity.

Single-phase and three-phase power are designed for different uses and purposes. Single-phase operates on one live conductor of electricity, 120 or 240 volts, within a 60-hertz cycle. Most residences operate on 120 volts for most appliances and power. Main panels built at residences have two 120 vac phases coming in to the home making the availability of single phase 240 vac for higher power applications such as swimming pool motor pumps or air conditioning compressors. The 240 vac power is derived from two 120-volt phases coming into the house. Single-phase systems are convenient for home residences.

Three-phase systems use three live conductors to operate equipment and machinery. Most three-phase systems in distribution centers operate on 480 volts. Three live conductors are used to power system motors for conveyors, transformers and other power distribution requirements. There are varying differences between three-phase power applications to single-phase power applications with advantages for either power structure.

For the technician, understanding the differences and functions for three-phase and single-phase power systems will increase their ability when troubleshooting and evaluating the overall operation of the equipment.

Interactive 7.4 Comparison of Single-Phase and Three-Phase Wave Forms



Tap then slide bar to compare diagrams of single-phase and three-phase wave forms.

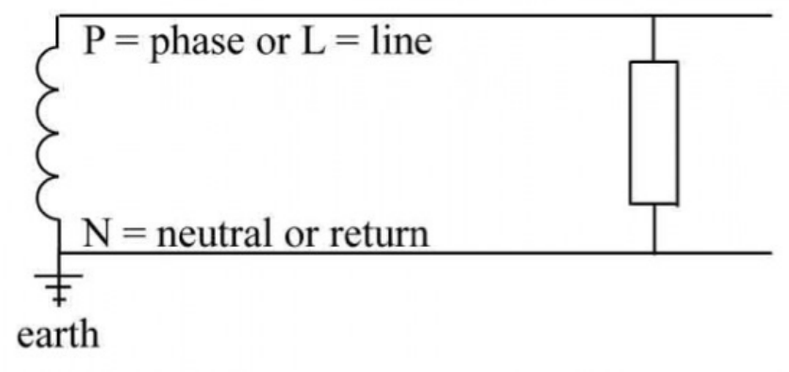
Movie 7.3 Three-Phase Electricity Video



Tap to view the video.

Ground Circuits

The ground of a circuit is the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the Earth. Ground circuits protect the equipment and operators of the equipment if there is a malfunction or electricity has no return path to a completed circuit. The ground circuit is connected to the exterior of the equipment, all sub panels and main panels, so in the event there is a pathway to the ground circuit, the voltage will follow the ground wire back to the main power panel dissipating the voltage through a pole drilled eight feet into the ground. It is important for the technician to ensure all equipment, panels, any power supply or devices providing or receiving power are grounded correctly for the safety of the operator and equipment.



Ground circuit diagram

Wiring

Wire is a slender flexible strand of metal, normally made of copper, usually insulated, and used to carry electricity throughout a system. Wires are the core of everything for the electrical world. Certainly there are wireless cell phones, remotes, car alarms and the list goes on, but these devices transmit signals, not voltage and can do little work. Wires are rated by the amperage they can carry. The greater the amperage and the longer the wire, the larger the wire needs to be. A wire that is a 6 gauge can carry more amps than a wire that is rated at an 18 gauge. This is because the 6 gauge wire is bigger with more copper than the 18 gauge wire. The technician does not need to memorize wire ratings, but needs to know where to verify and check if wire replacement is needed or an added load is being configured into an existing circuit.

Length (feet)	Current (amps)									
	5	10	15	20	25	30	40	50	60	70
15	16	12	10	10	8	8	6	6	4	4
20	14	12	10	8	8	6	6	4	4	4
25	14	10	8	8	6	6	4	4	2	2
30	12	10	8	6	6	4	4	2	2	2
40	12	8	6	6	4	4	2	2	1	1/0
50	10	8	6	4	4	2	2	1	1/0	1/0
60	10	6	6	4	2	2	1	1/0	2/0	2/0
70	10	6	4	2	2	2	1/0	2/0	2/0	3/0
80	8	6	4	2	2	1	1/0	2/0	3/0	3/0
90	8	4	4	2	1	1/0	2/0	3/0	3/0	4/0

American Wire Gauge (AWG)

Wire size application chart

Test Equipment



Typical DVOMs (Fluke)

Digital Volt Ohmmeter (DVOM)

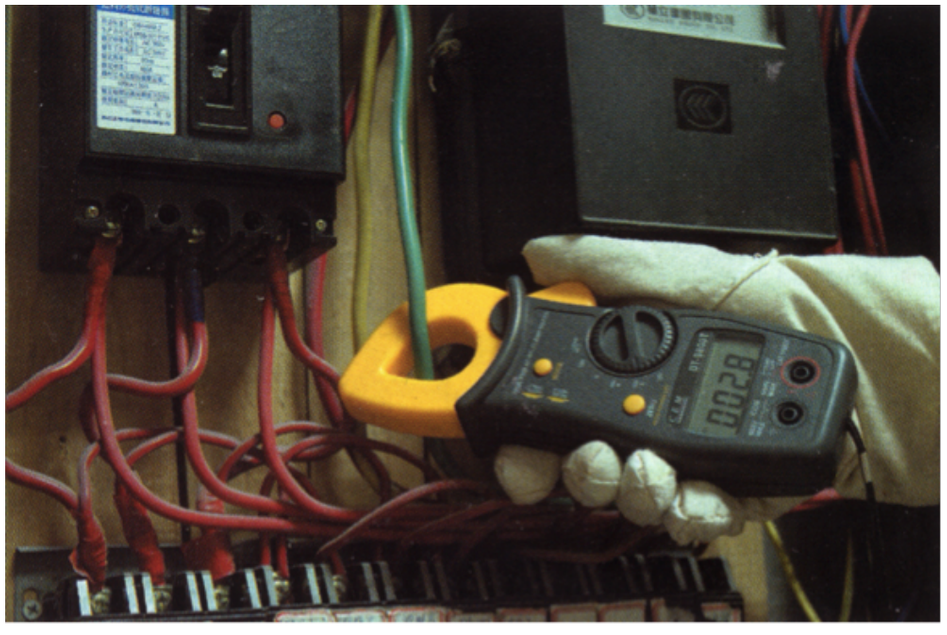
A multimeter, also known as a VOM (Volt-Ohmmeter) or DVOM, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter would include basic features such as the ability to measure voltage, current, and resistance. Digital multimeters (DMM, DVOM) display the measured value in numerals, and may also display a bar of a length proportional to the quantity being measured. A multimeter is a hand-held device useful for basic fault finding and field service work. They can be used to troubleshoot electrical problems in a wide array of industrial applications such as electronic equipment, motor controls, appliances, power supplies, and wiring systems.

DVOMs are an electrical technician's most used device. When troubleshooting a circuit a DVOM provides all data needed to isolate the problem and to make repairs. The accuracy and the testing functions that the DVOM provides, allows a technician to quickly isolate and repair a problem.

Current Probe

In electrical troubleshooting or monitoring, a current clamp or current probe is an electrical device having two jaws which open to allow clamping around an electrical conductor (wire). The probe measures magnetic energy as created by current flow through the conductor. This allows current in the conductor to be

measured without having to make physical contact with it or to disconnect it from the circuit. It also allows for measuring high currents with little or no safety concerns. When devices fail or are on the verge of failure, typically over or under normal current draws will be occurring. The ability to check the amperes in a circuit can prevent more damage to a device in a faulted state. Before the ammeter or current probe, circuits could still be tested for amperage with a DVOM being connected in series with a live circuit but only for low amperage circuits. Because the limits and danger of this test, DVOM in series, the amperage probe is much more versatile and safer as the probe simply clamps around the individual wires of the circuit without breaking the circuit. Learning this test is invaluable for the technician.



Using a current probe to test current draw

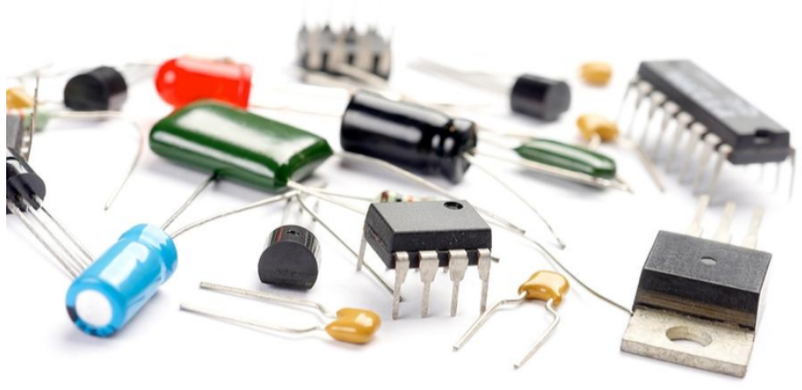
Testing Procedures

The testing procedures for electronics are many but the basics are checking for power, opens and shorts as related to the device as a system and at the component level. Checking for power is done by using a DVOM on the AC scale to test for normal operating voltages.



Testing for voltage

Solid State Semiconductor Devices



Different types of semiconductors

Principles

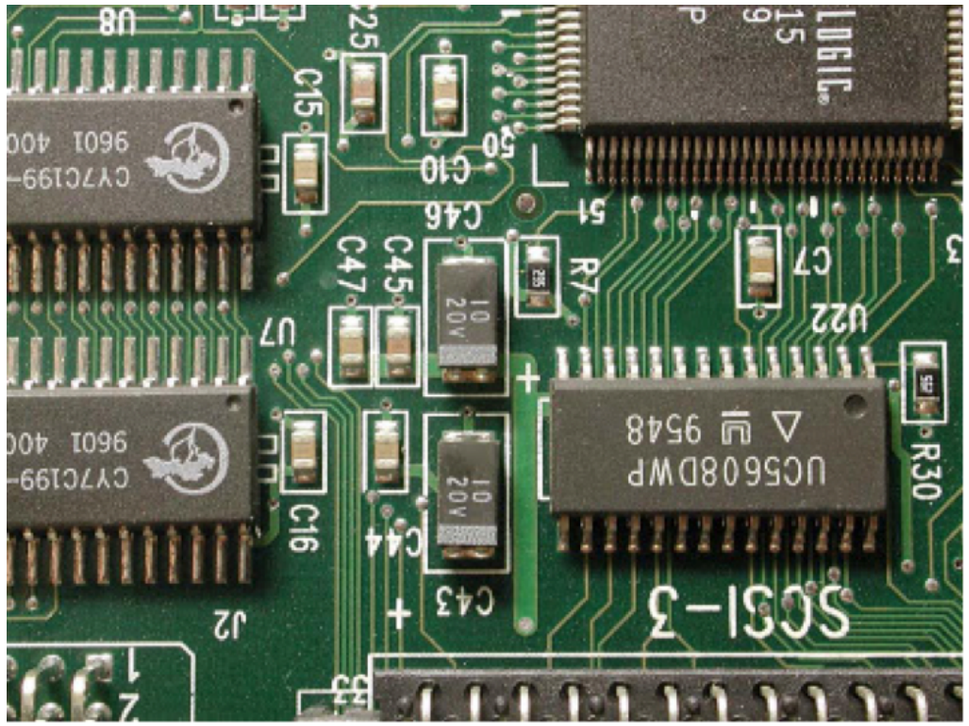
Semiconductors play a vital role in nearly every field of modern electronics, and they enable the production of everything from radios to computers and microprocessors. One of the most important applications for semiconductor materials involves their use in the creation of transistors, which are solid-state electron devices that form the basis for a vast range of electronic systems and equipment, particularly integrated circuits. The majority of semiconductor and transistor components are composed of silicon, which is highly useful for its distinct electron structure. By changing the electron arrangement in silicon or similar elements through the introduction of additional particles, it is possible to adjust the conductivity and resistivity levels of a material formed from these elements to create a semiconductor.

Semiconductors are the components of all electronics today. The ability to harness and manipulate voltages to precise specifications allows the creation of extreme electronic devices from microcomputers to varying robotics. For the technician, understanding the basic principles of semiconductor devices will aid in troubleshooting efforts to isolate failures in electronic boards or components. Some of these components include transistors, diodes, resistors, chips, and capacitors. Component or board level replacement, not individual semiconductor

replacement, is the most common for the service technician but the isolation of the component or board requires an understanding of the operation.

Printed Circuit Boards

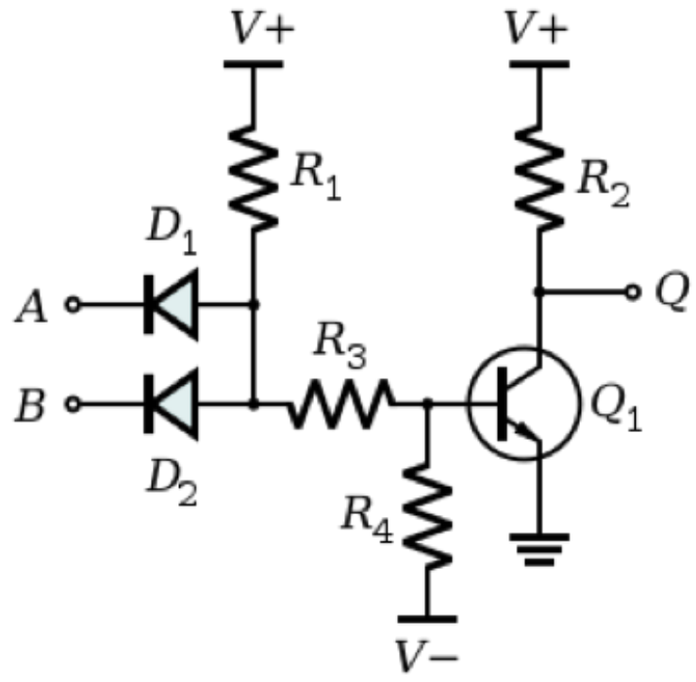
A printed circuit board is a flat plastic or fiberglass board on which interconnected circuits and components are laminated or etched. Chips and other electronic components are mounted on the circuits. Computers consist of one or more printed circuit boards, usually called cards or adapters. Printed circuit boards are typically attached to other boards providing some type of control or additional function to the device or unit. The printed circuit boards are interfaced with master boards to allow various functions for a device. For example, a computer may have an accelerated graphics board attached to the master motherboard giving more versatility of better graphics to the display monitor. Other boards could be for wireless Ethernet control and memory. For the most part technicians will troubleshoot to a bad board on a device. Troubleshooting to individual semiconductor level will typically happen at the manufacturer of the board. The goal is to isolate the board that has failed and replace that board so productivity in the distribution center is not compromised.



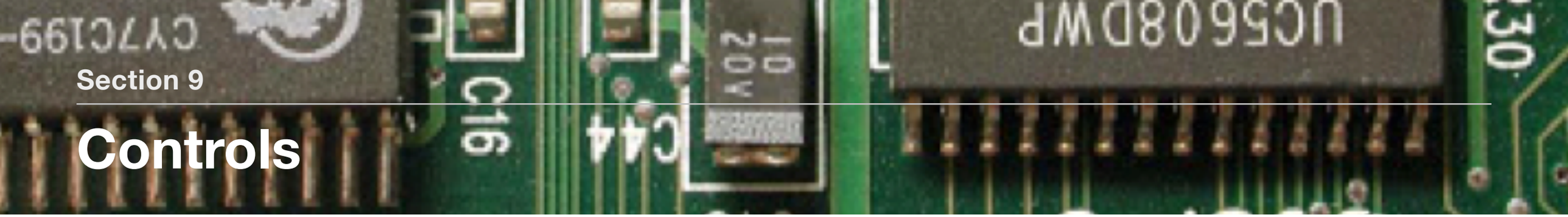
Integrated circuit board

Diode, Transistor

The diode is a two wire semiconductor that allows current to flow in one direction and block current flow in the other direction. The transistor is a three-wire semiconductor that allows voltage to flow through an electronic circuit when a signal has been received at the base. Most of this information is detailed at the engineering level, but the importance for the technician is to understand electronic fundamentals for troubleshooting. The idea is that no matter how technical a device gets with the electronics, there is always an output and an input, and if the technician can understand and isolate the basic principles of electronics, any device can be troubleshot.



Diode and transistor circuit



Controls

Electrical controls command, direct, limit or regulate an electrical function which normally controls a machine. For electrical and electronic applications, control can be separated into two parts. Control by the user, including but not limited to start and stop functions, emergency stops and fault conditions of the equipment. The second control for machinery is control regulated by the design and process of either the application or the programing functions which is normally a Programmable Logic Controller (PLC). All electrical equipment operating at high voltages typically have voltages separated into two categories. Power volts and control volts.

Power Volts – Power volts is power actually used for the machinery or equipment to operate as designed. For example 480 vac are typical power volts for machinery of conveyor motors in automated supply chain distribution centers.

Control Volts – Control volts is power that regulates, manipulates or as programmed, delivers a smaller voltage to a unit or device, such as a Solid State Relay (SSR), motor contactor, and PLC board to open or close the passage for the power volts to operate the corresponding machinery as designed. Control volts are typical 120 vac or less to include DC voltage.

Testing

Electrical testing is a procedure for determining the root cause of a failure. The proper application of knowledge, judgment, and application of information and proper use of supporting test equipment are all parts of testing. Testing in relation to electrical processes is the ability to look at the system by electrical theory and function to determine proper operations through correct or incorrect measurements. These measurements can be conducted by a DVOM to find readings for Volts, Ohms, Amps, and continuity.



Electrical testing of low voltage control circuits

Preventive Maintenance

Preventive Maintenance is the care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition. This is done by providing for systematic inspection, detection, and correction of failures either before they occur or before they develop into major defects. Preventative maintenance is the process of inspecting and calibrating or cleaning equipment for normal operations and correcting impending failures during scheduled downtime to prevent failure or downtime of equipment during production operations. As with all imperfections, preventative maintenance will not prevent all breakdowns, but implementing this process has proven to improve production through longevity of equipment operation for optimal and consistent use.



Performing preventive maintenance

Motors

Motors are devices that are electrically powered to provide movement in a circular or linear motion to perform work. Motors are fundamentally involved in every aspect of automation. This includes operations for scanners, conveyors, forklifts and belt drives. Motors can be used in various types of drives. These include direct drives, connected directly to the equipment needing the energy; indirect drives, connected to a gear box or by chain that is attached to the equipment needing energy; and linear drives and linear induction drives, motors moved by magnetism requiring no moving parts, but driving the equipment needing the energy.



Electric motor attached to a gear box used to drive a chains or belt

Electrical Controls

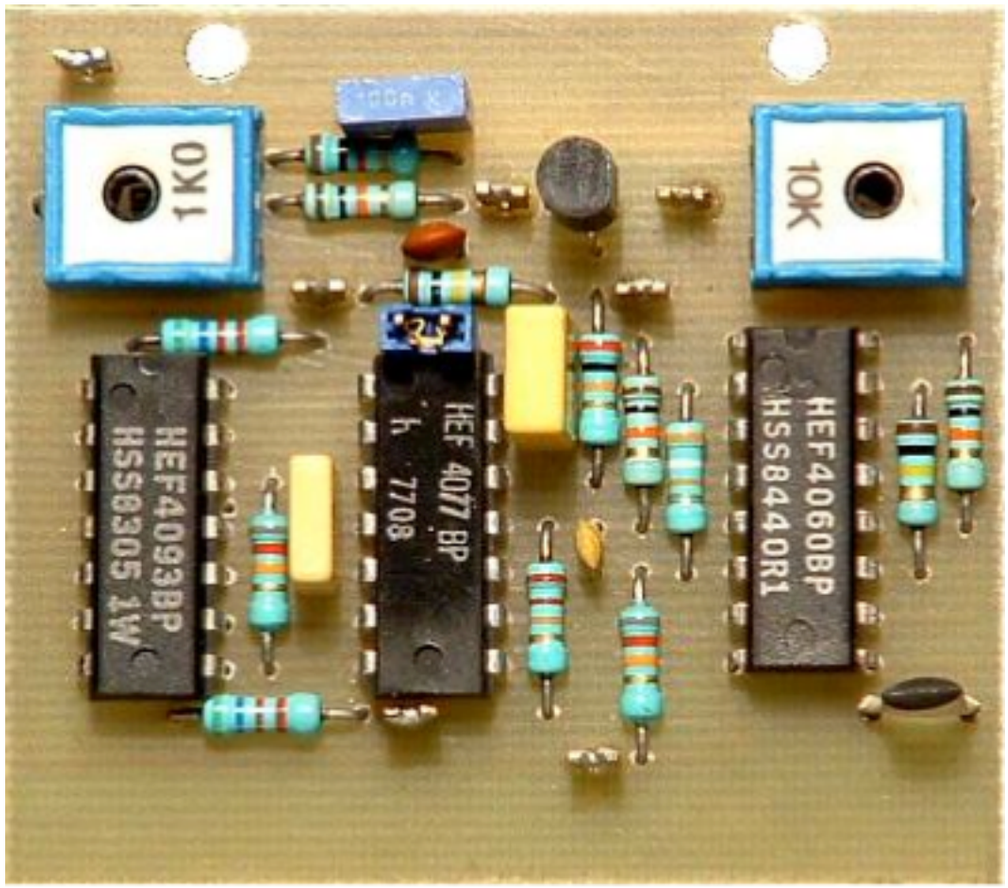
Electrical controls are any input device that controls the flow of current in a circuit. Control devices determine when equipment is energized or de-energized or may control the speed of an operation. Controls operate devices and equipment from remote locations for specific operations or functions of that equipment. Controls can include light switches, photocells, or energy management systems and software. At the electronic level, diodes and transistors, contactors, Programmable Logic Controls, inputs and outputs mange the system by controlling the functions. Control of devices allow for automated systems to operate as intended and equipment to operate for structured and specific design operations.



Electrical control panel

Electronic Components

Electronic components have the ability to amplify or control voltages or currents without mechanical or other nonelectrical command or they can switch currents or voltages without mechanical switches. Examples include electron tubes, transistors, and other solid-state devices. Components vary from device to device making up the basic structure for equipment operation and function. Components can include circuit boards, fuses, SSR (Solid State Relays), diodes, resistors, transistors, capacitors and much more. The importance of components for the technician is to know what components do what and how they are integrated within the equipment. Components that are important to the technician can be found in the equipment manual from the manufacturer. Some components are not end-user accessible and may be part of a bigger device. If the technician can identify the operation of the components for their equipment, the chances of a timely repair can be improved.



Components attached to a circuit board

Troubleshooting

Troubleshooting is the process of diagnosing the source of a problem. It is used to fix problems with hardware, software, and many other products. The basic theory of troubleshooting is that you start with the most general (and often most obvious) possible problems, and then narrow it down to more specific issues. In the world of industrial maintenance for specific skilled technicians, top rated technicians will be separated from average technicians by their ability to effectively troubleshoot. The differences show technicians replacing defective parts based on their tests compared to what they think, not related to the tests. Knowing a basic troubleshooting procedure will lead the technician to the problem, quickly allowing production to be down for a minimum time. As skill and knowledge increase, troubleshooting procedures will typically remain the same, specifically asking the right questions.

This module is focusing on Electrical applications, however there are several steps that can be applied to any process when troubleshooting to find and locate the fault. Below is a list of guidelines most technicians can follow, but every technician may have variances.

Troubleshooting Procedure

1) What is not working?

2) When was the last time it was working?

   a. Are there any visible evidence or smells?

3) Is it a power issue or mechanical issue?

   a. Power Issue?

      i. Does the equipment have power?

      ii. If not, is it a supply power or control power loss?

      iii. Possible problem, fuse, e-stop, logic process error? This will be defined by schematic interpretation.

   b. Mechanical issue?

      i. What mechanical device is not working?

      ii. If a motor, is the chain broken on the motor or is the motor seized by a bearing on the shaft?

      iii. If an electrical contactor, are the contacts binding mechanically?

4) Once step three has been verified, the next step is to isolate the problem. This example will suggest we have an electrical issue, specifically 120v loss to a contactor.

   a. Per the schematic and the technician using a DVOM for voltage check, where is the voltage reading at or not compared to where it should be or not in normal operation? This could identify open or shorted circuits.

b. Once the missing or irregular voltage has been determined in the circuit, what component is causing the error not allowing the electrical circuit to operate normally?

c. For example, if an estop, fuse, shorted diode or PLC control output error, circuit card error, etc., the troubleshooting procedure would move to the replacement of the faulty component or more questions, as defined in this troubleshooting procedure, would be considered in identifying the loss or irregular output of the 120v to complete the circuit.

5) Verify the faulty component and install a new part or correct the logic error.

6) Test the repair of the equipment for normal operation.

7) Monitor and reevaluate these steps to insure all processes associated with the faulty component are working normally.

Movie 7.4 Electrical Troubleshooting Video



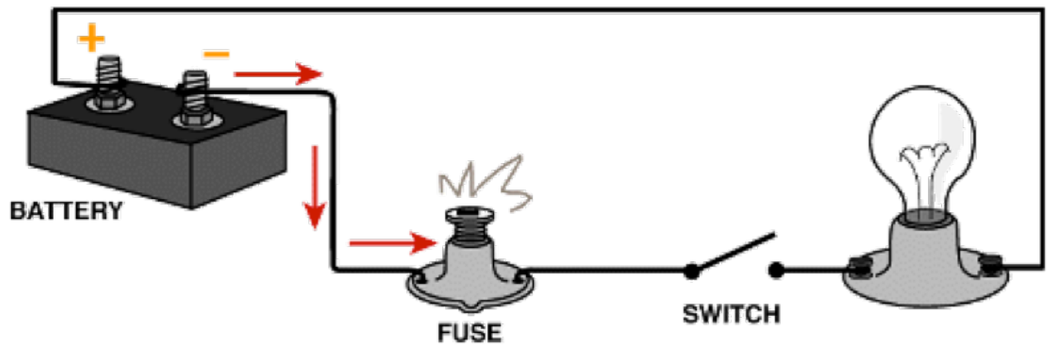
Tap to view the video.

Circuit Failures (Open, Short, High Resistance)

Circuit failures are errors of electrical flow from the source to the component for energy release then back to the source to ground to dissipate all energy not used by the component. Circuit failures can be from an open fuse to a shorted SSR – Solid-State Relay. Circuit failures can seem complicated by equipment design, but in the end the failures of all components are separated into two categories: open or shorted. High and low resistance can also be a factor, but are part of open and shorted circuits depending on equipment design.

Open

An open is an electric circuit in which the normal path of current has been interrupted. This is done by the disconnection of one part of its conducting pathways from another, or by the intervention of an electric component, such as a transistor. Open circuits prevent the flow of designed voltage and current from reaching components needing the energy to operate. The simple way to understand the open circuit is a break in the connection. Using a water hose as an example, if water is flowing out the end of the hose and suddenly stops, there is no water flowing due to a stop created by a break in the flow of water. It could be the water was turned off, the hose is kinked, or the hose is no longer connected to the water source. Thus there would be an open in the water circuit. Electricity operates on the same principle. Electricity travels through wires and components to make devices operate. If the device does not operate on the electrical side, it could be due to no power, a defective device or component or a break in the circuit. Understanding how to troubleshoot opens based on schematics and component operation will make the technician effective in problem isolation. An open circuit will not activate protection devices in the circuit since current flow is limited.



Open circuit with the switch open

Short

A short circuit is a faulty or accidental connection between two points of different potential in an electric circuit. This fault bypasses the load and establishes a path of low resistance through which an excessive current can flow. It can cause damage to the components if the circuit is not protected by a fuse. Short circuits will cause device non-operation or lack of control and will cause damage to the device. Simply understood, unlike an open circuit which does not deliver the voltage and current to a component, short circuits will send incorrect voltage to a component than cannot handle the voltage load, therefore destroying the component or device. For example, fuses are installed in many circuits to protect the wire and devices from shorts and incorrect voltage caused by shorts. Understanding the water hose concept, a short would be flow of water out of the middle of the hose through a defective section watering an area, not designated to be watered, decreasing pressure out of the end of the nozzle for the area needing a certain amount of water. Shorts sometimes can be identified more easily in a circuit due to component failure, but can also cause more destruction than open circuits.

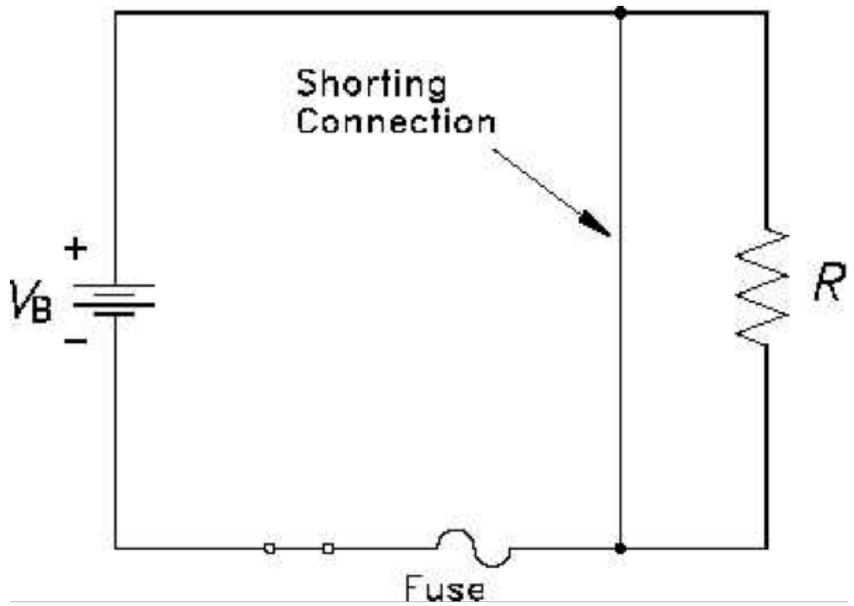
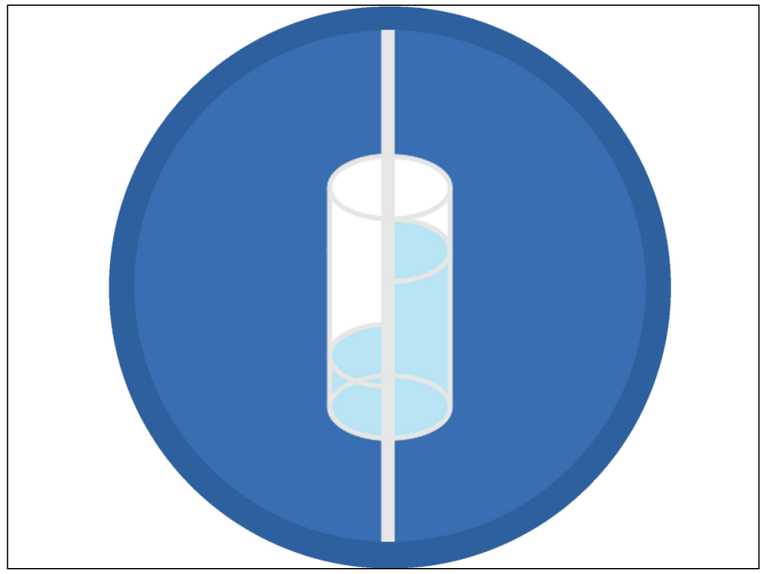


Diagram showing a short circuit

Component Failure

A defect in a component, circuit, piece of equipment, or system, which impairs operation significantly or that causes a failure is called a component failure or electrical fault. Component failures are the basis for any device not operating correctly. Component failures are the cause for open and shorted circuits and consistently will fail as all electronics fail at some point. Component failures include, open fuses, shorted diodes, open transistors, shorted bridge rectifiers, open electronic relays, open resistors, open contactor coils and so forth. Component failures are consistent, but technicians with strong troubleshooting skills and a solid knowledge base will be able to identify these issues and repair them quickly.

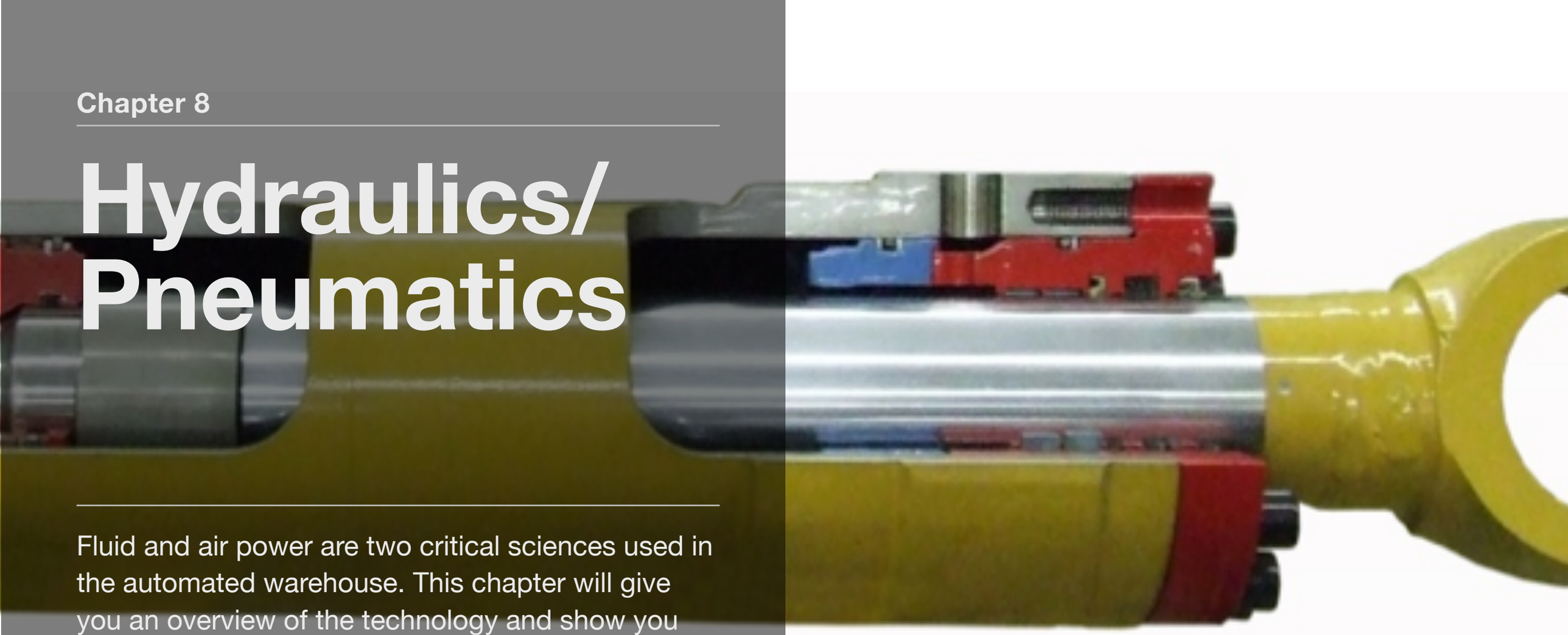
Interactive 7.5 Comparison of Resistor to Failed Resistor



Tap and then slide bar to compare images of working and failed resistors.

Chapter 8

Hydraulics/ Pneumatics



Fluid and air power are two critical sciences used in the automated warehouse. This chapter will give you an overview of the technology and show you how they facilitate the movement of product.



Section 1

Hydraulics Overview

History

The science of hydraulics goes back to prehistoric Egypt where canals and dams have been discovered. Water was moved or lifted by use of the Archimedes water screw and later by the piston pump to supply water from a lake or river to a community or agricultural area. In the 17th century Blaise Pascal discovered the principle that is the basis for modern hydraulic systems and is now called Pascal's Principle. Pascal's Principle states that in an undisturbed enclosed fluid, pressure is transmitted equally everywhere. This makes it possible to use enclosed systems to multiply applied forces and control movement.

Hydraulics as we use them today is the use of fluids to accomplish work and is used in automated equipment in a distribution center. The pressures and components of the system are designed to produce given movements and power outputs. The versatility of hydraulics allow for reliable operation and controllable and variable applications. Hydraulic fluid, normally mineral oil, is only slightly compressible so it maintains its volume, creating controllable and accurate movement in hydraulic components. Both pneumatics and hydraulics are applications of fluid power. Pneumatics uses an easily compressible gas such as air while hydraulics uses relatively incompressible liquid media such as oil. Most industrial pneumatic applications use pressures of about 80 to 125 pounds per square inch (550 to 690 kPa). Hydraulics applications commonly use between

1,000 to 5,000 psi (6.9 to 34 MPa), but specialized applications may exceed 10,000 psi (69 MPa).

Pressure

Three types of pressure affect the work that can be done. Atmospheric pressure is the pressure produced by the weight of the air mass around us. It varies with atmospheric conditions but is generally assumed to be 14.7 pounds per square inch (PSI) at sea level and creates a base pressure affecting everything. If you go to a higher elevation such as the mountains the pressure is less. Gauge pressure is the pressure within an enclosed system that is normally above atmospheric pressure and can be very high. Gauge pressure does the work creating mechanical movement of a hydraulic piston within a cylinder. Absolute pressure is the pressure above a perfect vacuum and is the total of atmospheric and gauge pressures. In the distribution center, gauge pressure is what is applied to the mechanics of operation and is the pressure the technician will be most concerned with.

Movement

Mechanical movement is produced by hydraulic pressure exerting force onto a sealed/sliding piston within a cylinder. This movement can be a lift for a pallet or a lift truck boom to pick merchandise. Most hydraulic applications in a distribution center are used for lifting or moving heavy items where control of the movement is critical.

Cylinders/Pistons

Hydraulic cylinders get their power from pressurized hydraulic fluid, which is typically oil. The hydraulic cylinder consists of a cylinder barrel, in which a piston connected to a piston rod moves back and forth. The barrel is closed on one end by the cylinder bottom (also called the cap) and the other end by the cylinder head (also called the gland) where the piston rod comes out of the cylinder. The piston has sliding rings and seals. The piston divides the inside of the cylinder into two chambers, the bottom chamber (cap end) and the piston rod side chamber (rod end / head end).

Common cylinder mounting options include flanges, trunnions, clevises and lugs. The piston rod also has mounting attachments to connect the cylinder to the object or machine component that it is pushing or pulling.



A dual action hydraulic cylinder cutaway

A hydraulic cylinder is the actuator or driven side of this system that does the work or movement. The drive side of the hydraulic system is the hydraulic pump, which brings in a fixed or regulated flow of oil to the hydraulic cylinder to move the piston with

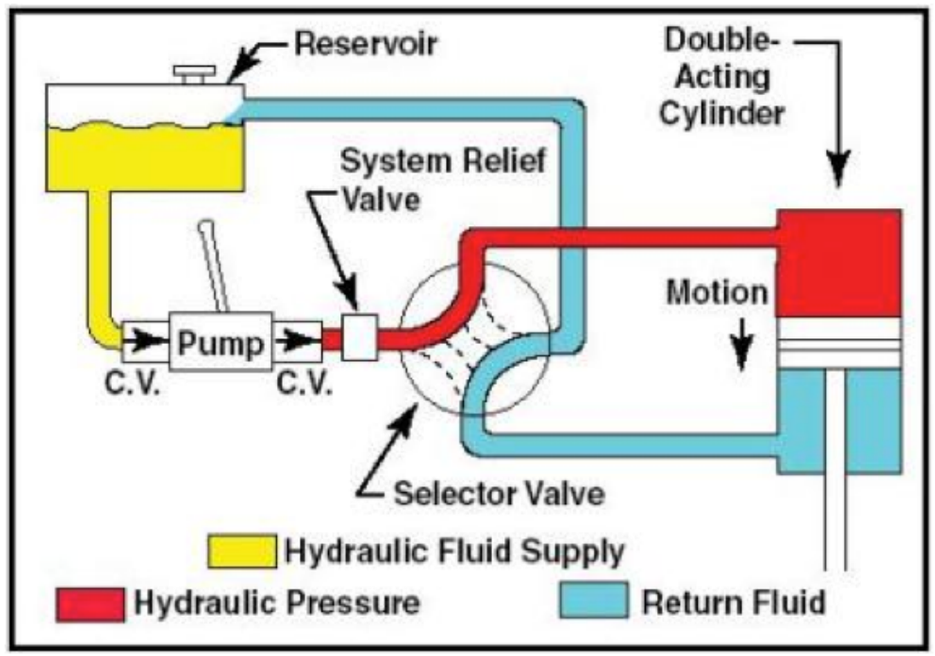
pressure and volume. The piston pushes the oil in the opposite chamber back to the reservoir. The movement or delivery of oil pressure is controlled by a hydraulic valve.



Hydraulic piston for fork movement on a lift truck

Diagrams

Pictorial diagrams are drawings and pictures that are used to show the relationships of components within the hydraulic or pneumatic system for fabrication, assembly or repair. They include each component and show the position and function. Cutaway diagrams show the internal detail of the system. This is the type of diagram that is used for the maintenance and repair of a system. The operation of the system can be determined by evaluating the cutaway. The graphic diagram is normally used during the design of the system and is characterized as line drawings using symbols to describe components and operation.



Cutaway drawing showing the internal motion of the piston and how it is controlled

Applications

The most common applications for hydraulics in a distribution center are for lifting. Lift trucks and pallet lifting devices are the items service technicians will be required to maintain. Equipment that lifts product from one level to another will constitute a large percentage of the technician's service and repair work.

Interactive 8.1 Hydraulics Applications



Tap to view images of hydraulics applications in the automated warehouse

Movie 8.1 How Hydraulic Ram Works Video



Tap to view the video.

Pumps

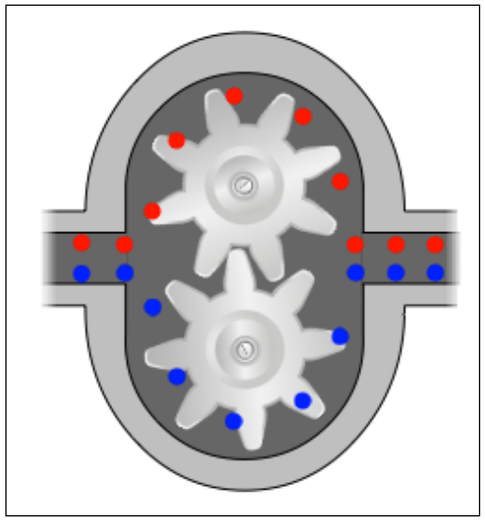
Hydraulic Pumps

Hydraulic pumps create the pressure and volume of hydraulic oil required to transfer and apply energy to a controlled component. Hydraulic pumps are used in hydraulic drive systems and can be hydrostatic or hydrodynamic. Hydrostatic pumps are positive displacement pumps while hydrodynamic pumps can be fixed displacement pumps, in which the displacement (flow through the pump per rotation of the pump) cannot be adjusted; or variable displacement pumps, which have a more complicated construction that allows the fluid flow and pressure to be adjusted.

Gear Pumps

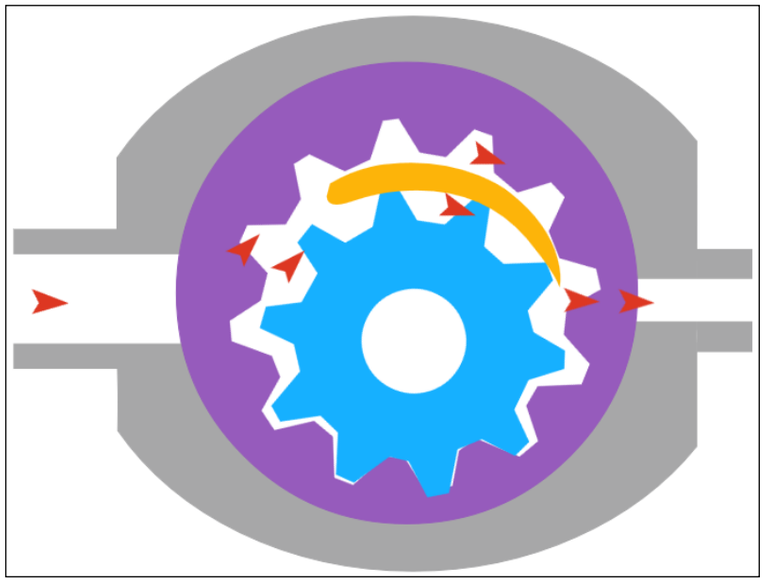
Gear pumps (with external or internal teeth) are simple and economical pumps. They have the lowest volumetric efficiency of all three basic pump types (gear, vane and piston pumps) and the lowest operating pressures (50 to 250 PSI). These pumps create pressure through the meshing of the gear teeth, which forces fluid around the gears to pressurize the outlet side. Some gear pumps can be quite noisy, compared to other types, but modern gear pumps are highly reliable and much quieter than older models. Another positive attribute of the gear pump is that catastrophic breakdown is a lot less common than in most other types of hydraulic pumps. This is because the gears gradually wear down the housing and/or main bushings, reducing the volumetric efficiency of the pump gradually until it is all but useless. This often happens long before wear causes the unit to seize or break down.

Interactive 8.2 Gear pump with external teeth - note the rotational direction of the gears



Tap to view demonstration of gear pump with external teeth. Note the rotational direction of the gears.

Interactive 8.3 Gear pump with internal teeth

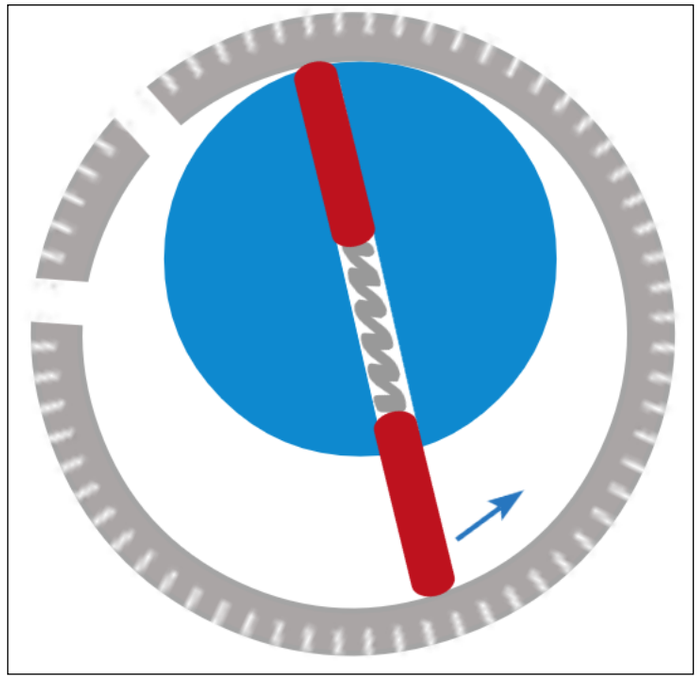


Tap to view a demonstration of a gear pump with internal teeth.

Rotary Vane Pumps

Rotary vane pumps (fixed and simple adjustable) have higher efficiencies than gear pumps, but are also used for mid pressures up to 2,640 PSI. Modern units can exceed 4,410 PSI in continuous operation, although vane pumps are not regarded as "high pressure" components. Some types of vane pumps can change the center of the vane body, so that a simple adjustable pump is obtained. These adjustable vane pumps are in general constant pressure or constant power pumps; the volume is increased until the required pressure or power is reached and subsequently the volume is decreased until equilibrium is reached. A critical element in vane pump design is how the vanes are pushed into contact with the pump housing, and how the vane tips are machined at this very point. Vane pumps are not as reliable as a gear pump due to the complexity of the pump.

Interactive 8.4 Fixed displacement vane pump

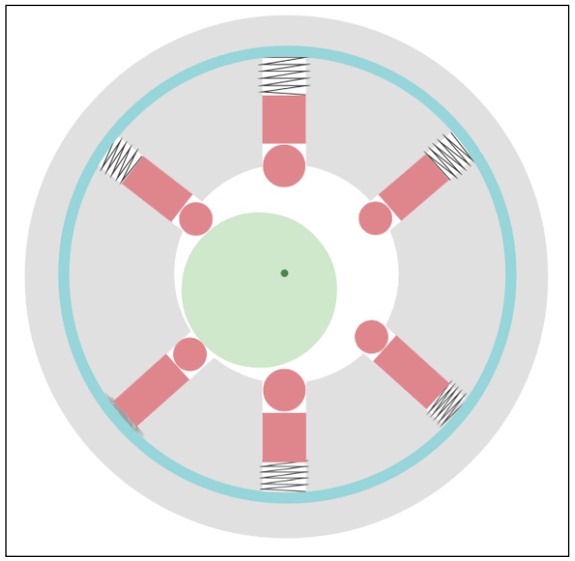


Tap to view demonstration of a fixed displacement vane pump.

Radial Piston Pumps

Radial piston pumps are used especially for high pressure and relatively small flows. Pressures of up to 10,000 PSI are normal. In fact, variable displacement is possible. The pump is designed in such a way that the plungers are connected to a floating ring. This floating ring can be moved horizontally by a control lever and causes an eccentricity in the center rotation of the plungers. The amount of eccentricity can be controlled to vary the discharge. The suction and discharge can be totally reversed seamlessly by shifting the eccentric to the opposite side. Hence both quantity and direction can be varied in a radial piston pump. Radial piston pumps are the most complicated and produce the highest pressures and therefore are not as reliable as the other type of pumps.

Interactive 8.5 Radial Piston Pump



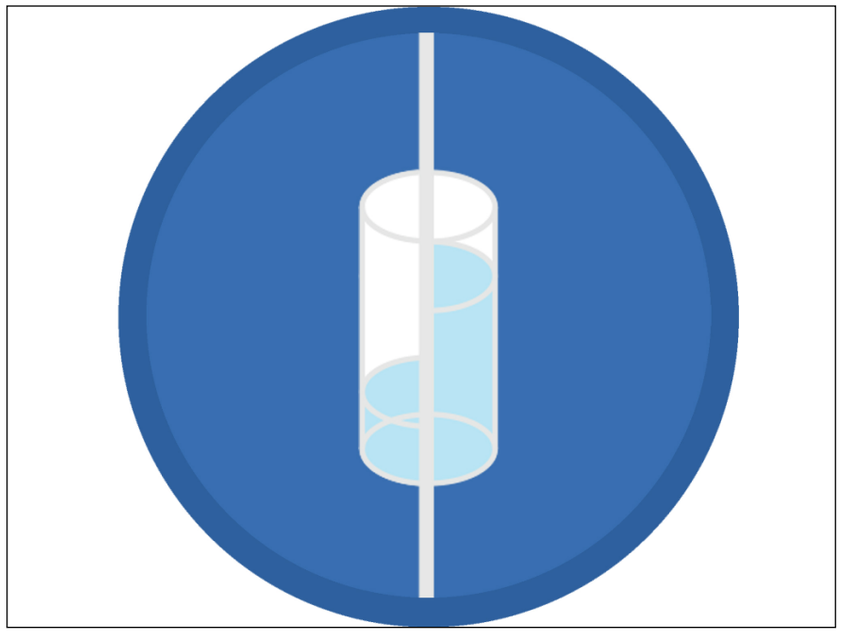
Tap to view demonstration of a radial piston pump.



Self contained hydraulic pump assembly with reservoir that is used to power a single piece of machinery or a small area of the distribution center

In a hydraulic system pressure control is normally achieved by using a mechanical valve that allows a controlled leakage of fluid to the reservoir at a given pressure. Since most hydraulic pumps are positive displacement this process is required to release the excess pressure and allow the pump to continue its operation. The valve is sprung and works with a check valve working against the spring which in some cases is adjustable.

Interactive 8.6 Comparison of Non-Adjustable and Adjustable Hydraulic Pressure Relief Valves



Tap and then slide bar.

Interactive 8.7 Hydraulic Controls



Tap to view images of hydraulic controls

Controls

Hydraulic controls direct the volume and pressure of the hydraulic fluid to the correct side of the cylinders to create movement and power. These valves are normally spool type valves that allow for positve control and little physical effort by the operator. Each valve may have multiple positions to allow a small number of valves to control multiple functions. This type of valve is simple and reliable with years of service life being the norm.

Filtering and Cooling

Hydraulic systems are closed systems so impurities should not collect in the system; settling reservoirs are a common method of removing any impurities that are developed in the system. If the system is under severe use such as a lift truck, filters will be installed in the fluid pick-up lines from the reservoir. Hydraulic systems under heavy use produce heat in the components and fluid. Some systems have coolers in the pick-up of the system to dissipate this heat.



Hydraulic fluid filter to remove impurities from the system



Section 2

Pneumatics Overview

History

Pneumatics is the use of pressurized gas (air) as an energy source. A pneumatic system is a combination of components that makes a controllable, adaptable and varying power source from pressurized gas. Air pressure is the most common gas used and is normally produced by a central compressor and used throughout the distribution center. Pressurized gas can be used to move pistons to move product, activate control relays or power devices. The versatility of air pressure and ease of delivery throughout the facility makes it a popular design choice.

Early use of air pressure utilized bellows to add air to a fire to increase temperatures and improve the combustion process. Pressurized air systems today are used as a drive device in applications that require a clean and simple application such as medical or electronic applications where hydraulic or electrical hazards are a concern or are expensive.

Pressure

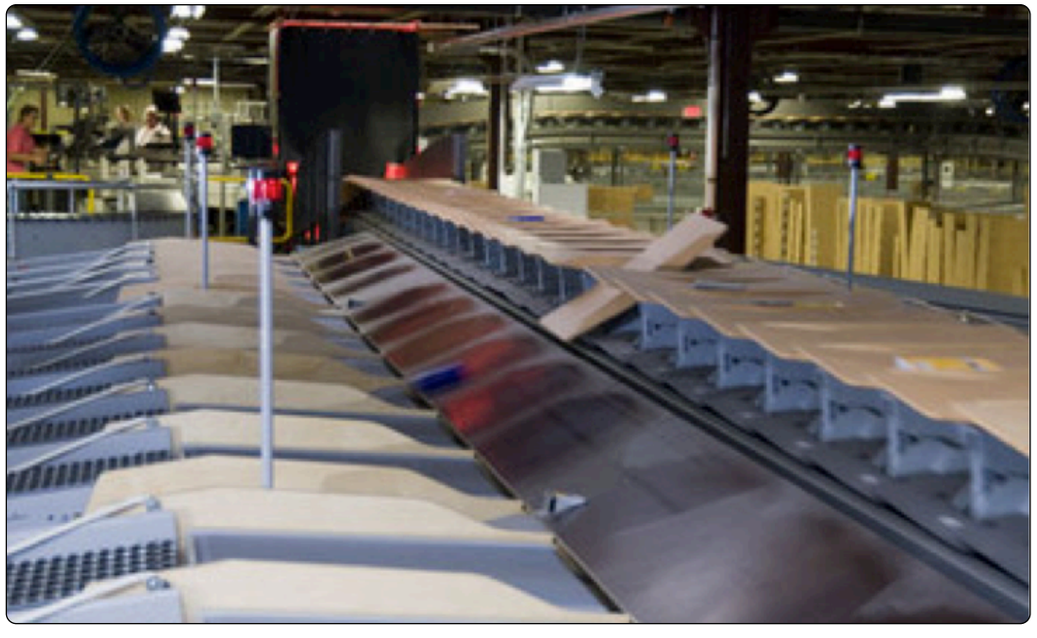
Air pressure is developed by a compressor by forcing air closer together and regulated to the PSI that is needed for the individual application. Air is self-forming so it can flow freely through the entire system and can be controlled for both pressure and volume. During compression the air becomes heated and when it expands it cools so during the compression stage air may need to be cooled to get maximum benefit. Unlike hydraulic fluid, air is compressible so a constant

supply is required within the enclosed system. Water or humidity within compressed air can be a problem to components and controls so most systems include a drier to remove the moisture and a filter to remove particulates.

Pneumatic Applications

Pneumatic motors are used to provide power for conveyors, as sliding pistons to move product during sorting or as control devices to activate components. They are also used as safety devices on conveyor lines or on components within the distribution center.

Interactive 8.8 Pneumatic Applications



Tap to view images of pneumatic applications in the automated warehouse.

Pneumatic Cylinders and Pistons

Pneumatic cylinders (sometimes known as air cylinders) are mechanical devices which use the power of compressed gas to produce a force in a reciprocating linear motion or a rotary air motor for circular motion.

As with hydraulic cylinders, air pressure and volume forces a piston within the air cylinder to move in the desired direction. The piston is a disc sealed to the cylinder attached to a piston rod which transfers the force it develops to the object to be moved. Air motors use air pressure and volume to create twisting force or torque which can be used to provide power to drive components. Engineers prefer to use pneumatics sometimes because they are quieter, cleaner, and do not require large amounts of space for fluid storage. Because the operating fluid is a gas, leakage from a pneumatic cylinder is clean and will not contaminate the surroundings, making pneumatics more desirable where cleanliness is a requirement.

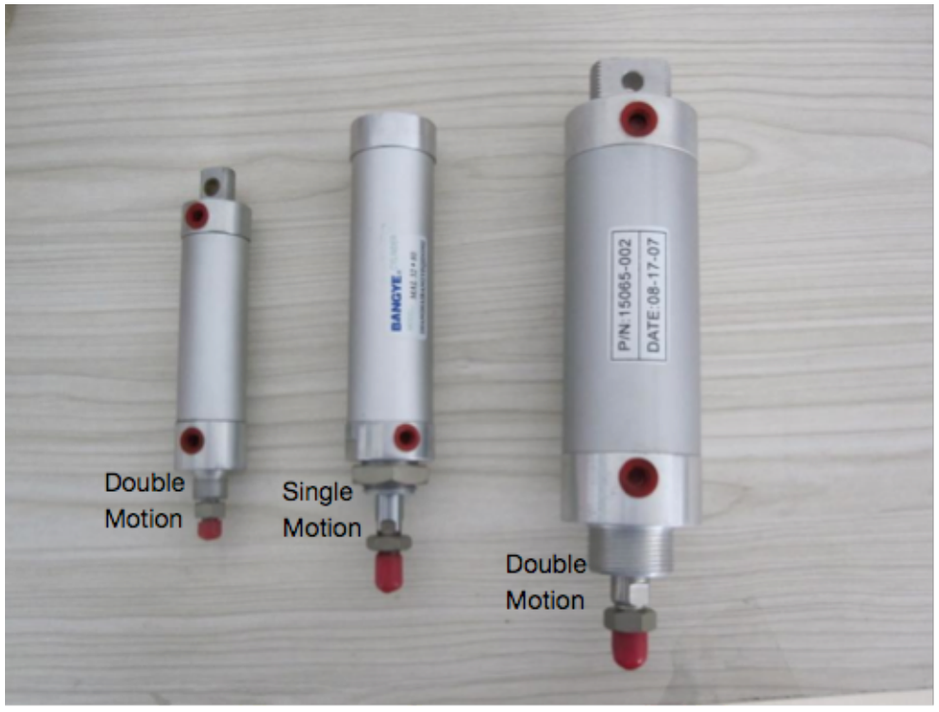
Single-Acting Cylinders

Single-acting cylinders (SACs) use the pressure of compressed air to push in one direction (usually out), and a spring to return to the original starting position. This type of cylinder has limited extension due to the space the compressed spring takes up. Another downside to SACs is that part of the force produced by the cylinder is lost as it tries to push against the spring. Because

of those factors, single-acting cylinders are recommended for applications that require no more than 4 inches of stroke length.

Double-Acting Cylinders

Double-acting cylinders (DACs) use the force of air pressure to move in both directions. They have two ports to allow air in, one for push or extension and one for pull or contraction. When one side of the piston is being moved by air pressure the opposite side is exhausting the air. This is then reversed to allow movement in the other direction. Stroke length for this design is not limited; however, the piston rod is more vulnerable to buckling and bending as the movement increases in length.



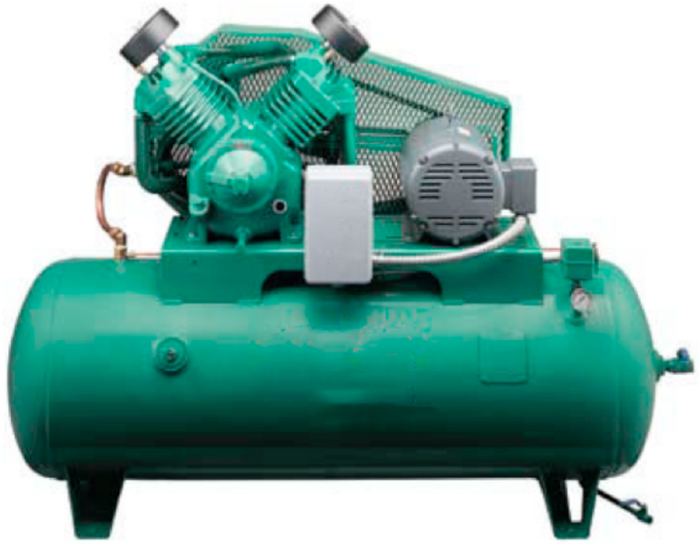
Single and double motion pneumatic cylinders

Air Compressors

An air compressor is a device that converts power (usually from an electric motor in a distribution center) into energy by compressing or pressurizing air, which on command, can be released in quick bursts. There are numerous methods of air compression, divided into either positive-displacement or negative-displacement types. In a pneumatic system the pressure control is normally done by cycling the compressor on and off to control the pressure in the reservoir tank. The line pressure control to a local component is done with a local mechanical pressure regulator. Since air is compressible, available and is expended after use, the control of the pressure and volume is not as critical as in a hydraulic system. During the process of compressing and cooling the air humidity and moisture will accumulate in the reservoir tank or plumbing of the system. This water is damaging and must be removed by draining the reservoir and placing drying filters throughout the system prior to the air entering a component. Large pneumatic systems with high volume may use a refrigeration dryer that cools the compressed air as it flows through to condense and remove the water.

Piston Compressors

A reciprocating compressor or piston compressor is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure (125 PSI). The intake gas enters the suction manifold through a filter, then flows into the compression cylinder where it is compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged into a reservoir tank or directly to the system.



Two stage piston air compressor

Rotary Screw Compressors

A rotary screw compressor is a type of air compressor which uses a rotary type positive displacement mechanism. They are commonly used to replace piston compressors where large volumes of high pressure air are needed, either for large distribution centers or to operate high-demand air tools. The gas compression process of a rotary screw is a continuous sweeping motion, so there is very little pulsation or surging of flow, as occurs with piston compressors.

Interactive 8.9 Compressor Images

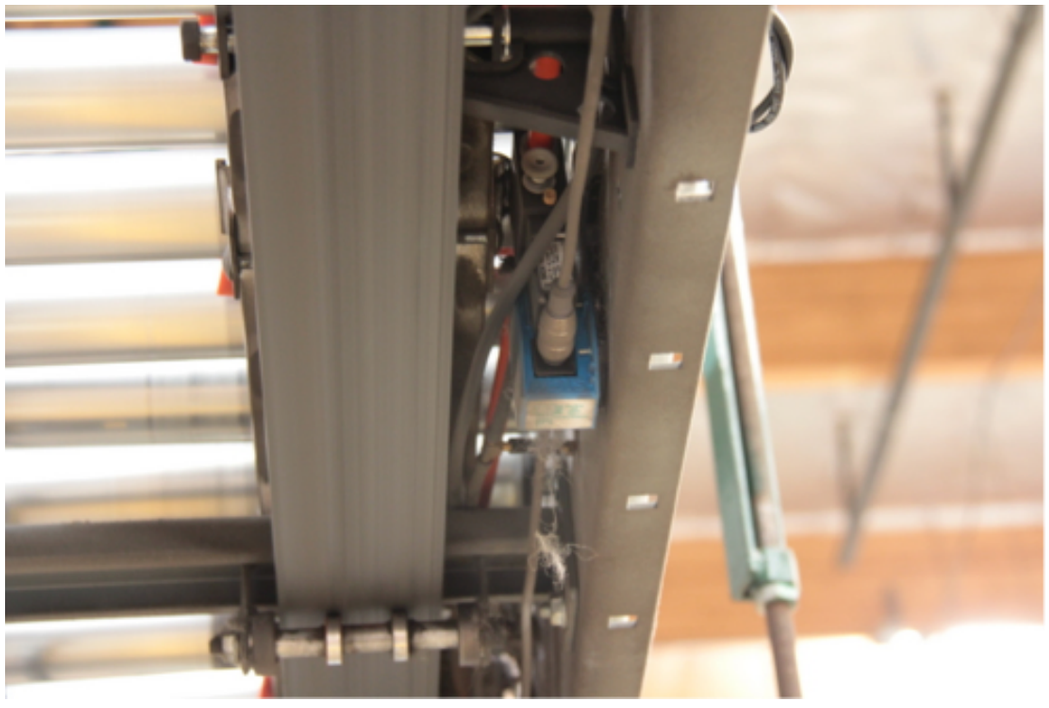


Tap to view images

Directional Control Valves

Directional control valves direct pneumatic pressure and volume to an actuator or a cylinder and piston to produce movement. They are normally a spool type mechanical or electrical valve that controls flow into different passages. They can be two or three channel controls that have neutral and control positions. They can also be on/off valves that produce a quicker response to provide

a surge of pressure and volume to an actuator to create movement. All of this control is normally done by an operating computer system that is directed through PLCs. Pneumatic systems are not as precise in their movement as hydraulic systems so they are normally directed to a full movement to mechanical stops.



Solenoid actuators converting electrical signals into air pressure control

System Maintenance

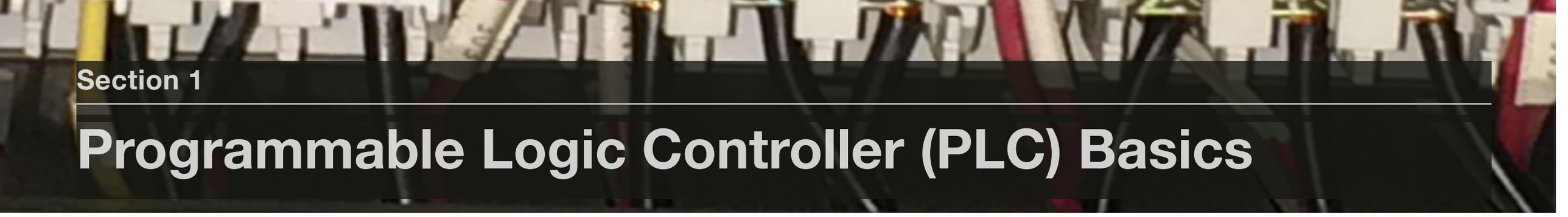
Hydraulic system maintenance is the process of timely replacement of filters and fluids or preventive rebuilding or replacement of components. Hydraulic systems require filter changes based on operating conditions and hours of operation. Scheduled replacement is best to limit failures and downtime. In hydraulic systems fluid changes are required, but the use of newer fluids has dramatically extended service intervals and in some cases fluids can last years without replacement. Monitoring of electrical devices that are used for driving motors or controls should be serviced based on the accumulated data for long-term reliability. Current draw and voltage drop tests can be done to test the operation of the devices. Monitoring pressures is a good indicator of the quality of the system and variations in outputs will indicate current or future problems.

Pneumatic systems have air filters at the inlet to remove impurities prior to the compression of the air and water filters are used after compression to eliminate any moisture that collects in the system. Large volume systems may use a refrigeration drier. Service or replacement of these devices is done on a scheduled basis. The draining of reservoir tanks and remote filter/driers is required often if not managed by an automatic system.

Chapter 9

Programmable Logic Controller (PLC) Basics

Logic controllers can be described as the brains of the automated warehouse. This chapter gives you an overview of the role of the PLC and how it integrates information from several different components to make the system function flawlessly.



Section 1

Programmable Logic Controller (PLC) Basics

Programmable logic controllers, commonly called PLCs or microprocessors, are used to automatically control various residential, commercial, and industrial electrical operations through programming logic in lieu of manual operations (turning switches on and off by hand). PLCs of today are in cars, energy management systems, supply chain operations, airplanes and any type of electrical control that can be imagined. PLC's premise is based on receiving voltages as input signals and releasing voltages as output signals to control circuits based on the order of the signals received and program design of the logic for rendering outputs. PLCs are solid-state devices that are programmed to command operations using low control voltage, 5VDC, to control low power and high power voltage systems from 24VDC/120VAC to 277VAC/480VAC and greater. PLCs offer many benefits for automated control of electrical systems: low cost maintenance, easily replaceable input and output boards; quick diagnoses for troubleshooting and repair, including benefits of being reprogrammed for changes to existing equipment and production operations to increase efficiency. PLCs high speed, low cost, highly reliable small devices with diverse abilities that increase productivity and quality by linking multiple machines and operations into one integrated system for maximum support for supply chain operations. Learning and mastering PLCs from basic operations to intricate programming will give an edge to any technician in the supply chain support for operations.

PLCs provide warehouse efficiency by integrating hundreds of inputs and power sources to control hundreds of outputs by one central control scheme known as ladder logic, the brains of programmable logic control. Below are examples of PLCs.

Several types of PLCs exist and provide controlled automation for a main conveyor and all associated equipment. The first and the oldest is a PLC 5 built by Allen Bradley with programming by Rockwell software: RSLogix™ 5 Software with RSLinx™ communication software.



Input and Output boards for connections to a PLC, SLC 500 series



RS200 Sorter PLC controlled conveyor transporting product and sorting by movement of the conveyor shoes

The PLC is a master controller for all the outputs and inputs for the travel conveyor. The conveyors within the automated warehouse are controlled by a series of speed inputs, photo cell inputs and other electrical associations by the master PLC controller via ladder logic programming for streamlined operation. The master controller consists of a PLC rack which includes a power supply, master controller and a chassis to interface communications between the cards and controller inputs and outputs for operation. Also on the controller board is an external EPROM – an erasable programmable read only memory chip that retains information when power is switched off, which is inserted into the main controller.

Typically EPROMs in most PLCs today are internal unless otherwise designed. The main purpose of the EPROM is to retain the logic of the PLC program in case of a power loss. If the ladder logic is only in the RAM (Random Access Memory), once there is a power loss from control power to the PLC, all the contents (ladder logic program) will disappear.

Individual input and output boards are critical to ladder logic operations within the PLC's main controller. It is important to note that inputs and outputs in PLC controlled environments are simply voltages. The inputs from electrical peripherals (photo cells, switches, start buttons, etc.) and output voltages (motor contactors, status lights, start sirens, etc.) control the system. These voltages vary from 120VAC to smaller 24VDC as designed.

The image on this page shows an example of a master controller station which allows the operator to control which inputs to the PLC are sent, thereby requesting a particular operation by the conveyor. Lights on the controller station are illuminated by outputs from the PLCs as input and output signals are received.



PLC 5 Master Controller with inserted EPROM, controlling the entire operation of a conveyor within a distribution center

This panel gives the operator manual control over PLC operations by turning inputs on and off when desired. The control the operator has in this case is the release of product from several conveyor lines into the merge area. Typically the auto control will run the conveyors, but at times due to physical errors on the conveyor, the operator may take control.



Operators' Control Station which can be used for manually switching and overriding PLC's Inputs or Outputs for operations indicated by illuminated lights

The lines of the conveyor will run one at a time for a set amount of seconds depending on each line's capacity and the logic in the PLC control. This creates a round robin cycle, allowing each conveyor to release product to the main conveyor in a timely and efficient manner.

It is important to note all PLC input wire markings are designated by 1 or 0. 1 is input and 0 is output. These numbers are the beginning number of PLC wire designations, sending voltage signals either going into a PLC module for input or exiting a PLC module as an output. Input boards have wires that are signal voltages coming in indicated by a 1 first and then followed by other numbers for wire circuit designation.



Merge of several conveyors moving product through timed intervals controlled automatically by the PLC controller and/or manually at the operators' control station

In addition to the wire markings for input and output, the SLC 500 series input and output module boards were designed to easily be replaced if an error occurred on the PLC board itself. The input wires would remain on the orange terminal block, which can be removed from this module by removing two screws: top and bottom. These screws do not have a wire connected to them. Once the screws are removed, the orange terminal strip will unplug from the PLC module. The PLC module can then be snapped out of the chassis for replacement or repair.

The SLC 500 series PLC is typically in one or two PLC racks to accommodate the size of the PLC system. This is dictated by the size and complexity of the automation.



PLC input board with wire markings beginning with 1 and followed by the circuit number

PLCs are housed by two racks, providing a communication interface for all the modules. For descriptions of a PLC rack, refer to the image on the right. First is the PLC power supply being darker gray in color with one red light showing, which provides power to the PLC chassis. Next is a PLC adapter converting Ethernet connections for communications from other PLCs and the master controller. Next are the PLC modules labeled red for input and orange for output. These are the components on the PLC chassis.



PLC rack of input and output boards

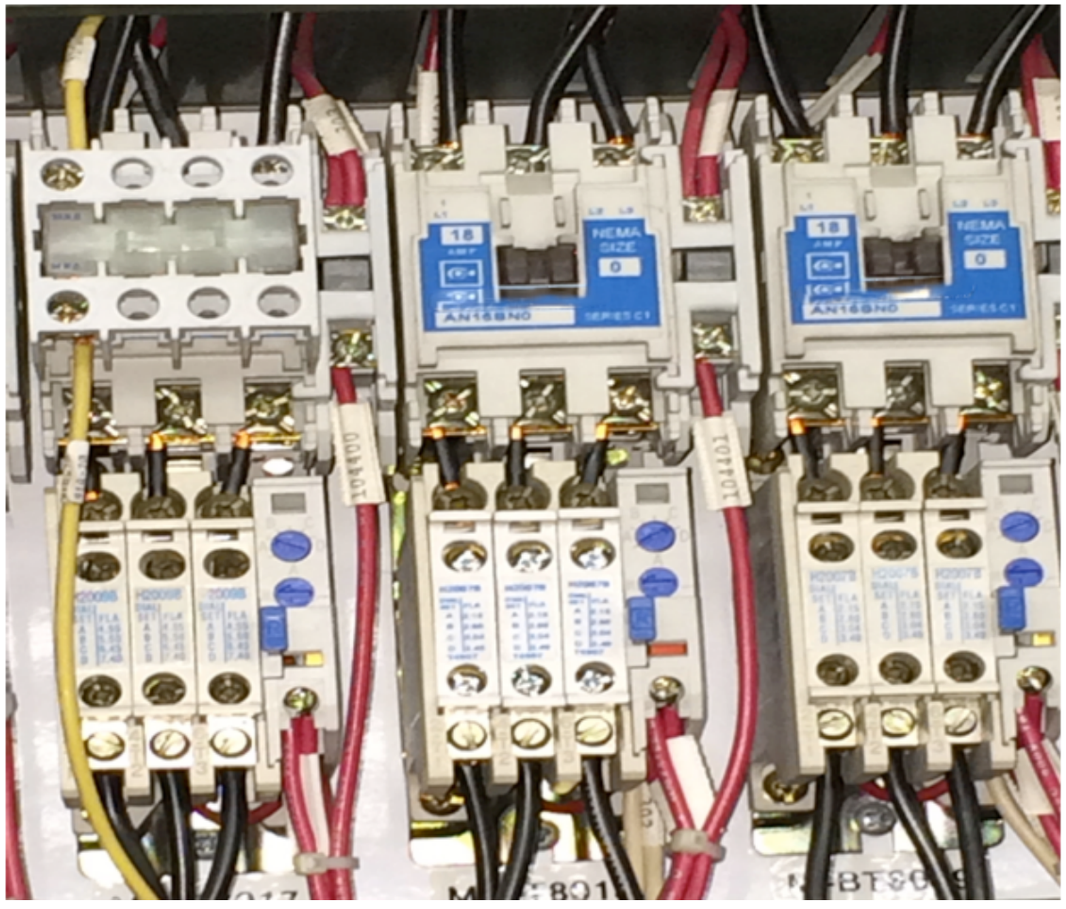
The lights on the output board, numbers 0 -17, illuminate when a signal indication for on is outputted. The logic of the PLC has been commanded to send voltage to an output device, such as a motor contactor. When the logic tells the output voltage to stop, the voltage will cease and the light will go out. Typically the lights give a true indication if voltage is present or not on the output terminal, however there are occasions where a light on or off may not indicate a true output on the terminal ID. In this case the output board is operating in error as the light should match voltage present or not on the terminal.



Output board Indicator lights to verify operational status

Motor starters provide 480VAC power to drive motors on the conveyor when energized. These starters receive their on signal, 120VAC, from PLC output boards when commanded by the PLC logic.

The input board status lights operate much the same as the output boards; the only difference, the signal, 120VAC, is coming into the PLC, not out.



Motor starters controlled by PLC outputs that activate a relay to provide current to start a motor



Input board indicator lights used to verify operational status

When an input device sends a signal to the PLC it will be indicated by an illuminated light for 0-17 terminal connections. Also note terminals 0-17 are separate input devices.

Within the PLC output device, a light “on” does not guarantee that 100 percent voltage is present on the input. These input and output module status lights operate on 24 volts DC and are controlled by internal relays on the PLC module itself. To completely verify a voltage signal is present on the PLC, a technician must check for the 120VAC with an approved DVOM, on the terminals for the designated connection to see if voltage is present. The internal relays on the modules will get stuck at times in the open or closed position whether or not the signal is present or not and in some cases give a false indication. The status lights are guidelines, not absolutes for voltage present or not.

The photocell is an input device for PLCs. The signal for this photocell is 120VAC and it is sent to input modules when blocked by product. These photo eyes can be used for a variety of operations within the logic of the PLC. Examples are to hold product, indicate a jammed condition on the conveyor, stop a portion of the conveyor, etc.

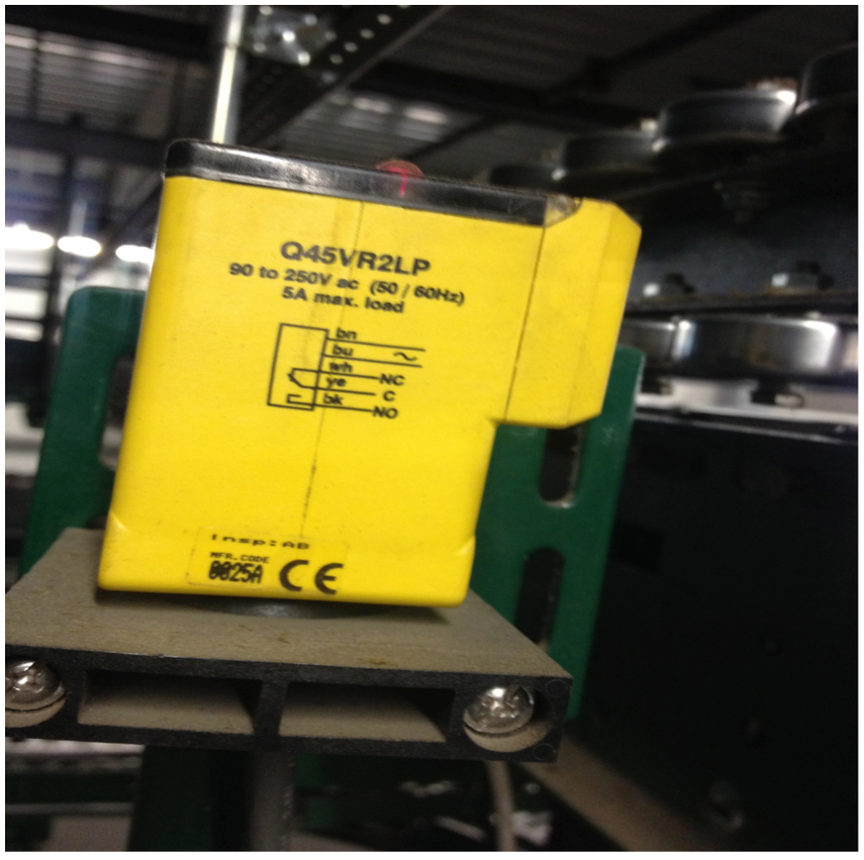


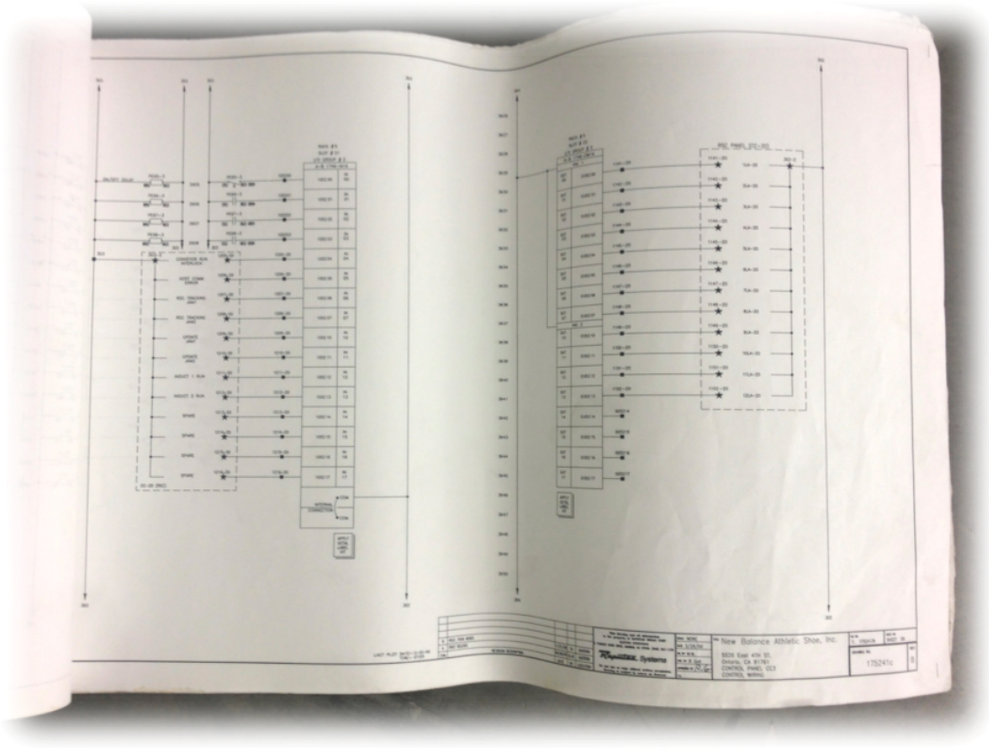
Photo Eye 120 Volt input to PLC input modules

A Digital Volt Ohmmeter (DVOM) is the preferred tool for checking voltages on PLCs. Fluke is one of the most accurate meters on the market and is typically the standard. Being able to analyze PLCs using a DVOM is critical for effective and accurate analysis for proper operation and troubleshooting. Operation of the DVOM by technicians takes training and experience to be safe, knowledgeable, comfortable and quick with the use of the meter.



DVOM reading 117.5VAC

PLC prints are simplistic in nature. The rule is if voltage is going into the PLC module the print is an input. If voltage is coming out of the PLC module the signal is an output. The schematic diagrams beginning from the left are input prints and the schematic diagrams on the right are output prints. Learning to read and understand PLC prints are just as important as learning the PLC process and control of automation.



PLC prints for signals for inputs and outputs which are used for tracing each circuit and troubleshooting

MicroLogix is another type of PLC used in distribution centers. These PLCs are smaller in size and are typically used for smaller operations and to control stand-alone automations and machinery.

The big advantage of the smaller PLCs when compared to more complex PLC systems is that the inputs and outputs are all integrated into one unit. In the PLC 5 and SLC 500 they have a

master controller and separate input and output modules. The MicroLogix controller is one simple unit. The input connections are on the top and the output connections are on the bottom. The MicroLogix controller, like the SLC 500 PLC, operates the internal relays operating on 24VDC. These relays switch the signal on and off, typically at 120VAC, as dictated by the PLC program turning on and off associated devices. These devices may be motors, mac valves, control power, etc.



PLC Controller MicroLogix 1000

The panel cover for the output connections is in the open position, showing the terminals for devices that will receive the signal, a designated voltage, for the output device to operate as determined by the PLC logic. The input connections are at the top of the unit under the cover. The PLC 5 controller runs off RSLogix5 software and MicroLogix runs off of RSLogix500 software. Each PLC controller typically has proprietary software for the ladder logic that is not compatible with other PLC controllers from different manufacturers.

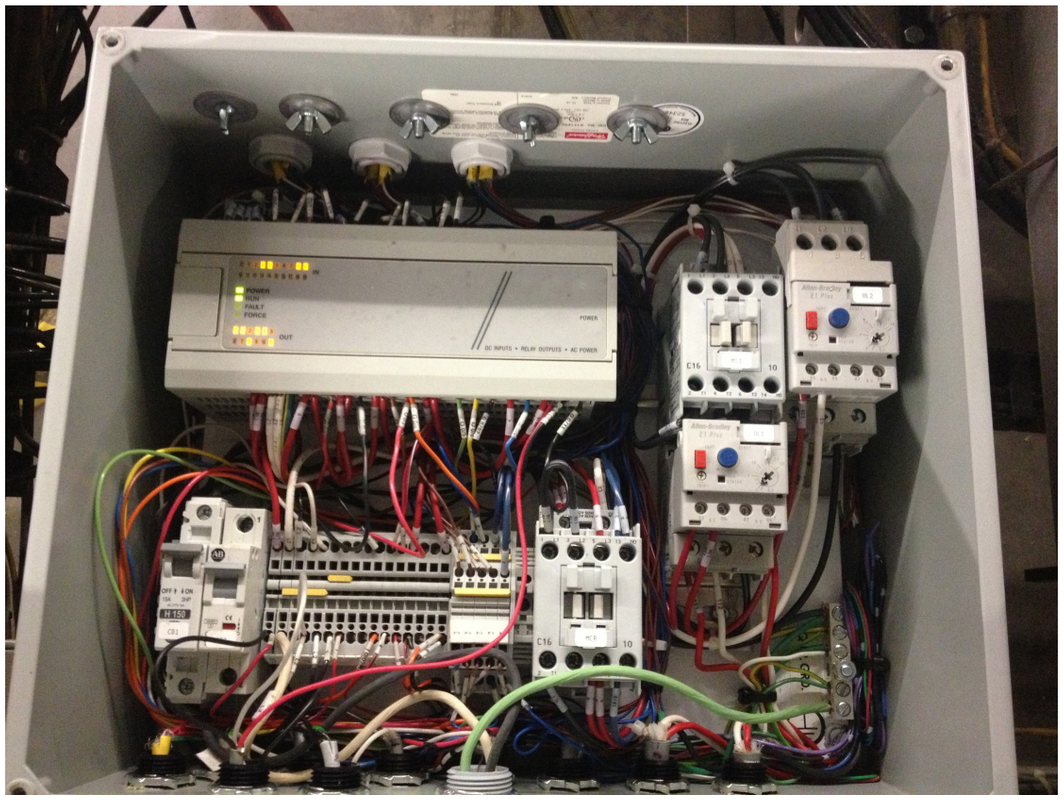


MicroLogix controller showing terminal connections for the outputs

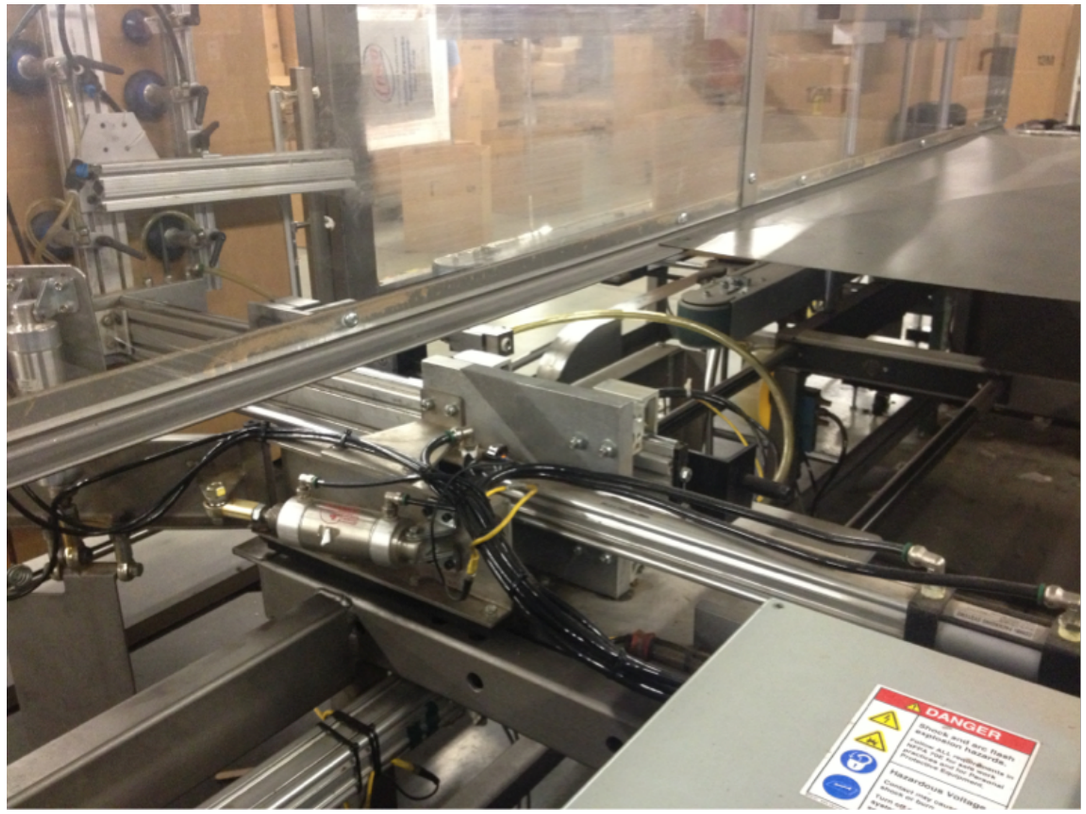
The MicroLogix PLC controller is the central controller of the operation. In the example on the next page, a Combination Box Machine is making product boxes from flattened boxes on a stack. Some of the inputs are photocells, start switches and emergency stop buttons. The outputs are motors for belt rotation,

Mac Valves controlling the output of air for cylinders, and other devices.

The combination box maker is completely controlled by PLC logic for full automation. In the picture on the right, the extend cylinder is reaching out to grab a box in the flat position from the stack and to pull it back to open it up into a formed box. This process is done by a series of compressed air cylinders controlled by Mac Valves and photocells controlled by the PLC logic in the MicroLogix controller.



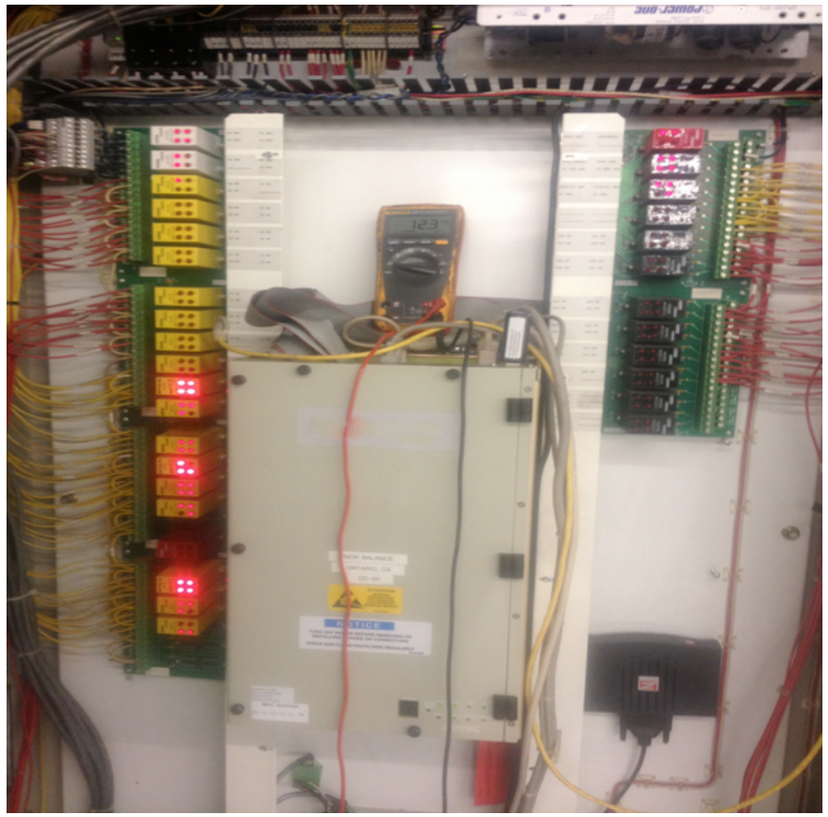
MicroLogix 1000 Controller for Combi Box machine



A box maker controlled by a MicroLogix Controller

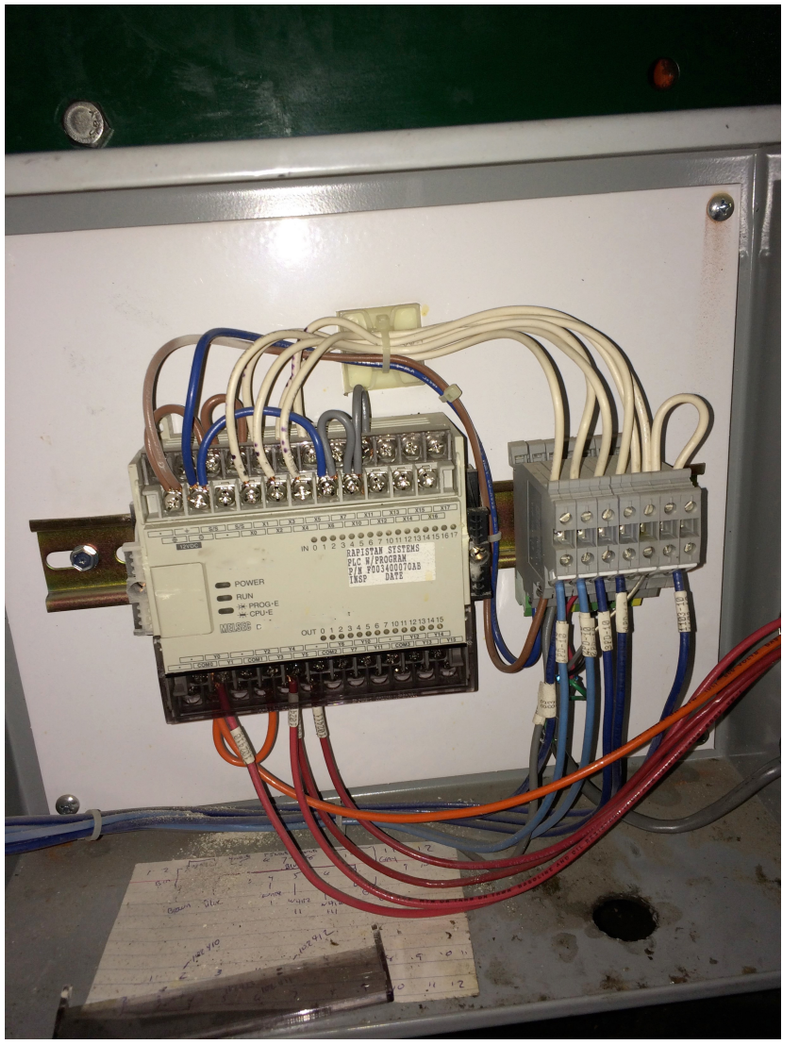
PLC Controllers often work with other computer controlled devices for automated operation. The computer controller receives inputs from various electrical peripherals, full photocells and update photocells to control product movement on the conveyor. Signals are sent to input devices called opto-blocks which covert a higher voltage signal to smaller voltages that a computer controller can process. The logic in the computer controller then sends a signal to an output block for an operation to occur.

This operation could be diverting product from a conveyor that is full to one that is not. The output device will also send signals to other controllers as inputs for the corresponding master PLC controller to allow another operation to occur. This process depends on the logic within the system and the complexity of the task, but is important to maintain movement of product and correct delivery of processes.



Computer controller with inputs and outputs

PLCs often work in unison with other PLCs even if the manufacturer is different. This versatility adds the capability of merging new technology with old without escalated costs.



A smaller PLC made by Mitsubishi, designed to work together with an Allen Bradley PLC 5 master controller

PLCs are the cornerstone of any automation operation. These examples are just a few of the operations inside an automated warehouse that are controlled by PLCs.



Overview of PLC-controlled automation

Chapter 10

Data Communications and Networking Foundations

Data communications and networking refers to the transmission of this digital data between two or more computers, devices or stations that allow data exchange. A basic understanding of data communications and networking is a critical skill in the modern manufacturing world.





Section 1

Overview

A multitude of machinery and devices are now connected in an advanced manufacturing facility. Connected devices can consist of computers, PLCs (Programmable Logic Controllers), sensors, conveyor systems, HMIs (Human Machine Interfaces), pumps, control panels and just about any other equipment or device found in the manufacturing facility. The connection between these devices is established using cable media or wireless media. The study of modern data communication begins with the familiarization with the Open Systems Interconnect (OSI) model.

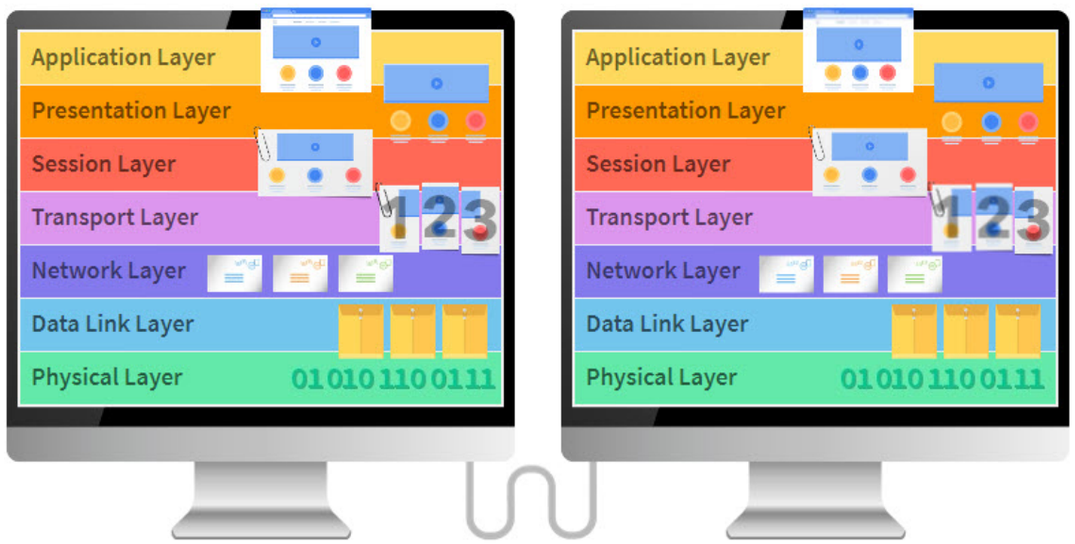


Section 2

OSI Model

The Open Systems Interconnection (OSI) model is a framework for describing the data exchange process. This model describes seven layers that communication devices use to communicate over a network. The OSI 7-layer model is used to visualize and communicate how networks operate, and helps plan, design, isolate and troubleshoot networking problems. OSI was introduced in 1983 by representatives of the major computer and telecom companies and was adopted by ISO (International Organization for Standardization) as an international standard in 1984. The model defines the functionality of each layer in the process, the recognized applications, services, and protocols running at each layer and the data encapsulation units used at each layer.

Interactive 10.1 OSI Model



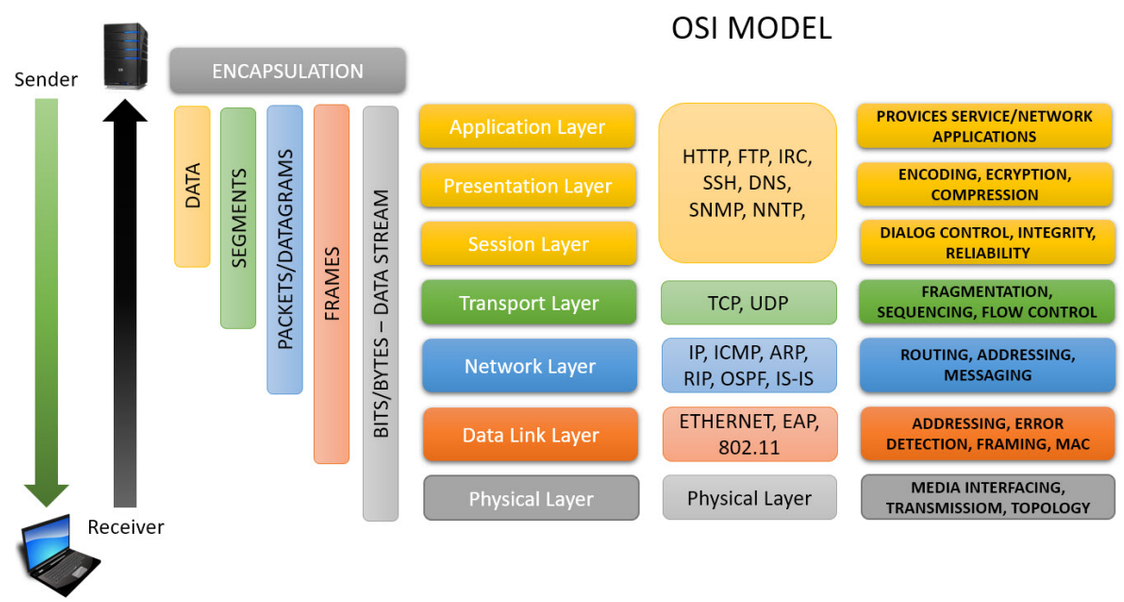
Tap to view an interactive

Layers of the OSI Model

The OSI model consists of a seven-layer architecture with each layer having specific functionality and purpose. All the layers work together to enable transmission of data from one device to another whether locally or across the globe. The seven layers from top to bottom are Application, Presentation, Session, Transport, Network, Data Link and Physical.

Layer 7 - Application Layer

The Application layer is at the top of the OSI Model. Network applications and services operate at the Application layer. These applications and services send and receive data across the network. This layer also serves as a window for the application services and users needing to access the network. This layer integrates network functionality into the operating system and enables communication across the network between clients and servers. Network services associated with this layer include HTTP (Hypertext Transfer Protocol), Telnet, FTP (File Transfer Protocol), TFTP and SNMP (Simple Network Management Protocol).



Layer 6 - Presentation Layer

The presentation layer serves as a translation service. The layer contains processes that encode and decode different types of data (text, measurements, images, audio, or video). For example, it may use the ASCII (American Standard Code for Information Interchange) code to send and receive text-based data, or WAV (Waveform Audio Format) encoding for audio data or AVI (Audio Video Interweave) for encoding video data. This layer will also use processes to compress or decompress data before and after transmission. The presentation layer can encrypt and decrypt data to protect the data confidentiality. The Presentation Layer

formats/presents data the destination system can accept. Examples include ASCII, GIF (Graphics Interchange Format), JPEG (Joint Photographic Experts Group) and MPEG (Moving Pictures Experts Group). It also formats, encrypts, and compresses data so that it can be sent across the network.

Layer 5 - Session Layer

The session layer is responsible for the dialog between devices, maintenance of sessions, authentication, and security controls. The layer allows the two processes to establish, use and terminate a connection. The layer also provides synchronization which refers to allowing a process to test or synchronize points as data is exchanged. An example would be a system sending 100 pages of graphics and text; the session layer can test the session after every 20 pages so to avoid restarting after all 100 pages have been sent. The session layer controls the type of dialog during a connection; this might include the ability to allow two systems to start communication in half-duplex or full duplex. Data at the Application, Presentation or Session Layers are referred to as just data.

Layer 4 - Transport Layer

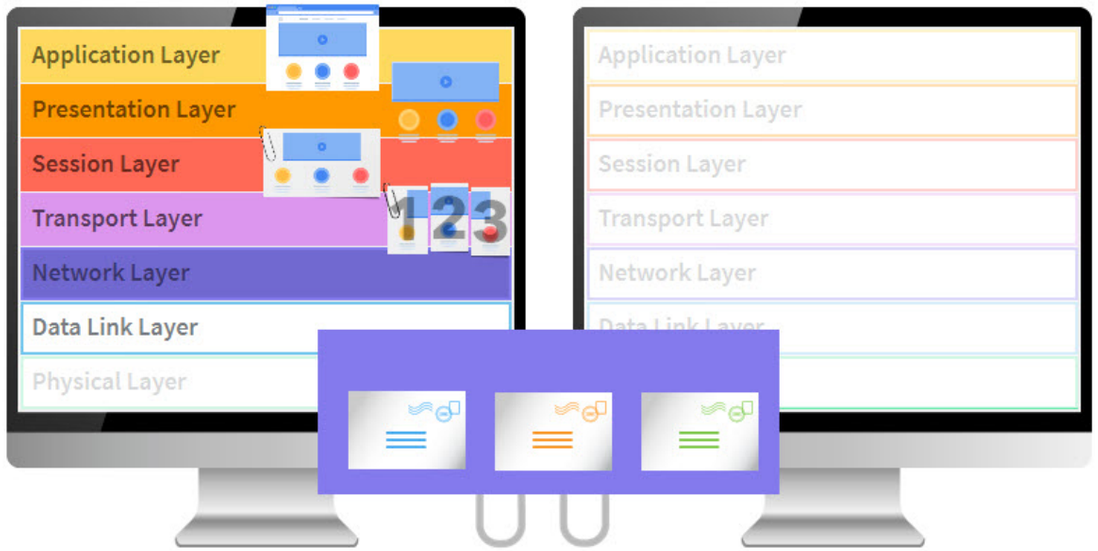
The Transport Layer provides a transition between the upper and lower layers of the OSI model. Transport Layer functions include end-to-end flow control, port and socket numbers, segmentation, sequencing, and combination and connection services - for either reliable (connection-oriented) or unreliable (connectionless) delivery of data. Transport layer protocols include TCP (connection-oriented Transmission Control Protocol) and UDP (connectionless User Datagram Protocol). This means one station must request and establish a connection before sending data or just sending the data before establishing the connection. The layer also provides error correction, speed control, quality control and reliability to the end user. The Transport Layer builds data units called segments which are numbered and sequenced. The transport services provide end-to-end delivery of the message transmitted. The Transport Layer also provides the acknowledgement of the successful data transmission and re-transmits the data if an error occurs.

At the sender's side, the port receives the formatted data from the upper layers, performs segmentation and implements flow control and error control to ensure proper data transmission. It also adds source and destination port numbers in its header to allow multiple simultaneous connections for operation without errors. Data received by the Transport Layer is then passed down to the network layer. On the receiver's side, the Transport Layer receives data from the Network Layer and segments and sequences the data before passing the data to the Session Layer.

Layer 3 - Network Layer

Network layer allows devices on different networks to communicate. The Network Layer responds to requests from the Transport Layer and issues requests to the Data Link Layer. The network layer is responsible for packet forwarding through

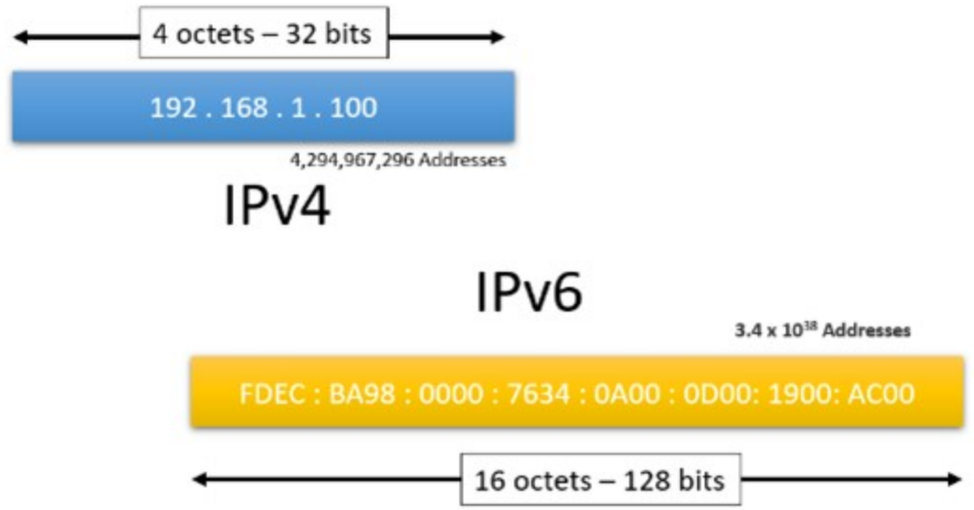
routers. Functions include identifying hosts and networks by using logical or IP (Internet Protocol) addresses, maintaining a list of known networks and neighboring routers, and determining the next network point where data should be sent. At the Network Layer, data units are called packets. This layer uses packets also called datagrams with IP addresses to deliver data between different networks. The Network Layer reads the IP addresses and routes the data to the appropriate destination network. The sender and receiver's IP addresses are placed in the header by the Network Layer. Network Layer functions include assigning network addresses, routing, route selection, error detection, testing network bandwidth, reliability, and distance.



Network Layer

Network Addressing

One of the most important concepts to understand when working on industrial networks is addressing. An IP address (Internet Protocol address) is a numerical representation that uniquely identifies a specific interface on the network. There are two current versions of network addresses IPv4 and IPv6. Addresses in IPv4 are 32-bits long. This allows for a maximum of 4,294,967,296 (232) unique addresses. Addresses in IPv6 are 128-bits, which allows for 3.4 x 1038 or (2128) unique addresses. The total usable address pool of both versions is reduced by various reserved addresses and other considerations.



IPv4 and IPv6 addresses

IPv4 Network Classes

The IP version 4 address system is divided into network classes. The IP classes are used to define the size and purpose for using the addresses. The summary of the IPv4 classes is below. When working with IP networks, technicians must understand subnetting and network classes. When IP networks were created, those involved decided on an address range of 32 binary digits or

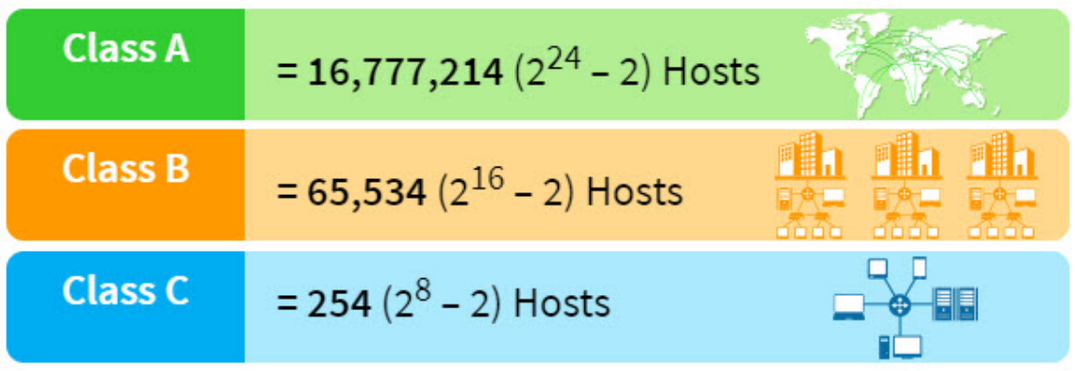
bits. Using a 32-bit address limited the number of addresses to 4 billion addresses (the highest address is 4,294,967,295).

Binary 32 bits = 1111 1111 1111 1111 1111 1111 1111 1111

Decimal = 4,294,967,295

Binary
11000001 01101100 01111110 00001010 (32bits)
Decimal Dot Notation
10.12.0.9 152.100.54.234 195.120.234.9 (4 sets of numbers from 0-255) separated by a dot

In the 1960's, this seemed to be enough addresses. No one could have imagined the Internet and the hundreds of millions of smart devices today, each requiring an IP address to communicate on the Internet. With an IPv4 address, there are five classes of available IP ranges: A, B, C, D and E. Only Classes A, B, and C are commonly used for network devices. Each class allows for a range of valid IP addresses.



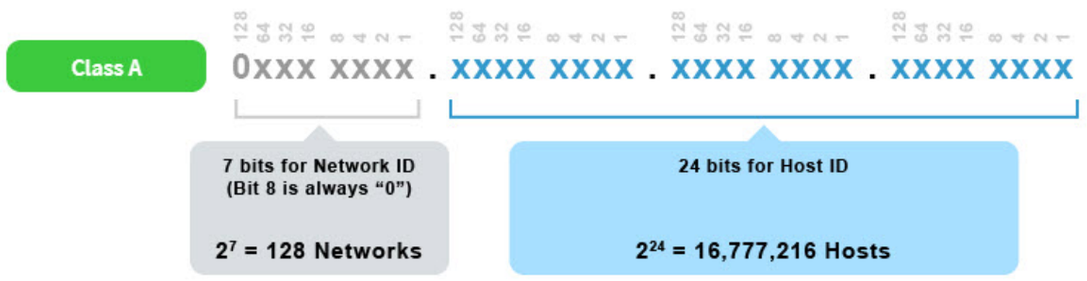
Class A, B, C

The IP address space was divided as follows:

- **Class A** was used for big organizations and provided up to 16,777,214 hosts on a network.
- **Class B** was used for mid-size organizations and provided up to 65,534 hosts.
- **Class C** was used for small networks with up to 254 hosts.
- **Class D** was reserved for multicasting and was reserved for research and future development.
- **Class E** was reserved for research and testing.

Class A Address

The IPv4 Class A addresses provide for the largest networks; however, there are only 126 of these addresses available. Class A addresses are IP addresses that are assigned to network devices, such as computers, and include all addresses in which the first bit of the first octet is set to 0 (zero). This includes all values from 00000001 to 01111111, or 1 to 127.

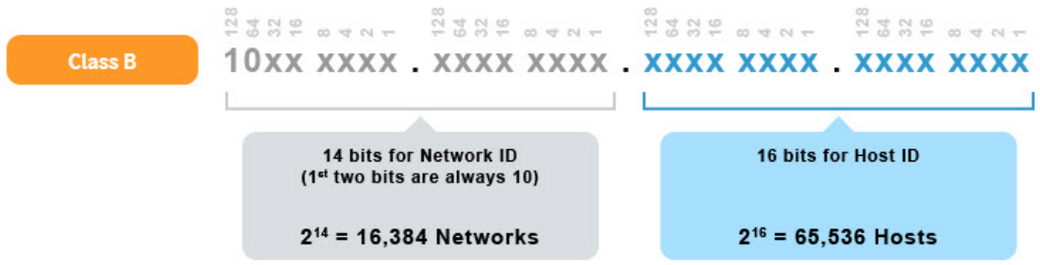


Class A Address

The network ID is not allowed to have all its bits set to 0 or all bits set to 1. The 127 network ID is excluded from this address class. Thus, the first octet ranges from 1 – 126. The default subnet mask for Class A is 255.255.255.x. Due to their size, Class A networks are commonly used by ISP providers.

Class B Address

An IP address which belongs to Class B has the first two bits in the first octet set to 10. Class B IP addresses range from 128.0.x.x to 191.255.x.x. The default subnet mask for Class B is 255.255.x.x. Class B has 16384 (214) Network addresses and 65534 (216-2) Host addresses.



Class B Address

Class C Address

The first octet of a Class C IP address has its first 3 bits set to 110, so Class C IP addresses range from 192.0.0.x to 223.255.255.x. The default subnet mask for Class C is 255.255.255.x.

Class C provides 2097152 (221) network addresses and 254 (28-2) host addresses.



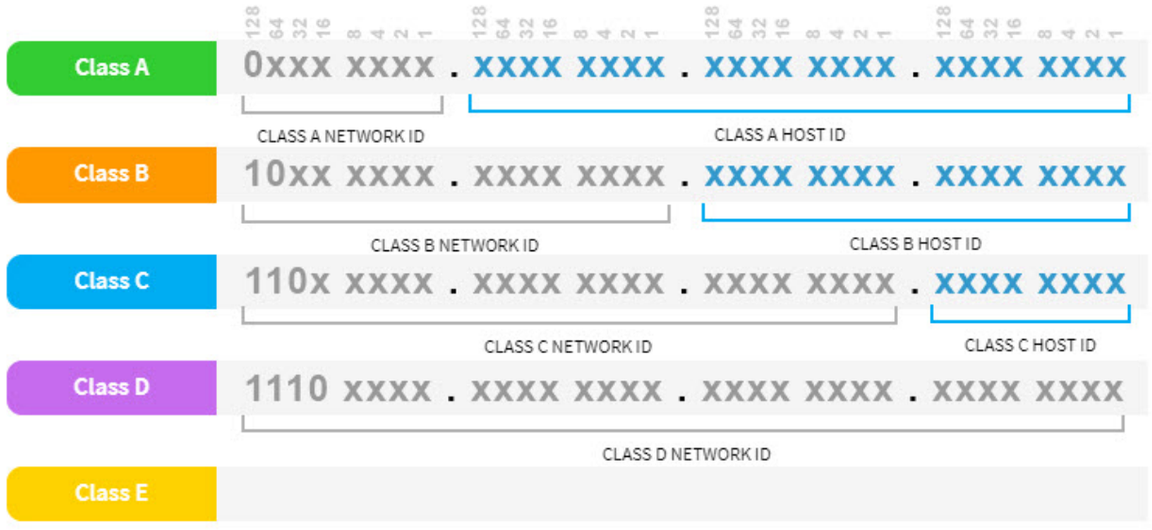
Class C Address

Class D Address

Very first four bits of the first octet in Class D IP addresses are set to 1110, giving a range of 224.0.0.0 to 239.255.255.255. Class D is reserved for Multicasting. Multicasting is the ability to have one stream of data sent to a pre-identified group of devices simultaneously. In multicasting, data is not designated for a particular host, so there is no need to extract a host address from the address. Class D addresses do not require a subnet mask.

Class E Address

This IP Class is reserved for experimental purposes and R&D (Research and Development). IP addresses in this class ranges from 240.0.0.0 to 255.255.255.254. Like Class D, this class does not require a subnet mask.

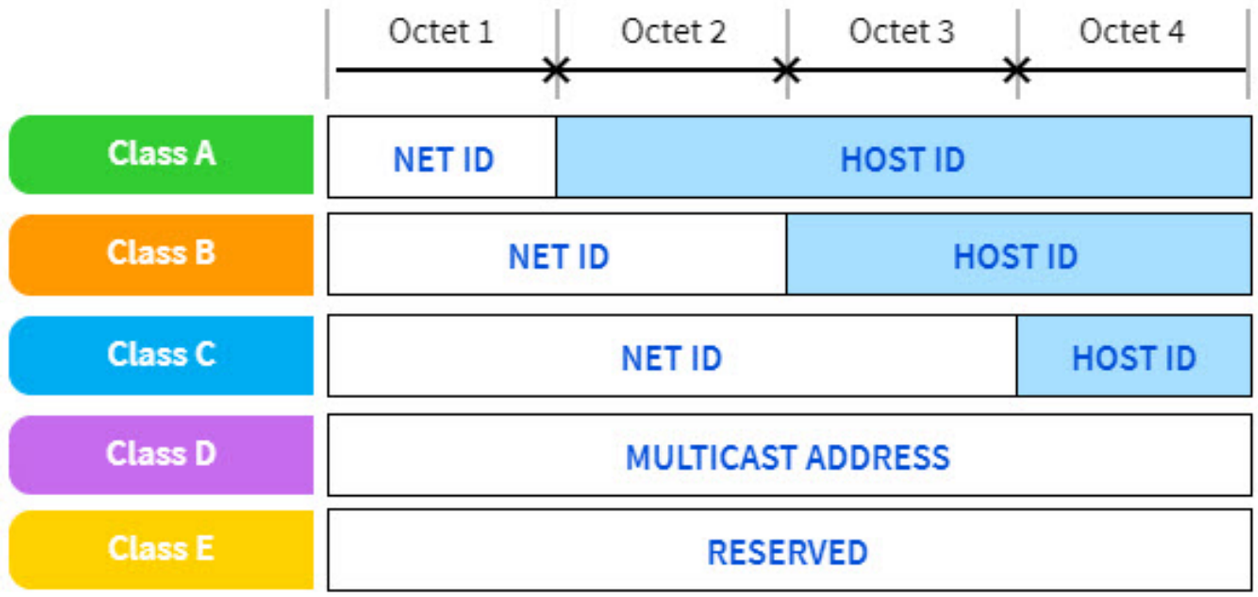


Class E Address

Addresses and Protocols

IP Address Space Allocation

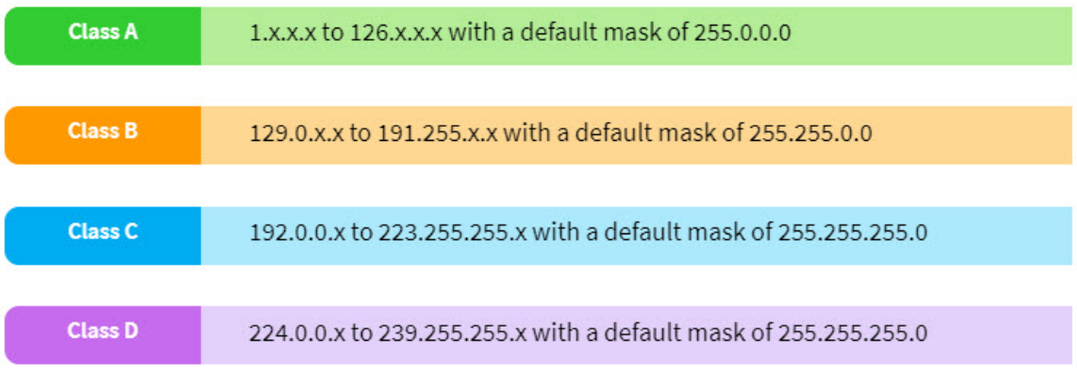
Remember that all IP addresses are 32 bits long. Every eight bits make up an octet. IP addresses are binary numbers but are typically expressed in decimal form (IPv4) or hexadecimal form (IPv6) to make reading and using them easier for humans. All IP addresses have two parts: 1) the network or subnetwork portion identifies the local network; 2) the host address portion identifies a local node for each local network. An IPv4 address is typically expressed in decimal-dot notation, with each octet represented by a number from 0-255 separated by a dot. An example IPv4 address would look like this: 10.30. 230.243 or 170.125.23.9 or 192.168.10.10



IP Address Space Allocation

Subnet Mask

A subnet mask is a number that defines a range of IP addresses available within a network. A single subnet mask limits the number of valid IPs for a specific network. Multiple subnet masks can organize a single network into smaller networks (called subnetworks or subnets). Systems within the same subnet can communicate directly with each other, while systems on different subnets must communicate through a router. A subnet mask hides (or masks) the network part of a system's IP address and leaves only the host part as the node portion of the address. It uses the same format as an IPv4 address. The mask has four sections separated by dots. Each octet can only use one of the following numbers: 0, 128, 192, 224, 240, 248. 252, 254, or 255. For example, a typical subnet mask for a Class C IP address is 255.255.255.0, 255.255.240, or 255.255.128.0.

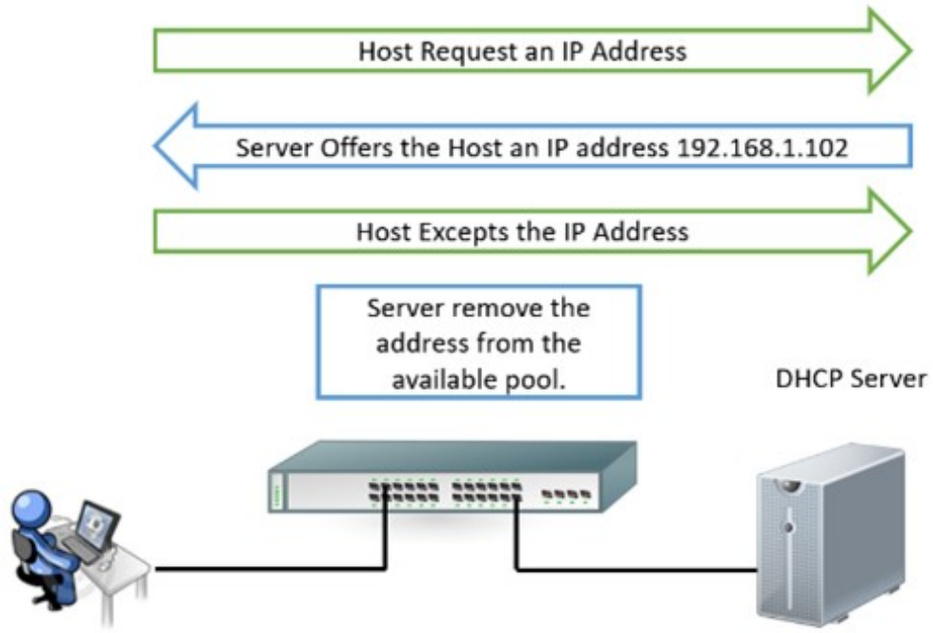


Subnet Mask

Internet Control Message Protocol (ICMP)

The Internet Control Message Protocol (ICMP) is used when information is transferred over a data communication network or Internet. Stations send and receive data using the TCP/IP protocol and ICMP to identify communication problems and test connectivity. If there is a problem with the connection, error and status messages regarding the connection are sent using ICMP, which is part of the Internet Version 4 Protocol. Network devices like routers use ICMP to generate and send error messages to the source IP address when network problems prevent delivery of IP packets. The PING command uses ICMP to test the network connection.

Dynamic Host Configuration Protocol (DHCP)



Dynamic Host Configuration Protocol (DHCP)

Dynamic Host Configuration Protocol (DHCP) is a protocol for assigning dynamic IP addresses to devices on a network. DHCP can provide a different IP address every time a station connects to the network or it can reserve the same address for the network device. All network devices can ultimately use DHCP. Dynamic addressing simplifies network administration because the software keeps track of IP addresses rather than requiring an administrator to manage the task. This means that a new device or piece of equipment can be added to a network without the trouble of manually assigning it a unique IP address. Many industrial environments use dynamic IP addressing for assigning addresses to devices like PLC, sensors, and HMIs.

Public Versus Private IP Addresses

Massive expansion of Internet devices over the last three decades have resulted in a shortage of IP addresses. To address this shortage, the development of reusable addresses called private addressed was introduced. The basic idea is that several ranges of IP addresses were removed from legal use on the global Internet. If these addresses are identified, they are dropped. These addresses could now be dedicated for ONLY internal or private use. This would allow an unlimited number of organizations to use the same private addresses within their private networks. When one of the devices on a private network needs to communicate on the global Internet, the device needs an assigned public address. Network Address Translation (NAT) translates the private IP address to a public IP address.

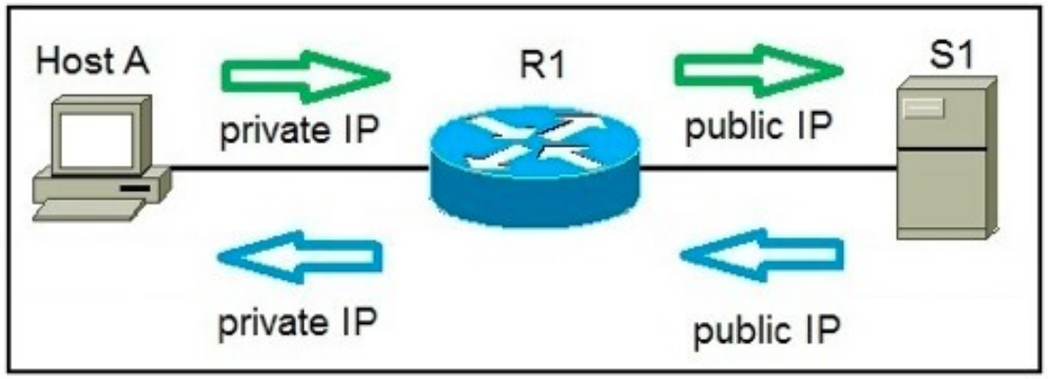
Network Address Translation (NAT)

Network Address Translation (NAT) is the process where an internal device uses a private IP addresses that must be translated to a global public address before accessing the global public Internet. The main use of NAT is to limit the number of public IP addresses an organization or company need due to the limited number available. The NAT protocol reserves public addresses and provides a level of address security. The table below is a list of the Private IP address ranges:

Private NAT Address Ranges		
Class “A”	10.0.0.0 to 10.255.255.255	16,777,216
Class “B”	172.16.0.0 to 172.31.255.255	1,048,576
Class “C”	192.168.0.0 to 192.168.255.255	65,536

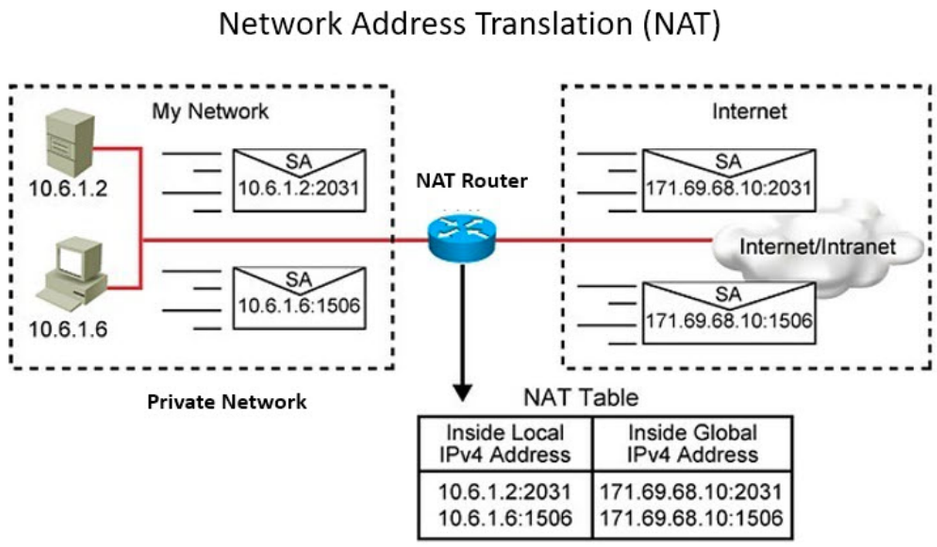
The private addressing scheme works well for computers that only access resources inside the local private network, including access to file servers and printers. Network switches inside the private network can route traffic between nodes inside the private network. However, to access resources outside the private network, like the Internet, devices must be assigned a public address to communicate with nodes in the public network.

This is where NAT comes into play. Internet requests that require Network Address Translation (NAT) are quite complex but happen so rapidly that the end user rarely knows it has occurred.



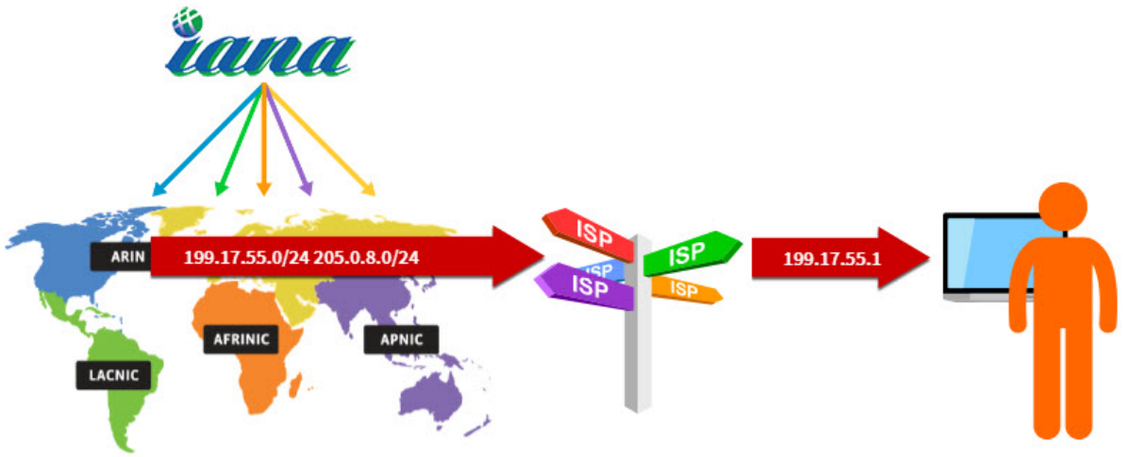
Network Address Translation (NAT)

A device inside a network makes a request to a node on the Internet. Routers within the network recognize that the request is NOT for a resource inside the private network, so they send the request to the router running NAT. The NAT router identifies the private address then translates the internal address to an external public address using a NAT translation table. The request passes through the router and is forwarded to the destination node on the public global network. The response from the destination node is then returned to the NAT router.



Network Address Translation (NAT)

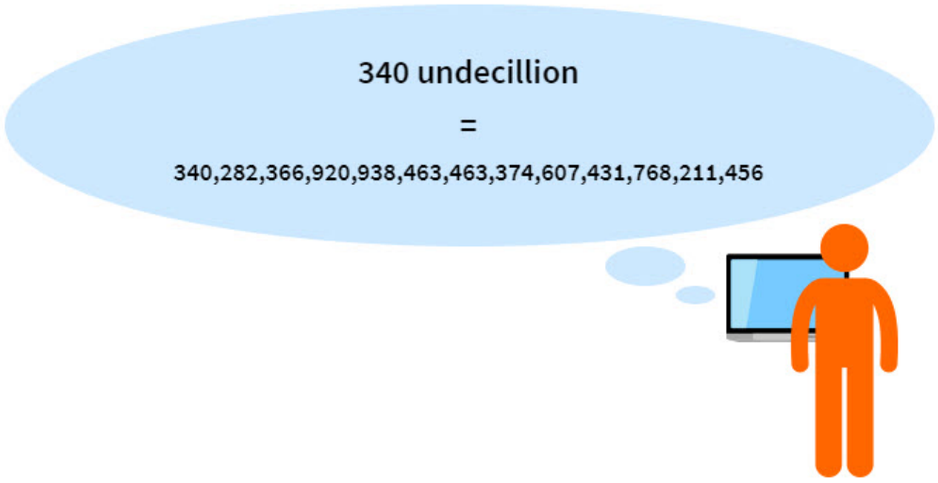
From the perspective of this node, it appears that communication is directly with the source node. When NAT is used in this way, all devices can share one global public IP address or can share a pool of global IP address. That means only one or just a handful of public addresses is needed for hundreds or even thousands of users on a private network.



Network Address Translation (NAT)

IP Version 6 Addresses

IPv6 was developed in the mid to late 90s. It is a 128-bit address space written in hexadecimal and provides 340 undecillion addresses. Compare this to IPv4 which provided 4.29 billion addresses. IP addresses are drawn from the Unallocated Address Number Pool, administered by the Internet Assigned Numbers Authority (IANA). Regional Internet Registries were formed to serve global regions around the world (such as ARIN for North American or LACNIC for Latin America). They allocate and manage the address space for their local region. IP address ranges then make their way to Internet Service Providers (ISP). The ISP assigns the IP address to the end user.



IP Version 6 Addresses

The hexadecimal numeral system (hex) is made up of 16 “digits” (base 16). The standard number system is decimal (base 10) which uses ten “digits”. Hexadecimal uses the ten decimal numbers plus six alpha characters for a total of 16 “digits” (0-9 A-F). IPv6 addresses are 128-bit addresses typically represented in hexadecimal.

Decimal

0 1 2 3 4 5 6 7 8 9

10^5	10^4	10^3	10^2	10^1	10^0
100,000	10,000	1,000	100	10	1

Hexadecimal

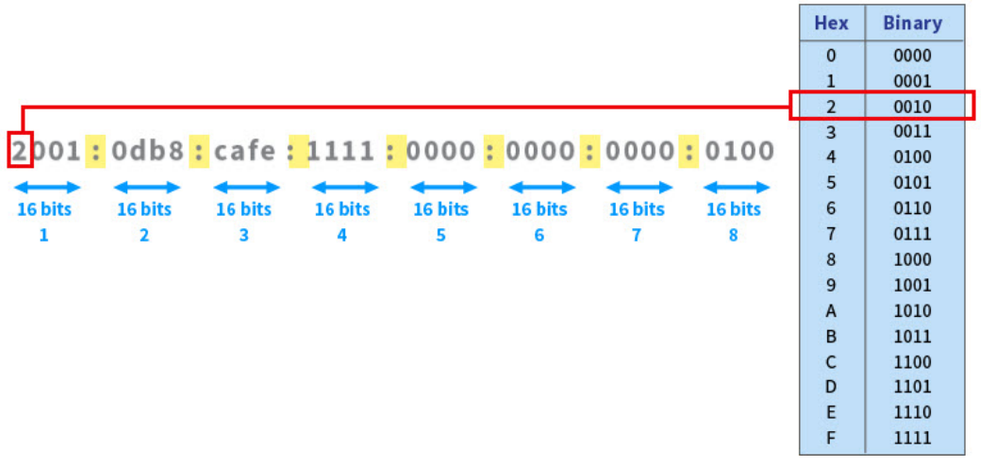
0 1 2 3 4 5 6 7 8 9 A B C D E F

16^5	16^4	16^3	16^2	16^1	16^0
1,048,576	65,536	4,096	256	16	1

Decimal & Hexadecimal

- One hex digit equals 4 bits.
- There are eight 16-bit segments that range between 0000 and FFFF.
- Each 16-bit segment is separated by a colon as depicted in the illustration.

To simplify the entry of IPv6 addresses, the address can be shortened. The reduction of an IPv6 address is known as the compressed format. There are several rules for compressing IPv6 addresses.



Address Simplification

Rule 1 is that any leading zeroes in any 16-bit segment do not have to be written.

Rule 2 is that any single, contiguous string of one or more 16-bit segments that are all zeroes can be represented with a double colon (::). If an IP address contains more than one string of contiguous all-zero segments, the longest string of zeroes must be replaced by the :: and if they are equal, the first string of zeroes uses the :: representation.



Rule 1 & Rule 2

Routers



Routers

Routers are used to interconnect switched networks through remote communication channels. Routers help transmit packets to their destinations by charting a path through the Internet of interconnected networks. Routers are intelligent devices, and they store information about the connections and delivery paths to other networks. Routers can also be used to divide internal networks into two or more subnetworks. Routers use routing protocols to calculate the cost or efficiency of sending information via a specific route or path. Routing protocols are divided into two categories based on how they calculate route cost.

Distance-vector routing protocols determine the best route for data packet delivery based on distance. Distance-vector routing

protocols measure the distance by the number of routers a packet must pass--one router counts as one hop. Distance-vector routing is performed by every router simply broadcasting its entire routing table every thirty seconds. This created excessive network traffic and proved to be very inefficient and unreliable. Routing Interconnect Protocol (RIP) is a distance-vector protocol.

Link-state routing protocols only communicate with directly linked neighbor routers. They only need to send communication to maintain a neighbor relationship and notify neighbors of local link changes in status. Link-state routers are updated from all the routers in the entire network by passing information from a router to the nearest neighbor router. Rather than continuously broadcast its routing tables as does a distance-vector protocol, a link-state protocol router only notifies its neighboring routers when it detects a change. Examples of link-state routing protocols include Open Shortest Path First (OSPF) and Intermediate System to Intermediate System (IS-IS).

Network Firewalls

A network firewall is a network security device that monitors incoming and outgoing network traffic and decides whether to allow or block specific traffic based on a defined set of security rules. A network firewall can be hardware, software, or both. Packet-filtering firewalls, the most common type of firewall, examine packets and prohibit them from passing through if the packets do not match rules within an established security Access Control List (ACL). This type of firewall checks the packet's source and destination IP addresses. If packets match those of an "allowed" rule on the firewall, then the packet is trusted to enter the network.

Stateful Firewalls

Packet-filtering firewalls are divided into two categories: stateful and stateless. Stateless firewalls examine packets independently of one another and lack context, making them easy targets for hackers. In contrast, stateful firewalls remember information about previous traffic and are therefore considered much more secure. Most routers can also serve as firewalls.

Router Versus Firewalls

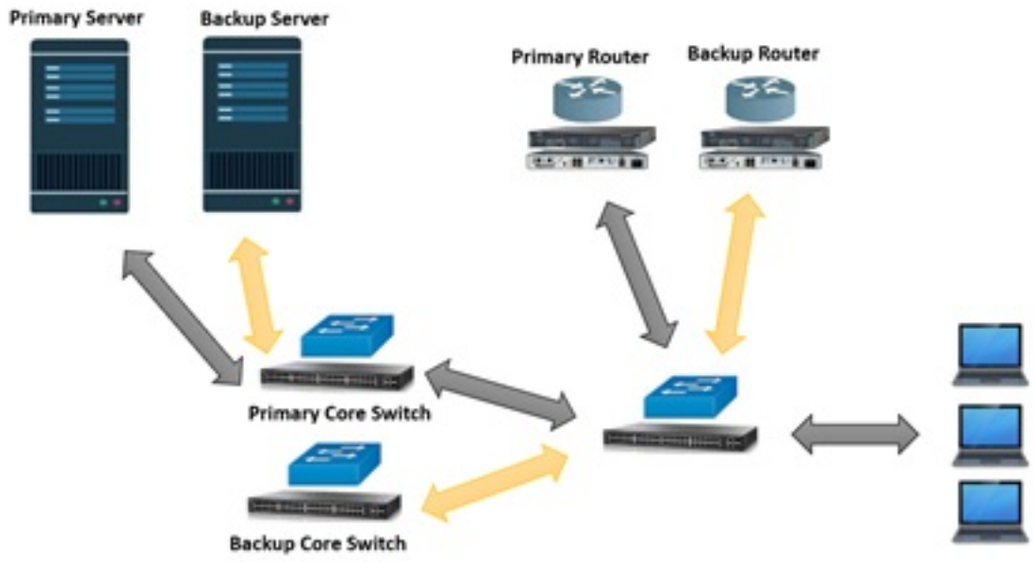
Routers are the first line of defense, and they must be configured to pass only traffic that is authorized by network administrators. The routes themselves can be configured as static or dynamic. If they are static, they are manually configured. Dynamic routers learn routes and rules from other routers around them and use information to build their routing tables and ACLs.



Stateless and Stateful Firewalls

Network Availability

Network availability occurs when the network and devices and equipment connected to the network are available when needed and function properly. Network availability is measured by the average percentage of time during which the network is performing its intended function. The network technical staff must account for natural disasters, power outages, equipment failure and cybersecurity attacks. Building system redundancies increase network availability.



System redundancies to increase availability

Network Redundancy

Network redundancy is the process of adding additional instances of network devices and lines of communication to help ensure network availability and decrease the risk of failure along critical data paths. There are two common forms of network redundancy.

Fault Tolerance

Fault-tolerant redundant systems provide full hardware redundancy by mirroring applications across two or more identical systems that run in tandem. When properly designed and installed, fault-tolerance will maintain service should anything go wrong with the primary system since the backup systems will take over with no loss of service. Fault tolerance is ideal for an operation in which any amount of downtime is unacceptable (such as an industrial or manufacturing setting). Fault-tolerance redundant systems are complex and often expensive to implement.

High Availability

A software-based, high-availability redundant system uses clusters of servers that monitor one another and have failover protocols in place. If something goes wrong with one server, the backup servers take over and restart applications that were running on the failed server. This approach to network redundancy requires less infrastructure and is less expensive. This type of redundancy can result in temporary disruptions.



Section 3

Layer 2 – Data Link Layer

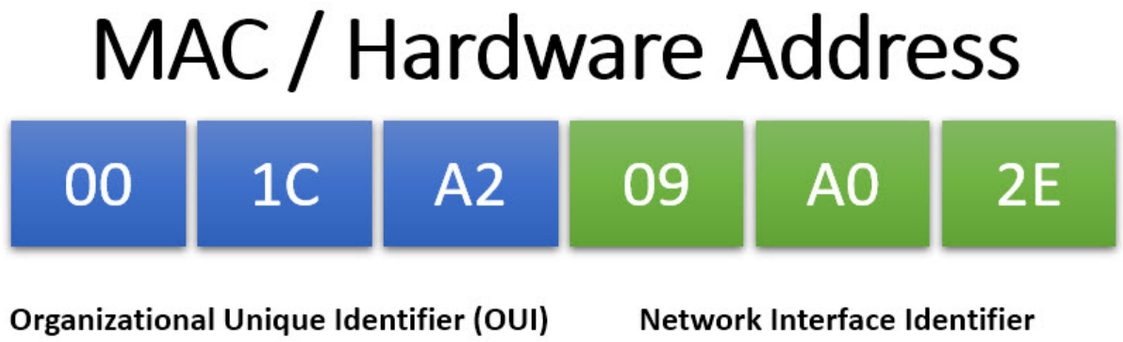
When building a network in a manufacturing environment, the Data Link Layer solutions are some of the most complicated decision an organization must consider. Traditional information networks are based on the very popular Ethernet standard and TCP/IP protocols. Most industrial and manufacturing networks are transitioning to the Ethernet standard and variations of the TCP/IP protocols. These standards allow for great integration with information systems and communication including access to the Internet. The Data Link Layer consists of two sublayers: the Media Access Control (MAC) sublayer and the Logical Link Control (LLC) sublayer. The MAC sublayer controls device interaction and media access control. The LLC sublayer deals with building frames, addressing, and multiplexing. The Data Link Layer is responsible for the node to node delivery of the message. It uses a 48-bit hardware or MAC address to communicate. The main function of this layer is to make sure data transfer is error-free from one node to another, over the local physical layer. When a packet arrives in a network, it is the responsibility of this layer to transmit it to the host using its MAC address. The packet received from the Network Layer is further divided into frames depending on the frame size of the network interface card (NIC). The LLC sublayer encapsulates the sender and receiver's information and MAC addresses in the frame fields or header.

Address Resolution: Address Resolution Protocol (ARP) is a network protocol used to discover the hardware or MAC address of a device from an IP address.

Address Resolution Protocol is used when a device wants to communicate with some other device on a local network but does not know the device's MAC address. The sending device uses ARP to translate IP addresses to MAC addresses. The device sends an ARP broadcast request that contains the IP address of the receiving device. All devices on a local network segment see the message, but only the device that has that IP address responds with the ARP reply message. The reply will contain the destination machine's MAC address. The sending device now has the MAC address which it stores in a table (the ARP table) and can send the packet to the destination station. ARP request packets are sent to the broadcast addresses (FF:FF:FF:FF:FF:FF for the Ethernet broadcasts and 255.255.255.255 for the IP broadcast).

Framing: Framing is a function of the Data Link Layer. It provides a way for a sender to transmit a set of bits that are meaningful to the receiver. This can be accomplished by attaching special bit patterns to the beginning and end of the frame.

Physical addressing: After creating frames, the Data Link Layer adds the physical addresses (MAC address) of sender and/or receiver in the header of each frame. The address is forty-eight bits in length. The address is typically represented by twelve hexadecimal digits. The first six are assigned to the manufacturer of the device. The final six are assigned to the device's interface to provide global uniqueness.



Physical addressing

Error control: The Data Link Layer provides the mechanism of error control in which it detects and retransmits damaged or lost frames.

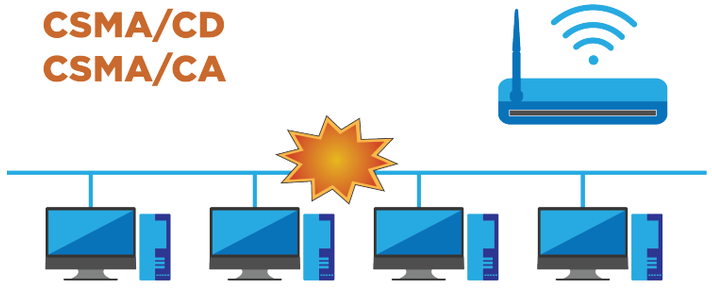
Flow Control: The data rate must be constant on both sides or the data may get corrupted. Flow control coordinates that amount of data that can be sent before receiving acknowledgement.

Access control: When a single communication channel is shared by multiple devices, the MAC sub-layer of the Data Link Layer helps to determine which device has control over the channel at a given time.

Layer 2 Services and Protocols

The MAC sublayer is responsible for media access control or MAC methods. A media access control method refers to how data moves from one network device to another and how the network device gains access to the media and controls the transfer of data packets over the network. The most important factor here is to ensure proper and timely delivery of the data

packets without collisions, interference, or errors. The two most common types of network access control are Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).



Collision Detection and Collision Avoidance

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

This is a media access method which defines how devices gain access to the media (cable or wireless) to send or receive data. Carrier Sense Multiple Access with Collision Detection requires each station on the LAN (Local Area Network) to continually listen to (test) the cable for the presence of a signal prior to transmitting. Multiple access means that there are many devices attempting to transmit and compete for the opportunity to send data (i.e., they are in contention). If no signal is detected, devices can access the media to send data. This can result in two or more stations sending data at the same exact time resulting in a data collision on the cable. Collision Detection means that when a collision is detected, the stations will stop transmitting and wait a random length of time before retransmitting the data. Because CSMA/CD works to control or manage collisions rather than prevent them, network performance can be degraded with heavy data traffic. More traffic will lead to a greater number of collisions and retransmissions in a network. CSMA/CD is used on Ethernet networks.

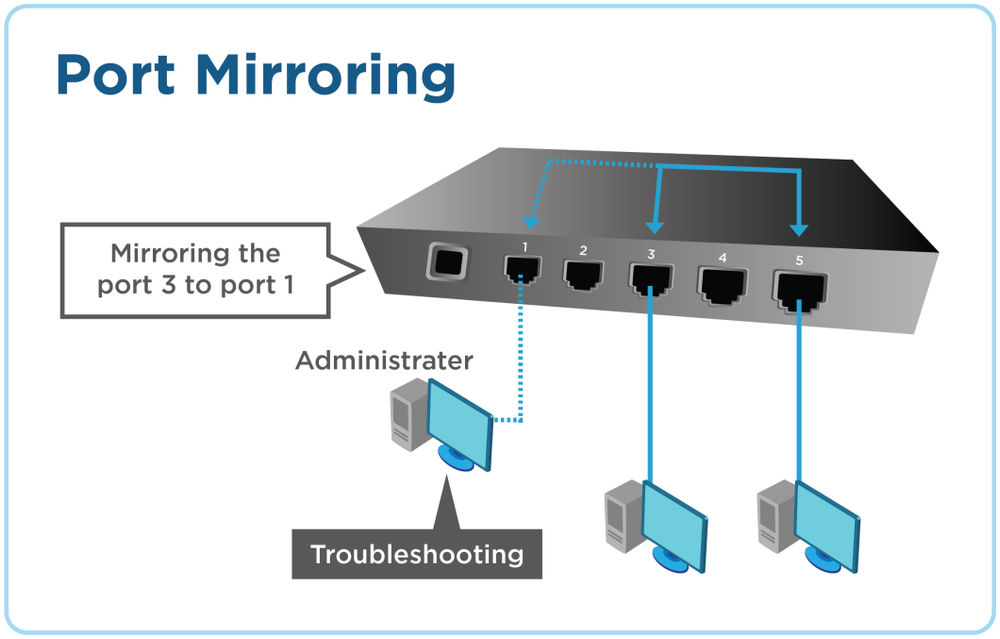
Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) is a media access method very similar to CSMA/CD. The difference is that the CD (collision detection) is changed to CA (collision avoidance). Instead of detecting and reacting to collisions, CSMA/CA tries to avoid them by having each device signal its intention to transmit before transmitting. In effect, the transmitting device gives a “Request” prior to transmitting. Although CSMA/CA can prevent collisions, it comes with a cost in the form of the additional overhead incurred by having each workstation broadcast its intention prior to transmitting. Thus, CSMA/CA is slower than CSMA/CD. CSMA/CA is used on wireless networks.

Port Mirroring

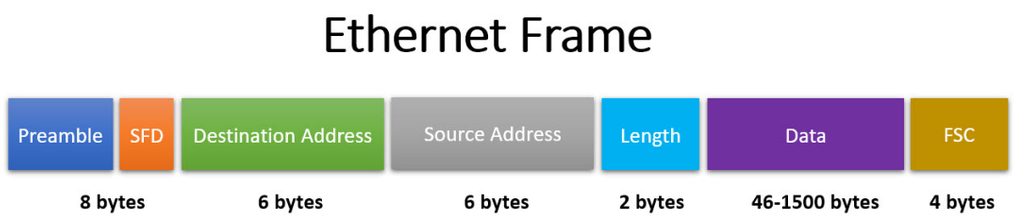
Port mirroring is a technique of copying and sending network packets transmitted as input from a port to another port of a switch. It is a network monitoring technique implemented on network switches to capture and analyze traffic to or from a

system under attack. This feature enables network administrators to protect the network and collect evidence for audits or law enforcement investigations.



Mirroring port 3 to port 1

Ethernet Protocol



Ethernet protocol

Ethernet is a local area network set of protocols which serves the physical and data link layers. Ethernet operates on a bus or star topology. The Ethernet protocols define the cable properties, bandwidth, and the framing of data. The frame construction formats data before it is transmitted across the wire or through the airwave. The format is used to synchronize the communication between the sender and receiver station, address the data with source and destination MAC addresses, define the amount and type of information being sent and test for errors during communications.

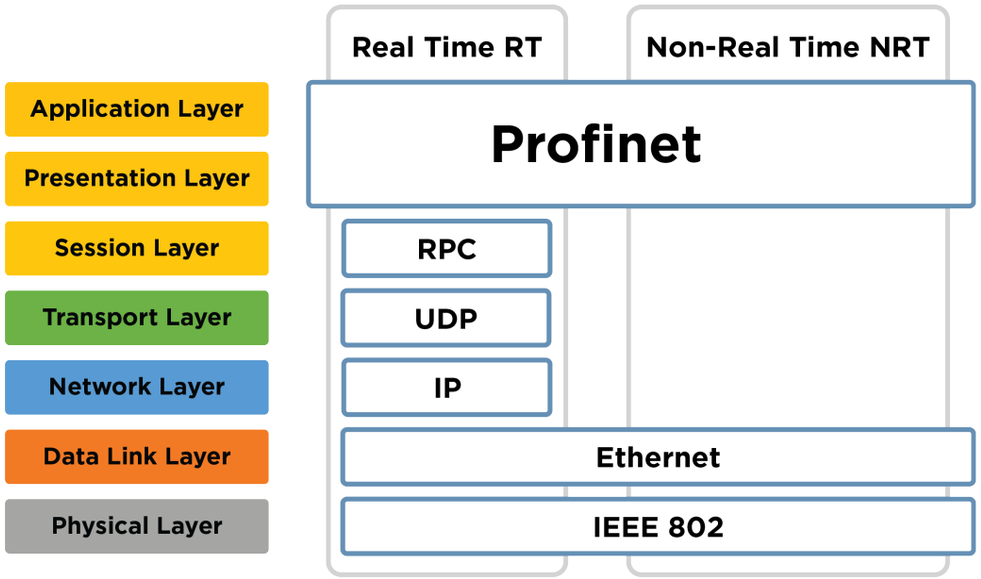
Legacy Industrial Communication Protocols

Legacy industrial communications networks were built on an assortment of serial-based interfaces originally created by different companies and manufacturers for their specific devices and equipment. Many of the protocols became de-facto standards in the industry. This resulted in a very complex and incompatible collection of network devices. Industrial automation equipment companies were compelled to implement many of these protocols to allow integration of their products. These serial-based protocols, including PROFINET, are an industry technical standard for data communication over Industrial Ethernet, designed for collecting data from, and controlling equipment in industrial systems, with a particular strength in delivering data under tight time constraints.

PROFINET

PROFINET became one of the leading Industrial Ethernet Standards in the market. This technology is supported by many product vendors. PROFINET IO is one of two open Ethernet

standard automation “views” developed by Profibus. The PROFINET IO protocol focuses on data exchange between Programmable Controller, PROFINET CBA (Component Based Automation) is intended for distributed automation systems. PROFINET can operate using different channel communications.



Profinet

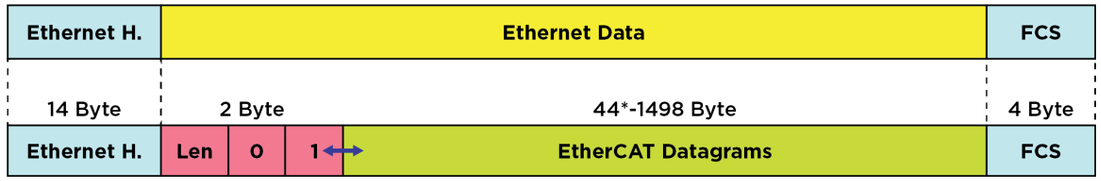
Real Time (RT) Channel

Delays or latency can create problems in a “real time” (RT) industrial automation protocol. PROFINET supports the “Real Time” channel to reduce communication delay. The RT channel skips the encapsulation steps in the Network, Transport and Session layers. This means that the frames exchanged over the RT channel have low latency; however, there is no IP address. And that means that RT frames cannot be routed between LANs.

Non-Real Time (NRT) Channel

Inability to route packets can be a real problem on large networks. To address this issue PROFINET supports a “Non-Real Time” (NRT) communication channel. It uses all the layers of the OSI (Open Systems Interconnection) model and provides an IP addresses for routing between networks. This allows PROFINET supervisors to access devices from across network boundaries and even over the Internet.

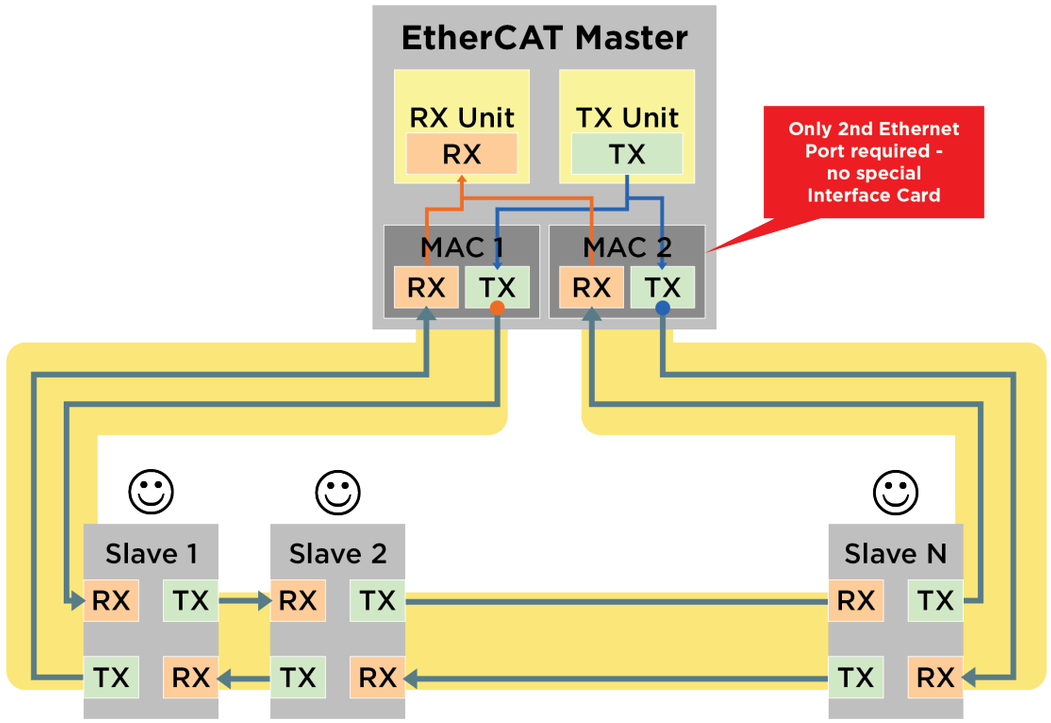
EtherCAT



EtherCAT

EtherCAT is considered a fast, low cost, and flexible Ethernet network protocol. It consists of a master with several slaves. It can deliver real-time Ethernet communications to automation applications. EtherCAT is scalable and can provide connectivity for entire automation systems, from PLCs all the way down to the I/O and sensors. EtherCAT can support up to 65,535 nodes in a system. An important feature of EtherCAT is that it is optimized for processing data and using standard IEEE 802.3 Ethernet frames. Each node processes its datagram and inserts the data into the Ethernet frame. EtherCAT is hardware based at the MAC layer, so it results in minimum processing latency, enabling a fast response time. Since EtherCAT is a MAC layer protocol and is transparent to the higher-level protocols such as TCP/IP, UDP,

Web server, etc. The EtherCAT protocol is based on a master/slave design that supports cabling redundancy in a ring configuration.

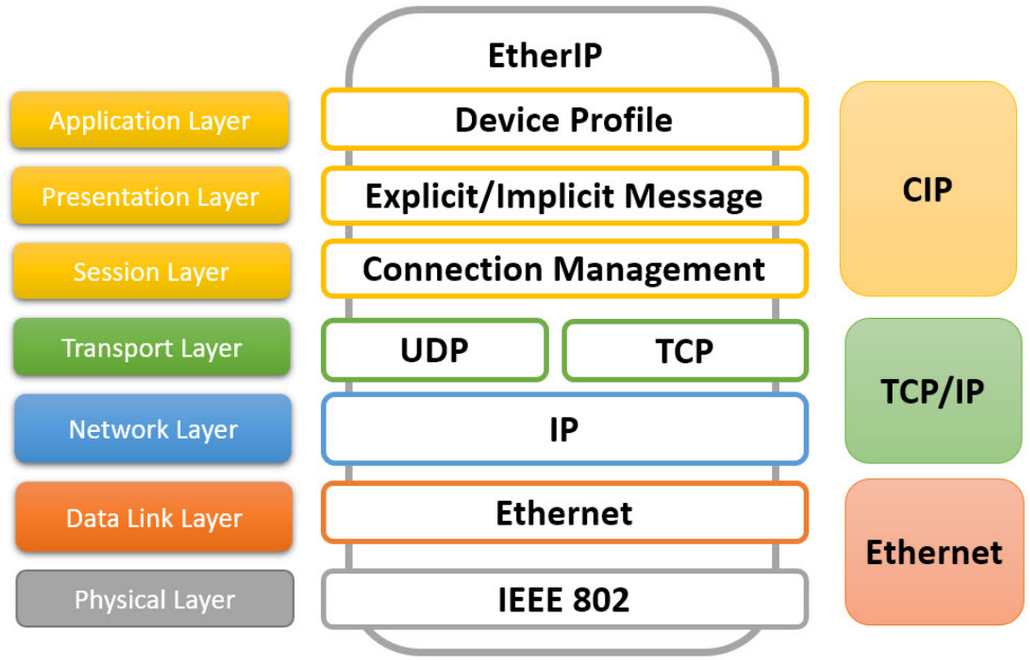


EtherCAT Master

EtherNet/IP

EtherNet/IP is another industrial Ethernet protocol originally developed by Rockwell Automation and now managed by the Open DeviceNet Vendors Association (ODVA). EtherNet/IP uses standard Ethernet with switches; it can have an unlimited number of nodes in a system. Unlike EtherCAT, which is a MAC-layer protocol, EtherNet/IP is an application-layer protocol built on top of TCP/IP. EtherNet/IP uses standard Ethernet physical, data link, network, and transport layers, while using the Common Industrial Protocol (CIP) on top of TCP/IP.

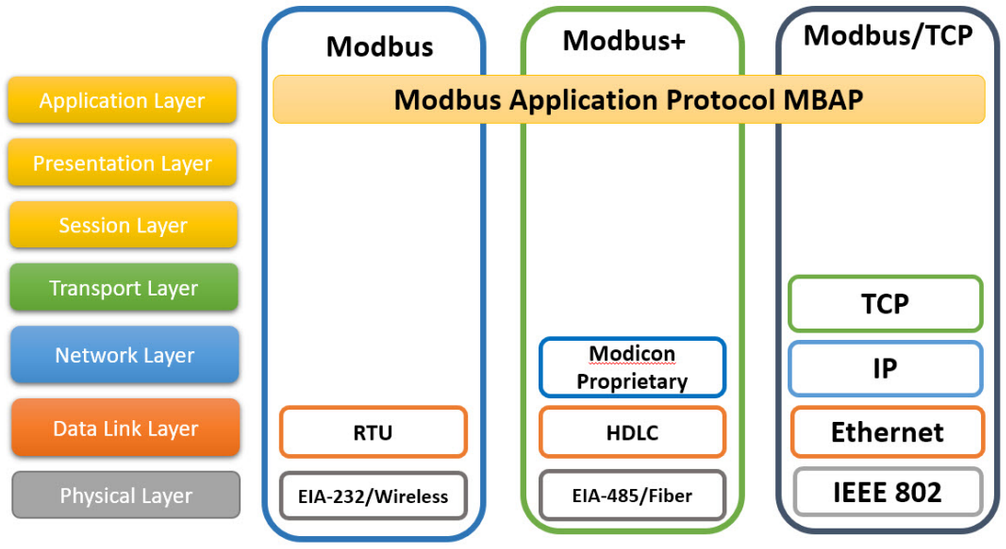
Common Industrial Protocol provides a common set of messages and services for industrial automation control systems. Common Industrial Protocol where it can be used with multiple physical layer media. EtherNet/IP establishes communication from one application node to another through CIP connections over a TCP connection. Ethernet/IP can establish multiple CIP connections over one TCP connection. This enables one network across many different end points in a factory floor.



EtherIP

Modbus

Modbus is a data communications protocol originally published by Modicon in 1979 for use with its programmable logic controllers. Modbus has become a de facto standard communication protocol and is now a commonly available means of connecting industrial electronic devices. There are three different implementations of Modbus: Modbus, Modbus+ and Modbus TCP. As Modbus evolved, it would incorporate more compatibility with traditional TCP/IP networks.



Modbus

MODBUS TCP/IP is a variant of the MODBUS family intended for supervision and control of automation equipment. Specifically, it covers the use of MODBUS messaging in an ‘Intranet’ or ‘Internet’ environment using the TCP/IP protocols. The most common use of the protocols at this time are for Ethernet attachment of PLC’s, I/O modules, and ‘gateways’ to other simple field buses or I/O networks.

Spanning Tree Protocol (STP)

Industrial data communication networks depend on a high level of reliability. One of the most important network protocols that enable reliability is the Spanning Tree Protocol (STP). Spanning Tree Protocol is a network protocol that builds a reliable loop-free and redundant logical networks. The basic function of STP is to prevent switching loops which are created when multiple pathways or connects are created in a network. The STP algorithm identifies redundant pathways and automatically place the redundant pathways in standby until needed. This action is needed to prevent loops from causing broadcast storms and making the MAC address table unstable. All modern-day switching device support the Spanning Tree Protocol (STP).

Understanding How STP Works

Spanning Tree Protocol was defined by IEEE 802.1D, and the purpose is to provide loop-free switch operations and still support redundancy in LAN design. Switching devices running STP exchange information with one another to discover loops on the network, and then block certain redundant links to eliminate the loops. If an active link fails, STP activates a running standby link with the highest priority to ensure network connectivity. As the scale of LANs continues to grow, STP has become an increasingly important LAN protocol. Spanning Tree Protocol

Algorithm elects a Root Bridge, Root Port, and Designated Port. These are determined by things like MAC addresses, bandwidth or manual STP priority settings.

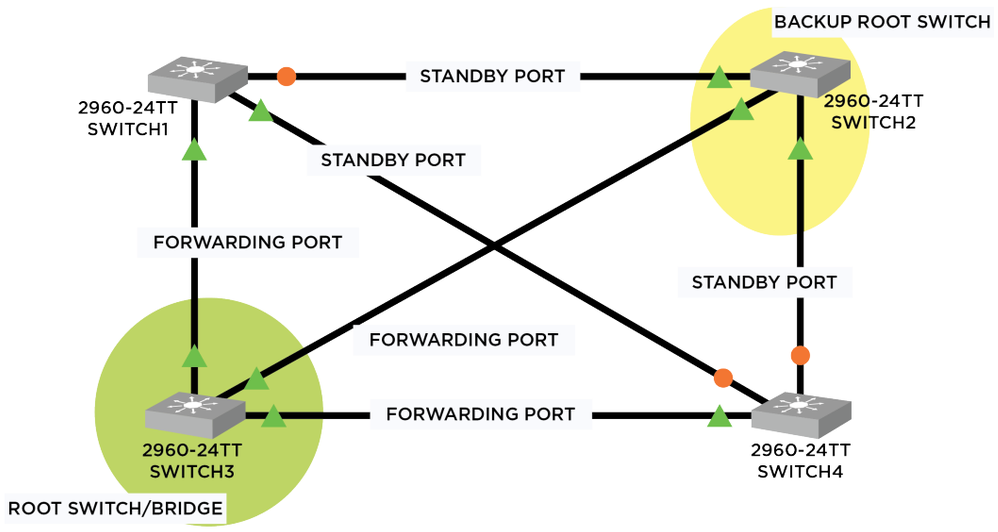
Root bridge: There is only one root bridge on the entire STP network. The root bridge is the logical center not necessarily the physical center of the network. Typically, the root bridge should have high performance and be located at a higher layer of the network. When the network topology changes, the root bridge will be re-elected accordingly. It is recommended that you manually configure the root bridge and secondary root bridge by setting the priority value as the lowest on the network. Configure an optimal core switch as the root bridge to ensure stability of the STP Layer 2 network.

Root port: The root port on an STP device has the smallest path cost to the root bridge and is responsible for forwarding data to the root bridge. Among all STP-capable ports on a device, the port with the smallest root path cost is a root port. This can be done manually or automatically by bandwidth and MAC address. An STP device has only one root port, and there is no root port on the root bridge.



Section 4

Layer 1 - Physical Layer



Physical Layer

The first and lowest layer of the OSI reference model is the physical layer. It is responsible for the physical connection between the devices. The physical layer contains information in the form of bits. It is responsible for transmitting individual bits from one node to the next. When receiving data, this layer will get the signal received and convert it into 0s and 1s and send them to the Data Link layer, which will put the frame back together. The functions of the physical layer include:

Bit synchronization: The physical layer provides the synchronization of the bits by providing a clock. This clock controls both sender and receiver thus providing synchronization at bit level.

Bit rate control: The Physical layer also defines the transmission rate or agreed upon transmission speed or the number of bits sent per second.

Physical topologies: Physical layer specifies the way in which the different, devices or nodes are arranged in a network. The node may be connected by a cable or wireless signal. The wire topologies would include bus, star, or mesh topology.

Transmission mode: Physical layer also defines the way in which the data flows between the two connected devices. The various transmission modes possible are: Simplex, half-duplex and full duplex.

Protocols

In data communications and networking, a protocol is a set of rules for formatting or processing data. Network protocols can also define the physical attributes or process that must be performed to operate the network. Network protocols are like a common language for computers. The computers within a network may use vastly different software and hardware; however, the use of protocols enables them to communicate with each other regardless.

TCP header:

00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Source Port																Destination Port															
Sequence Number																															
Acknowledgment Number																															
Data Offset				reserved				ECN				Control Bits				Window															
Checksum																Urgent Pointer															
Options and padding :::																															
Data :::																															

Protocols

A list of communication protocols is maintained at http://networksorcery.com. This website defines each protocol and provides a description of the encapsulation of the most common networking protocols.

Network Standards

Networking standards ensure the interoperability of networking technologies by defining the rules of communication among networked devices. Networking standards are developed and exist to ensure products from different vendors can work together in a network without risk of incompatibility. Standards are developed by different standards organizations. These organizations can be created by professional organizations like the Institute of Electrical and Electronics Engineers (IEEE), industry groups like the International Telecommunication Union (ITU) which is made of telecommunication policy makers and regulators, network operators, equipment manufacturers. Standards organizations can also be government lead like the American National Standards Institute (ANSI); which serves as administrator and coordinator of the United States private-sector voluntary standardization system. There are also international standards organizations like the International Organization for Standardization; which is an international standard-setting body composed of representatives from various national standards organizations. The organization promotes worldwide proprietary, industrial, and commercial standards including the OSI model.

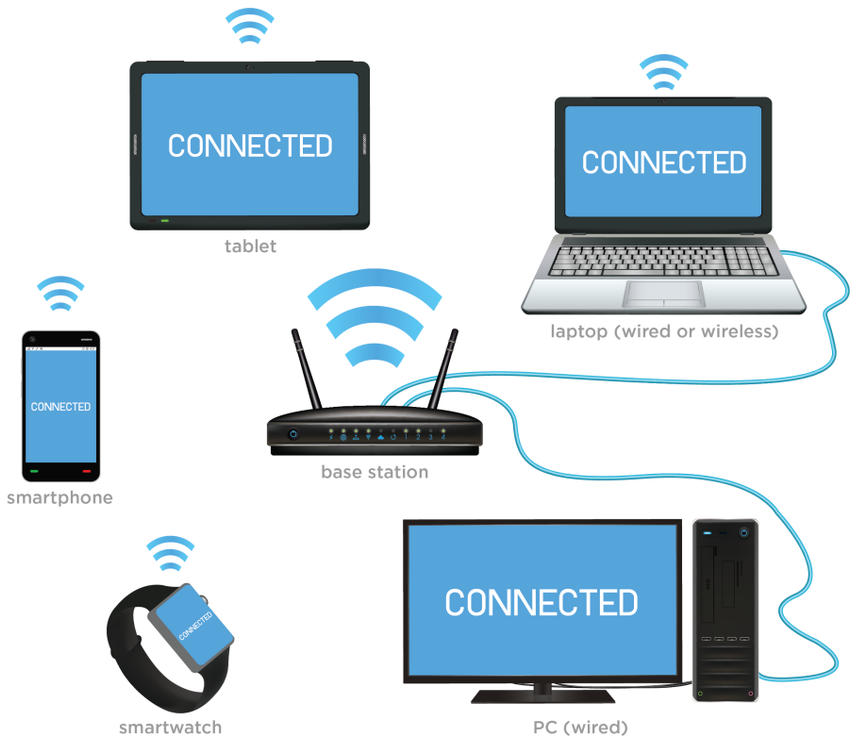
Network Types

There are several different types of communication networks in today's highly connected world. These communication networks can be described by their size as well as their purpose. The size of a network can be expressed by the geographic area they can cover, or the number of devices supported. Networks can cover anything from a handful of devices within a single room to millions of devices spread across the entire globe. Today's manufacturing technical workforce may need working knowledge of each of

these networks. In general, communication network fall into these categories:

- Personal area network (PAN)
- Home area networks (HAN)
- Local area network (LAN)
- Metropolitan area network (MAN)
- Wide area network (WAN)

Personal Area Network



PAN

A personal area network, or PAN, is a computer network that enables communication between devices near a person. PANs can be connected by wired, such as USB or FireWire, or they can be wireless, such as Wi-Fi, Bluetooth, ZigBee, Radio-frequency identification (RFID), and ultrawideband (UWB). Each of these technologies are different but can be mixed and matched to form a PAN. Typically, the range of a PAN is just a few meters from the user.

Home Area Network (Smart Home)

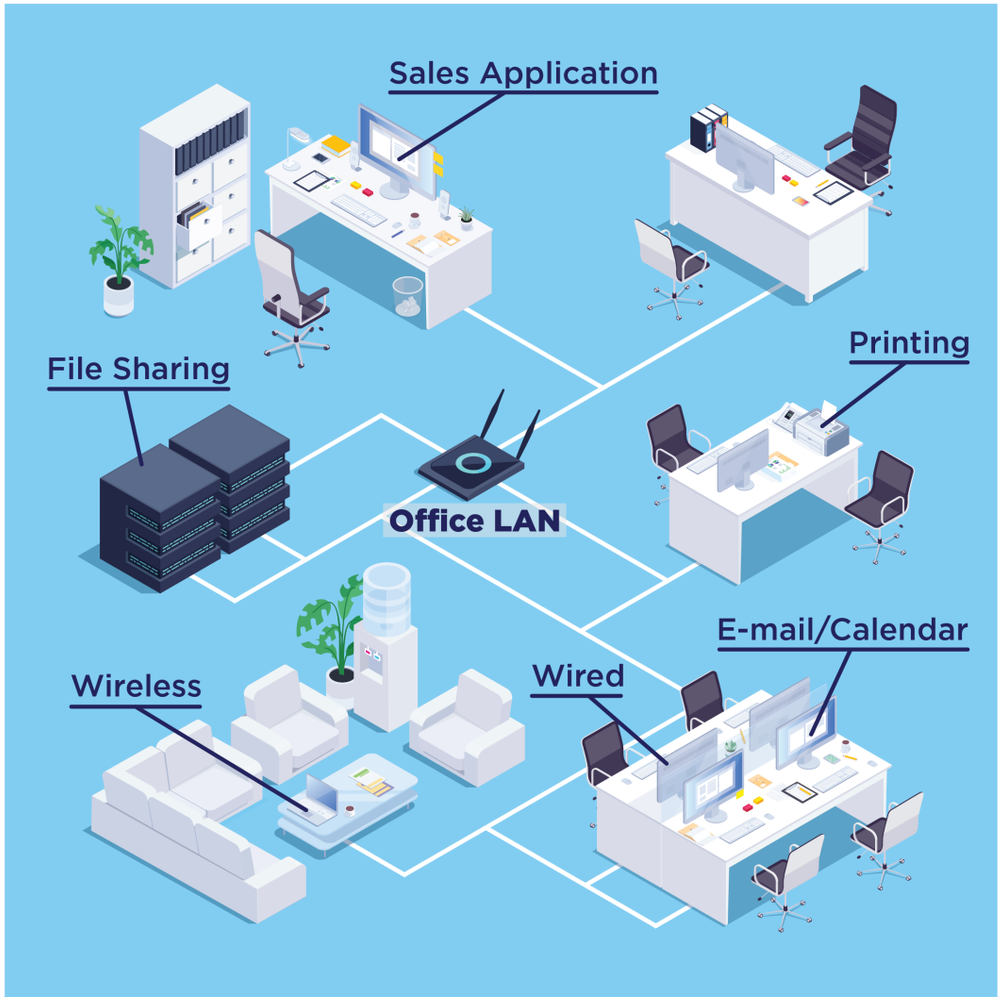


HAN

With the innovation of new smart home technologies many PANs are now used by multiple people in the home and have become known as Home Area Networks (HAN). A home area network (HAN) is a network contained within a the home and typically connects a person's digital devices, from computers, printers, audio systems, phones, personal peripheral devices, televisions, video games, cameras, thermostats, lights, door locks, video doorbells, smart garage doors, home security systems, smart appliances, and other digital devices that are controlled and monitored in a smart home.

Local Area Network

A local area network consists of a device at a single site, typically an individual office building, plant floor and facility like a library. A small LAN may only connect a handful of devices, while larger enterprise LANs can accommodate thousands of computers. LANs are typically used for single sites where people need to share resources among themselves but not with the rest of the outside world. LANs can be wired with cable, hubs switches and routers, or be connected using wireless technology Wi-Fi or 802.11 using access points of wireless routers. Most LANs combine wired and wireless devices to provide maximum performance and convenience. A local area network is typically designed to provide digital communications and to sharing resources, such as stored data, access to printers. They are also used to provide organizational services like email, file sharing, streaming video, electronic processes like payroll, inventory control and accounting.

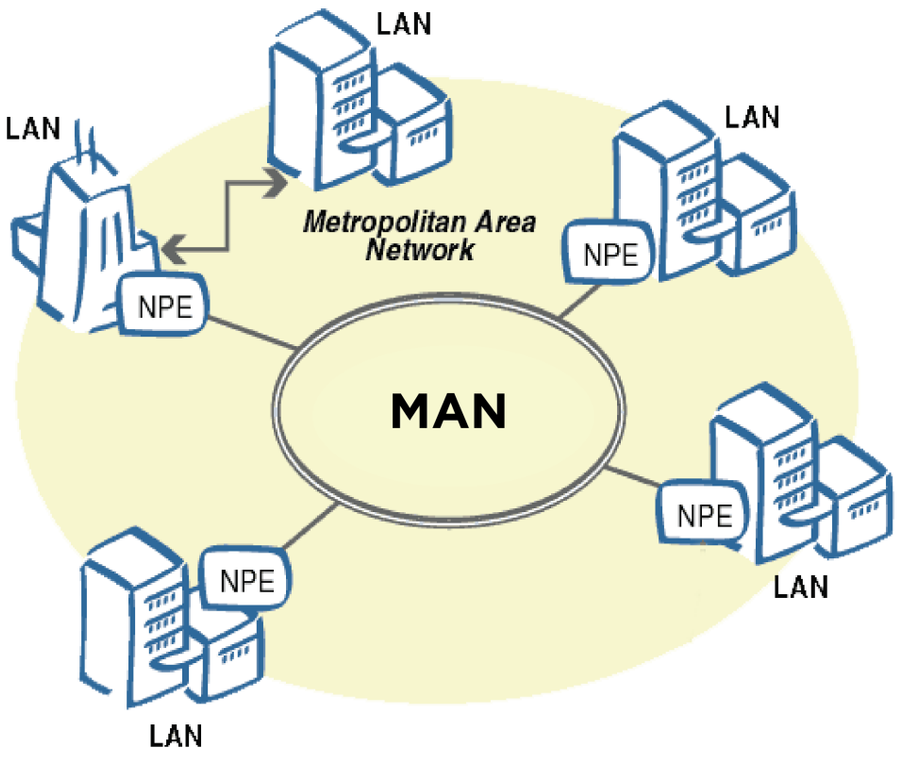


LAN

Metropolitan Area Network

A metropolitan area network, or MAN, is typically formed by the connection of several local area networks across an entire region or city. Like LANs, a Metropolitan area network can use wired and wireless technologies. A MAN will connect different facilities with high speed services to meet the organization needs to share

resources and better manage organizational needs. They are normally designed to support many users from different locations. A MAN is typically used to share common resources with a regional organization like a regional library systems or water treatment facilities that serve a county or township. Depending on the configuration, this type of network can cover an area from several miles to tens of miles. A MAN is often used to connect several LANs together to form a bigger network administered by a central office.



MAN

Wide Area Network

A wide area network, or WAN, occupies a very large area, such as an entire country or the entire world. A WAN can contain multiple smaller networks, such as LANs or MANs. The Internet is the best-known example of a public WAN. Wide Area networks are frequently established by service providers to better connect businesses, schools, governments, or the public. These organizations can use the network to relay and store data or communicate with other users and are not limited by geographic limitations if they have access to the established WAN. WANs are essential for international organizations; WANs allow them to carry out their daily tasks without delay. Employees from anywhere can use a business's WAN to share data, communicate with coworkers or simply stay connected to the greater data resource center for that organization.



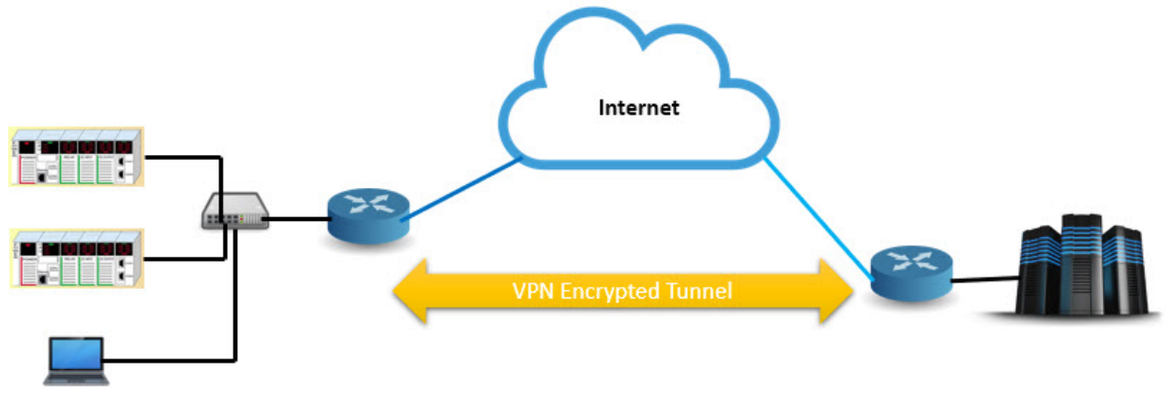
Section 5

Purpose of Special Networks

In terms of purpose, many networks can be considered general purpose, which means they are used for everything from sending files to a printer to accessing the Internet. Some types of networks, however, serve a very particular purpose. These networks are critical to build and support networks in manufacturing environments. These networks based on their purpose include:

- Storage area network (SAN)
- Enterprise private network (EPN)
- Virtual private network (VPN)

Storage Area Network (SAN)



Storage Area Network (SAN)

Storage area networks are found in many manufacturing facilities. A storage area network (SAN) is a dedicated high-speed network or subnetwork that interconnects and provides access to shared pools of storage devices use users or services on a network.

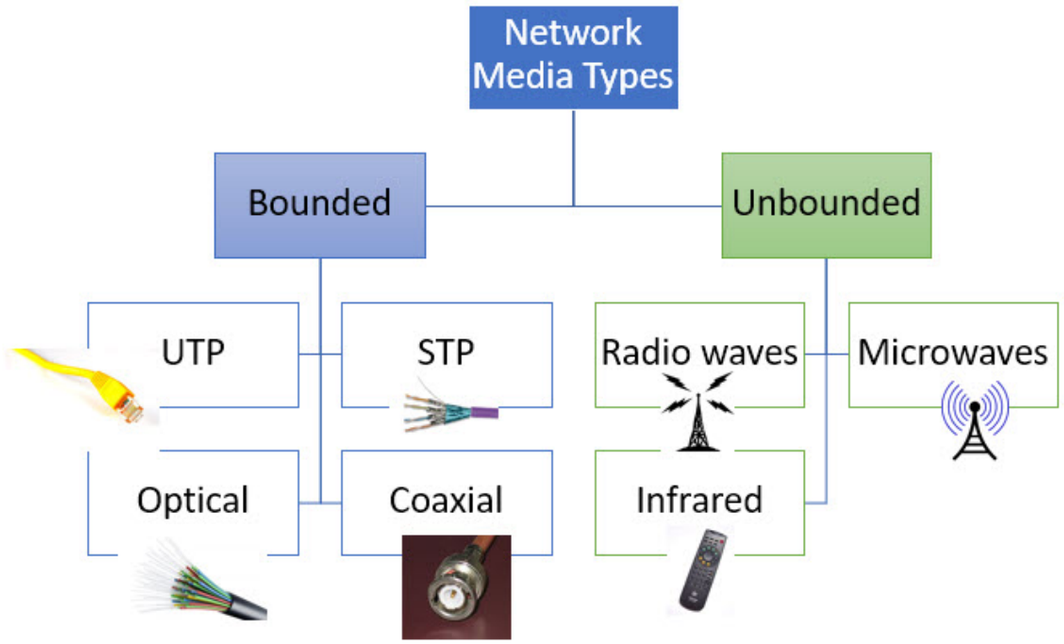
SANs are primarily used to access storage devices, such as disk arrays and tape libraries from servers so that the network devices can access and utilize these storage resources.

Virtual Private Network (VPN)

A virtual private network, or VPN, plays an important role in connecting remote users and connects one facility to another in a geographically different location. VPNs provide secure remote communication using an encrypted connection over the Internet from a device to a network or from one network to another network. The encrypted connection helps ensure that sensitive data is safely transmitted. It prevents unauthorized people from eavesdropping on the traffic and allows the user to conduct work remotely.

Network Media Types

Network media refers to the actual path or communicational channels over which an electrical signal travels as it moves from one device to another. The most common types of network media include twisted-pair cable, coaxial cable, fiber-optic cable, and wireless. Most modern data communication networks in manufacturing facilities require a combination of these media.



Media types

Twisted Pair Cable

Twisted pair cabling is by far the most common type of cabling used in communication networks. At some point, all networks require some wired cabling and most of the time twisted pair cabling is the media of choice. Twisted pair cabling is a type of wiring in which two conductors of a single circuit are twisted together for the purposes of improving electromagnetic compatibility. This is an inexpensive solution that is easy to install and can be used to connect most hard-wired devices. Twisted pair cabling comes in two designs, shielded and unshielded.

Shielded Twisted Pair (STP) Cabling

Shielded twisted-pair cable wraps the signal-carrying wires in a conducting shield as a means of reducing the potential for electromagnetic interference.

The signal-carrying wires typically consist of four pairs of wire twisted together. The pairs are normally colored orange, green, blue, and brown. The shielding is made of a metal foil. Some STP cable will have an additional foil that wraps around all four pairs as well. This type of cabling is more expensive the unshielded twisted pair cabling but has better immunity to possible electro-magnetic interference. It is required in faculties that have many sources of electrical magnetic interference like factory floors.

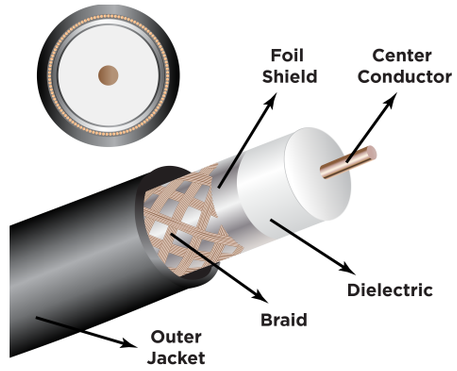
Unshielded Twisted Pair (UTP)

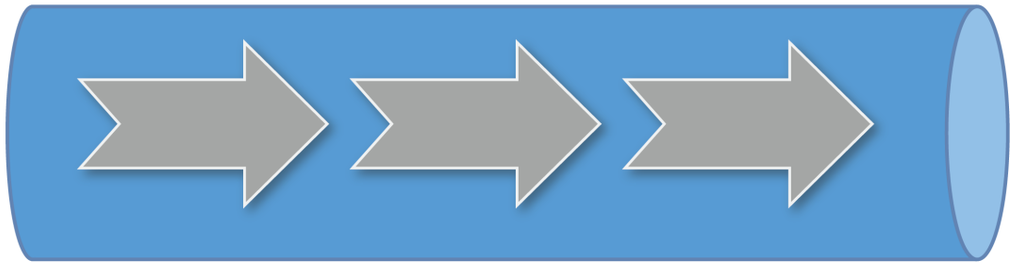
Unshielded twisted pair (UTP) cables are widely used data communications and telephone networks. UTP cable is constructed like shielded twisted pair cabling without the metallic foil shielding. This makes it less expensive but more susceptible to electro-magnet interference. UTP cables is more popular that STP, however many manufacturing facilities may require STP.

Coaxial Cable

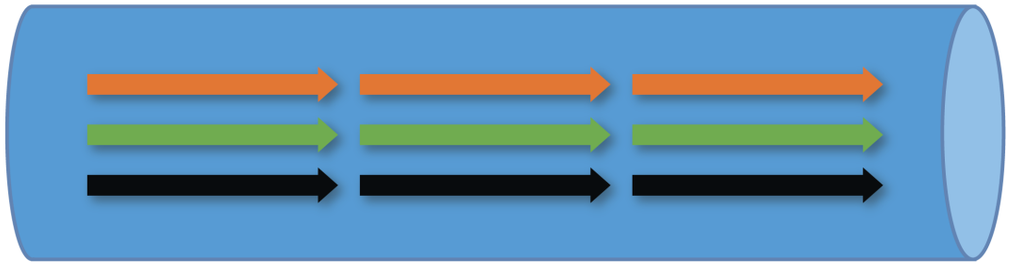
Coaxial cable, or coax is a type of electrical cable consisting of an inner conductor surrounded by a concentric conducting shield. The two conductors are separated by a dielectric. Coaxial cables also have a protective outer sheath or jacket. Coaxial cable can be a very good alternative to twisted pair for special applications like signals from an antenna to a network router or access point.

Coaxial cables can transmit information in two modes: baseband mode which is dedicated cable bandwidth and broadband mode in which the cable bandwidth is split into separate ranges and can carry several signals simultaneously to cable TV stations.





Baseband

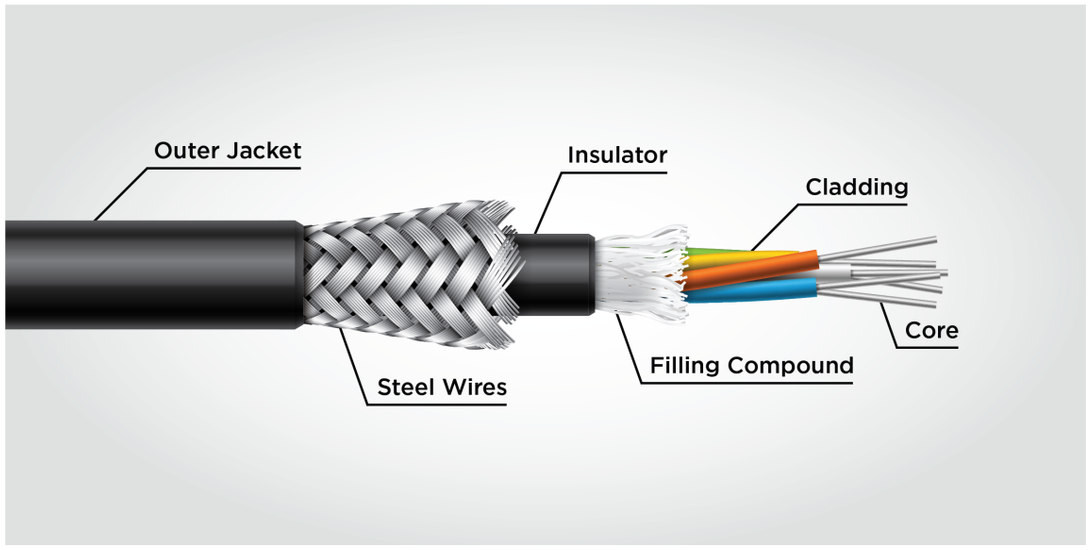


Broadband

Coaxial cable

Fiber Optic Cabling

Fiber optic cable is a high-speed data transmission medium. It contains tiny glass or plastic filaments that carry light beams. Digital data is transmitted through the cable via rapid pulses of light. Fiber optic cabling is more expensive and more difficult to install; however, it provides a media, is immune to electromagnetic interference and provides much higher bandwidth and throughput speeds. Fiber Optic Cable can also span much longer distances than twisted pair cabling or coaxial cabling. There are many different types of fiber optic cabling and connectors. Some provide much higher speeds and longer distances, but each of these characteristics comes at a higher price.



Fiber Optic Cable

Wireless Media

Wireless media carry electromagnetic signals that represent the binary digits of data communications using radio, microwave, or infrared frequencies. As a networking medium, wireless is not restricted to conductors or pathways, as are copper and fiber media. Wireless media provides the greatest mobility options of all media. Wi-Fi is the most widely used wireless networking technology. Wireless Fidelity or Wi-Fi allows computers and other devices to communicate over a wireless signal. It describes network components that are based on one of the 802.11 standards developed by the IEEE and adopted by the Wi-Fi Alliance.

Network Performance or Speed

Speed is one of the most important things used to measure network performance. Network performance is typically defined by throughput or bandwidth. How fast packets or units of data travel from source to destination or sender to recipient determines how much information can be sent within a given timeframe.

Bandwidth Versus Throughput

Network bandwidth is the theoretical maximum rate of data transfer across a given path, media type, circuit, or network. The term throughput actual measures rate of data transfer across a given path, media type, circuit, or network. To summarize, throughput is an actual measure of how much data is successfully transferred from source to destination, and

bandwidth is a theoretical measure of how much data could be transferred from source to destination. Throughput measures speed while bandwidth is only indirectly related to speed. A benchmark can be used to measure throughput. In data transmission, network throughput is the amount of data moved successfully from one place to another in a given time period, and typically measured in bits per second (bps), as in megabits per second (Mbps), gigabits per second (Gbps) or terabits per second (Tbps).

Network Performance Issues

There are many potential problems that affect network performance. It is important to have a basic understanding of these potential issues that can affect the network performance and in turn operation of the manufacturing environment.

Latency problems – latency is the time required to transmit a packet across a network. Latency may be measured in many ways: round trip, one way, unicast, multicast, broadcast, wired, wireless and machine-to-machine and network to network. Latency may be impacted by any element in the chain, which is used to transmit data: workstation, devices, network links, hubs, switches, routers, firewalls, and network services.

Congestion - Like road congestion, network congestion occurs when a network is not able to adequately handle the traffic flowing through it. While network congestion is usually a temporary state, there are issues that can result in continuous network congestion. There are five common causes to network congestion:



Network congestion is like road congestion

- **Over-subscription** – too many users, devices, generated traffic on a signal network is called over-subscription.
- **Design/Misconfiguration** - Poor network design or misconfigurations can also cause network congestion.
- **Device overload** – The over-utilized or central of common devices like hubs, switches, routers, access points, firewalls or servers can cause congestion.
- **Faulty devices** – one of the most common causes of network congestion is fault devices. These devices can trigger excessive

data generation, logging, errors, and auto-recovery actions. Each of these can result in creating network congestion.

- **Security attack** – one of the most common causes of network congestion today are network attacks. These attacks can make individual devices or the entire network unavailable.

Quality of Service (QoS)

Quality of service (QoS) is the description or measurement of the overall performance of the network and network services. Quality of Service is also a set of technologies that work on a network to guarantee its ability to dependably. It is based on the concept of guaranteeing high-priority traffic and limited lower priority traffic on the network. QoS technologies accomplish this by providing differentiated handling and capacity allocation to specific flows in network traffic. This enables the network administrator to assign the order in which packets are handled, and the amount of bandwidth afforded to that application or traffic flow.

Network Topology

Network topology is the arrangement and physical connection of the devices in a communication network. Network topology can refer to the physical or logical layout of a network. It defines the way different nodes are placed and interconnected with each other. There are two types of network topologies: physical and logical. Physical topology emphasizes the physical layout of the connected devices and nodes, while the logical topology focuses on the pattern of data transfer between network nodes. The physical and logical network topologies of a network do not necessarily have to be identical.

However, both physical and network topologies can be categorized into five basic models:

- **Bus Topology:** Bus topology describes a network in which all the devices/nodes are connected sequentially to the same backbone or transmission line. This is a simple, low-cost topology, but its single point of failure presents a risk.

- **Star Topology:** Star topology describes a network in which all the nodes in the network are connected to a central device like a hub or switch via cables. Failure of individual nodes or cables does not necessarily create downtime in the network, but the failure of a central device can. This topology is the most preferred and popular model.

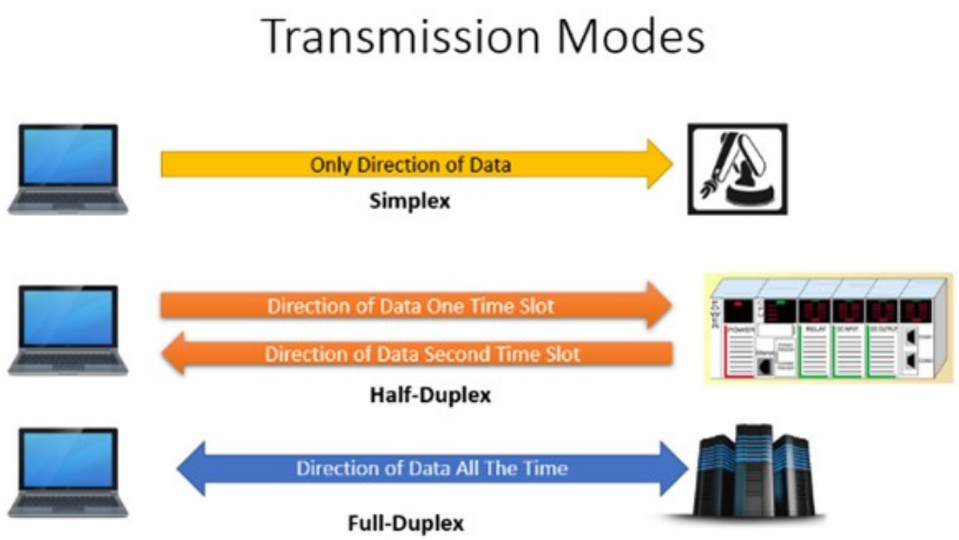
- **Ring Topology:** Ring topology describes a network in which all network devices are connected sequentially to a backbone as in bus topology, except that the backbone ends at the starting node, forming a ring. Ring topology shares many of bus topology's disadvantages, so its use is limited to networks that demand high throughput.

- **Hierarchical Topology:** Hierarchical topology describes a network in which one root node is connected to two or more sub-level nodes, which themselves are connected hierarchically to sub-level nodes. Physically, the tree topology is like bus and

star topologies; the network backbone may have a bus topology, while the low-level nodes connect using star topology.

- **Mesh Topology:** Mesh topology describes a network in which the topology in each node is directly connected to some or all the other nodes present in the network. This redundancy makes the network highly fault-tolerant, but the escalated costs may limit this topology to highly critical networks.

Data Transmission Modes



Simplex, Half-Duplex, Full-Duplex Transmission

Transmission mode means transferring of data between two devices. It is also known as communication mode. Communication networks are designed to allow communication to occur between individual devices that are interconnected. There are three types of transmission modes:

- **Simplex Mode:** In Simplex mode, the communication is unidirectional, like a one-way street. Only one of the two devices on a link can transmit, the other can only receive. The simplex mode the transmitting device uses the entire capacity of the channel to send data in one direction. Example: Computer Keyboard. The keyboard can only introduce input; the monitor can only give the output.
- **Half-Duplex Mode:** In half-duplex mode, both devices can transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa. Half-duplex mode is used when there is no need for communication in both directions at the same time. The entire capacity of the channel can be utilized for each direction. An example is a walkie-talkie in which messages are sent one at a time and messages are sent in both the directions.
- **Full-Duplex Mode:** In full-duplex mode, both devices can transmit and receive simultaneously. In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction. This sharing can occur in two ways.
  - Either the link must contain two physically separate transmission paths, one for sending and other for receiving,

or the capacity is divided between signals travelling in both directions. Full-duplex mode is used when communication in both directions is required all the time. The capacity of the channel, however, must be divided between the two directions. Example: Telephone Network is communication between two persons by a telephone line, through which both can talk and listen at the same time.

Data Communication Network Devices

Network devices are physical and provide the ability for devices on a data network to communicate and interact with other devices. There are many different types of network devices. Here are a few of the most important network devices and a brief description of what they do.

Hubs



Hub

Hubs are the simplest type of network device used to interconnect computers and other network devices. They are used to connect multiple computer and networking devices together. Hubs can only transmit in half-duplex mode.

A hub also acts as a repeater in that it amplifies signals that deteriorate after traveling long distances over connecting cables. Hubs do not perform packet filtering or addressing functions; they just send data packets to all connected devices. Hubs operate at the Physical layer of the Open Systems Interconnection model.

Bridges

Bridges are used to connect two or more network segments together. They can also connect a network device from one segment to a device on another segment. The basic role of bridges is to store and forwarding frames between two more different network segments. Bridges do use hardware or Media Access Control (MAC) addresses in determining which network segment to forward frames. By examining and storing at the MAC address of the devices connected to each segment, bridges can forward the data or block it from crossing. This allows bridges to operate in full-duplex mode.

Bridges can also be used to connect two physical LANs into a larger logical LAN. Bridges work only at the Physical and Data Link layers of the OSI model. Bridges are used to divide larger networks into smaller sections. They act as the interconnect and traffic cop between the two physical network segments. Bridges

have become obsolete in recent years and have been replaced by switches, which offer more functionality. Switches are sometimes referred to as “multiport bridges” because of how they operate.

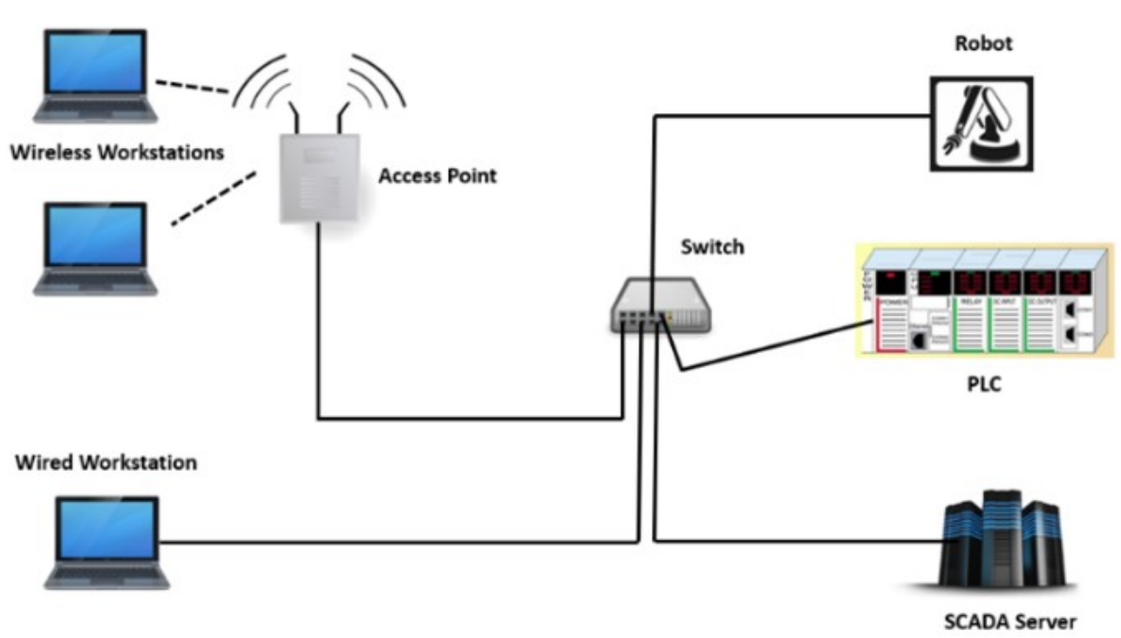


Bridge

Access Point

Access points are like wireless hubs and or bridges. Access points work at the second OSI layer, and can operate either as a bridge connecting a standard wired network to wireless devices or as a hub to just pass data between wireless device on the wireless network.

Access points (APs) consist of a transmitter and receiver (transceiver) device used to create a wireless LAN (WLAN). APs operate in the half-duplex mode between wireless devices. Access points typically are separate network devices with a built-in antenna, transmitter, and adapter. Depending on the size of the network, one or more APs might be required to provide full coverage. Additional APs are used to allow access to more wireless clients and to expand the range of the wireless network. Each AP is limited by its transmission range or distance a client can be from an AP and still obtain a usable signal and data process speed. The actual distance depends on the wireless standard, the obstructions and environmental conditions between the client and the AP. Higher end APs have high-powered antennas, enabling them to extend how far the wireless signal can travel. To connect to a wireless AP, you need a service set identifier (SSID) name. 802.11 wireless networks use the SSID to identify all systems belonging to the same network, and client stations must be configured with the SSID to be authenticated to the AP.



Access point

Switch

Switches have a more intelligent role than hubs and APs. A switch is a multiport device that improves network efficiency. Switch build and maintain a MAC table of all devices directly connected. This table allows the switch to forward traffic to only the destination device or intermediate device for a destination. Switches improve network efficiency over hubs by limiting the amount of traffic generated and providing full-duplex communications. Switches also improve network security because the virtual circuits are more difficult to examine with network monitors.

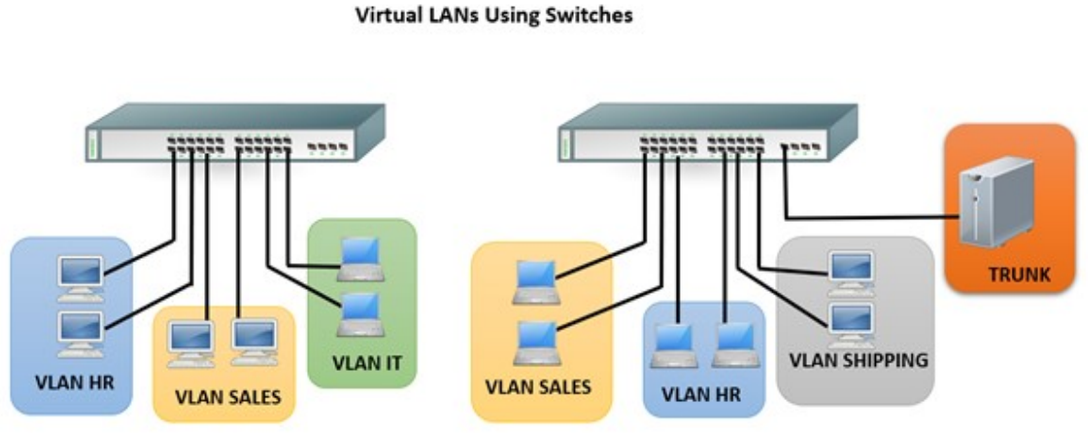
Remember hubs and APs forward all traffic to all connected devices. A switch works at both the physical layer and the data link layer of the OSI model. A multilayer switch is a high-performance device that supports the same routing protocols as routers.



Switch

Virtual Local Area Networks (VLANs)

Virtual local area networks, or VLANs, have become important feature of modern industry and manufacturing networks. As network complexity increases and the amount of data created, collected, and commutated our networks will become more congested and require smarter designs. Originally, a LAN connected a group of devices based on the physical connection to a hub or switch. Now devices must be associated based more on the organizational function. Many LANs now connect devices via wireless internet, rather than Ethernet, although most LANs use a combination of both connectivity types. VLANs eliminate the physical limitations of the physical connections. Now a signal switch or wireless access point can logically group station across the entire organization by port assignment. Each port can be assigned to a Virtual LAN anywhere in the network. Ports can be configured also as VLAN trunks which allow them to be connected to all VLANS in the network.



VLANs



Section 6

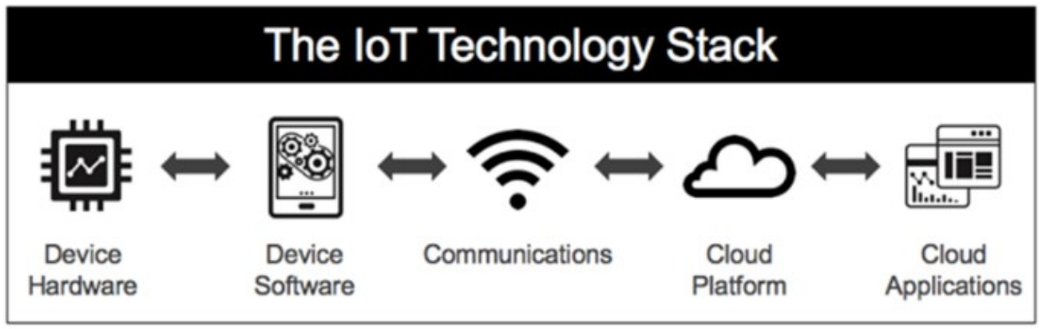
The Internet of Things (IoT)

The Internet of Things (IoT) describes a growing industry of digital technology being harnessed to the Internet in ways that will improve the lives of every person on this planet. Millions of people around the world are connected to the Internet in one way or another. The numbers of IoT devices that operate twenty-four hours a day are growing exponentially. An ever-increasing number of people now rely on more than one smart device to perform their work, improve their lives, and communicate with their community. These devices include smartphones, fitness and health trackers, home automation devices, smart cities applications and highly automated facilities. So how is it possible for so many devices to be connected?

What is the IoT?

The Internet of Things (IoT) is the connection of millions of smart devices and sensors linked to the Internet. These connected devices and sensors collect and share data for use and evaluation by many organizations. These organizations include businesses, municipalities, government agencies, hospitals, and individuals. Internet-of-Things technologies are possible, in part, due to the advent of inexpensive processors, miniaturization, and wireless high-speed communication networks. Previously inanimate objects such as doorknobs or light bulbs can now be equipped with intelligent sensors that can collect and transfer data to a network. The IoT industry uses a basic framework which consists of several technological layers that all play a role in establishing a transformative

application and provide a faster return on Investment. The IoT stack applies to consumer, home, and industry-grade IoT projects.



IoT stack

Layer 1 – Device Hardware

Devices constitute the “things” part of the Internet of Things. Devices act as the interface between the physical and digital worlds. They are the first layer of the IoT technology stack. One of the main purposes of the device is to collect data. The device selection is determined by the amount and type of data to collect. For simple data collection needs, a single processor sensor may be suitable. For more complex data collection, an industrial device that houses many sensors, a powerful processor, local storage, and a gateway may satisfy the need.

Layer 2 – Device Software

Device software is required to bring intelligence into the device hardware transforming it into a “smart device.” Device software is the second layer of the IoT technology stack. Device software facilitates the notion of “software-defined hardware”. Software-defined hardware means a particular hardware device can serve multiple applications depending on the embedded software installed. Device software enables critical functions like communication with the Cloud or other local devices. The software often enables real-time analytics, data acquisition from the device’s sensors, and control. Cloud communication differentiates IoT based systems versus traditional automation and process control. Software serves as the glue between the real world (hardware) and Cloud applications. Device software can include firmware, embedded operating systems, communication processing and code used to read and control the device features.

Layer 3 – Communications

Communications refer to the interface that enables the device to send and receive data with the rest of the world. Communications include both physical networks connection technology and the protocols used to control the communications. Selecting the right communication mechanisms is a critical part of effective IoT deployment. The most popular communication technologies include Bluetooth, UWB, RFID, Wi-Fi, WAN, LAN, 4G, 5G, LoRA (Long Range), and other emerging technologies.

Layer 4 – Cloud Platform

The cloud platform is the backbone of the IoT solution. Software as a service (or SaaS) is a way of delivering applications over the Internet as a service. A cloud platform or SaaS provides the

infrastructure that supports critical areas such as data collection and management, analytics, and cloud APIs.

Layer 5 – Cloud Applications

The end-user applications are the part of the system that people will use and to interact with and operate. These applications are web-based or on desktop, mobile, and even wearable devices. Even if a smart device has its own display, people will utilize a cloud application as the main point of interaction with solutions. This allows access to smart devices anytime and anywhere, which is one of the major benefits of IoT connected devices.

The IoT Market

There are currently over 3 million new devices connected to the Internet each month. Researchers estimate that there will be over 50 billion active devices by 2025. Some examples of intelligent connected sensors are smart doorbells, garage doors, thermostats, sports wearables, pacemakers, traffic lights, and parking spots. The limit of different objects that could become intelligent sensors is limited only by our imagination. Modern digital networks make all this possible. The world is quickly being covered with networks that allow digital devices to interconnect and transmit anywhere at any time.

Edge Computing

Edge computing brings computation and data storage closer to the end devices that collect the data, rather than depending on a remote central location. The advantage is data, especially real-time data, does not suffer latency issues that can affect an application's performance. In addition, companies can save money by having the processing done locally, reducing the amount of data that needs to be processed in a centralized or cloud-based location. Edge computing is a distributed computing model that brings computation and data storage closer to the location where it is needed, to improve response times and save bandwidth. Edge computing is transforming the way data is being collected, processed, stored, delivered, and used from billions of devices around the world. The explosive growth of internet-connected devices continues to drive edge-computing systems. Faster networking technologies, such as 5G wireless, will enable edge computing systems to accelerate the formation of real-time applications, personal healthcare, self-driving cars, improved logistics and more effective manufacturing to market intelligence. Fog computing refers to extending cloud computing to the edge of an enterprise's network. Also known as Edge Computing or fogging, fog computing facilitates the operation of computing, storage and networking services between end devices and cloud computing data centers.

Chapter 11

Cybersecurity

Understanding the importance of data and information security is absolutely paramount in today's automated warehouse. This chapter discusses what you will need to have for cybersecurity awareness and how to plan for the needs to protect an automated warehouse.



Section 1

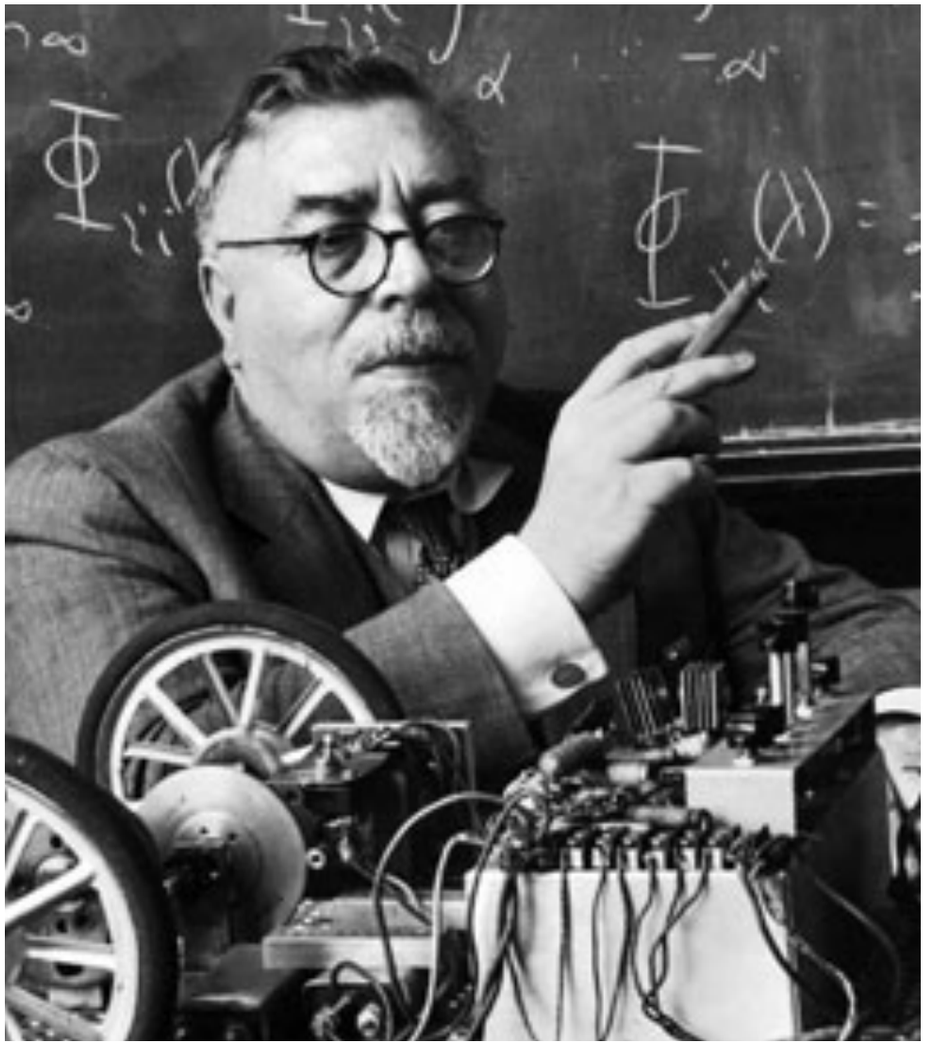
Overview

The protection of data, information, and systems is vital in the automated warehouse as adversaries and bad actors are attempting to acquire intellectual property or sabotage your system for financial gain. This chapter will prepare you for understanding and implementing a good cybersecurity posture and help you prepare for the inevitable attack on your warehouse and its devices.



Section 2

Definitions



Dr. Norbert Wiener

Cyber History

In order to discuss cybersecurity, we should understand where the term “Cyber” was first coined. “Cyber” is a Greek word for navigator, but it was first used by a Dr. Norbert Wiener, MIT professor, where he used it in the word cybernetics way back around the year 1948. Cybernetics is described as the science of communications and automatic control systems in both machines and living things.

Now that you know where the word “cyber” originated, we need to discuss cybersecurity. Prior to the year 2000, we called this information assurance or information security, but now, it is more commonly known as cybersecurity.



Cybersecurity

Cybersecurity is really about the right mindset from all the employees; we'll find later in the chapter that the weakest link really is the human element or the employee. The cybersecurity personnel must create a culture within the company and preserve trust between themselves and their employees in your automated warehouse. You must prepare under the assumption that an attack will occur.

To be sure, cybersecurity is all about balancing business management versus risk management. Risk management can be tricky to do because you are always struggling with wanting more security, but dealing with the fact that most employees just don't want to be annoyed by more security procedures as they go about performing their jobs as effortlessly as possible with the least amount of compliance. For instance, in order to protect your company with stronger passwords, let's say you implement a policy in order for every employee's password to be at least 25 characters long with mandatory changes of the password every month. I promise you that you will have very demoralized employees or quite possibly a mutiny revolting against too many restrictions, even if it is the best thing for the company.

The easiest definition for cybersecurity is the description of what we call the **CIA Triad**. The CIA Triad is not to be confused with the federal government program CIA, but it's an acronym for Confidentiality, Integrity, and Availability and often represented by using a triangle for each of the parts.



Confidentiality is what you and I think of when we think of cybersecurity or privacy. We don't want just anyone to know our grades, or maybe our health records, or our financial records. Confidentiality assures that private or confidential information is

not made available or disclosed to unauthorized individuals. Loss of confidentiality is the unauthorized release of information; and in the business world, this is known as a data breach.

Integrity in the cybersecurity world might mean something a little different than what you might be thinking. Integrity is often about how trustworthy a person might be. However, what is meant here is the integrity of the data and how we must guard against any unauthorized changes to that data. This includes that no unauthorized edits, additions, or deletions. In the health care field, protection of the integrity of a patient's data could mean life or death. For instance, if the prescription automated system is hacked, a hacker could change just one byte of data for a patient changing their "allergic to penicillin" status from YES to NO. The hacker could then program the prescription automated system to deliver a couple of doses to the patient. This is a serious situation and could end in death for that patient. We must guard against improper information modifications or destruction because in an automated warehouse, you might have several connected components such as robotic cells, CNC machines, or other physical devices that might cause harm or death if a hacker changed safety parameters or even programmed something that wasn't planned.

Finally, the last component of the CIA Triad is **Availability**. Availability ensures that systems work properly, and service is not denied to authorized users. Ensuring timely and reliable access to all connected systems is vastly important to the production of systems in an automated warehouse. If the materials or processes are stopped, that means that money is not being made and could cost the company due to the disruption of the physical or computing systems. The more critical a component or service is, the higher level of availability will be required. For instance, if a system that provides authentication of users and devices goes down and all of the automation is tied to this most critical system, that could mean that your entire operation may be down for hours, and time is money. This loss of service translates into a large financial loss in not only production, but also in employee productivity--which may even impact your customers as well.

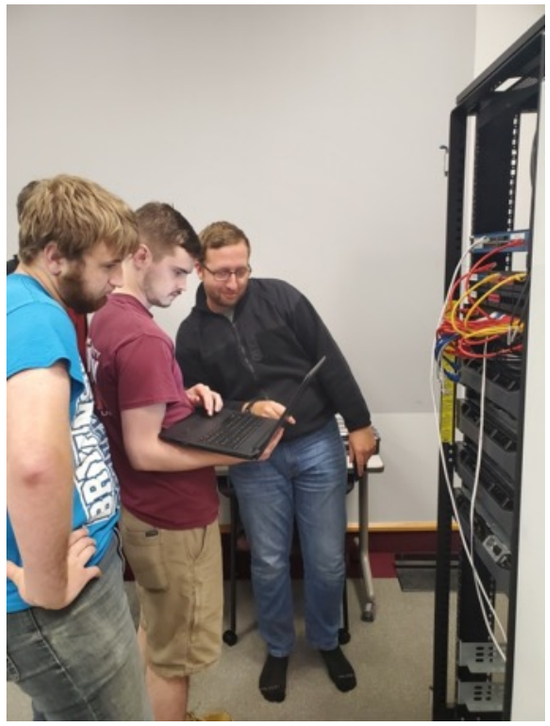
Now, we said that the easiest definition for cybersecurity was to use the CIA Triad, and this is a wonderful and simple definition. However, in reality, cybersecurity is so much more. It is really a combination of the following:

- Hardware
- Software
- Policies / Procedures
- Plans
- Training
- Physical Security
- Personnel Security

Let's break down each of these bullet points to better describe what each point means. When most people think of cybersecurity for their automated warehouse, they might have **hardware** first come to mind. Hardware can be something as simple as a firewall between you and the internet to more complicated appliances such as Intrusion Detection Systems (IDS) or Intrusion Prevention Systems (IPS). Both of these appliance type cybersecurity products give the automated warehouse a more sophisticated approach to proactive cybersecurity. Cybersecurity software in an automated warehouse usually consists of some sort of anti-malware installed on the endpoints (or actual employee computers). The combination of both hardware and software protection gives a better defensive posture against potential hackers or bad actors.

Policies and procedures tend to go hand in hand, but they are distinctive in the cybersecurity posture. You might already be familiar with a cybersecurity policy right now. Your school or place of employment might have a policy regarding passwords. Perhaps your password policy states that you must have a minimum of eight characters with at least one special character embedded in the password. That's a good example of a cybersecurity policy. Policies make up a substantial bulk of information security systems and can play a large role for the employees' guidance on your cybersecurity stance. Remember, it is always a balancing act between business management and risk management, and you will need to determine what's best for the automated warehouse. It can be difficult to achieve the balance between ease of use for the employees and security controls.

Procedures tend towards complementing policies. For instance, a procedure may be when your password policy states that after 90 days, employees must change their password and the procedure ensures that they do this (and not reuse one of their old passwords).



Plans consist of step-by-step instructions that describe security control executions in case of incidents. For instance, if there was an attack of ransomware, one of the most prominent attacks in recent times where an intruder locks up your information and requests a ransom to be paid to unlock it, you should have a plan

ready to implement in order to get your automated warehouse data.

You need to be prepared to get your automated warehouse back to 100% operations with minimal data loss. Plans take time to develop, document, and periodically update, but are necessary to have ready for most contingencies.

Training for your employees in your automated warehouse is very important as one of the most common attack surfaces is the human element. This human attack surface refers to vulnerabilities created by your employees, personnel, or outsiders such as social engineering, human error, and trusted insiders. We will discuss social engineering later in the chapter as it important to strengthen your posture by maximizing training.

Physical Security also known as infrastructure security protects the information systems from physical interaction. You are already familiar with this as I'm sure your home has a door lock. The door lock allows anyone with a key, or a person who has been authorized, access to unlock the door and enter. Physical security is not only just worrying about human-caused threats, but should also incorporate



both environmental threats and technical threats. For example, one automated warehouse had their servers located in a cool and secure basement, but found that basement could be prone to flooding after a massive snowstorm started to thaw. Natural disasters are a source of a wide range of environmental threats to data centers or operations in an automated warehouse. Physical security options could consist of finger-print readers, combination locks, or other types of authorized entry-controlled systems and the correct option should be considered for each application.

Finally, we need to discuss **Personnel Security** as the last part of cybersecurity. This is one of the most critical items to remember as you may be called to a position of a cybersecurity authority and may be put in a position to hire new personnel. Upon hiring new personnel, and especially Information Technology (IT) staff, it's always best to get a background check and a reference check of the potential employees. Remember that IT personnel typically have more authority over the automated warehouse data and information than regular employees or leadership and can do more damage to the company if they are bad actors. This type of threat is called an insider threat, and we'll discuss other threats later in the chapter. Besides background and reference checks, a prudent cybersecurity posture is to always give personnel a l**east privilege** principle. **Least privilege** means every process and every user of the company should operate with the least set of privileges necessary to perform tasks. Even the Chief Executive Officer (CEO) should not get access to every system or every file

in system as it is a risk. If the CEO gets hacked, then the hacker has access to all systems.

Cybersecurity can be made up of the three concepts of the CIA Triad as it does embody the fundamental security objectives for both data and information security. However, as you can see, there are many items to consider when trying to keep your automated warehouse safe from cyber predators.



Section 3

Threats, Attacks, and Attack Vectors

Threats

Threats come in many ways, and they don't necessarily need to come from an attack. **Threats** are defined as any circumstance, incident, or event that has the potential to adversely impact your organization and its operations through an information system. Threats for automated warehouses come in many forms. We mentioned during our physical security discussion that we must account for destruction or accidents due to nature-induced activities. These nature-induced incidents could be something as serious as flooding, but could come in other such forms such as tornadoes, fire, or even earthquakes. It's difficult to prepare for every contingency, but you must account and prepare for most natural threats that could happen in your geographic environment.

Before we go any further, we do need to discuss how to prepare for such threats. **Plans** can assist you in preparing for most, but not all threats. Plans consist of action items for countermeasures to prevent a particular incident or accident, but also how to recover from these cybersecurity events. You cannot account for all contingencies, but you can prepare for the different types of risks. You might seem overwhelmed now contemplating all the threats, but you should group your thoughts and then perform a triage on your list of items. **Triage** allows you to take the most likely of those treats and sort and address the most critical first. Later in

the chapter, we will discuss **Cybersecurity Frameworks** which will direct and assist you in preparing for all sorts of threats and will even guide you in making plans for such threats.

Before we discuss actual attacks, there are four different types of threat consequences from active or passive attacks. These types include **Unauthorized Disclosure, Deception, Disruption,** and **Usurpation.**

Unauthorized Disclosure is an event or circumstance where an attacker gains access to information or data and the attacker is not authorized. For instance, an attacker may gain and steal intellectual property from your systems that belong to you or your clients in your automated warehouse. This is commonly known as a data breach.

Deception is an event or circumstance where an attacker may introduce false information in order to achieve a goal. Perhaps someone impersonates a trusted individual to gain unauthorized entry into your building or server room.

Disruption is described as an event or circumstance that prevents a correct operation of system functions or services. An attacker may gain access to your production line system in an automated warehouse and significantly shut down the line costing both time and profit to your organization.

Finally, **usurpation** is an event that results in control of operation and system functions by an attacker. The attacker may cause a system component to perform an unsafe function that could be detrimental to the safety of employees and operational crew. Perhaps the attacker gained control of a robotic cell system in the automated warehouse and caused the cell to perform maneuvers that could physically injure employees near the area.

Now that we understand the different threats to an automated warehouse system, let's discuss more threats regarding actual attacks on your information systems.

Attacks

A **cyberattack** is a malicious and intentional attempt by an attacker to disrupt or breach an organization's data and information systems, usually in order to gain some type of benefit. The attackers' motives may vary, but they do gain some benefit either simply for personal reasons of bragging or they want to acquire some sort of financial gain by stealing information to sell to competitors (or simply lock up the system for some ransom). They may have political or ideological reasons behind their attacks. Although their motives may be different, the results are the same as their attacks cause consequences that usually cost your automated warehouse recovery time, lost money, and perhaps even your organization's reputation and trustworthiness in the eyes of your clients and customers.

Attacks come in generally three forms: **hardware attacks, software attacks,** or **human attacks.** Let's start with **hardware attacks.**

Hardware attacks' main threat is the threat to the availability of the computer systems. Hardware is the most vulnerable to cyberattack and usually consists of an attack directly on your systems, whether it is your frontline networking systems or even inside your automated warehouse. For example, it was reported in 2018 that manufacturing plants in China had implanted tiny network monitoring and control chips on motherboards made for a United States manufacturer. Hardware attacks have come a long way and are continuing to grow smaller, less expensive, faster, and more complex.

Software attacks may be what you think of when you think of hacking. Hackers love to use software attacks because they are effective and easy to implement in to target their victims. Today, it is very common to install anti-malware (protection against malicious software) in order to protect our end points from cyberattacks.

Malware refers to different types of malicious software programs which include viruses, worms, ransomware, and Trojans. There are many ways to get malware into a computer on your automated warehouse floor, but typically, it requires the user to take some action to install the software. Hackers may send it to employees as an attachment in an email or even hide it on a website as a pop-up alert or an advertisement. This brings us to what is known as social engineering.

Movie 11.1 What is Social Engineering?



Tap to view a video

Finally, we come to the hardest attack to prevent called the **human attack**. We call these types of attacks, **social engineering**. Social engineering is a type of attack where the attacker uses deception in order to deceive or manipulate their victims to gain access to the computer systems. We will spend a little more time exploring these types of attacks as they are the most common cyberattack from hackers and, unfortunately, the most successful.

Attack Vectors

Let's dive into different types of **social engineering**, or human attacks, which could infiltrate your automated warehouse. Attack vectors can be described as the paths that hackers take to infiltrate your systems and are expressed by different types of attacks. We mentioned hardware and software attacks in the previous section, but with social engineering, and utilizing a blending of both types of attacks, social engineering attack vectors cause many of the breaches, infiltrations, and usurpation amongst organizations including automated warehouses.

The most common attack vector and the most discussed in the cybersecurity realm is **phishing**. Education continues to improve with users and employees regarding email type attacks. We have software in place on the incoming servers to filter and search for blatant phishing attacks, as well as end-point software to protect our users, but this attack vector is still causing havoc in the industry. While we are discussing phishing, another term you should know is **spear-phishing** where a phishing attack is targeting an individual or organization.

For instance, an attacker may want to target the Information Technology director of a company to further infiltrate the company. Social engineers (hackers that utilize deception) will research the target victim in order to better understand that victim and how to trick her or him into falling into their trap. The social engineer may even target the victim's phone by spoofing a friend or co- worker's number and sending the victim a text with a link to click. This is called **SMShishing** (or SMS phishing) and can cause the victim's phone to be compromised including the hackers listening to all the phone calls and getting other valuable information.

In the video below, which is a commercial for the networking company Cisco, you can watch the tools and techniques of a social engineer as she brings down a company. Her motives are quite different from what you might be expecting, as she sees herself doing a job as an employee and takes pride in her accomplishments.

Movie 11.2 Cisco - Anatomy of an Attack



Tap to view a video

Sometimes hackers will phish a victim into clicking on and going to a website that is familiar with the victim. Using deception, they will target the victim by making a website that appears to look like the one they are expecting. They will use this website to have the

victim type in their credentials; they store every keystroke and now know both the username and password. This type of attack is called **Pharming** and is used together with other forms of social engineering in order to get a victim's information.

Like Pharming is the **bait and switch** technique where a hacker buys advertising space on website and lures the victim to click on an ad. Hackers make their ads attractive and attempt to get the victim to click on the ad which leads to a malware-infested website. There the victim may be lured to download a software package that contains adware or malware and usually leads to total usurpation where the hacker has full control of the system, computer, and network. This can be especially dangerous in an automated warehouse as this type of attack could lead to other warehouse systems getting infected. It's always best to have a policy in place where the users cannot install unauthorized programs without the support (and verification) of the Information Technology team.

When surfing the internet, there is a possibility that when you browse, your personal data, such as IDs, username, passwords, and even browser history can be compromised. These bits of information are stored in a special cache and location on web browsers called cookies. This information is a major target for hackers and using your information from cookies, they can browse the internet using your digital identity. This type of attack is called cookie theft. **Cookie theft** is usually performed via a pass-through machine that is watching the victim's IP packets pass through. It's important to protect yourself and your employees at your automated warehouse with training and stress that it's important that users only input their personal data and passwords on secure or encrypted websites. Secure websites encrypt the data from the browser through the network and makes it difficult or sometimes impossible for hackers to use the pass-through method. We'll talk about encryption later in the chapter.

Another type of attack method that utilizes all three attack types (hardware, software, and human) is the **keylogger**. This hacking technique utilizes a simple software program that is capable of recording keystrokes from your keyboard. It can be used to get all of the victim's credentials as they type. Keyloggers can be left at a victim's location, dropped by a social engineer, while the device is disguised as a USB charger. Maybe the target finds it in the parking lot of their automated warehouse. However, it is no ordinary USB charger, but might contain radio chips to listen to the most prominent cordless keyboards on the market. If a victim uses the USB port to charge their device, it may also attempt to infiltrate that device.

Another vector that is used to infiltrate an organization is flash drives. These flash drives might be dropped by a social engineer in your automated warehouse parking lot in the hope that one of your employees pick it up and insert into your computer systems. You must design a policy against using outside **flash drives**, or

any type of USB drives, without the consent and approval of your Information Technology team. Training your employees on this type of attack vector is also prudent and encouraged as they might not know about the different types of vectors that a hacker can use.

We discussed using radio chips, so let's discuss the most commonly used radio, our WiFi networks. Fake **wireless access points** (WAP) are another simple deception technique used by hackers. Hackers set up shop in or near local businesses like coffee shop or hotels and create fake SSID (service set identifiers) that appear to be legitimate to get unsuspecting victims to log on to their networks. This technique utilizes a **man-in-the-middle attack** whereas the hacker watches the victim pass through a rogue network. The hacker then gets the victim's data. The use of a quality Virtual Private Network, or VPN, can protect the victim from these types of cyberattacks.

Another attack vector that you will need to be prepared for at the automated warehouse is the **Denial of Service** (DoS) or Distributed Denial of Service attack. The hacker targets a system's network, communication, or servers which are flooded with traffic to exhaust its capacity and bandwidth. During this attack, the organization is helpless, for both incoming and outgoing internet traffic and will wreak havoc on operations for your warehouse. Many times an organization that is hit with a DoS attack is targeted for something worse. The DoS attack could be a prelude to a larger attack on your organization in order for the hackers to compromise devices while the victim is dealing with the situation of the denial of service attack.

We listed quite a few attack vectors and discussed the different types of attacks. However, these are but a few of the vectors that can be used against an automated warehouse. We will discuss cybersecurity frameworks later in the chapter in order to better prepare and plan for such attacks. It's always best to implement proper cybersecurity practices and cybersecurity strategies to ensure that your automated warehouse infrastructure, as well as your company's sensitive data, are fully protected.



Section 4

Encryption and Cryptology

Cryptology

When coming up with your automated warehouse policies, plans, and procedures, you should be aware of how encryption works and have a better understanding of the process of secure communications. Encryption is a very challenging subject, and many people don’t understand much about it or its benefits. Not considering encryption could expose you to vulnerability where hackers could hurt your warehouse.

Simply put, **cryptology** is the study of the conversion of plain text to cipher text and the other way around. The definition of cryptology is also called the study of encryption and decryption. If we mention cryptology, we must mention its subset called **cryptography**. Lots of people misunderstand the difference between cryptology and cryptography as they seem similar. However, as cryptology is both the study of encrypting and decrypting information, cryptography is a subset, and it is the study of only encryption and not taking that encryption back to plain text.

Encryption is the process of scrambling text, data, or files in order to make them unreadable without the proper access and authority. In your automated warehouse, you are likely to handle a lot of sensitive data including your client’s information, product property information, upcoming projects, expansion plans,

success strategies, and internal employee/client communications. Encryption ensures that this information is scrambled and kept from unauthorized access. Files, folders, entire disks, and other hardware containing data should be encrypted. It is a good policy that you encrypt also any flash drive that your employees use on a day-to-day basis in case they accidentally drop or lose that flash drive. We previously discussed that when you or your employees are surfing the internet, we needed to make sure that the connection in their browser is secure before entering any kind of personal or sensitive data like usernames and passwords. We mentioned flash drives in the previous section noting that no outside flash drives should be used or plugged into your automated warehouse computer systems. Deploying your Information Technology team's encrypted flash drives, as well as training for your employees, will help protect your organization and its sensitive information.

Now that we see a great use for encryption, let's get into more details and learn more about this important element of cryptographic algorithms. In this section, we will discuss symmetric encryption; hash functions or hashing; and, finally, public-key encryption, also known as asymmetric encryption.

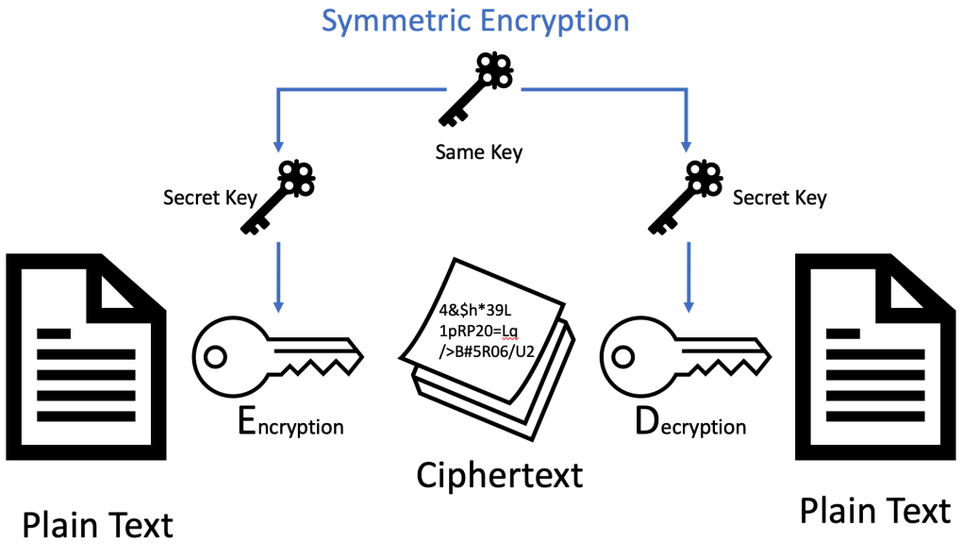
Symmetric Encryption

We begin with symmetric **encryption,** also referred to as conventional encryption, which is used predominantly to provide confidentiality. Symmetric encryption is a method of encryption, or the scrambling of the information, where communication utilizes a single key for both encryption and decryption. This key must be shared between both parties communicating so that the message can be decrypted by the receiving party. This was the only type of encryption in use prior to about 50 years ago. In fact, many individuals and groups used this type of encryption from Julius Caesar to the German U- boats in World War II. It's still a viable option even today as many present-day military, commercial users, and diplomats use it for secret communication.

A symmetric encryption has five main ingredients:

1. **Plain text:** the original communication or message that will be fed into the algorithm for encryption
2. **Encryption Algorithm:** the mathematical encryption algorithm to be used in order to perform various substitutions and transformations on the plain text input
3. **Secret Key:** the input to the encryption algorithm which determines the exact substitutions and transformations to be performed by the algorithm
4. **Ciphertext:** the scrambled output after the encryption has been applied
5. **Decryption Algorithm:** the reverse of encryption algorithm using the same secret key in order to get the exact

substitutions and transformations which will produce the original plain text



Symmetric encryption relies on two requirements for secure use. These are a strong encryption algorithm and sender and receiver receiving copies of the secret key in a secure fashion. Both parties must ensure that the key remains secure because if an attacker or hacker discovers the key and knows the algorithm, all the information in the communication can be readable.

There are many examples of symmetric encryption used today, and here are some of the more popular symmetric encryption algorithms:

- Advanced Encryption Standard (known as AES)
- Data Encryption Algorithm (known as DES)
- Blowfish
- International Data Encryption Algorithm (known as IDEA)
- RC4, RC5, RC6 (designed by Ron Rivest of RSA Security starting in 1987)

Symmetric Encryption may have some disadvantages when being used in your automated warehouse. For example, it is extremely difficult to manage the secret key if your infrastructure is decentralized or spread across different locations. Also, with the advent of quantum computing, which we won't cover in this chapter, the National Institute of Standards and Technology (also known as NIST), suggests that the current method of utilization of symmetric keys will be broken and a new method will have to be found.

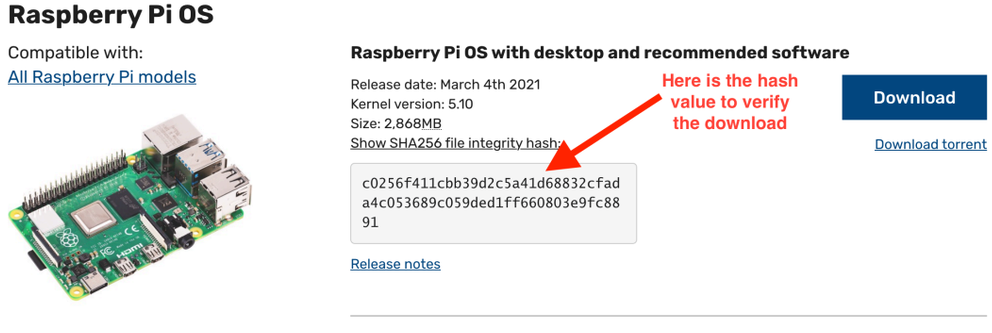
Hashing

Hashing is an alternative to encryption, but the main factor of hashing is that it is a one-way cryptographic function while encryption is designed to work both ways. Hashing functions are not reversible, and the output of a hashing function is a fixed-length string of characters called a **hash value.** These hash values are not necessarily meant to be kept secret because they cannot be converted back to the original plain text.

However, they are useful because one important property of a hash is that the plain text, after conversion, must always have the same hash value.

We need to mention hashing because it is always the preferable way to store passwords in a database. The reason is that if a hacker compromises the database, they won't get access to the plain text passwords and there is absolutely no reason for you to ever know the user's plain text password. For many web applications, after the user enters their username and password on a secure website, the password goes through the hashing function in order to determine if that same hash value exists in the database for that user. If so, then the user is allowed to enter the website. If it fails, the web application then notifies the user that it was a bad password and to possibly try again. The web application holder never keeps the plain text password, but only takes the input from the website and hashes it to find the correct hash value stored for that user.

Hashing also comes in handy in order to verify a download from a website. Many places where you can download files, applications, or documents, you might see a hash value located on the site for you to check your download to ensure it has not been tampered with from an attacker. In the image below, you can see that after a user downloads a copy of the Raspberry Pi Operating System, used on the Internet of Things (IoT) Raspberry Pi computer, a user can run the hash algorithm to verify that the resulting hash value is the same as the website. If the hash values are different, that means that the downloaded operating system has been tampered with and should be considered suspect and not used.



There are many examples of hashing algorithms used today, and here are some of the more popular hashing methods:

- MD5, developed in 1991, is considered old by today's standards and not suggested to be used.
- SHA-1 (Secure Hash Algorithm 1) was designed by the National Security Agency (NSA) in 1995 and was recommended by NIST and uses 160 bits for its algorithm.
- SHA-256 is based on the SHA-1 algorithm, but uses 256 bits and is considered the standard hashing algorithm today.

Remember that hashing has its functions and is used in today's automated warehouse when a one-way encryption is needed. Hashing can be used to store encrypted passwords without actually storing the plain text password in case a hacker breaks into your system. It can also be used to verify your downloads in your warehouse where the files, documents, or applications that your users utilize have not been tampered with in any way.

Asymmetric Encryption

Asymmetric Encryption, also known as public key encryption, is a mix of private key and a public key, utilizing two separate keys. This contrasts with the symmetric encryption, which only uses one key. The use of two keys has profound implications in the automated warehouse as it makes it much easier in the areas of confidentiality, key distribution, and authentication. The private key must be kept secret to its individual holders while the public key can be made available to anybody and out in the open to the public.

The public key encryption was first publicly proposed by two individuals named Whitfield Diffie and Martin Hellman in 1976. The **Diffie-Hellman key exchange** encryption, as it's commonly known, revolutionized encryption and was the first of its kind in roughly a thousand years. For the first time, a single secret key didn't have to be shared in order to decrypt the ciphertext. They used a method of encryption based on prime numbers and the fact that it is easy to multiply two large prime numbers, but harder to figure out what two prime numbers were used in the first place.

Asymmetric or public-key encryption uses five (six counting both the Private and Public Key) main ingredients:



Martin Hellman (left) and Whitfield Diffie (right)

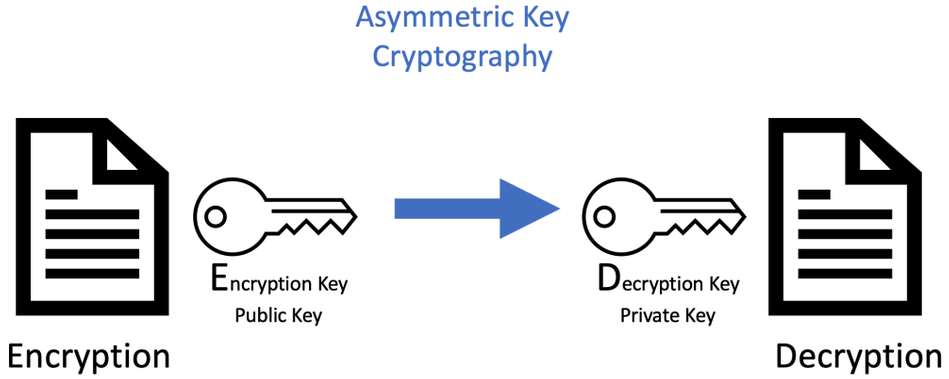
Plain text: This is the original communication or message that will be fed into the algorithm for encryption.

Encryption Algorithm: This is the mathematical encryption algorithm to be used in order to perform various substitutions and transformations on the plain text input.

Private and Public Key: This is a pair of keys selected so that they will be utilized in the encryption algorithm.

Ciphertext: This is the scrambled output after the encryption and depends on the plain text and the key.

Decryption Algorithm: The algorithm uses the input or ciphertext and matching key in order to decipher and produce the original plain text.

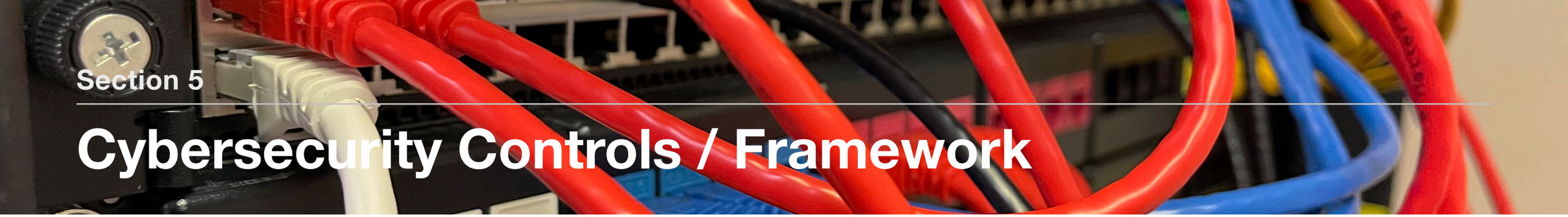


Remember that public key systems are characterized using an algorithm using two keys, one held privately and one available publicly. Depending on the types of applications that are needed in your automated warehouse, you may need to utilize this type of encryption method.

There are many examples of asymmetric encryption or public key encryption used today and here are some of the more popular algorithms:

- Diffie-Hellman Key Exchange
- RSA, one of the first public key schemes published in 1978 by Ron Rivest, Add Shamir, and Len Adleman from the Massachusetts Institute of Technology (MIT)
- DSS, or the Digital Signature Standard, published by the NIST
- Elliptic Curve Cryptography, known as ECC, is challenging the RSA as the standard.

Typically, asymmetric cryptography is used in the following day-to-day applications that are needed to encode and decode text including emails (using the PGP verification), web browsers (using SSL/TSL for encoding), and cryptocurrencies like bitcoin.



Section 5

Cybersecurity Controls / Framework

Cybersecurity Frameworks

Now that you have a basic introduction to cybersecurity, you might be a little bit anxious if you were to be asked to oversee cybersecurity in your automated warehouse. However, don’t fret because there are solutions provided for you in order to accomplish getting your warehouse training, plans, policies, procedures, and security controls in place. You do not have to reinvent the wheel! We will discuss two frameworks, sometimes called cybersecurity controls, that will assist you in getting ready to prepare for your information security.

Cybersecurity Frameworks or Cybersecurity Controls direct and assist you in preparing for all sorts of threats and will even guide you in making plans for such threats, including natural incidents, that may occur in your organization. Frameworks consist of a set of documents defining the best practices that an organization can follow in order to manage the cybersecurity risk. An automated warehouse faces challenges of ensuring that its cybersecurity protects its computer systems and data. Your warehouse will need a well developed strategic cybersecurity plan to protect the critical infrastructure and production lines as well as the warehouse information systems. Many of these controls and frameworks complement each other and can conform and work together to cover regulations.

One of the most popular frameworks to use was developed by the Center for Internet Security (CIS). The **CIS Critical Security Controls** are a set of cybersecurity best practices and defensive actions that help defend and protect against attacks and threats in your automated warehouse. The CIS Controls are currently on version 7 and consist of 20 cyber defense recommendations surrounding organizational security.

They are divided into three distinct categories: Basic, Foundational, and Organizational. Each of the 20 CIS Controls is further divided into sub-controls.

Let's do a simple description of each control.

Basic CIS Control:

1. Inventory and Control of Hardware Assets: Actively track and manage all of your hardware devices' throughout your warehouse, including networking devices, IoT, and infrastructure.
2. Inventory and Control of Software Assets: Have a software inventory in place to actively track and manage all of your software running on your computer system.
3. Continuous Vulnerability Monitoring: Continuously scan your assets to identify potential threats and vulnerabilities and address them before they become a problem.

CIS Controls V7

Basic	Foundational	Organizational
1 Inventory and Control of Hardware Assets	7 Email and Web Browser Protections	17 Implement a Security Awareness and Training Program
2 Inventory and Control of Software Assets	8 Malware Defenses	18 Application Software Security
3 Continuous Vulnerability Management	9 Limitation and Control of Network Ports, Protocols. and Services	19 Incident Response and Management
5 Secure Configuration for Hardware and Software on Mobile Devices, laptops, Workstations and Servers	10 Data Recovery Capabilities	20 Penetration Tests and Red Team Exercises
6 Maintenance, Monitoring and Analysis of Audit Logs	11 Secure Configuration for Network Devices, such as Firewalls, Routers and Switches	
	12 Boundary Defense	
	13 Data Protection	
	14 Controlled Access Based on the Need to Know	
	15 Wireless Access Control	
	16 Account Monitoring and Control	

4. Controlled Use of Administrative Privileges: Monitor user and access controls and ensure that only privileged accounts have authorized access to critical systems.
5. Secure Configuration for Hardware and Software on Mobile Devices, Laptops, Workstations, and Servers: Establish and

maintain security configurations based on the organization's approved configuration standards.

6. Maintenance, Monitoring, and Analysis of Audit Logs: Collect, manage, and analyze the audit logs of events to detect anomalies.

Foundational CIS Control Category:

7. Email and Web Browser Protections: Secure and manage web browsers and email systems against web-based threats to minimize the attach surface.

8. Malware Defenses: Control the installation and execution of malicious code at multiple points in your organization to prevent attacks.

9. Limitation and Control of Network Ports, Protocols, and Services: Track and control activity across ports, protocols, and services on network devices to reduce the scope of attacks through service vulnerabilities.

10. Data Recovery Capabilities: Set up processes and tools to ensure that your organization's critical information is properly backed up and have a trustworthy data recovery system in place for data restoration to overcome attacks that jeopardize critical data.

11. Secure Configuration for Network Devices, such as Firewalls, Routers, and Switches: Establish, implement, and manage the security configurations of network devices to prevent attackers from taking advantage of vulnerable default settings.

12. Boundary Defense: Detect, prevent, and control the flow of information across your network boundaries to prevent attackers from gaining access by bypassing boundary systems.

13. Data Protection: Identify and segregate sensitive data, and implement a combination of processes including encryption, data infiltration protection schemes, and data loss prevention techniques to ensure private and integrity of sensitive data.

14. Controlled Access Based on the Need to Know: Track, control, and secure access to critical assets such as information, resources, and systems.

15. Wireless Access Control: Track, control, and secure your wireless local area networks (WLANs), access points, and wireless client systems to prevent attackers from tampering with your perimeter defenses.

16. Account Monitoring and Control: Actively manage the entire life cycle of your systems and application accounts, from their creation, use, and dormancy to deletion to prevent attackers from exploiting legitimate, but inactive user accounts.

Organizational CIS Control Category:

17. Implement a Security Awareness and Training Program: Implement an integrated plan to identify, develop, and instruct employees on the specific skills and abilities they should possess to support the defense of the enterprise according to their functional role in the organization.

18. Application Software Security: Regularly test all your in-house developed and acquired software for vulnerabilities.

19. Incident Response and Management: Develop and implement a defined incident management system in your organization to discover attacks quickly, effectively contain the damage, eradicate the attacker's presence, and restore operations swiftly.

20. Penetration Tests and Red Team Exercises: Periodically test your defenses to identify gaps and assess your organization's readiness to attack by conducting penetration tests.

This was a very brief and simple review of the CIS Critical Security Controls; if needed in your automated warehouse, you will be able to get a more prescriptive and descriptive description for each of the controls.



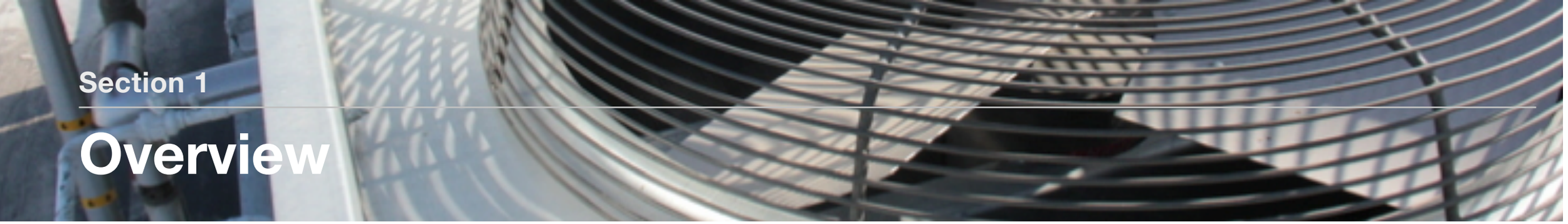
NIST Cybersecurity Framework (CSF)

Now that we have discussed the CIS Critical Security Controls, let's discuss the **NIST Cybersecurity Framework (CSF)** developed by the National Institute of Standards and Technology for Improving Critical Infrastructure Cybersecurity. The CSF is a set of guidelines that an automated warehouse can follow to identify, detect, and respond to cyberattacks. The NIST

Chapter 12

Heating, Ventilation and Air Conditioning

Climate control is a critical need for many distribution centers. This chapter explains the theory behind refrigeration and heating and explains how this technology is used in today's warehouses.



Section 1

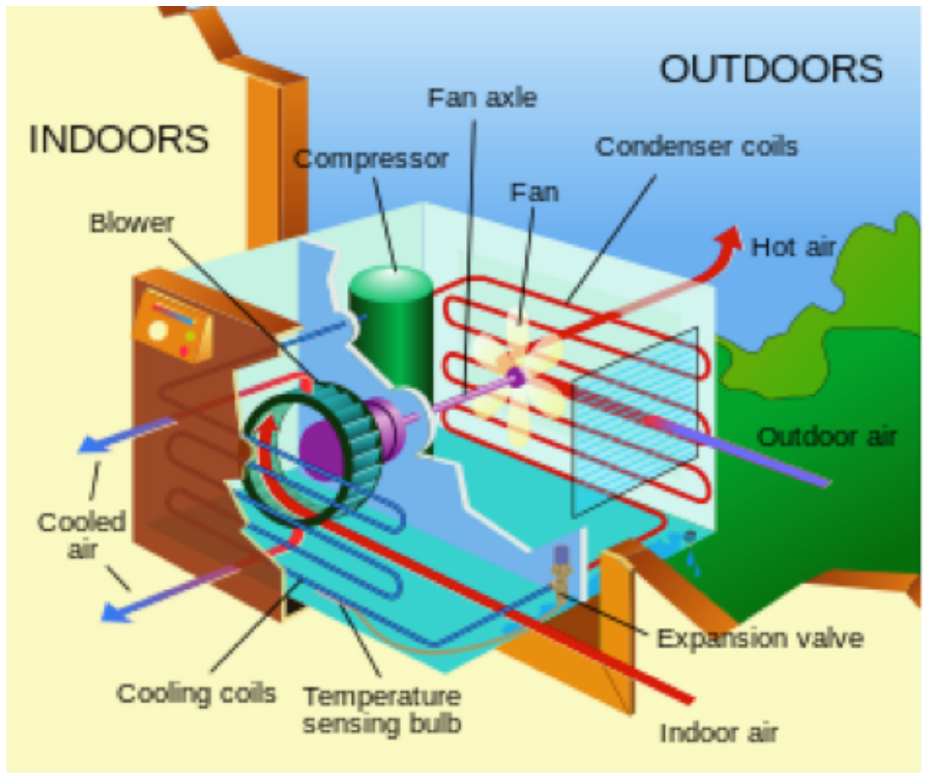
Overview

Heating, ventilation and air conditioning is the process of altering the properties of air (primarily temperature and humidity) to conditions that are more comfortable for people or the needs of products. More generally, air conditioning can refer to any form of technological cooling, heating, ventilation, or disinfection that modifies the condition of air.

An air conditioner is a major home appliance, system, or mechanism designed to change the air temperature and humidity within an area. The system is used for cooling and sometimes heating depending on the air properties required at a given time. The cooling is typically done using a simple refrigeration cycle, but sometimes evaporation is used, commonly for comfort cooling in buildings and motor vehicles. In construction, a complete system of heating, ventilation and air conditioning is referred to as HVAC.

Air conditioning can also be provided by a process which uses pumps to circulate a coolant (typically water or a glycol mix) from a cold source (exterior system) to an entire building. These systems can create cold or hot liquids that circulate throughout the building and can have heat exchangers at different locations. These systems can have very high efficiencies and simplify the operation, making it more efficient. Large facilities like distribution centers or other large buildings use these systems.

Typical air conditioning system showing the components



Window air conditioning unit

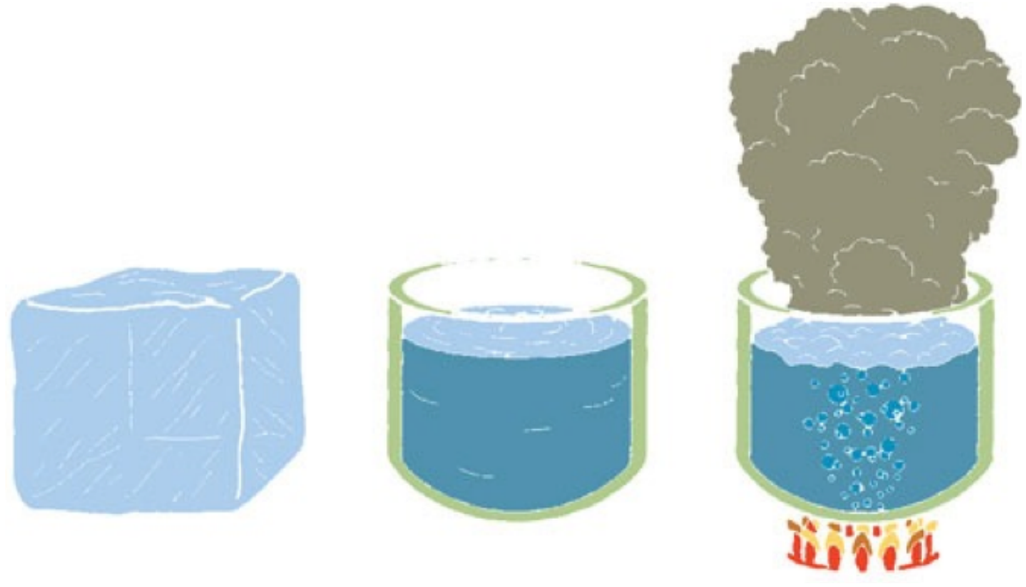


Section 2

Physical Principles

Change of State

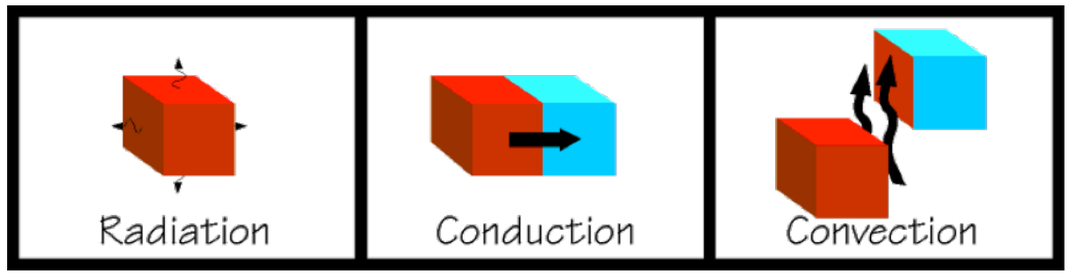
On earth, matter is found in one of three different phases or states: solid, liquid, or vapor (gas). The state depends upon the nature of the substance, the temperature, and the pressure or force exerted on it. Water occurs naturally in all three states: solid ice, liquid water, and water vapor, depending upon the temperature and pressure. Pure water below 32 degrees is a solid, 32 degrees to 212 degrees (at sea level pressure) is a liquid and 212 degrees or above (at sea level pressure) is a gas.



Three states of matter

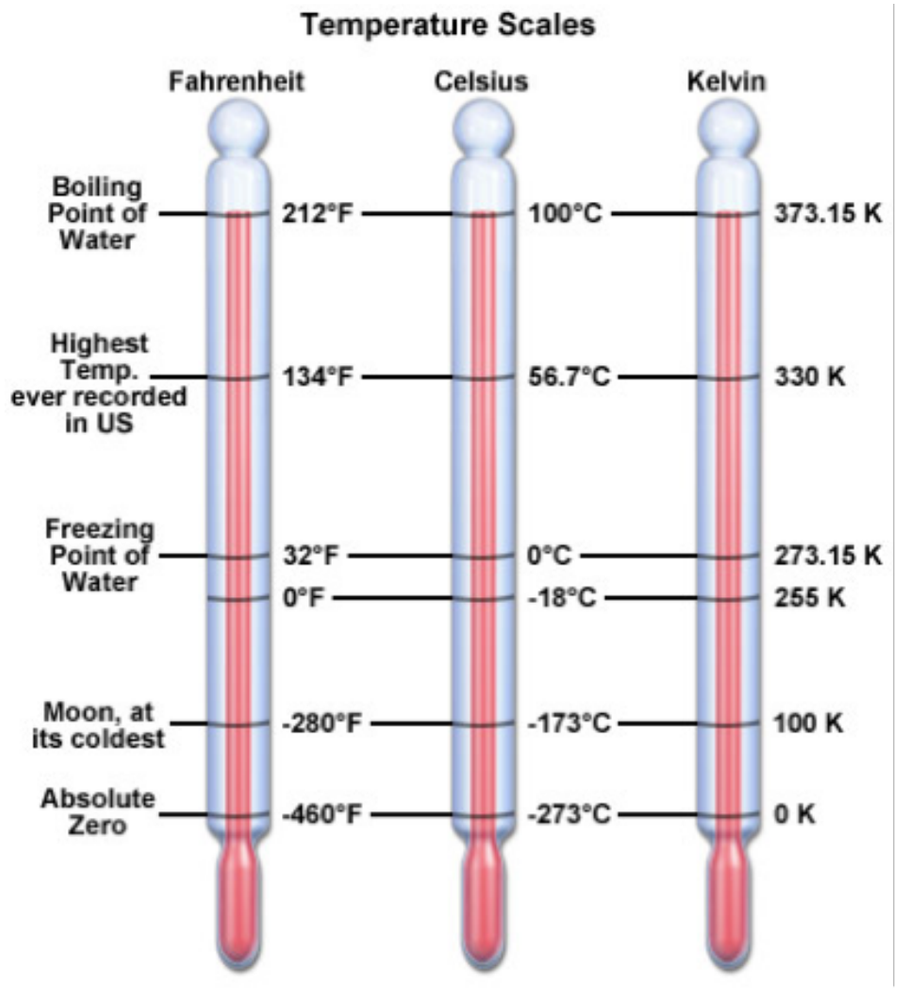
Heat and Temperature

Heat transfers by three processes: Radiation, Conduction and Convection. Heat will flow from the hot object into the cold object which is called conduction. When heat is transferred by a substance in the gaseous state, the process is called convection. When an object is cooling by removing heat to the surrounding area it is called radiating heat.



Heat transfer processes

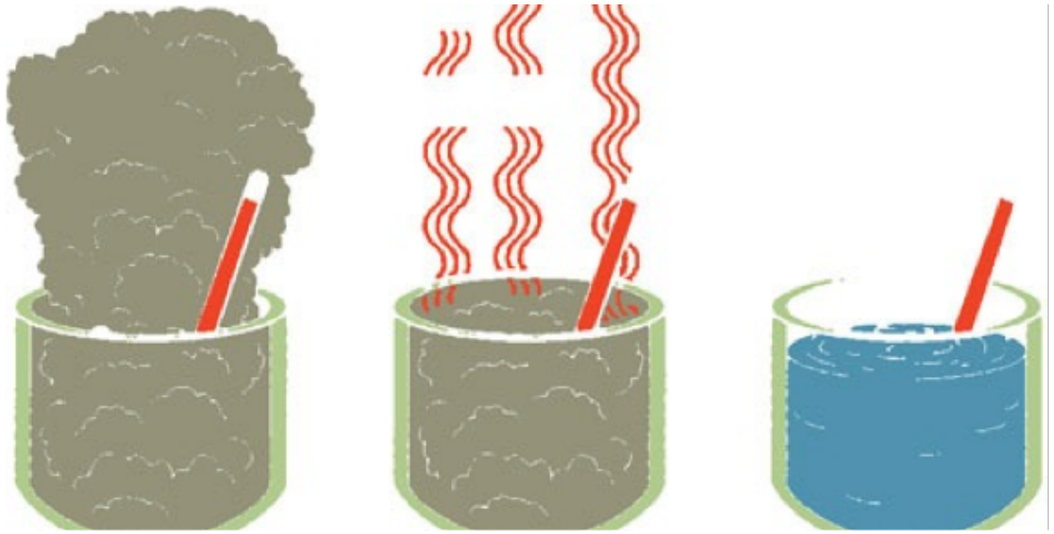
Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called heat. The intensity of vibration depends on how much kinetic energy, or energy of motion, the atom or molecule contains. We measure the level of this energy as temperature. Heat and temperature are not the same. Temperature is measured in degrees. Heat is measured in calories (c). The calorie is a metric unit that expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius. Heat is also measured in British Thermal Units (BTU). One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories.



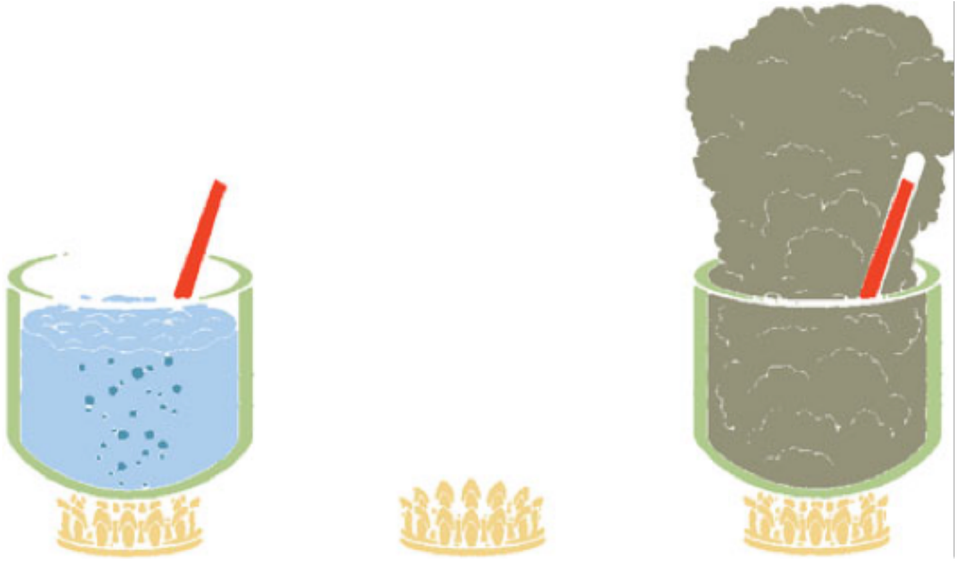
Temperature classification scales used for comparison

Latent Heat

Latent heat is heat that is needed to change a substance from one state to another. Imagine that a solid or a liquid is being heated on a stove. When the solid reaches its melting point, or the liquid reaches its boiling point, their temperatures stop rising. The solid begins to melt, and the liquid begins to boil. This occurs without any change in temperature, even though heat is still being poured in from the burner. This giving off and absorbing of heat energy is heat transfer that makes the HVAC system efficient. It is the change of state that allows the systems to work by absorbing large amounts of heart energy.



Heat is given off when converting a gas to a liquid, but the temperature can be the same.



Heat is absorbed to change the state from a liquid to a gas, but the temperature is the same.

Temperature/Pressure Relationship

The pressure on a substance will change the temperature required to change its state. As the pressure increases, the temperature required to change from a liquid to a gas (evaporation) increases. As the pressure decreases, less heat and a drop in temperature is needed to change from a gas to a liquid (condensation). During evaporation heat is absorbed and during condensation heat is given off. This pressure theory allows for controlling temperature in HVAC components by controlling the pressures, which then becomes the basic concept of temperature control in a given environment (room AC, freezer, and refrigerator). Refrigerant in an AC system is the heat transfer element and the change of state of the refrigerant absorbs and expels large volumes of heat energy. This is accomplished by the pressure on the refrigerant being controlled by the pressures within the system.

Refrigeration systems control the pressures within to control the temperatures at given places within the system. The temperature must be higher to give off heat to the surrounding air.

Temp	Pres	Pres		Temp	Pres	Pres		Temp	Pres	Pres
°F	R134	R12		°F	R134	R12		°F	R134	R12
-60	21.6	19.0		29	25.3	27.7		70	71.2	70.2
-55	20.1	17.3		30	26.1	28.5		75	78.8	77.0
-50	18.7	15.4		31	26.9	29.3		80	86.8	84.2
-45	16.9	13.3		32	27.8	30.1		85	95.4	91.8
-40	14.8	11.0		33	28.6	30.9		90	104.0	99.8
-35	12.5	8.4		34	29.5	31.7		95	114.0	108.3
-30	9.8	5.5		35	30.4	32.6		100	124.0	117.2
-25	6.9	2.3		36	31.3	33.4		105	135.0	126.6
-20	3.7	0.6		37	32.2	34.3		110	147.0	136.4
-15	0.1	2.4		38	33.1	35.2		115	159.0	146.8
-10	1.9	4.5		39	34.1	36.1		120	171.0	157.7
-5	4.1	6.7		40	35.0	37.0		125	185.0	168.6
0	6.5	9.2		41	36.0	37.9		130	199.0	181.0
5	9.1	11.8		42	37.0	38.8		135	214.0	193.5
10	11.9	14.6		43	38.0	39.7		140	229.0	206.6
15	15.0	17.7		44	39.0	40.7		145	246.0	220.3
20	18.4	21.0		45	40.1	41.7		150	263.0	234.6
21	19.2	21.7		46	41.1	42.6		155	281.0	249.5
22	19.9	22.4		47	42.2	43.6		160	299.3	265.1
23	20.6	23.2		48	43.2	44.6		170	340.8	297.3
24	21.3	23.9		49	44.3	45.7		180	385.6	333.2
25	22.1	24.6		50	45.4	46.7		190	434.8	372.2
26	22.9	25.4		55	51.3	52.0		200	488.9	414.3
27	23.7	26.1		60	57.5	57.7				
28	24.5	26.9		65	64.1	63.8				
	inch Hg. Figures are Vacuum									

Temperature/Pressure chart for refrigerant

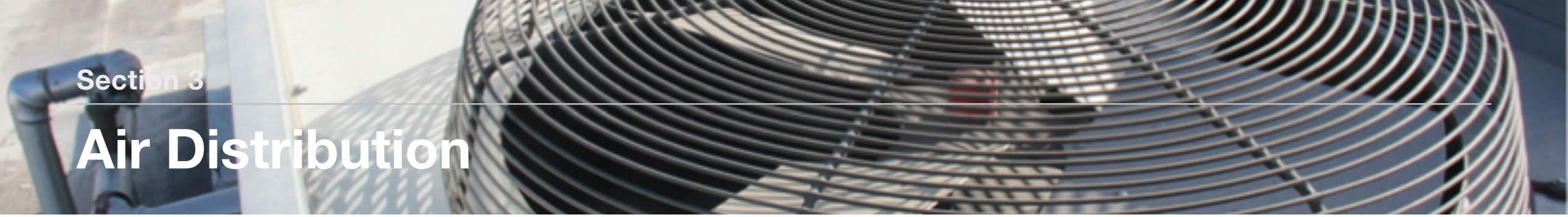
Humidity

Humidity plays a major role in personal comfort and efficiency of an air conditioner or refrigeration system. Humidity depends upon the amount of water vapor present in a volume of air and the temperature of that air mass. The amount of water vapor in the air tends to be higher near lakes or the ocean because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low. Relative humidity is the percentage of moisture is present in the air compared to how much moisture the air is capable of holding at that temperature. Humidity has an influence on heat transfer because energy is used to condense the humidity while not changing the temperature of the treated or cooled air, so the greater the humidity the less efficient an air conditioning system will be.

	Air Temperature (Degrees F)										
Relative Humidity	70	75	80	85	90	95	100	105	110	115	120
0%	64	69	73	78	83	87	91	95	99	103	107
10%	65	70	75	80	85	90	95	100	105	111	116
20%	66	72	77	82	87	93	99	105	112	120	130
30%	67	73	78	84	90	96	104	113	123	135	148
40%	68	74	79	86	93	101	110	123	137	151	
50%	69	75	81	88	96	107	120	135	150		
60%	70	76	82	90	100	114	132	149			
70%	70	77	85	93	106	124	144				
80%	71	78	86	97	113	136	157				
90%	71	79	88	102	122	150	170				
100%	72	80	91	108	133	166					

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Humidity chart for comfort



Section 3

Air Distribution

Air distribution is normally accomplished when ducts are used for heating, ventilation, and air conditioning (HVAC) to deliver and remove air. Air flows include supply air, return air, and exhaust air. Ducts also deliver, most commonly as part of the supply air, ventilation or outside air. As such, air ducts are one method of ensuring acceptable indoor air quality as well as thermal comfort.

A duct system is often called ductwork. Planning, sizing, optimizing, detailing, and finding the pressure losses through a duct system, is called duct design.

Supply and Return Air

Most spaces that use climate control will be required to deliver supply air and return air. Supply air is delivered to a space after it has been cooled or heated by the system. The same amount or volume of air must be removed from the space to be returned to the system for retreatment and create a flow of air to continually control the temperature of the space. Most systems are of this recirculating air type. Exceptions to recirculating air are in areas where germs or bacteria are a concern such as hospital rooms and some food processing and storage facilities.

Interactive 12.1 Supply and Return Air Images



Tap to view supply and return air images.

Blower motors

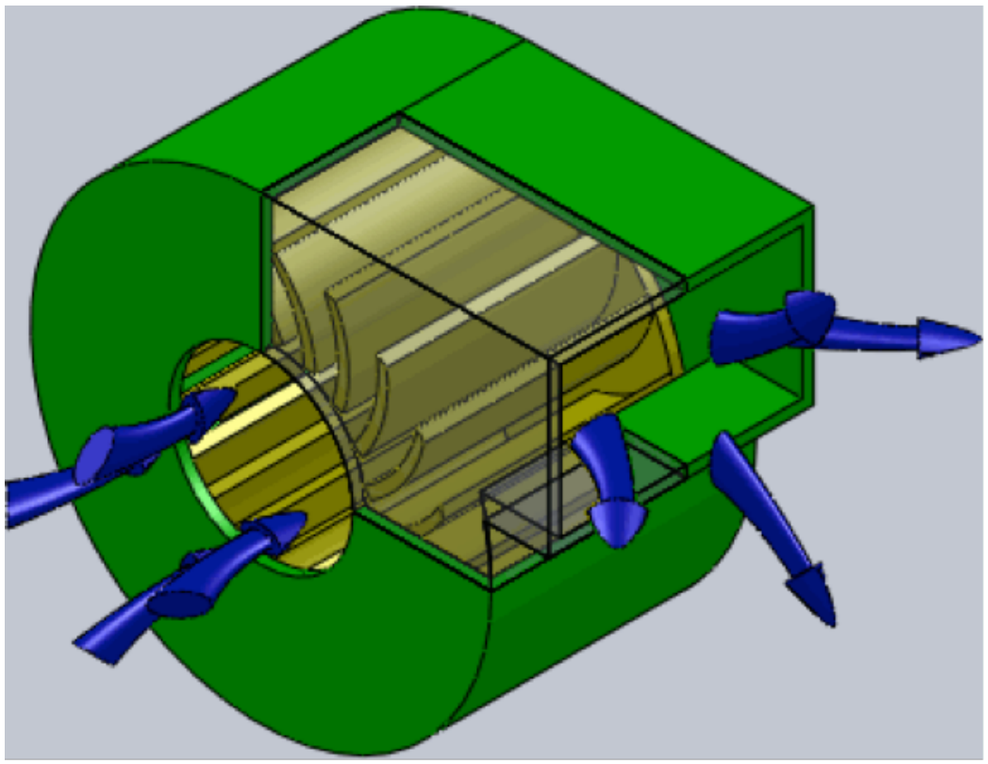
Electric blower motors are driven by 120 or 220 VAC, single or three-phase electricity, depending on the power rating. Motors under two horsepower or 1,500 watts will normally be driven by 120 VAC, with larger motors being driven by 220 VAC or higher. The motors are controlled by the system and may be of multiple or variable speed dependent on the application. The motor in operation with the fan will create pressurized supply air and suction side return air to complete the air flow through the controlled space.



Blower motor

Fans

Most air delivery fans to move treated air (evaporator fans) are of the squirrel cage design because they are very efficient and quiet. The size of the fan will be determined by the amount of air to be moved and its capacity will be rated in cubic feet per minute (CFPM) of air flow. Large spaces with high demands can have fans in excess of five feet in diameter, but most are about 18 to 24 inches in diameter. External heat dissipation fans (condenser fans) are normally of the blade design since noise is normally not a concern and vertical air flow is efficient.



Operation of a squirrel cage fan

Interactive 12.2 Fan Images



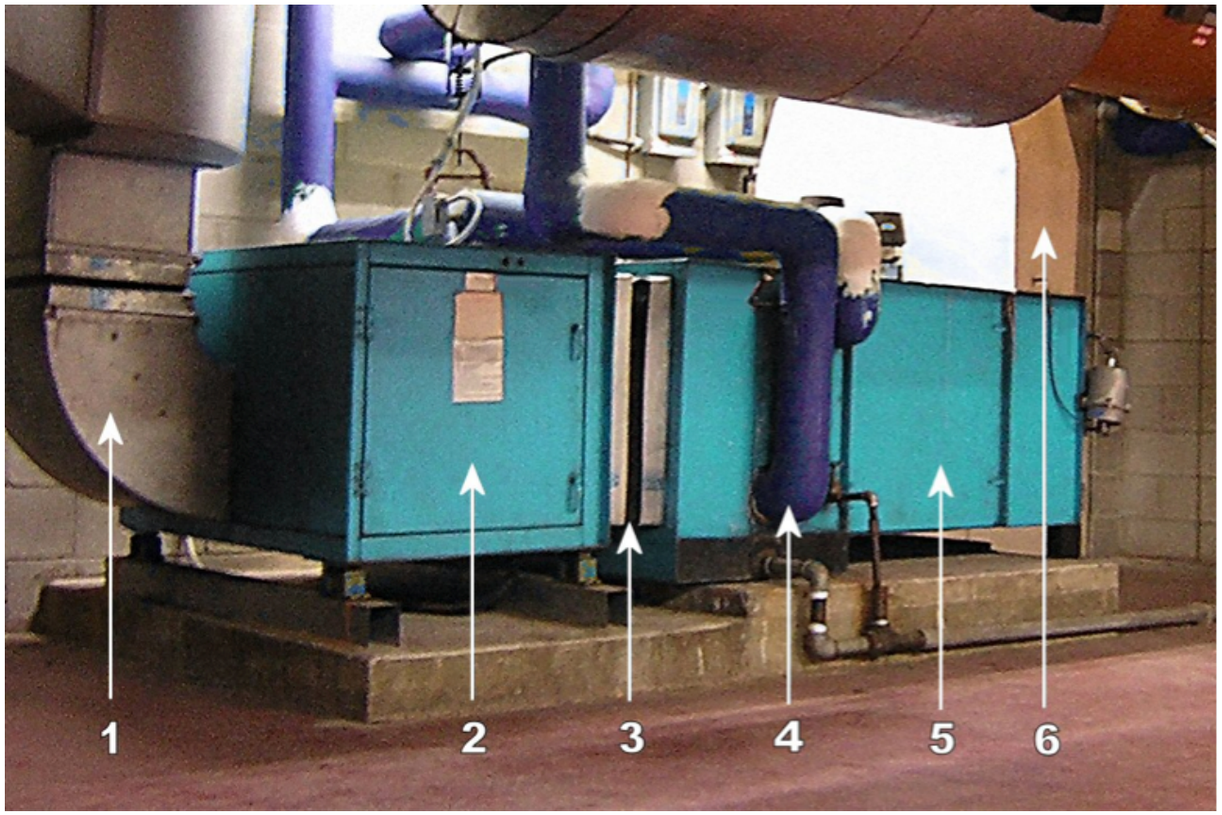
Tap to view images of fans

Air Handlers

An air handler, or air handling unit (often abbreviated to AHU), is a device used to condition and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system. An air handler is usually a large metal box containing a blower, heating or cooling elements, filter racks or chambers, sound attenuators, and dampers. Air handlers usually connect to a duct work ventilation system that distributes the conditioned air through the building and returns it to the AHU. Sometimes AHUs discharge (supply) and admit (return) air directly to and from the space served without ductwork. Small air handlers, for local use, are called terminal units, and may only include an air filter, coil, and blower; these simple terminal units are called blower coils or fan coil units. A larger air handler that conditions 100% outside air, and no recirculated air, is known as a makeup air unit (MAU). An air handler designed for outdoor use, typically on roofs, is known as a packaged unit (PU) or rooftop unit (RTU).



Roof mounted package AC/Heating unit



Commercial Air Handler Parts

1-Supply duct

2-Fan compartment

3-Flex connector

4-Heating and cooling coil

5-Filter area

6-Return and fresh air duct

Filters

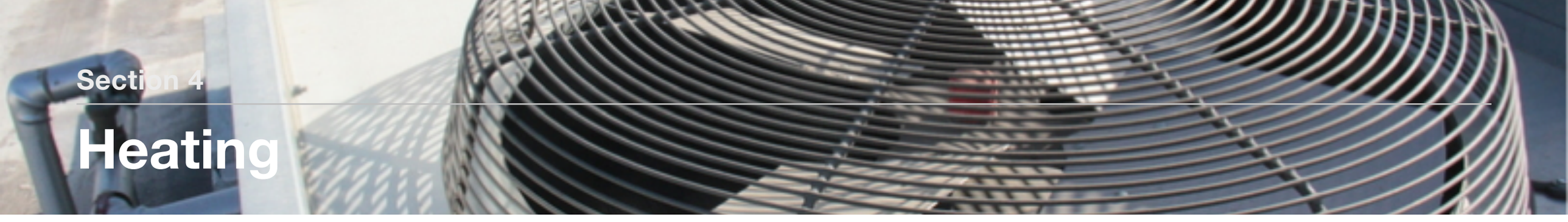
All air that is recirculated in the HVAC system or is brought into the system from outside must be filtered. The filters are paper or fiberglass replacement components that filter dust and dirt from the air before it is delivered to the conditioned space.



Paper (left) and fiberglass (right) element filters



Filter changing on roof units



Section 4

Heating

A heating system is a mechanism for maintaining temperatures at an acceptable level, by using thermal energy within a home, office, or other facility. Most often, heating is part of an HVAC system. A heating system may be centralized or distributed.

Heated Water System

A hot water or steam heating system uses heated water produced in a boiler or heated tank to circulate throughout a facility to heat spaces. A sealed hot water system provides a form of central heating in which the water used for heating usually circulates independently of the building's normal water supply.

An expansion tank contains compressed gas, separated from the sealed-system water by a diaphragm to allow expansion. This allows for normal pressure changes in the system. A safety valve allows water to escape from the system when pressure becomes too high, and a valve can open to replenish water from the normal water supply if the pressure drops too low. Sealed systems offer an alternative to open-vent air systems, in which steam can escape from the system, and gets replaced from the building's water supply via a feed and central storage system. The circulation of this heated water is pumped through insulated pipes throughout the facility and used with air flow devices to heat any space.



Expansion tank



Centralized hot water or steam boiler

Fueled Heating

The use of natural gas or oil has become the standard for most heating today. It can be used as a heater of water to transfer heat or can be used directly to heat air which is distributed to the space. Filters and blowers are used to direct and clean the air before it enters the controlled space. The use of different energy sources is dependent on the local area and the supply of energy sources.

Interactive 12.3 Fueled Heating Images



Tap to view fueled heating images

Electric Heating

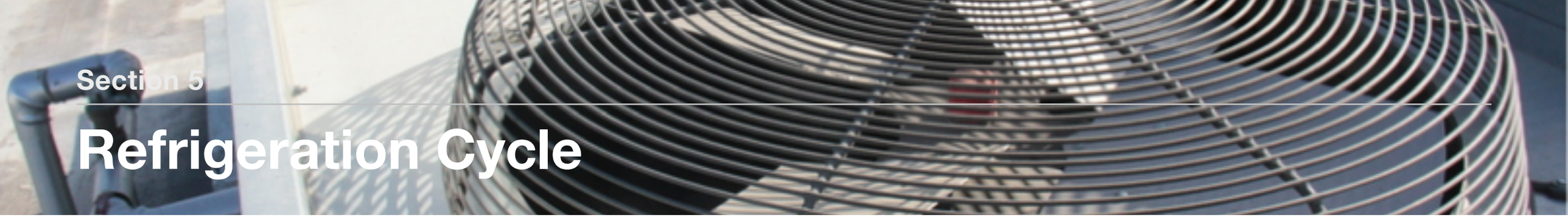
Electric heating or resistance heating converts electricity directly to heat. Electric heat is often more expensive than heat produced by combustion appliances like natural gas, propane, and oil. Electric resistance heat can be provided by baseboard heaters, space heaters, radiant heaters, furnaces, wall heaters, or thermal storage systems.

Electric heaters are usually part of a fan coil which is part of a central air conditioner. They circulate heat by blowing air across the heating element, which is supplied to the furnace through return air ducts. Blowers in electric furnaces move air over one to five resistance coils or elements which are usually rated at five kilowatts. The heating elements activate one at a time to avoid overloading the electrical system. Overheating is prevented by a safety switch called a limit controller or limit switch. This limit controller may shut the furnace off if the blower fails or if something is blocking the air flow. The heated air is then sent back through the home through supply ducts.

In larger commercial applications, central heating is provided through an air handler.



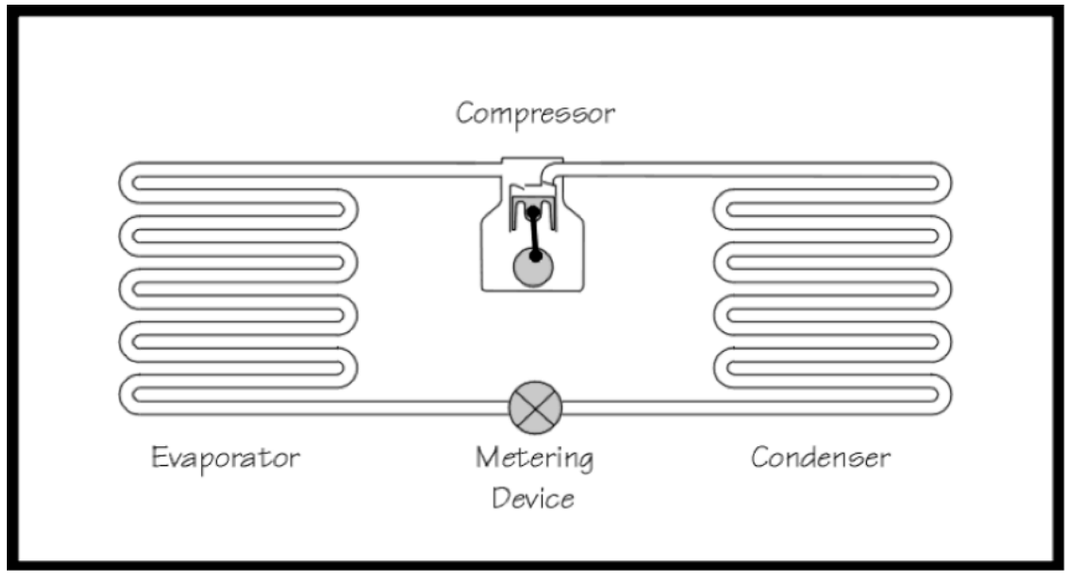
Electric space heater



Section 5

Refrigeration Cycle

The four main components in a mechanical refrigeration system are the compressor, condenser, metering device and evaporator. Any components beyond these basic four are called accessories. The compressor is a vapor compression pump, which uses pistons or some other method to compress the refrigerant gas and send it to the condenser. The condenser is a heat exchanger, which removes heat from the hot compressed gas and allows it to condense into a liquid as it gives off heat energy. The liquid refrigerant at slightly over outside air temperature is then routed to the metering device. This device restricts the flow by forcing the refrigerant to go through a small hole or control valve, which causes a pressure drop. As the pressure drops to a liquid, it lowers the boiling point and makes it easier to evaporate as it absorbs heat energy. When a liquid evaporates it will absorb heat from the surrounding area. This component where the evaporation takes place is called the evaporator. The refrigerant is then routed back to the compressor to complete the cycle. The refrigerant is used over and over again, absorbing heat from one area and relocating it to another. The definition of refrigeration is to remove and relocate heat.



Air Conditioning schematic of the four major parts of the refrigeration cycle

Compressors

Air conditioning compressors have two basic functions: to create pressure differences to recirculate refrigerant throughout the system and to increase and decrease pressures to allow for a flow of heat energy to a lower temperature to transfer heat. Four types of compressors are used: piston or reciprocating, scroll or centrifugal, vane and screw. Each type of compressor has advantages and the type used is dependent on volume and the size of the system. Compressors create high side pressures that heat the refrigerant above the outside temperature to make sure heat dissipation exists in the condenser and refrigerant changes from a gas to a liquid. The compressor also produces suction on the low side of the system at a much lower pressure, which allows the evaporator to absorb heat energy, changing the refrigerant from a liquid to a gas, which is used to cool the desired space.

Interactive 12.4 Compressor Images



Tap to view compressor images.

Components

Condensers

The condenser is a heat exchanger that gives off heat energy to the outside air and condenses hot gaseous refrigerant to a lower temperature liquid. It utilizes the principles of heat transfer to move heat from a high temperature to a lower temperature. The purpose is to dissipate heat so that the refrigerant gas can condense back into a liquid in preparation for a return trip to the evaporator. If the hot compressed gas is 135 ºF and the outside air being sucked through the condenser fins is at 90 ºF, heat will flow from high to low so heat is dissipated. Heat will have been removed from one place and relocated to another as the definition of refrigeration describes. As long as the compressor is running it will impose a force on the refrigerant to continue circulating around the loop and continue removing heat from the condenser.

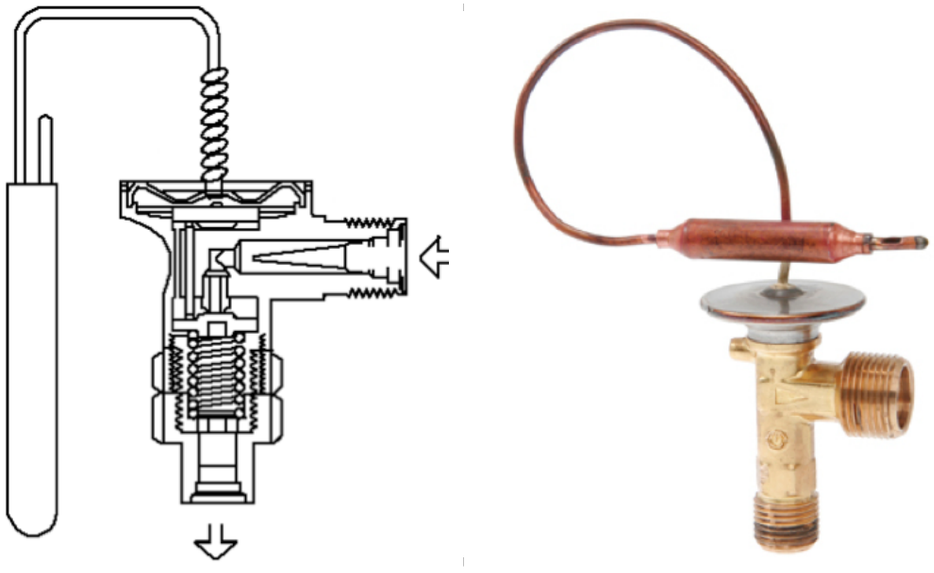


Condensers with fans

Expansion Devices

The expansion valve removes pressure from the liquid refrigerant to allow expansion or change of state from a liquid to a vapor in the evaporator.

The high-pressure liquid refrigerant entering the expansion valve is quite warm. This may be verified by feeling the liquid line at its connection to the expansion valve. The liquid refrigerant leaving the expansion valve is quite cold. The orifice within the valve does not remove heat, but only reduces pressure. Heat molecules contained in the liquid refrigerant are thus allowed to spread as the refrigerant moves out of the orifice. Under a greatly reduced pressure the liquid refrigerant is at its coldest as it leaves the expansion valve and enters the evaporator.



Schematic and Pictorial view of an expansion valve

Evaporators

An evaporator is a heat transfer device that transfers heat from the recirculating air to the system refrigerant, lowering the air temperature. When the liquid refrigerant reaches the evaporator, its pressure has been reduced, dissipating its heat content and making it much cooler than the recirculating fan air flowing through it. This causes the refrigerant to absorb heat from the warm air and reach its low boiling point rapidly about (34 degrees). The refrigerant then vaporizes, absorbing the maximum amount of heat. This transfer of heat cools the space by removing the heat energy from the delivered air.

This heat is then carried by the refrigerant from the evaporator as a low-pressure gas through a hose or hard line to the low side of the compressor, where the whole refrigeration cycle is constantly repeated.



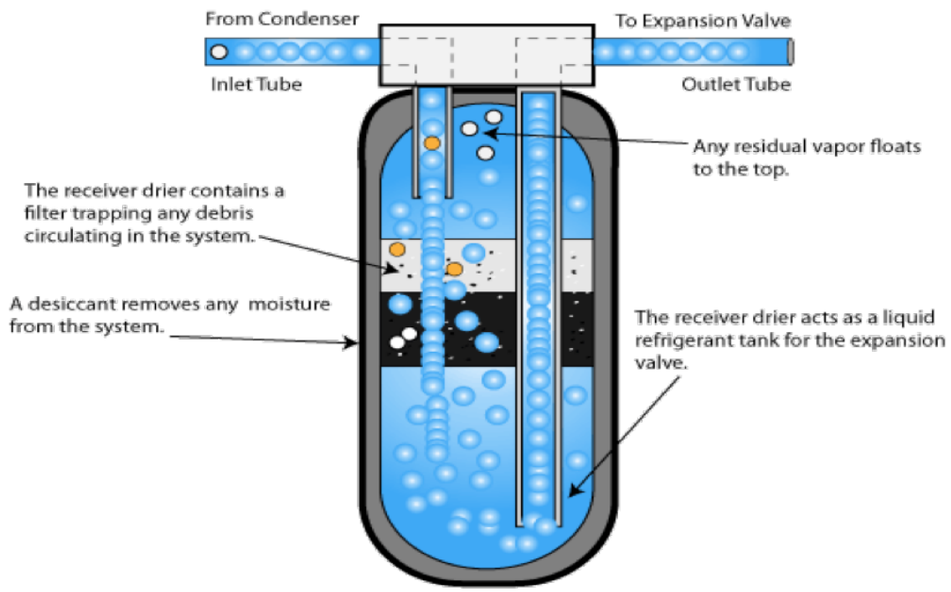
Evaporators for a commercial refrigerator

Receiver/Drier

The receiver/drier is a liquid storage tank for the refrigerant flowing from the condenser. This insures that the necessary liquid refrigerant is consistently supplied to the expansion valve under all operating conditions. At the most demanding times of the day, the opening expansion valve relies on this storage tank to provide the evaporator core its supply of liquid refrigerant.

The receiver drier also contains a desiccant capable of absorbing moisture from the refrigerant, and a filter that collects any unwanted debris in the system. Any time this desiccant is exposed to the atmosphere, it will absorb moisture and humidity from the air, and it must be replaced, so during service never leave a system open. Also, any time the compressor is replaced, the receiver drier must be replaced as well. This is because any debris in the system from the compressor is trapped in the filter located inside the drier.

Refrigerant from the condenser enters the receiver drier through the inlet port. The vapor rises to the top while the heavier liquid refrigerant drops to the bottom. It passes through the filter and desiccant and is then stored in the bottom of the tank. As the expansion valve opens and closes, the liquid refrigerant is drawn into the outlet port tube of the receiver drier, through the high pressure line, and into the expansion valve.



Receiver/drier diagram



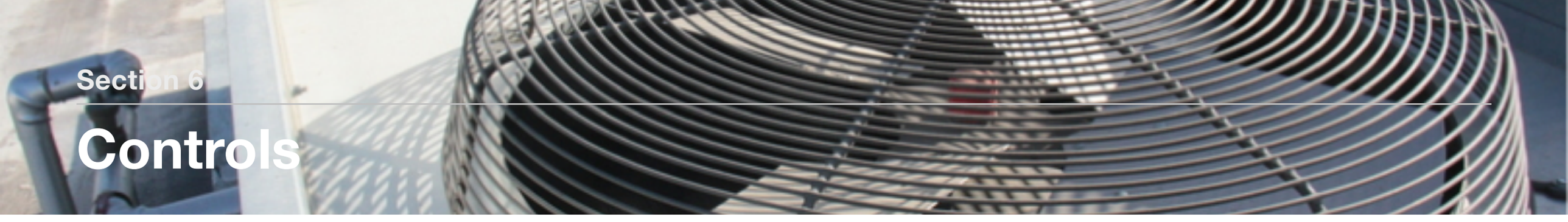
Receiver/Drier in use

Chillers

A chiller is a machine that removes heat from a liquid via the refrigeration cycle. They work opposite of a heated water system used for heating. This liquid can then be circulated through insulated pipes throughout the facility to heat exchangers to cool air or equipment as required. In air conditioning systems, chilled water is typically distributed to heat exchangers, or coils, in air handling units or other types of terminal devices which cool the air in their respective space(s). The water is then recirculated back to the chiller to be cooled again. These cooling coils transfer sensible heat and latent heat from the air to the chilled water, thus cooling and usually dehumidifying the air stream.



Large volume chiller to distribute cold water



Section 6

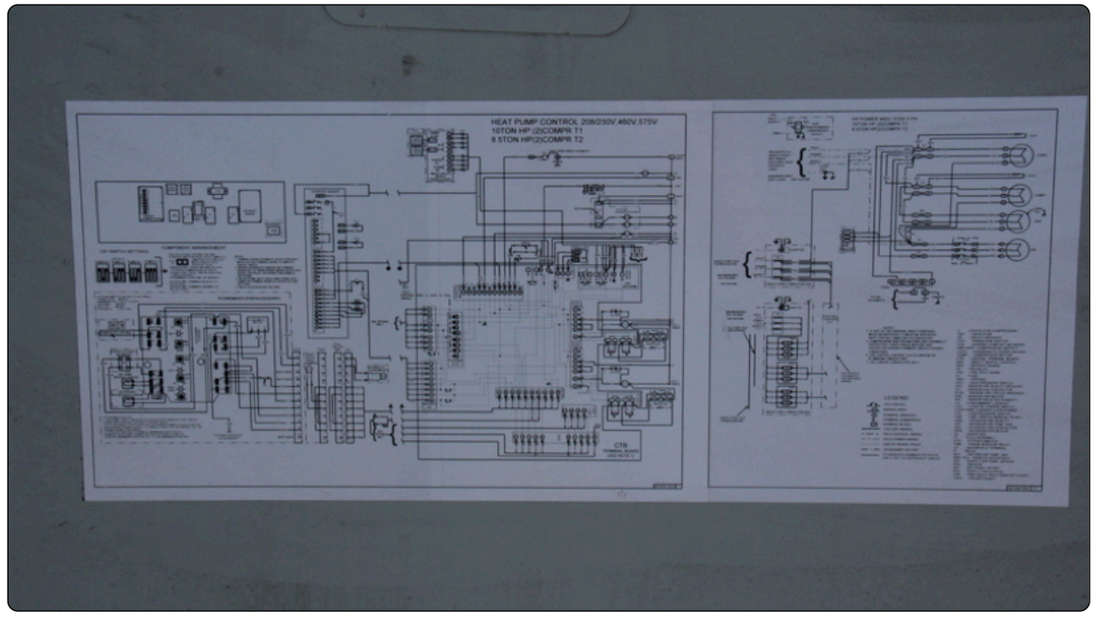
Controls

Controls for HVAC systems include electric/electronic, pneumatic, temperature sensing by pressure, space temperature sensing, flow control for cooling and heating and pressure sensors throughout the system. The design of the system will provide control for safety, temperatures and for self-diagnosis.

AC System Controls Schematic

Schematic diagrams of the control circuits are the roadmaps for technicians to evaluate the operation and troubleshoot any failures or operational concerns. They are developed by the supplier or installer, included with the equipment when installed and available on the equipment for easy access and in a central information data base of paper copies or computer memory.

Interactive 12.5 Controls Images



Tap to view images of controls.

AC System Controls

Thermostats

Thermostats are devices that maintain a selected temperature in the controlled space. They control the HVAC system by controlling the correct pressures within the refrigeration system, air flow in the distribution system and air temperatures.

A programmable thermostat is a thermostat, which is designed to adjust the temperature according to a series of programmed settings that take effect at different times of the day. Programmable thermostats may also be called setback thermostats or clock thermostats.

Heating and cooling losses from a building (or any other container) become greater as the difference in temperature increases. A programmable thermostat allows reduction of these losses by allowing the temperature difference to be reduced at times when the reduced amount of heating or cooling would not be objectionable.



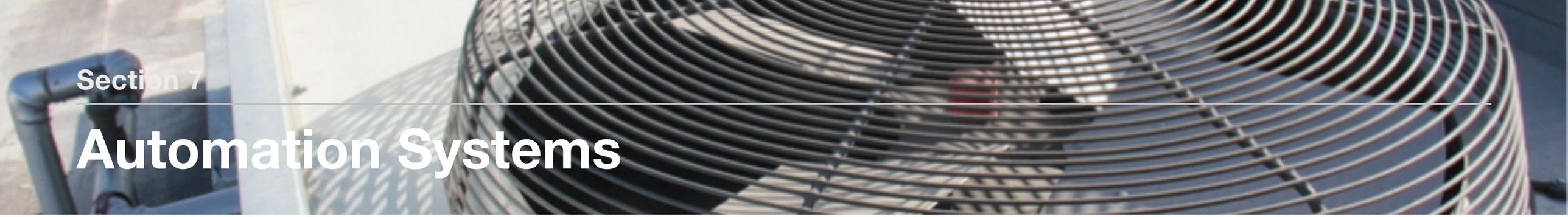
Thermostatic control panel

Pressure Switches

Pressure switches control temperatures in the evaporator by controlling the pressures within the system and the safeties installed on units to protect the unit, compressor, and anyone working on the unit. Pressure switch values vary from unit to unit and with the type of refrigerant in the unit. Usually, there are two types of pressure switches: high pressure switches (compressors, condensers) and low pressure switches (evaporators). It is important to remember that there are multiple causes for safeties tripping. A complete diagnostic of the refrigerant side of the system is necessary to determine the cause if the safety trips. Pressures are one part of the diagnostic, but amp draw of the compressor along with electrical diagnostics may be needed.



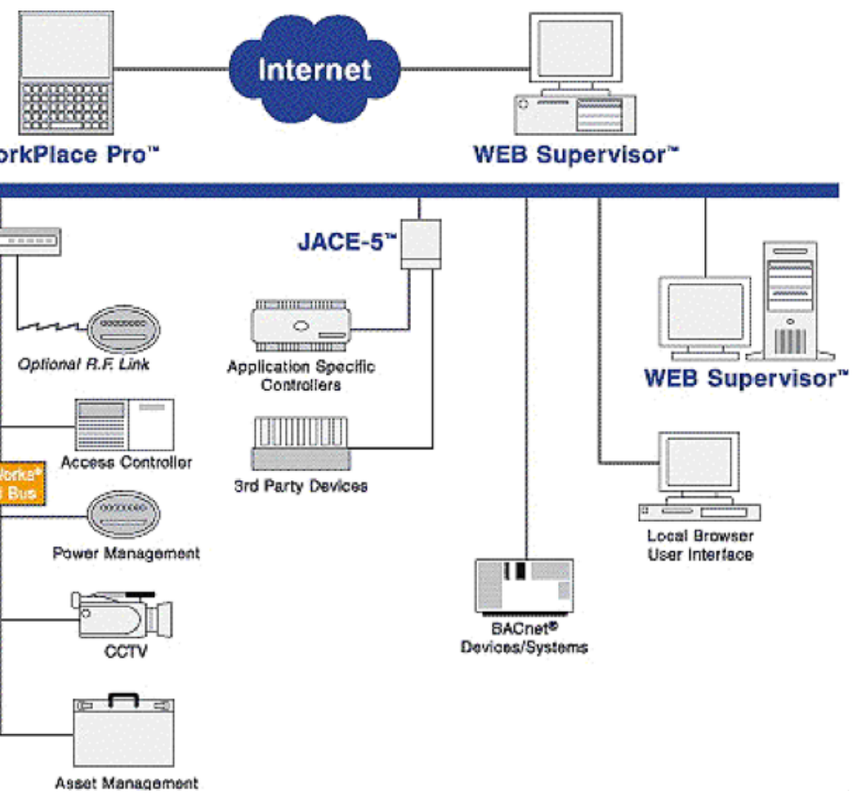
High and low pressure switch combination



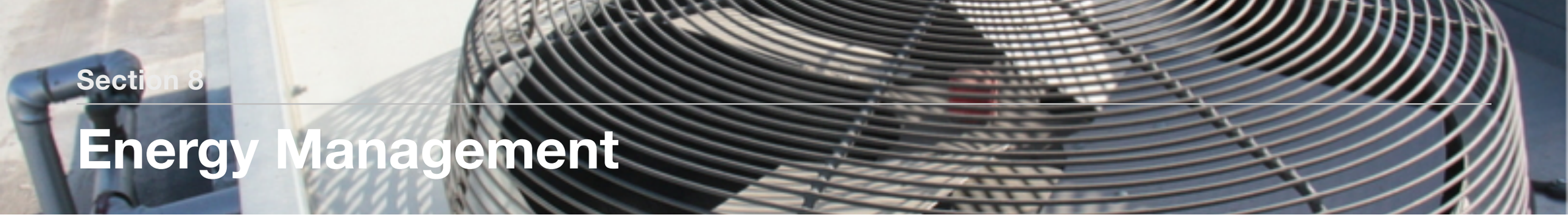
Section 7

Automation Systems

Improvements in technology and computer controls have allowed for the development of fully integrated HVAC systems that have become accurate, cost effective and energy efficient systems. The total control and feedback delivered by these systems allow for constant monitoring of the system to control temperatures and to self-diagnose to make the automated warehouse the most productive it can be. Worker comfort and product temperature and humidity control create an environment for quality distribution and worker productivity.



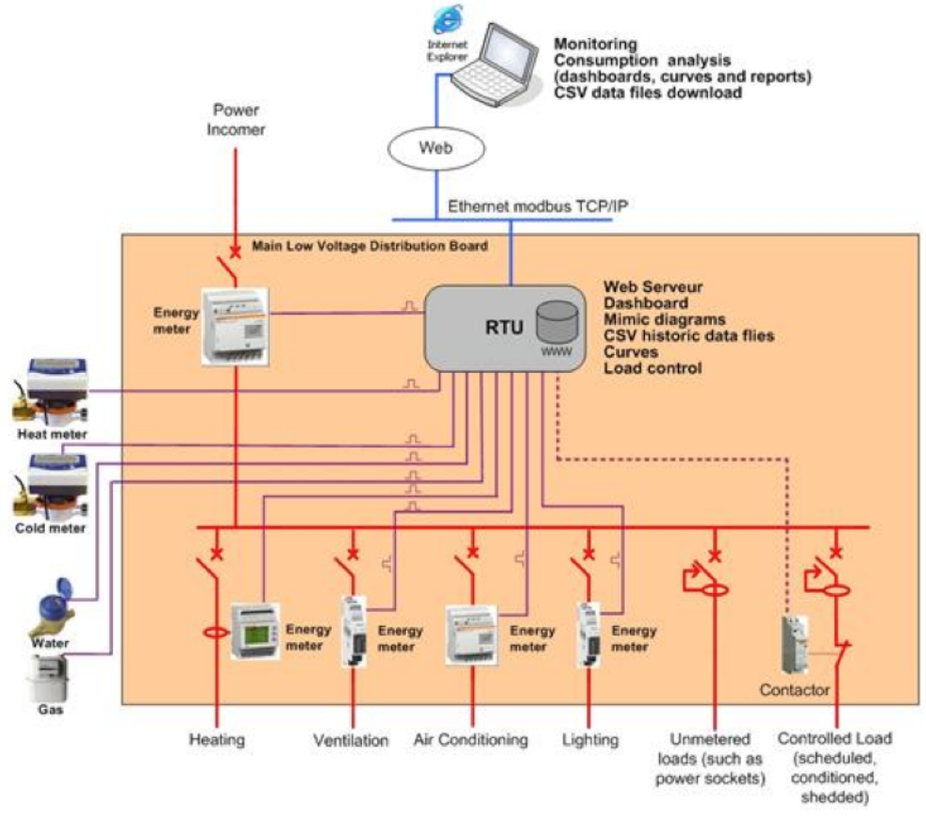
Pictorial view of an automated system



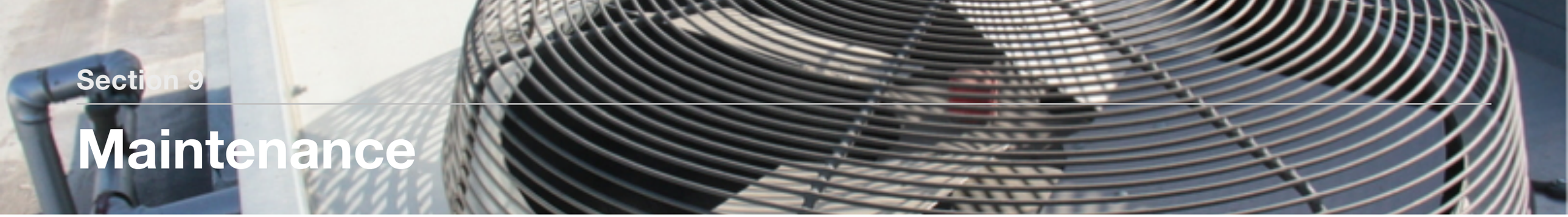
Section 8

Energy Management

HVAC is a large electrical energy consumer for a distribution center. Efficient operation of the system can be a major financial benefit to the company. Energy management includes planning and operation of all energy-related production and consumption units. Evaluating the systems and how they are operated will require a long range plan for design, purchase and operation of the HVAC system. Changes to the system and constant maintenance will help in controlling the costs and related failures.



Energy management system



Section 9

Maintenance

Scheduled Maintenance

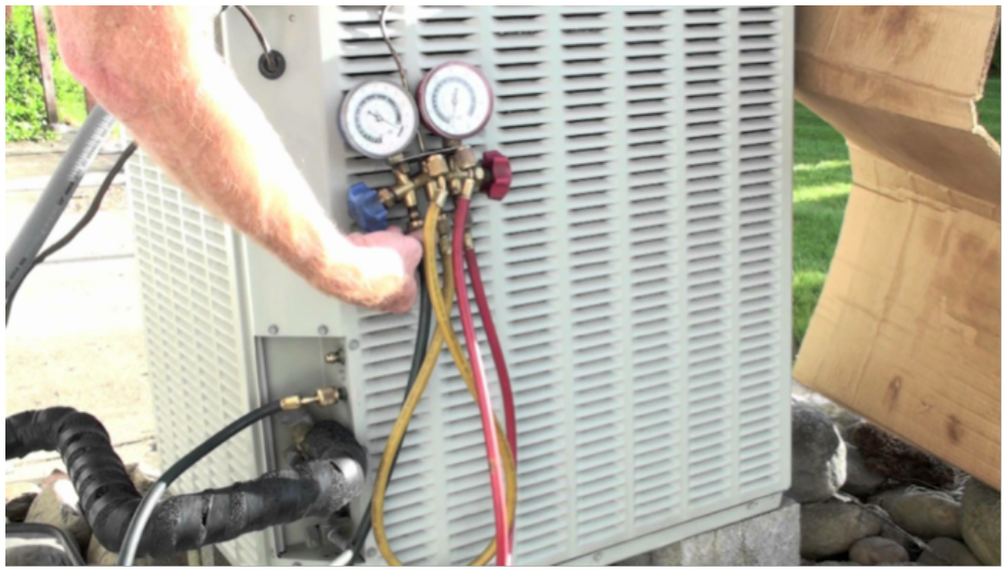
The changing of filters and drive belts are the major replacement service items that are done as scheduled maintenance on an air conditioning and heating system. The cleaning of the condenser and evaporator are done periodically depending on the environment the system is operating in. Dirt and dust collecting on these items affect the efficiency of the system so cleaning needs to be done.



Changing filters

Pressure Monitoring

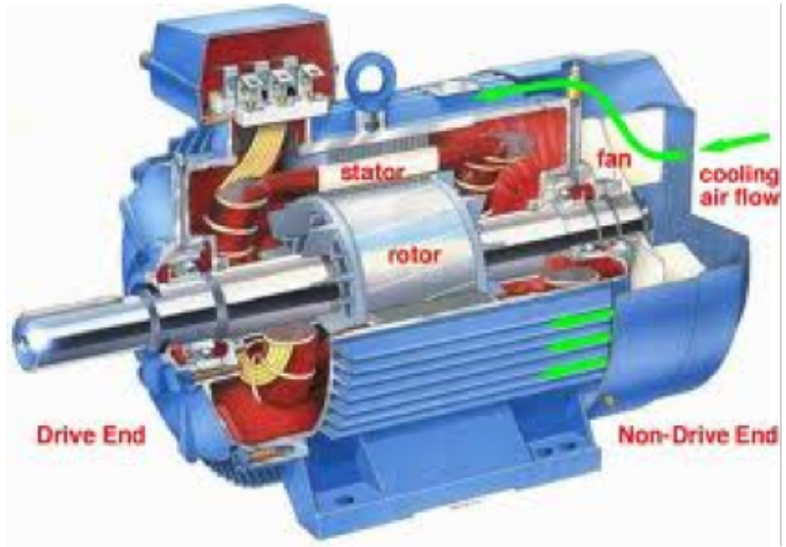
HVAC systems are trouble free and little maintenance is required when considering that most of the systems are in operation continuously. Monitoring refrigerant pressures is normally not required unless a temperature change exists, but this monitoring can expose a possible problem, such as a leak, before it becomes a failure.



Monitoring the high and low pressures

Motors and Belts

Motors to drive AC fans and compressors are reliable and require little or no maintenance. If they become noisy or fail to start, a problem exists and is a reason for repair or replacement. Supply voltage and current or electronic controls are usually the failure and not the motor.



AC motor for driving a fan or compressor

Most belt drives use standard V-belts, which have a trapezoidal cross section creating a wedging action on the pulleys. V-belts depend on friction as they are part of a wedging mechanical system.

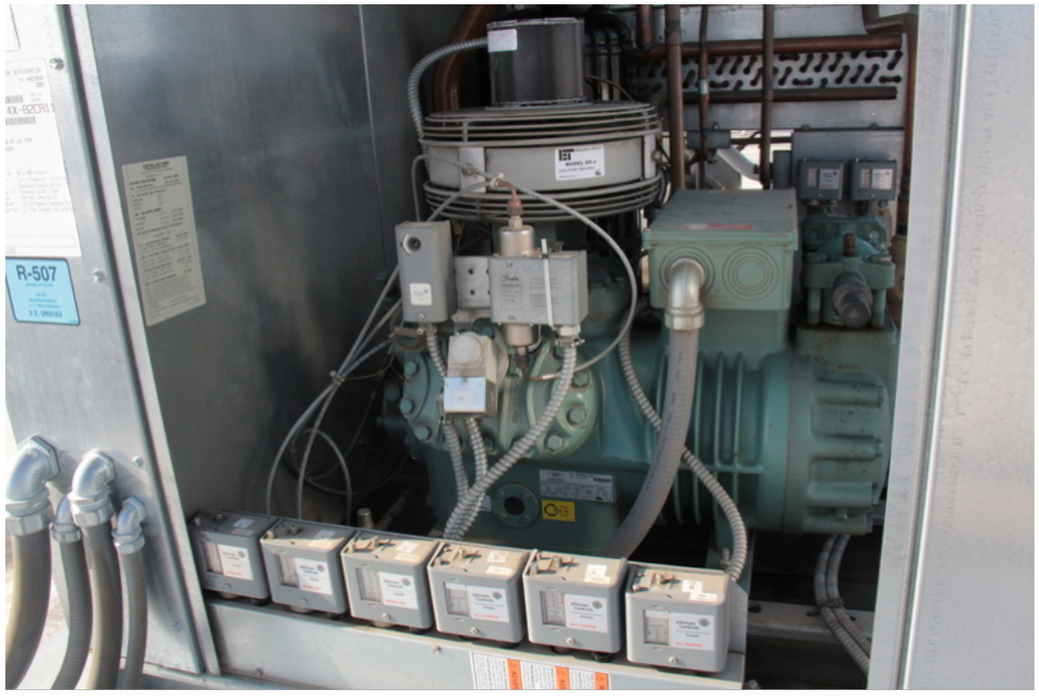
V-belt drives can run as high as 95-98 percent efficient at the time of installation. They are manufactured in a wide variety of materials, cross sections, banded multiples, reinforcement styles, and constant and variable speed configurations. Low acquisition costs, wide availability, and quiet performance make them a popular power transmission solution. In most commercial applications the V-belt drive is the critical link and the only mechanism for mechanical transfer of power from the electric motor to the driven shaft/fan/blower.



Belt drive fan with reduction pulley

Compressors

Compressors are very reliable and when operation is critical, redundant and back-up systems are usually in place. Smaller compressors are normally not serviced or maintained but simply replaced. Larger compressors are maintained and can be rebuilt on a scheduled basis. This eliminates failure, which effects productivity.



Compressor with controls

Troubleshooting

Troubleshooting is done on the system when a failure of a component has occurred or the operation of the system is not producing proper temperatures. Isolating the problem normally involves diagnosing three different areas: non-operating systems, operating systems or control issues. If the system is not functioning the failure of a component or control is the probable cause. Use of electrical test equipment and pressure gauge sets will be the starting point for repair. If the system is operating, but not to the proper temperatures, the problem can be isolated by pressure checking with the gauge set and the ducting control for air flow.



Frozen evaporator due to low temperature in the evaporator



Repairing a condensing unit

Controls

Troubleshooting the controls for an air conditioning system will include the use of electrical test equipment to isolate where the failure has occurred. The lack of operation can be from sensors that have failed, supply voltages being lost, system direction not being delivered or safety switches disabling the system to avoid additional mechanical failure. The challenge for the technician is to isolate which area is causing the problem. This will require schematics and testing techniques and needs to be done quickly as to not compromise productivity or comfort. Newer systems will be part of the overall computer management system so interaction with the data base may be required.



Repairing AC controls

Air Handling

Air handling troubleshooting will include filter replacement or cleaning, verification that heating and cooling elements are open and allow air flow, blowers and fans are operational and that any baffles or directional valves are operational. The movement of air can be as simple as a direct duct to deliver supply and return air or as complex as a system with communication to the computer control device to vary speeds and volume depending on demand and location of the required cooling or heating.

Chapter 13

Welding

Welding and fabrication are skills many supply chain technicians possess. Having the ability to quickly and safely make repairs that require welding skills is critical to the efficiency and reliability of our nation's automated warehouses.



Section 1

Overview



Welder joining round tube

In many automated distribution centers the supply chain technician is required to know the foundations of basic welding and fabrication. Welders use several different types of equipment depending on the project being fabricated or repaired. In this section, you will review the different processes as well as the equipment needed to be successful.

Welding is a process used during fabrication or repair that joins metals by creating a bond from melted materials. This is done by melting a small area of the materials where they contact and adding a filler material to form a pool of molten material that when cooled becomes a strong joint to adhere the metals. Welding requires very high local temperatures (3,000 degrees minimum) which are produced by different energy sources. Energy sources include a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. Welding in support of a distribution center is used as a fabrication technique and for doing repair work and is usually a portable gas or electric arc welding process. Welding is a hazardous undertaking and precautions and planning are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.



Section 2

Gas Welding and Cutting

Oxyacetylene welding and cutting are processes that use acetylene and oxygen blended in a torch to weld or cut metals. Pure oxygen, instead of air, is used to increase the flame temperature to allow localized melting of the material. The flame produced by the combination of acetylene and oxygen can reach temperatures above 3,500 degrees, which will melt most steels at a localized area. The size of the torch and mixing tips determine the heat produced and the size of the weld. Recently, gas welding has been less widely utilized in industrial applications as other specifically devised technologies have been adopted. It is still used for welding small pipes and tubes, as well as repair work. Oxyacetylene has an advantage over electric welding and cutting processes in situations where accessing electricity (using an extension cord or portable generator) would be more difficult. Gas welding and cutting is more self-contained making it more portable. Welding metal results when two pieces are heated in a small area to a temperature that produces a shared pool of molten metal to include both pieces to be joined that when cooled will join or adhere. The molten pool is generally supplied with additional metal called filler which is the same type of metal.
In oxyacetylene cutting, a torch is used to heat metal to its melting temperature. A pinpoint stream of pressurized oxygen is then sprayed through the liquid pool burning the liquid metal into a metal oxide that blows away from the material separating the joined pieces. This process is intense and can be dangerous without the proper equipment and planning.

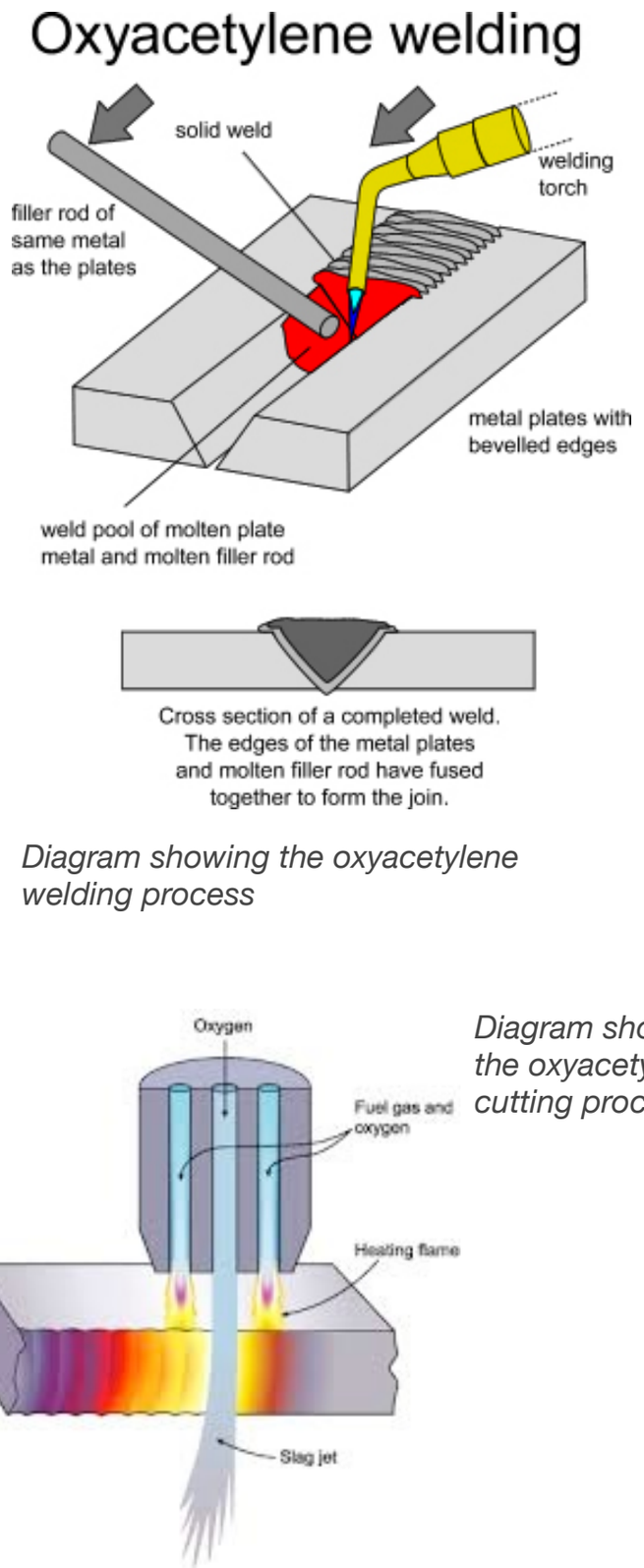


Diagram showing the oxyacetylene welding process

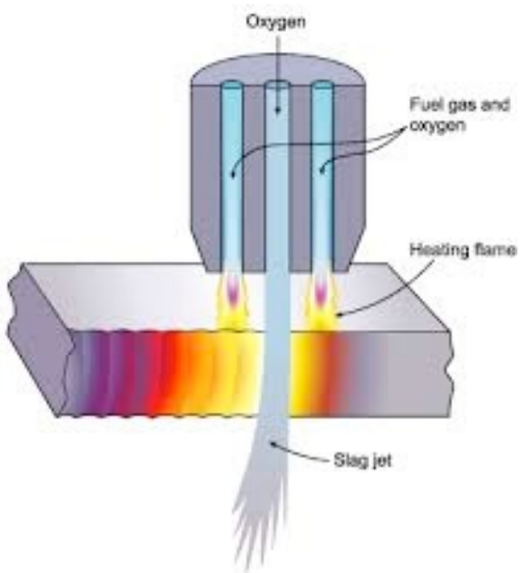


Diagram showing the oxyacetylene cutting process

Oxyacetylene welding and cutting equipment is normally portable and includes a cart with an oxygen bottle, acetylene bottle, controllable pressure regulators, hoses and an assortment of torches.



Oxyacetylene cutting



Portable oxyacetylene welding equipment



Section 3

Arc Welding

Arc welding is a type of welding that uses electrical power to create an electric arc between an electrode and the base material, which provides intense heat to melt the metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is usually protected by some type of shielding gas, vapor, or slag to protect the weld from outside air which causes oxidation, weakening and porosity to the welded joint. Arc welding processes may be manual, semi-automatic, or fully automated but in support of the automated distribution center, manual processes are most common. First developed in the late part of the 19th century, arc welding became commercially important in ship building during the Second World War. Today it remains an important process for the fabrication of steel structures and repair work.

Arc welding equipment used for construction and repair is made up of a power source, conductive wires and material or rod holders. The equipment requirements change when more exotic processes and materials are used, but this is not as common in the automated distribution center.

Arc welding or “stick” welding is the most common type of welding done for fabrication and repair. This process uses a consumable rod and adjustable heat control to melt the material and provide additional filler material to feed the weld and is the most simple of welding processes. Wire feed welders of the flux core

type or shielded gas type are used in manufacturing processes or in a controlled environment. Wire welding processes are faster and require less clean-up of the weld.

Interactive 13.1 Arc Welding Images and Diagrams



Tap to view arc welding images and diagrams.

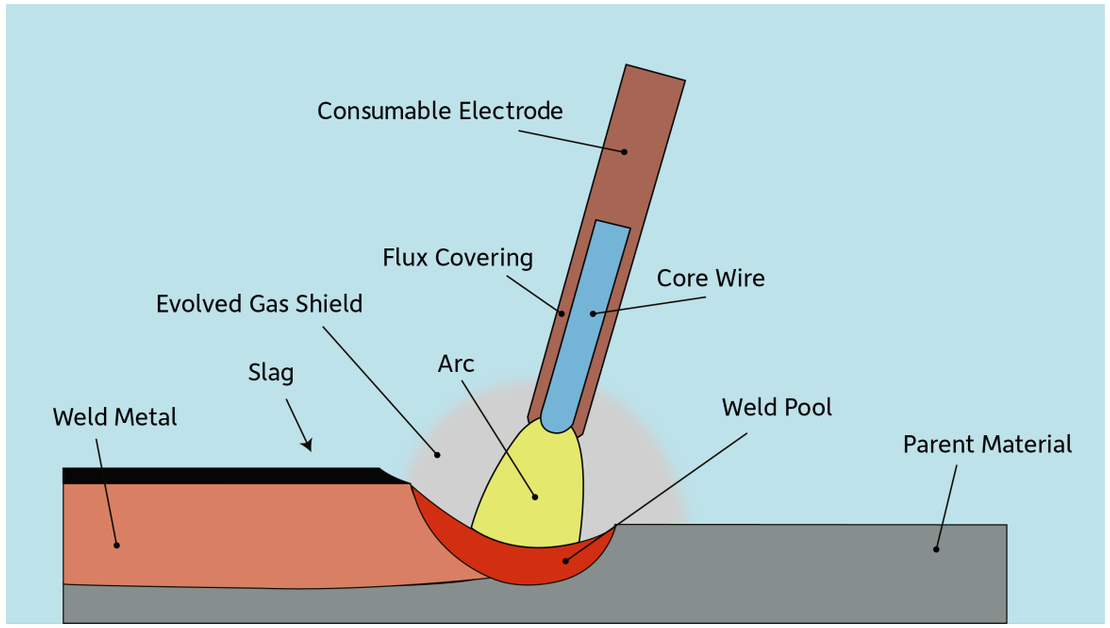


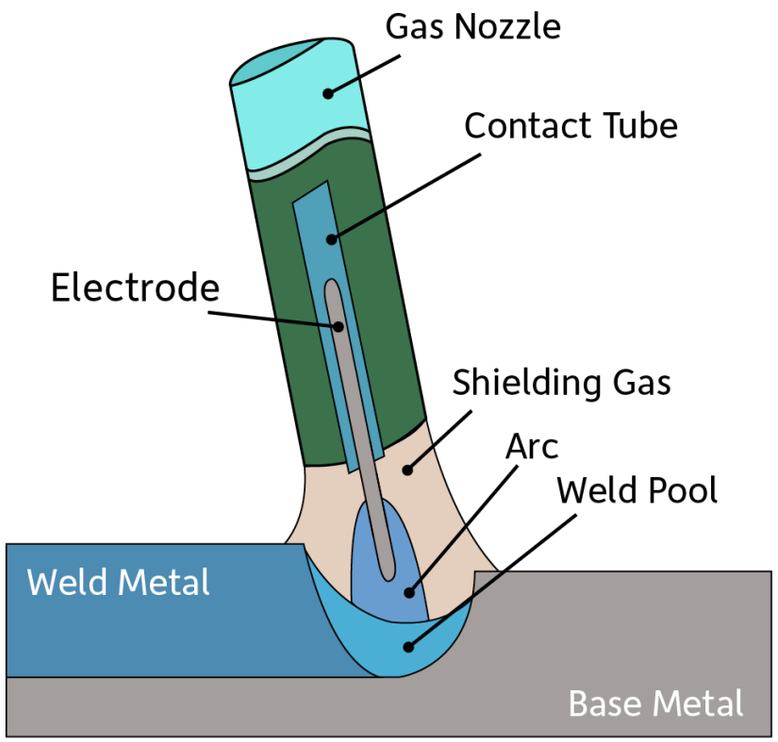
Diagram of the arc welding process



Section 4

Wire Feed Welding

The wire feed type of welding process (gas metal arc welding or GMAW) automatically feeds wire to the weld as filler at the same time it creates the arc to make heat. This type of welding is faster than conventional arc welding. Arc heat and wire feed speed is adjustable to fine tune the welding process.



Wire feed welding process (GMAW)

Arc welding that uses a non-consumable electrode (gas tungsten arc welding or GTAW) is used for materials that are more exotic (aluminum, stainless steel) and where quality control is critical. This process uses a hand feed filler rod to supplement the weld pool, which allows better control over the weld. The equipment used is more expensive and is becoming more common in today's automated distribution centers.



Wire feed welding

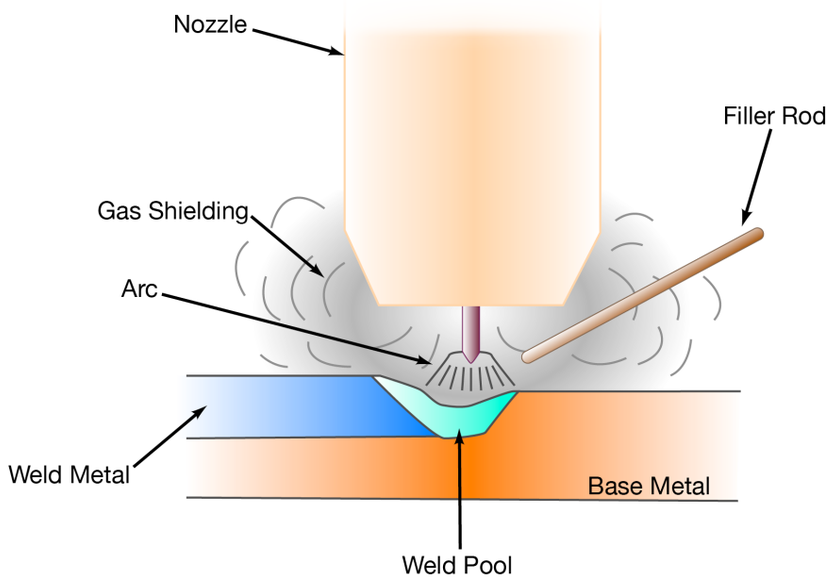
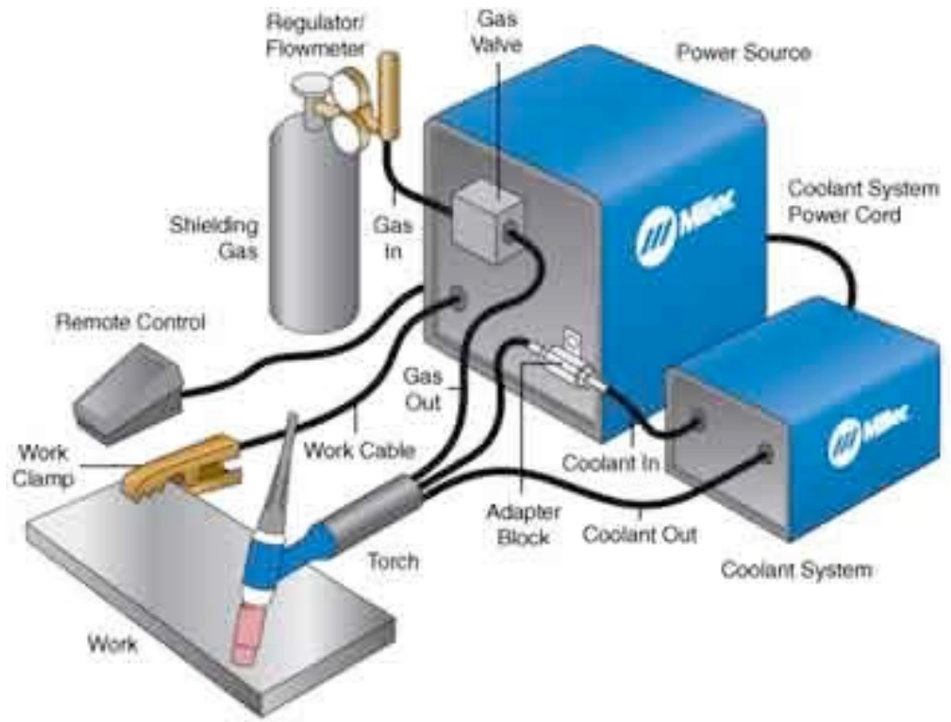


Diagram of the process of non consumable electrode welding



Non-consumable electrode welding equipment (GTAW)



Section 5

Welding Safety and Precautions

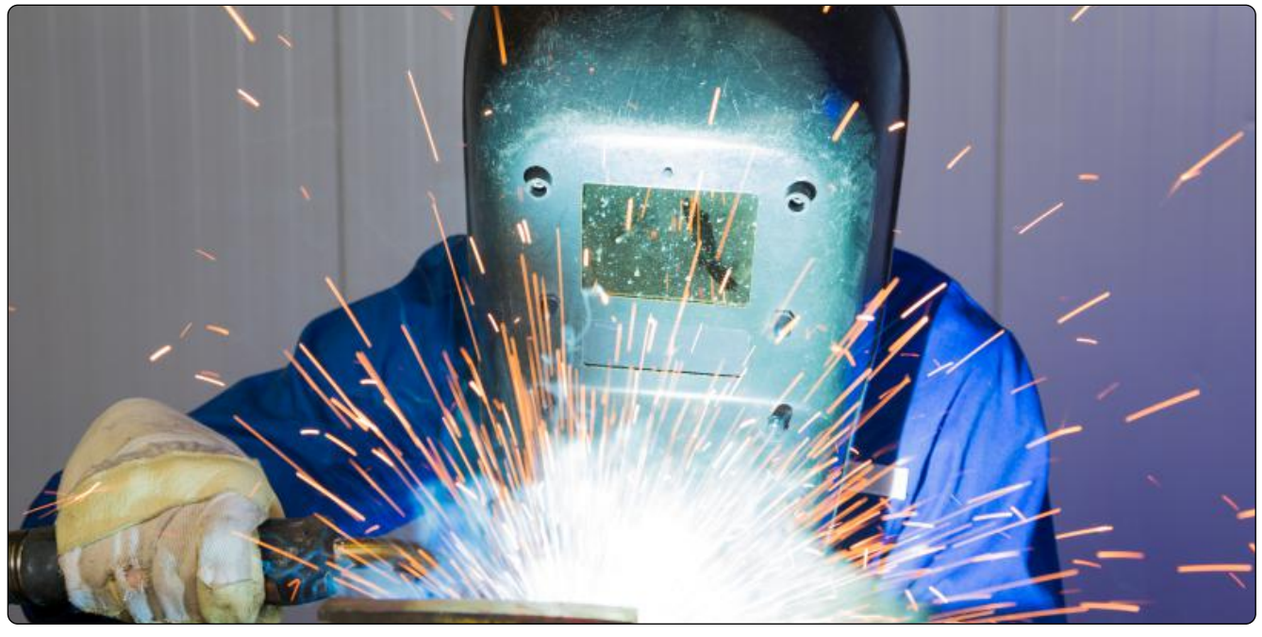
Welding, cutting and metal fabrication can be dangerous and unhealthy if the proper precautions are not taken. With the use of new technology and proper protection, risks of injury to personnel or to the surrounding facility can be greatly reduced. Since many common welding procedures involve extreme heat in the form of an open electric arc or flame, the risk of burns and fire is always a concern. To prevent injury, welders wear personal protective equipment in the form of heavy leather gloves and protective long sleeve jackets to avoid exposure to extreme heat and flames. Additionally, the brightness of the weld area leads to a condition called flash burn in which ultraviolet light causes inflammation of the cornea and can burn the retinas of the eyes. Goggles and welding helmets with dark UV-filtering face plates are worn to prevent this exposure. Since the early 2000s, some helmets have included a face plate which instantly darkens upon exposure to the intense UV light, which makes visibility easier prior to beginning a weld. To protect bystanders, the welding area is often surrounded with protective translucent welding curtains that don’t allow the harsh light to be damaging to the surrounding area.

Welding personnel are often exposed to dangerous gases and particulate matter. Welding processes produce smoke containing particles of various types of hazardous materials. The size of the particles in question tends to influence the toxicity of the fumes, with smaller particles presenting a greater danger to the respiratory system. Gases, such as carbon dioxide, ozone, and fumes

containing heavy metals, can be dangerous to welders lacking proper ventilation and training.

The use of compressed gases and flames in many welding processes poses an explosion and fire risk. Some common precautions include limiting the amount of oxygen in the air, and keeping combustible materials away from the workplace. Before any welding or cutting processes are started, proper planning is needed to minimize risks and to isolate the activity from the surrounding areas.

Interactive 13.2 Personal Welding Protection Equipment

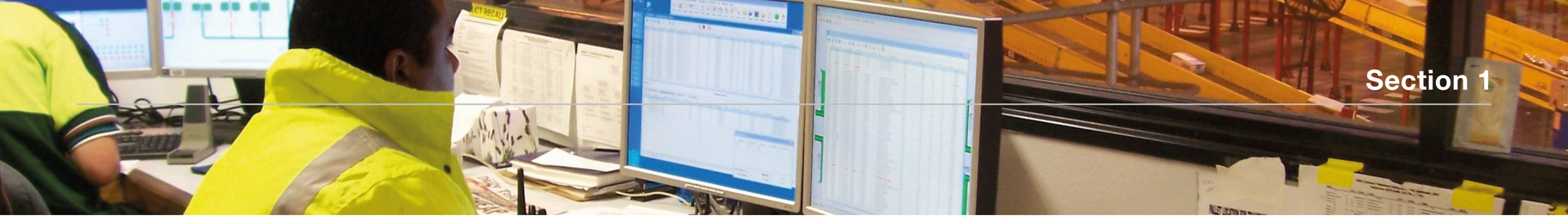


Tap to view images of personal protection equipment for welding

Chapter 14

Workplace Communications

Even the most highly-skilled supply chain technicians struggle to succeed if they cannot communicate effectively. This chapter gives you real world advice to improve the way you communicate with your coworkers, supervisor and equipment vendors.



Introduction

Companies depend on supply chain technicians to service and maintain systems and equipment within tightly scheduled downtime to meet high demands and deadlines. Equipment failure and shut-downs are costly and often frustrating. While failures are often unforeseen and shut-downs necessary for long-term system operation and maintenance, the frustration of a system being off-line for repairs and maintenance may end up being directed at the supply chain technician. For this reason, it is critical that supply chain technicians practice quality customer service skills and clear communication in everyday workplace activities. In a recent National Center for Supply Chain Automation survey of supply chain firms, the need for supply chain technicians trained in soft skills and customer service ranked 4th out of 18 desired training needs. Implementing fundamental, yet essential, customer service and communication techniques will minimize operational frustration, increase productivity and positively impact your own performance and potential advancement within the industry.

The Essentials of Customer Service

Think back to an instance when you experienced outstanding customer service. What made it so great? Was it because they did something unexpected? Did they exceed your expectations? How about a time when you received poor customer service? What made it so bad?

Customer service occurs both internally and externally. When we think of customer service we often think of consumers interacting with a sales associate or a customer on the phone with a company representative. These types of interactions involve external customer service where the company or business is directly serving and interacting with the consumer or public. Internal customer service exists within the company or organization and is seen in the service and interaction between departments, such as the sales staff interacting and supporting the finance department at a new car dealer or supply chain technicians interacting and supporting the equipment operators. Both internal and external customer service are critical to the success and health of an organization.

To evaluate how well we are delivering customer service, we must consider five items: reliability, assurance, tangibles, empathy and responsiveness. Reliability in customer service is doing what you say you are going to do. Reliability is found in both internal and external customer service. Reliability is about keeping the service promise and doing what you say you will do for the customer or other department. If you don't keep these service promises you become unreliable and being unreliable will very quickly cause your customer to lose faith in your ability to deliver your product or service. For example, if you tell a co-worker in the morning you will get to the service repair he/she requested for a piece of equipment and by the end of the day you don't, then you become unreliable. Likewise, if you tell a vendor you will call back by 3:00 p.m. and you forget to, you will quickly become unreliable in your vendor's eyes. Make sure you follow-up and do what you say you will do.

Quality customer service also requires you to provide assurance. Customers (external) and co-workers (internal) want to feel assured that you know what you are doing. Have you ever walked into a store to make a purchase and realized you knew more about the product than the sales person? How did that make you feel? Have you ever asked a coworker to assist on a project or task and felt like they had no idea what they were doing? To project assurance to your coworkers, know your stuff! People will gain confidence and trust in you, and they will perceive you as being knowledgeable in your job. Make sure you know your equipment and systems well. Also know your organization and how your department fits within the rest of the company.

Since the actual maintenance and/or service you provide to the company will be hard to physically see, demonstrating tangibles is a little trickier. Understand, it is often very difficult for an operator to see the internal parts you replaced, for an operator to see a difference in operation due to routine lubrication, or for the operator to know the optical sensors were routinely calibrated last night. Your internal customers may not be able to see the actual service or repair you performed, however, they will see more of what you do in the extra details of your work. This extra detail is often the tangible component to service work. Your internal

customers will notice when you take care of the details, even on a subconscious level. Special details like leaving the equipment cleaner than when you arrived to service it, paying attention to them and listening attentively when they are relaying a problem, being thorough in your written documentation, or returning service inquiries in a timely manner are all tangible examples of great customer service provided by the supply chain technician.

The last two components of customer service are empathy and responsiveness. Empathy means putting yourself in your customer's place. It means treating the customer as you would want to be treated and not seeing them as just a number. Remember that even your supervisor is a potential internal customer. Try to put yourself in their shoes and imagine how you would feel if you were them. Listening is the first step in empathy. Make sure you let the customer explain his/her needs without interruption. Listening tells a customer that you think what they have to say is important – which means you think they are important. Often customers just want a chance to vent their feelings. We will discuss listening in detail later in this chapter.

Lastly is timeliness and responsiveness. Today, timeliness is more critical to a person's view of customer service than ever before. Americans want things fast and they don't like to wait. It is evident in our ability to access information, how we shop and our access to people. Commerce is a prime example of timeliness. We can locate multiple suppliers of goods and services on the Internet, compare prices and previous reviews, and then have the item shipped instantly to our door the next day (this also validates the importance of supply chain technicians). Because this global need to quickly move products exists, supply chains are designed to run at the most efficient rate possible, thereby making responsiveness the most critically watched customer service trait of the supply chain technician. To maintain a high level of responsiveness, it is critical to only make a promise you can keep. If you don't, your customers will grow more frustrated not knowing how long the wait will be. Also make sure to acknowledge down times and make these down times known by ensuring your co-workers and supervisor know what is happening and how long they will need to wait for the equipment to be operational again.

In the end, great customer service is achieved when you make the service your priority and have a positive attitude. Being polite and enthusiastic will make you approachable to your co-workers. Make sure you follow these eight practices when you are dealing with your internal customers.

1. **Know your product or service.**
2. **Listen to the consumer and their complete story or problem.**
3. **If you do not understand something, ask questions to ensure understanding.**
4. **Maintain clear and effective communications.**
5. **Keep your customers informed and contact them if something changes.**

6. **Be certain to solve the problem.**
7. **Always follow-up because it demonstrates your concern.**
8. **Apologize and ensure it is sincere and timely. If the customer perceives you as insincere they will probably get even more upset!**

When providing quality customer service, do not wait to find out why there is a problem or what caused the problem before saying you are sorry. The sooner you apologize, the better. The solution to every problem, whether big or little, should start with a sincere apology. An apology is simply an acknowledgement that things aren't going right in your customer's eyes. It doesn't mean you're admitting you did something wrong. Often it is all the customer (internal or external) needs to hear. If you do not want to say "I'm sorry" because it feels like taking on too much of the blame, consider saying "Thank you for bringing this to my attention" instead. Lastly, do not blame others in your organization for a service breakdown.

Barriers to Effective Communication

Dealing with an Upset Individual

Clear communication eliminates misunderstandings and reduces troubleshooting time. However, personnel issues may prevent a quick resolution of a maintenance problem and communication with an individual who is upset or frustrated can be very difficult to do. If you are unable to communicate the issues to a supervisor, then you will have to work it out with the aggravated person (who could be the supervisor anyway). This is best accomplished by remaining calm and listening carefully to an explanation of the problem without interruption. This will allow time for the individual to collect their thoughts and calm down. Emphasizing a willingness to work with the individual, as a team, will expedite finding a solution. Focus the efforts on the equipment problems and take clear notes during the conversation, as necessary. Avoid discussing related personnel issues and identify the specific steps to be taken and the time frame required to return the equipment to service. Then discuss the options and agree on the appropriate action to take.

It is important to understand that most communication problems stem from a misunderstanding. To humorously illustrate this point, watch this classic bit by two of the most iconic comedians ever to do stand up.

Movie 14.1 Who's on First Video

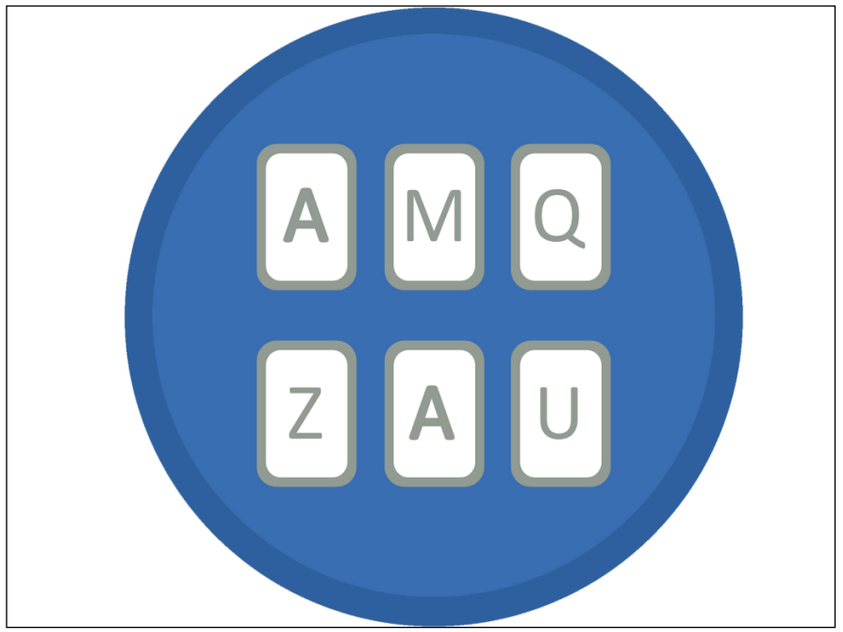


Tap to view the video.

Nonverbal Communication

At least 70% of what is communicated is done without speaking a word during face-to-face communications. This 70% is referred to as nonverbal communication. When nonverbal signals send a different message than the words we are communicating, those around us can become confused and skeptical of our motives and actions. Nonverbal communication can include voice signals, which puts emphases on certain words to change the meaning of what you say. Consider the following statement, "I didn't say you had a bad attitude." Depending on where you put the inflection or emphasis when it is spoken can completely change the meaning or the interpreted understanding. Putting the inflection on the word "I" in the sentence implies that I didn't say it, but somebody else did. Putting the emphasis on the word "bad" might communicate that one's attitude isn't bad, but something is wrong with it. Body signals are another form of nonverbal communication and can completely change the meaning of your spoken message.

Review 14.1 Understanding Body Signals



Tap to complete a matching exercise.

Additional nonverbal communications signals can include objects, space and time. You can indicate a tremendous amount about your willingness to communicate with others based upon how you place objects such as furniture, counters and desks. Regarding space, most North Americans prefer to maintain a distance of between a foot and a half and two feet between

others when they are communicating. When we decide to eliminate that distance and huddle close to others to communicate it sends a very distinct nonverbal communication message to others who may be witnessing the conversation. What is it? It communicates secrecy and that others are not privy to hear what is being said.

Regarding time signals, consider what message someone sends when they are on time, not on time, when they keep someone waiting, or are not available/can't make time for someone? How you handle your time with others communicates messages non-verbally. For example, someone who is always late to a department meeting might communicate: "I don't think this meeting is very important." Or if someone never has the time to meet with you, it might communicate: "I don't want to spend any time with you because I don't like you."

Hierarchical Loss of Communication

Most organizations are shaped like a triangle. They usually have a CEO/President at the top, Vice Presidents, District Managers, Regional Managers, Managers, Leads, etc. Because of the layers within an organization, communication can become distorted, diverted and/or discontinued as it moves from one layer to the next. To illustrate, if during the communication chain someone makes the decision that the information does not need to be shared with the next level in the chain, communication discontinuance occurs. If a vital piece of information is omitted or perhaps information is added that did not need to be included, distortion of the communication occurs. Lastly, if the communication is delivered to the wrong persons in the organization (often due to a distortion of the communication earlier in the chain), diversion occurs and the intended recipient never receives the information.

You may have seen loss of communication in the workplace already or perhaps witnessed it in a church or other community-based organization. There is a good chance you even played a game as a child to see just how much communication can be distorted, diverted or discontinued within a communication chain. Do you remember playing the "gossip game" as a child, maybe in school? The teacher had everyone arrange themselves in a circle and then gave the first person in the communication chain a statement. This person then whispered the statement in the ear of the next person, and then they whispered it into the ear of the next person and so on. At the end of the chain the person would say out loud what they have been told. The result is often humorously different and even farther from the original statement as the communication chain gets longer.

Jargon

Jargon is a set of special words or expressions that are used by a particular profession or group and are difficult for others to understand. Their use is like a type of shorthand between members of a particular group of people; often jargon is meaningless outside of a certain context and unnecessarily

complicated. It is more often than not, used to impress, rather than to inform, your audience.

Supply chain technicians will have their own jargon or "lingo." By learning the jargon for your industry, you will develop a deeper understanding of its culture and commonly used phrases. It is important to recognize that other departments in your organization may have their own jargon that you may not completely understand nor will they completely understand your technical jargon. It is critical that interdepartmental communication is kept as free from jargon as possible, unless the terms are used organization-wide. Technical terms are often very specific to certain teams within the organization. Be careful in their usage as it may decrease your customer service, cause delays in completing the task, cause frustration, or cause a mistake to be made.

Another reason to avoid jargon in communication is that in today's multicultural workplaces, differences in cultures and languages can hamper communication and using jargon will only increase misunderstanding. Cultural barriers can create a unique workplace environment where workers are expected to behave in a particular way to gain acceptance. Language barriers can result, not only when workers have different native languages but when others use jargon, buzzwords or terminology that is unfamiliar to non-native language speakers or even new employees. Therefore, when working with non-native language speakers and new employees, recognize that they may not understand what is being communicated and may be too embarrassed to ask for clarification. This lack of them seeking understanding could cause them to make a mistake on the job or provide the wrong service.

Listening Skills

Whether internal or external, to serve your customers within the supply chain you need to know the who, what, when, where, why and how. You must know who your customer is, what they want, when they want it, how they want it, where they expect to receive it, why they want it, how long they expect to wait, and what else they may be expecting along the way. Sound difficult? Well, the only way to understand these things about your customer is to listen to what they say and ask questions to ensure they say it. When you listen well to your customers, you…

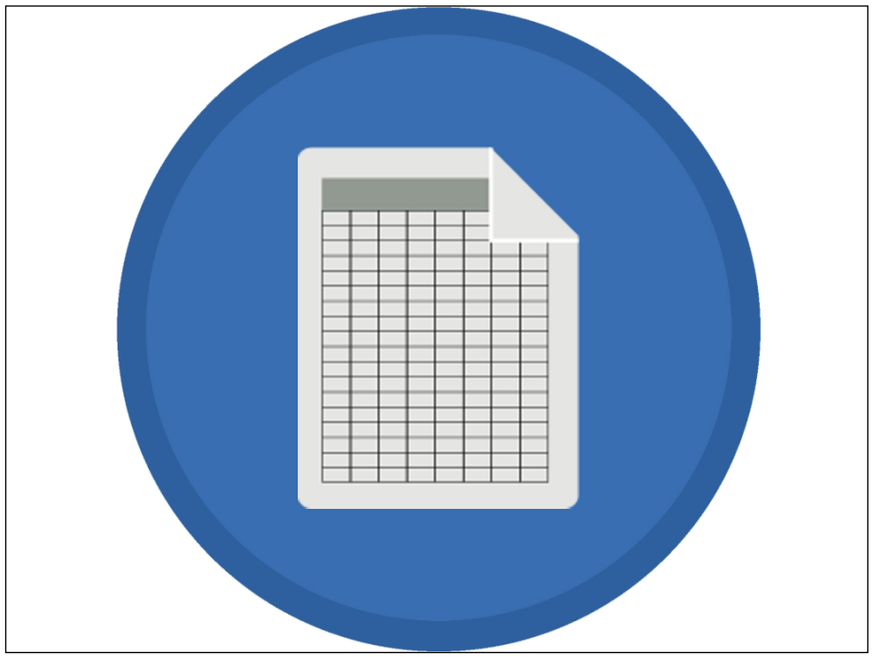
1. Figure out what the customer really wants and needs.
2. Avoid misunderstandings and mistakes.
3. Build long-term relationships.

Self-Assess Your Listening Habits

As a listener, how frequently do you practice the following listening behaviors? Complete the interactive Listening Habits activity to self-assess your listening habits and evaluate your overall listening skill.

One of the most important listening skills to develop is active listening. Active listening requires that you understand what is

Review 14.2 Listening Habits



Tap to learn more about your listening habits.

being communicated from the speaker's point of view and it requires you as the listener to concentrate on what is being said by the speaker and tune out the hundreds, if not potentially thousands, of distracting thoughts. It also requires that you listen with empathy and put yourself in the speaker's shoes. Additionally, you must practice acceptance and a willingness to take responsibility for getting the full-intended meaning from the speaker. By practicing acceptance you will listen objectively without judging what is being said. This is perhaps the hardest listening skill to master because we are easily distracted by content that we do not agree with.

So, for your customers, coworkers and supervisor to feel assured that you know what you are doing and that you will be able to help them, they need to feel like you are listening. Good body language, such as eye contact, leaning forward, not looking around or doing something else while they are talking (like checking text messages on your mobile phone) will assure them that you are listening. Asking questions and summarizing what they said can be great way to help them to feel assured.

Practice These Effective Listening Strategies

1. Take the time to listen.
2. Avoid doing most of the talking yourself.
3. Avoid distractions.
4. Act interested in what the other person says.
5. Ask questions.
6. Summarize.
7. Be empathetic.
8. Do not lose your temper.
9. Do not interrupt.
10. Jot down notes and review them.
11. Use active listening techniques.

How to Speak in the Positive

No one likes being around negative people. As a supply chain technician your job will be to keep the system running at maximum efficiency and capacity. You may often be the bearer of bad news regarding down times and expensive repairs. Do your best to bring bad news forward with a positive spin. Instead of saying, “the system will be offline for the next 24 hours,” say, “I pinpointed the failure and am having the replacement part shipped overnight, I’ll be in first thing tomorrow and will have it operational by noon.” Putting a positive spin on your communication will reduce the frustration your internal customers might experience.

Review 14.3 Speaking in the Positive



Tap to open interactive worksheet. Rewrite the negative phrases into positive phrases.

Written Communication

As a supply chain technician, a significant portion of your communication will be written. You will be tasked with filling out repair orders, work logs, equipment maintenance journals, incident reports and many other internal and possibly external forms. Preventative maintenance and repair orders will be a common form of your everyday communication and may be on paper or completed electronically through a computer software system. Regardless of the medium, it is critical your written communication is clear, complete and concise.

Incident Reports

For incident reports such as injuries or hazardous waste spills, you must ensure the forms required by your department, organization and/or oversight agency are filled out completely and properly. For these forms you are the reporter and recorder of the incident; you are identifying the what, when, and who. For these documents, be sure that all lines are filled in completely; you are printing legibly, pressing down hard enough if it has multiple copies, and giving just the facts. There is no need to inject opinion or your subjective assessment of the incident; doing so may lead to potential litigious action. It is important that these forms remain objective and list exactly what occurred.

Preventative Maintenance Work Orders/Logbooks

Preventative maintenance is scheduled work required to keep equipment and supply chain systems in peak operating condition.

The work is planned and scheduled for completion to minimize emergency repairs and to ensure efficient operation. Work orders and/or logbooks are used to organize and plan scheduled maintenance. These documents will detail specific tasks to be completed along with time, date, name, and location of the equipment, work detail, scheduled completion date/time, and sometimes future recommendations by the technician (such as additional service needed). When filling out these forms, ensure you are thorough and have recorded the information accurately. These forms will often serve as a basis for future maintenance and insufficient or missing information could lead to costly and unforeseen repairs.

Not all service work will be planned. Sometimes equipment breaks down and requires immediate attention. If this occurs, the supply chain technician will likely receive a Repair Order (RO) or Emergency Repair Order (ERO). These repair orders may or may not be different than the previously mentioned repair orders for scheduled maintenance. The biggest difference is that now the supply chain technician must be able to diagnose the failure and determine the best course of action to return the equipment to working order. Scheduled maintenance does not require a diagnosis by the supply chain technician.

Maintenance repair orders or service log books essentially require journaling the preventative maintenance once it is completed; however, repair orders for malfunctioning, broken or poorly operating equipment will require three major statements in order to be considered complete and thorough. Each of these repair orders must have a complaint statement, a cause statement, and a remedy statement. This is often referred to in the service industry as complaint, cause, remedy, or CCR. As a supply chain technician, you will be expected to write thorough and complete CCR statements.

INSTRUCTIONS

This form will be used in requesting special work to be done by school maintenance staff.

Forward original and one copy to the business office. Retain REQUISITIONER'S COPY. Please allow ample time for scheduling the work to be done.

PALO VERDE
COMMUNITY COLLEGE DISTRICT
BLYTHE, CALIFORNIA
WORK ORDER

Date _____ _____

Room or Location _____ Date Required _____

Describe work to be done: (IN DETAIL)

Signed _____

Check appropriate square: ☐ Original Request ☐ Confirming Verbal Request

Title _____

DO NOT WRITE BELOW THIS DOUBLE LINE

Business Office: ☐ Approved ☐ Not Approved

Budget Classification for Labor: _____ Signed _____, Business Mgr.

Workman Assigned _____ Date Work to Start _____

Date Work Completed _____ Signature of Workman _____

Reason why work not completed on time, or other remarks: (Use other side of sheet)

WHITE-MAINTENANCE COPY YELLOW-REQUISITIONER'S COPY PINK-SCHEDULING COPY WEEKS PRINTING

Sample work order form

Complaint

Most likely, the supply chain technician will not document the complaint. Instead, it will be documented by the supervisor or by the operator of the equipment. Nevertheless, that does not mean they should not be held to the standards of documenting a

thorough complaint statement. This may be one of the most critical steps in ensuring a speedy diagnosis and repair of the equipment. The reason is that the complaint statement should be a guide to the technician, not a hindrance or diversion. The statement needs to include all the relevant information to allow the technician to narrow down and diagnose the equipment quickly. Consider these two complaint statements:

“Sorter #3 is not working properly. Check and repair sorter.”

“The operator on shift three says Sorter #3 is not reading and sorting large parcels.”

The second statement is much more complete and gives the technician an idea of what is going on. It also gives the technician a scenario to try and recreate to verify the equipment malfunction. Statement #1 is so vague that a technician may never know that it only messes up when large parcels are being processed. As a matter of fact, the technician may go look at the piece of equipment during the day and find it working perfectly fine, unless they happened to sort large packages that day. This is so important for a supply chain technician to do their job effectively that he/she may need to train the staff and/or supervisor writing the repair order to be very thorough when completing the complaint section.

Job Name		Date					
Unit Tag							
Model #		Time					
Serial #							
Full Load Design	Operating Condition						
	Operating Code						
	Last Diagnostic						
_____degF	LCHW Setpoint						
	Current Limit Setpoint						
	Start #						
	Run Hours						
_____Volts	Volts – AB						
_____Hertz	Volts – AC						
	Volts – BC						
	Amps L1						
	Amps L2						
	Amps L3						
	Amps AVG						
_____RLA	% of RLA						
	Oil Sump Temperature						
	Oil Temperature to Bearings						
	Oil Level						
	Low Oil Pressure						
	High Oil Pressure						
	Net Oil Pressure						
	Operating Purge Pressure						
	Operating Purge Oil Level						
	Purge Starts						
	Purge Run Hours						
_____PSID_____gpm	CHW PSID						
_____degF	CHW Temperature in						
_____degF	CHW Temperature out						
_____degF	CHW Temperature Differential						
	CHW Makeup Water						
	Evaporator Temperature						
	Evaporator Pressure						
_____PSID_____gpm	CW PSI Differential						
_____degF	CW Temperature in						
_____degF	CW Temperature out						
_____degF	CW Temperature Differential						
	Condenser Temperature						
	Condenser Pressure						
	Cooling Tower Makeup Water						
	CHW Makeup Water						
	Operator Initials						

Sample page from a logbook

Cause

The cause section is completed only by the supply chain technician and allows a place for the technician to document what exactly has occurred to produce the equipment failure. For potential warranty reasons, potential future litigious situations and internal budgeting, this section must be precise. Most importantly, it allows a place for the technician to put their expertise down in writing. Cause statements must include what happened and how it happened. Here are examples of two cause statements:

“no power to RFID” or “Open wire on Circuit 132, between junction block J3 and RFID control module”.

The second example gives a very clear image of what failed and allows the technician to make suggestions for repair. These suggestions must be classified by the supply chain technician as either a requirement or a recommendation. Understanding the difference between these two terms is critical and can save time and costly repairs.

Use the term “required” when:

- Part no longer performs intended purpose
- Part does not meet a design specification (regardless of performance)
- Part is missing

Use the term “recommended” when:

- Part is close to the end of its useful life (just above discard specifications, or weak; failure likely to occur soon, etc.)
- To address a customer need, convenience, or request (to stiffen ride, enhance performance, eliminate noise, etc.)
- To comply with maintenance recommended by the equipment’s Original Equipment Manufacturer (OEM)

Basically, when you use the term required, you are saying the repair must be done right now. However, when you use the term recommended, you are saying that it does not have to be done immediately, but it should be done soon.

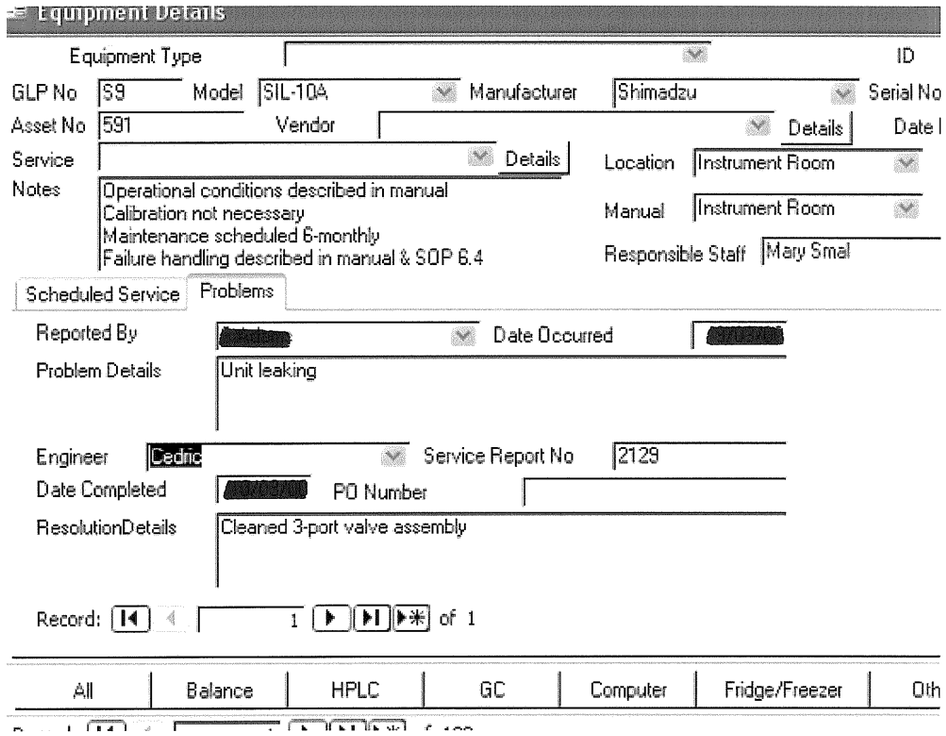
Remedy

The remedy section is a place where the supply chain technician records the action completed on the piece of equipment. Once again this section should be precise, thorough, and completed by the supply chain technician. Building on the statements in the cause section, compare these two remedy sections:

“Repaired open wire.”

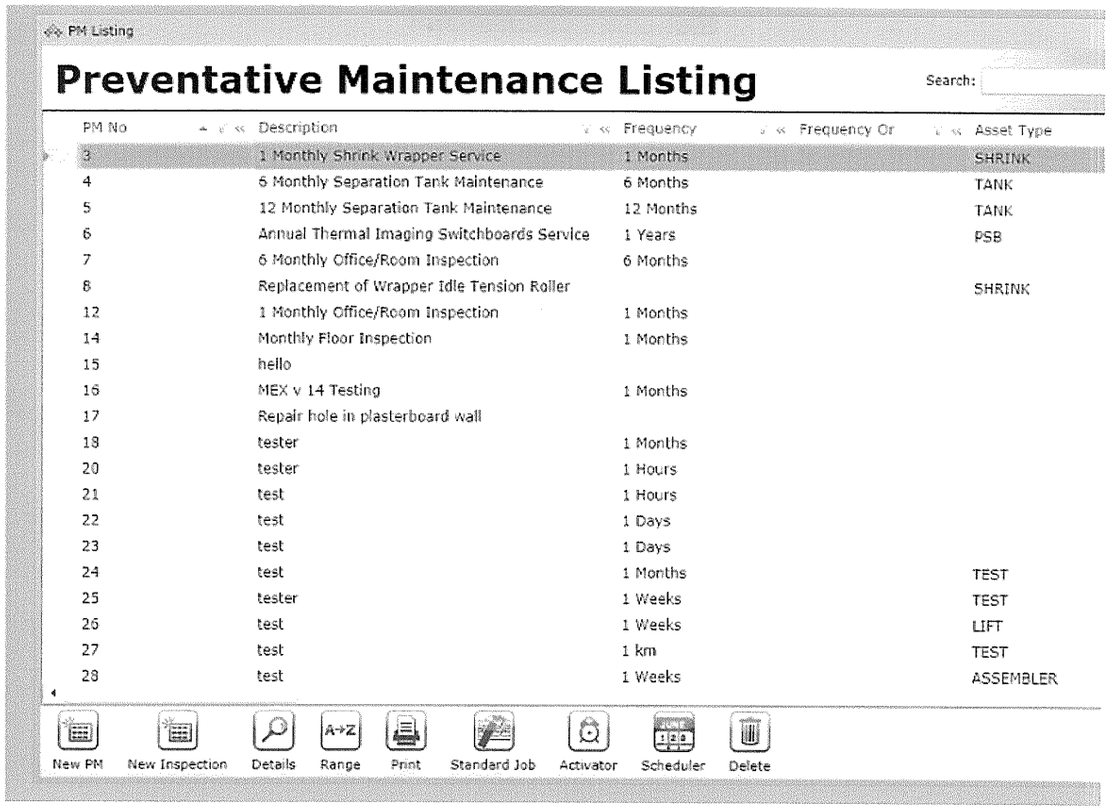
“ Replaced 36-inch wire section between junction block J3 and the RFID controller. Tested system with various size parcels and system operated as designed.”

Repair Orders



Sample repair order

Preventative Maintenance



Sample preventive maintenance form

Telephone Communication

Remember, whether you are interacting with someone inside or outside of your company, that person is your customer! Always remember that exceptional customer service is why people choose your company over another. In all your dealings, strive to employ these six key attributes:

1) Friendliness

2) Empathy

3) Accuracy

4) Professionalism

5) Promptness

6) Honesty

Electronic Communication

In today's electronic world, professional communication by email is critical to your success within your organization. Email is viewed by many as a "casual" form of communication, therefore people can often times come across as unprofessional when sending emails. It is important to remember that an email is a written form of communication and is a representation of your professionalism. Emails are easily forwarded, so it is important to be clear, organized, and professional when you send them out.

When communicating via email try to have the email bring closure to work, not create more work for you. Always ask yourself if calling or visiting the recipient would be a better way to communicate. If you do write an email, it should be short and whenever possible your point made in just the subject line or the space in the preview pane. Also, do not assume other people are staring at their screens, waiting for your email—it may take a day, two days or longer for them to respond. Lastly, regarding your personal time management, a good rule is to never spend more than five minutes dealing with an email. When you go over this limit, stop and make a phone call.

Movie 14.2 Six Common Customer Expectations



Tap to view the video.

Review 14.4 Call Holds and Transfer Worksheet



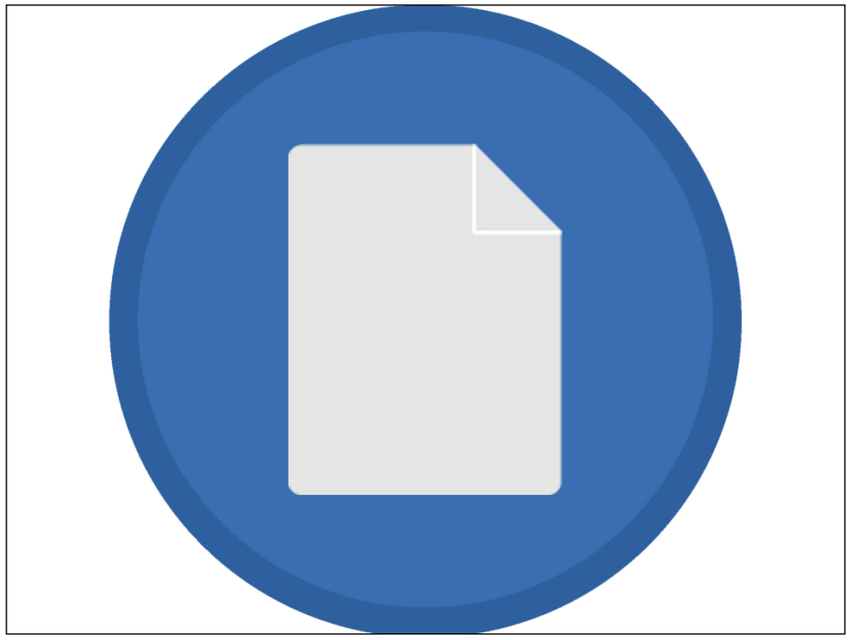
Tap to test your knowledge of call holds and transfers.

Review 14.5 Electronic Communication Worksheet

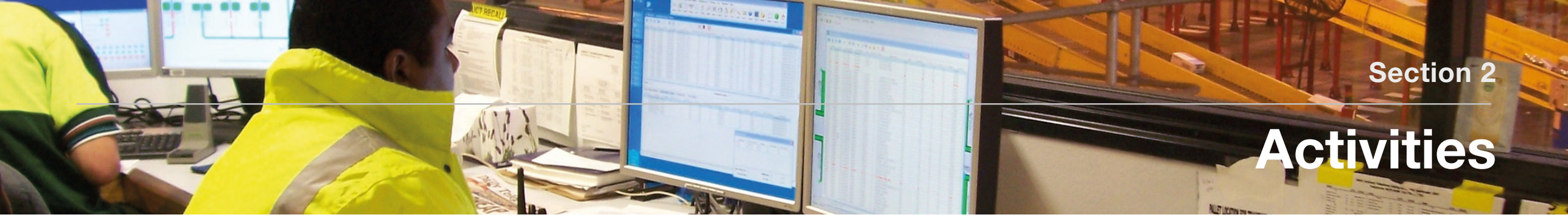


Tap to test your understanding of electronic communication in the workplace.

Interactive 14.1 Facilities Maintenance Work Order Procedures

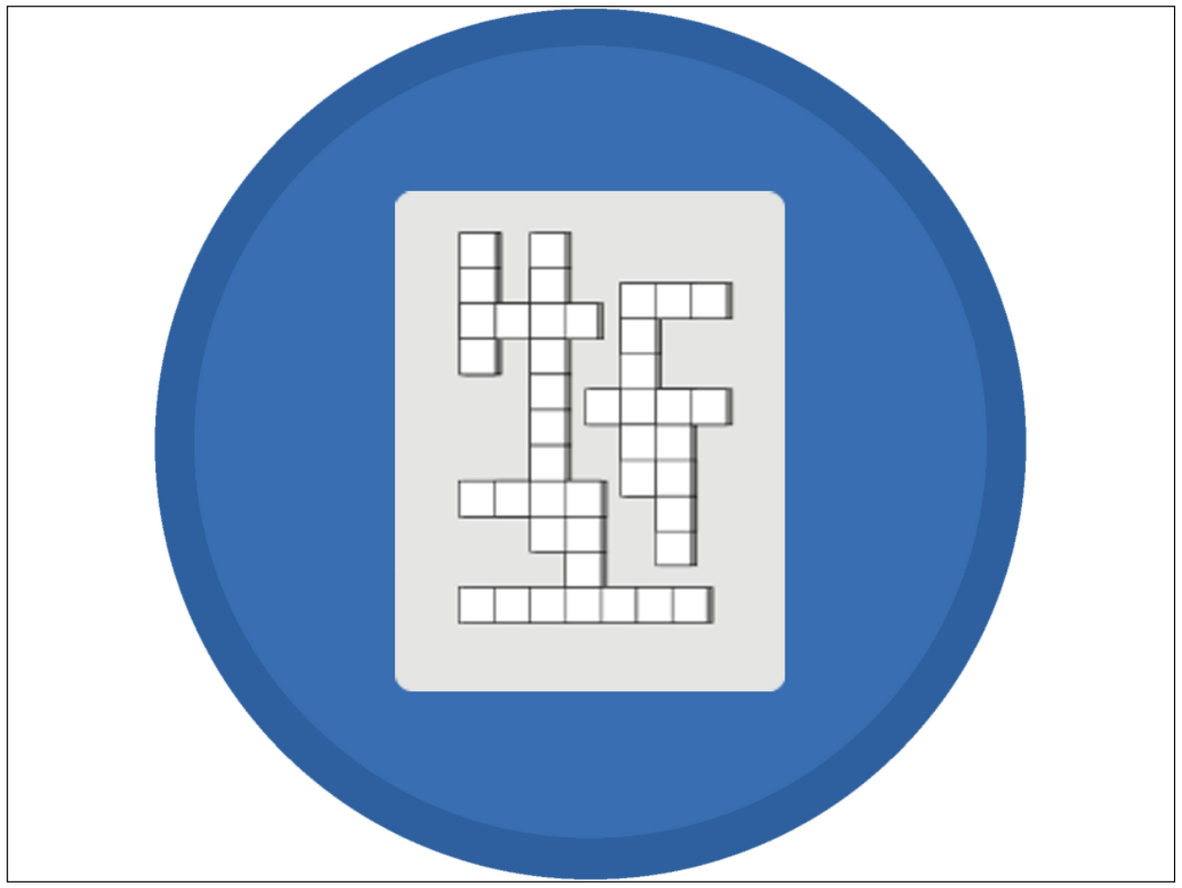


Tap for information related to facilities maintenance work order procedures.

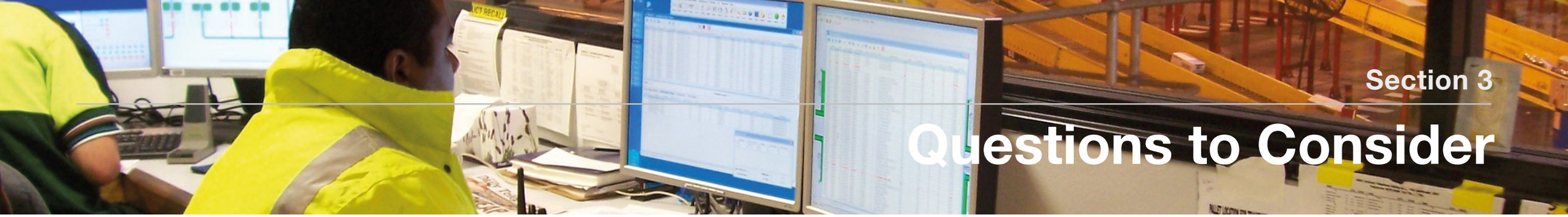


Activities

Review 14.6 Communication Crossword



Tap to complete crossword puzzle.



Questions to Consider

My Personal Communication/Customer Service Action Plan

Students should respond to the following three statements as a written homework assignment or during a class discussion as directed by the instructor.

1. Three or more communication/customer service behaviors that I already do well are:

2. Three or more communication/customer service behaviors that I was reminded of during this class that I will begin to do again are:

3. Three or more new communication/customer service behaviors that I will begin doing when I return to my job are:

Glossary

AC

Alternating current is a type of electrical service that is provided into large buildings at 220/440 volts at 60 Hertz (cycles). This power is used for large motors and controllers of equipment.

AC/DC I/O Interface

A discrete interface that converts alternating current (AC) voltages from field devices into direct current (DC) signals that the computer can use. It can also convert DC signals into proportional AC voltages.

Accumulator

A container which stores fluid or air under pressure; used as an energy source or to absorb hydraulic and pneumatic shock. Common types are piston, bladder and diaphragm.

Accuracy

A measure of capability to repeat the same task multiple times without error.

Address Resolution Protocol (ARP)

Network protocol used to find the hardware or MAC address from an IP address

Aisle

The space between storage areas that provides access by material handling equipment and/or personnel.

Alignment

Positioning of a sensor so that the maximum amount of the emitted energy reaches the receiving sensing element.

American Standard Code for Information Interchange (ASCII)

Format for text files using 7-bit binary numbers for characters

Analog-to-Digital Converter (A/D)

A device that translates analog signals from field devices into binary numbers that can be read by the processor.

Anchoring

Attaching of a structure to the foundation or slab.

Angles

The intersection of any two planes, lines or sides.

Antenna

The tag antenna is the conductive element that enables the tag to send and receive data. Readers also have antennas which are used to emit radio waves. The RF energy from the reader antenna is "harvested" by the antenna and used to power up the

microchip, which then changes the electrical load on the antenna to reflect back its own signals.

Artificial Intelligence (AI)

A subfield of computer science dealing with the development of computer programs that solve tasks requiring extensive knowledge.

AS/RS (Automatic Storage & Retrieval Systems)

An acronym that refers to a variety of systems under computer control for automatically depositing and retrieving goods from defined storage locations.

Atom

Basic structure of all matter.

Audio Video Interleave (AVI)

Multimedia format for audio and video data in a file for synchronous playback

Automated Dispenser

A series of vertical product dispensers which deliver individual units of products onto a conveyor.

Automatic Data Capture

The technology that support the identification and direct collection of data into a computer system or other micro-processor-controlled device without using a keyboard. Such technologies include bar code, radio frequency data communication, radio frequency identification and other emerging technologies.

Automatic Guided Vehicle System (AGVS)

AGV consists of one or more computer-controlled wheeled load carriers (normally battery powered) that runs on the plant floor (or if outdoors on a paved area) without the need for an onboard operator or driver. AGVs have defined paths or areas within which or over which they can navigate. Navigation is achieved by any one of several means, including following a path defined by buried inductive wires, surface mounted magnetic or optical strips; or alternatively by way of inertial or laser guidance.

Automatic Identification

A term that covers methods of collecting data and entering it directly into computer systems without human involvement. Technologies normally considered part of auto-ID include bar codes, biometrics, RFID and voice recognition.

Automation

A system that uses programmable equipment for production with less worker intervention. The equipment is capable of being altered and controlled by the program depending on the product.

Axis

The point that something, such as a tool, rotates around. The number of axes of a robot varies, but the majority of industrial robots are 4-axis or 6-axis.

Bar Code

A standard method of identifying product information of a particular item. The bar code is made as a label with bars and spaces representing numeric code that is input as data.

Bar Code Reader

A device used to identify and read a bar code symbol.

Battery Backup

A battery or set of batteries that will provide power to the processor’s memory in the event of a power outage.

Bearing Life

The minimum expected life, in hours, of a group of bearings that are operated at a given speed and loading.

Bearings

Supporting devices that allow mechanical rollers to spin freely without load.

Benchmarking

A measurement process that establishes goals, operating targets and production expectations and can be used for comparison in an effort to achieve maximum efficiency of operation to include job evaluation, rating of performance, cost estimating and standards.

Broadband

The transmission of data where two or more signals share the same conductor. In more popular terminology, broadband is taken to mean high-speed data transmission.

Buffering

The process of storing "back-up" or reserve stock/inventory to absorb expected variations in usage between the time reorder action is initiated and the first part of new orders are received in stock.

Bumpers, Dock

Pieces of rubber or other resilient material located at the floor level of a dock opening to cushion and protect the building from truck trailer impact.

Cable Reel

An electrically, manually or spring-loaded device used to accumulate power cable on a reel so as to keep the cable from interfering with the piece of equipment to which the cable is bringing power.

Carousel

Carousels are a technology used to store items for eventual picking or retrieval in a circular motion (a type of AS/AR).

Carrier

Also known as a trolley. A unit that travels on the bottom flange of a monorail or patented track beam, jib crane or bridge girder to transport a load. Also refers to a trucking line used to transport materials to and from a distribution center.

Carts

Wheeled devices, generally made from plastic and/or metal, utilized to move items within a warehouse, distribution center or manufacturing facility.

Cavitation

Occurrence when air is being drawn into the suction side of a hydraulic pump which displaces fluid and becomes compressible.

Chain Conveyor

A form of powered conveyor used to transport heavy unit loads such as pallets and industrial containers.

Chocks (Wheel Chocks)

Triangular blocks of rubber, wood, or metal placed in front of, between or behind truck wheels to prevent accidental trailer movement.

Code

A collection of regulations related to a particular trade or environment. Computer language for programming operating parameters.

Collision Prevention

The use of sensors to detect the presence of objects and, through the use of integrated controls, prevent a collision between two objects from occurring.

Common Industrial Protocol (CIP)

Protocol for industrial automation applications

Compression

The creating of pressure on a gas.

Compressor

Device used to pressurize gases and rated by maximum pressure and volume.

Computer Aided Design (CAD)

A computer software system that allows the user to "draw" and design objects "on a screen" as opposed to the traditional method of drafting and prototyping.

Conductor Bar

Track mounted insulated bar used to transmit electric current to a vehicle.

Contrast (Optical)

The ratio of the amount of light falling on the receiver in the “light" state as compared to the “dark" state.

Controller

A device by means of which the operator controls the speed, acceleration, torque and/or direction of motor driven equipment.

Conveyor

A horizontal, inclined, or vertical device for moving or transporting bulk material, packages, or objects in a path predetermined by the design of the device, and having points of loading and discharge, fixed or selective.

Conveyor Belt

A belt used to carry materials and transmit power required to move the load being conveyed.

Cross Belt Sorter Conveyor

Another form of the tray sorter is where the tray is replaced by a short belt conveyor section with its direction of travel orientated perpendicular to the line of travel of the main train. At the proper moment the belt stepper motor is energized, propelling its load to either side and the desired takeaway lane.

Cross Docking

The process of moving merchandise from the receiving dock to shipping without placing it into storage locations. Information regarding the merchandise will be entered into the inventory and a transaction for shipping posted within one posting cycle.

Cubing

The amount of space occupied by an item or the volume within a system or building.

Cumulative Trauma Disorder

An injury that may be the result of stresses from repetitive motions such as twisting of the body during product movement or keyboard entry.

Current

Movement of electrons.

Cycle Time

A measurement of time required to order, fulfill, and deliver products and stock items. The two (2) major components of cycle time are order cycle and replenishment cycle.

Cylinder

A cylinder is a cylindrical tube that contains pressure allowing a sliding piston to apply force and motion.

Data Rate (Data Transfer Rate)

Speed in a radio frequency identification system, the rate at which data is communicated between transponder and the reader/interrogator, expressed in baud, bits or bytes.

Data Transmission

The use of sensors to transmit data via pulse-modulated light beam systems typically from host stations to mobile carriers such as AGVs or stacker cranes.

DC

In electrical terms, direct current (as opposed to AC which is alternating current). This very safe power is used to control sensors, motors, and manipulators for material handling.

Demurrage

A term associated with the charge (monetary) that can be levied against a shipper or consignee who detains a container, truck, ship or railroad car beyond the allotted time for loading and unloading of that piece of transport equipment. Such a monetary "penalty" is used to offset the loss to the carrier as a result of the delay. "Detention" is another word used for demurrage.

DIN Standard

Abbreviation for “Deutsches Institut fur Normung.” A collection of German industry standards that are recognized throughout the world.

Diode

Electronic one way check valve that controls the direction of current.

Dispersion angle

The degree of the angle of light.

Displacement

Size of a pump based on the volume of flow.

Distortion

Any disturbance that causes an unwarranted change in the form or intelligibility of a signal.

Domain Name System (DNS)

Naming system for computers, services, or other resources connected to the Internet or a private network

Drawing Legend

Information on a drawing providing a part or assembly number, a date, the name of the person who made the drawing with approvals, the scale, when it was first issued, and the current date and latest revision number.

Dryer

Device that removes moisture from fluids or gases.

Dunnage

Materials or devices used in the securing and/or bracing of products during shipments.

Duty cycle

The length of time an item is turned on or that a reader can be emitting energy.

DVOM (Digital Volt Ohm Meter)

Portable, hand held testing equipment used to test for voltage, amperage or resistance.

Earplugs

Personal protection device to protect and conserve hearing.

Extensible Authentication Protocol (EAP)

Point-to-point (P2P) wireless and local area network (LAN) data communication framework for authentication

Effective Beam

The usable beam diameter in photoelectric transmitted beam sensing which equals the lens diameter of the light source and receiver.

Electrification

The track mounted conductor system by which the moving equipment receives its electrical power. All of the electrical components that go into providing power to an electric overhead crane or jib crane. These components may include power bar, collectors, collector rings, pendent stations, and tagline/ festooning.

Electronic Communication Network (ECN)

Forum or network for financial products trading outside traditional stock exchanges

Electronic Data Interchange

Communication of a data message, or messages, automatically between computers or information management systems, usually for the purposes of business transactions. A process by which the purchasing operation of one company is electronically linked with the order entry operation of another in order to "speed" ordering, reduce the amount of paperwork and keep errors to a minimum.

Emergency Stop

An equipment control that immediately stops motion and tasks of the system by cutting off the drive power.

End-Of-Arm Tooling (EOAT)

Application tools that are located at the end of the robot arm.

EPROM (Erasable Programmable Read-only Memory)

A type of nonvolatile, programmable, read-only memory.

Ergonomic

The design of working conditions to better accommodate the human body's capabilities and limitations (human factors). Ergonomics is also known as the study of work tasks with an emphasis on reducing to a practical minimum the physiological cost of doing the work.

EtherNet/Industrial Protocol (EtherNet/IP)

Protocol adapting the Common Industrial Protocol to standard Ethernet.

Failure Analysis

Using Maintenance Diagnostics tools, i.e. infra-red heat sensors, to locate hot spots in motors and controls, to locate the problems and repair before a fire could occur.

Feedback

A signal from equipment about conditions as they actually exist, rather than as the computer has directed them to exist.

Fiber Optics

Transparent fibers of glass or plastic used for conducting and guiding light energy. Used in photoelectrics as "light pipes" to conduct sensing light into and out of a sensing area.

File Transfer Protocol (FTP)

Protocol for computer files transfer on network

Filter

A device incorporated into a hydraulic or pneumatic system to remove contaminants from the oil or air.

Firewall

A firewall works as a barrier between networks, such as between a Local Area Network and the Internet. The firewall ensures that only authorized users are allowed to access the one network from the other. A firewall can be software running on a computer, or it can be a standalone hardware device.

First aid

Emergency treatment given to an injured person prior to professional medical care being available.

Fluid Power System

The transmission and control of power through the use of fluid pressure and volume.

Four-way fork entry

Openings on all four sides of a pallet or the base of a pallet container, which allow fork truck handling from any of the four sides.

Free Span

The distance between supports in a storage rack.

Frequency

The number of cycles a periodic signal makes in a unit of time. Usually expressed in Hertz (cycles per second).

Galling

The bonding, shearing, and tearing away of material from two contacting or sliding surfaces. Normally a result of lack of maintenance or part failure.

Gear Motor

A commonly used term that transmits power through a motor and gear reduction.

Gear Ratio

The comparison between the diameters of the drive gear or sprocket versus the diameter of the driven gear or sprocket.

Geometric Dimensions/Tolerances

A measurement technique that expresses position or form tolerances to establish construction sizes or repair tolerances.

Global Positioning System (GPS)

Developed for and managed by the United States military, GPS is a satellite navigation system. It consists of 24 satellites above the earth. They transmit radio signals to receivers placed on ships, trucks or other large assets that need to be tracked.

Graphics Interchange Format (GIF)

Bitmap format for images

Ground

Electrical reference point at which electrical circuit voltage can be measured or returned.

Harness

Distributes fall-arresting forces throughout the body.

Hazardous Motion

A possible dangerous or harmful motion.

Human-machine interface (HMI)

Hardware and software components for handling human-machine interactions

Hydraulic Motor

Motors that produce power that are driven by hydraulic pressure and volume that develop high torque and occupy a small space.

Hydraulic Pumps

Pump that pressurizes hydraulic fluids. They are rated by pressure and volume capacity.

Hypertext Transfer Protocol (HTTP)

Protocol for information systems where hyperlinks connect to hypertext documents

Hysteresis

The ratio of the distance the object travels between the points at which the sensor is turned on and off to the distance the object is from the sensor.

ID Filter

Computer software that compares a newly read identification (ID) tag or label with those within a database to establishing a match.

Industrial Trucks (Fork Lifts)

Wheeled vehicle used in the plant or distribution center, in the dock area (and in some cases also in the yard or on construction sites) to pick up, transport and deposit single loads. May be powered manually, by gasoline, propane or electrically.

Input Device

Any connected equipment, such as control devices (e.g., switches, buttons, and sensors) or peripheral devices (e.g., cathode ray tubes and manual programmers), that supply information to the central processing unit. Each type of input device has a unique interface to the processor.

Inputs/Outputs (I/O's)

The digital I/O's in a network is used to connect any device that can toggle between an open and a closed circuit. If, for example, a door switch is used as an input device, opening the door could trigger the upload and the sending of notification messages that the door is open. An output might, for example, be used to automatically start a siren when there is a motion detection trigger.

Inspection Tools

Calipers, micrometers, and other precision measuring tools to determine wear on parts.

Intelligent Reader

A term that is sometimes used to describe a reader that has the ability to filter data, execute commands and generally perform functions similar to a personal computer.

Interlock

The control of a device starting or stopping which is dependent upon the action of another device.

Intermediate System to Intermediate System (IS-IS; also written ISIS)

Routing protocol for moving information a network or connected computers or devices

International Standards Organization (ISO)

An organization established to promote the development of international standards.

Internet Control Message Protocol (ICMP)

Supporting protocol used by network devices for error messages and operational information with connecting to another IP address

Internet Protocol (IP)

Standard for directions as to where and how to go for packets over networks

Internet Relay Chat (IRC)

Protocol for text communication

Inventory Control

Maintaining specified product quantity to ensure product availability and planning needs.

Isometric Drawing

A three-dimensional type of drawing that shows both the horizontal and vertical sides of the object.

Joint Photographic Experts Group (JPEG)

Extension for image file

Just-In-Time (JIT)

The practice of timing inbound material flows so that they can arrive just in time before they are required. This results in smaller inventories. A JIT system requires close links among forecasting, production, scheduling, and purchasing groups as well as suppliers and carriers.

Kitting

The light assembly of component parts and sub-assemblies. Performed primarily by warehouse personnel.

Ladder Diagram

An industry standard line drawing for representing relay logic control systems.

Laser

An acronym for light amplification by the stimulated emission of radiation. Converts energy into laser light which, in turn, can be used to control the direction and movement of material handling equipment.

LED (Light Emitting Diode)

A semiconductor that emits a small amount of light when current flows through it in the forward direction. In photoelectric sensors, LEDs are used both as emitters for sensing beams and as visual indicators of alignment or output status.

Lever Type Limit Switch

A limit switch that uses a lever as the actuator for the purpose of coming into physical contact with the object to be detected.

Lifting Capacity

The rated load of a material handling lifting device (i.e., scissors lift, hoist) applied as uniformly distributed load.

Limit Switch

An electrical stop switch actuated by the motion of a machine or equipment.

Lockout/Tagout

An OSHA standard for the Control of Hazardous Energy. It addresses the practices and procedures necessary to disable

machinery or equipment, thereby preventing the operation while employees perform servicing and maintenance activities. The standard describes limiting operation of equipment that is electrical, mechanical, hydraulic, pneumatic, chemical or thermal.

Machine Vision

A system which takes digital pictures of objects and codes and sends the pictures to a computer for interpretation.

Maintenance

Activities that are done at a regular or scheduled time to increase productivity and eliminate breakdowns.

Maintenance Diagnostics

A process by which the frequency, amount and cost of maintenance to buildings and machines is evaluated on an on-going basis.

Maintenance Log

A log that contains entries of machine breakdowns and repairs over a given time.

Manipulator

A movement assist device that is often equipped for handling different types of loads.

Material Handling

The movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal.

Memory

The part of a programmable controller that stores data, instructions, and the control program either temporarily or semi-permanently.

Mezzanine

Structural area that provides a secondary level to increase usable floor space in a distribution center.

Microprocessor

A silicon chip that is the heart of a computing system that is capable of performing the program execution, control, and data-processing functions of a central processing unit.

Moving Picture Experts Group (MPEG)

Alliance which sets standards for media coding, and file formats for various applications.

MSDS (Material Safety Data Sheet)

Acronym for the documents describing the hazard information about a given chemical or product.

National Electrical Manufacturers Association (NEMA)

NEMA standards are used to specify suitability of sensor and sensing system enclosures for various sensing environments.

Nestable pallet

A plastic pallet designed in such a way as to allow the pallet to fit or "nest" in another so as to facilitate better use of storage space. Pallets in which foot design is such that the pallets can stack within each other when empty.

Network News Transfer Protocol (NNTP)

Application protocol for sending Usenet news articles (netnews) between servers and posting and reading articles by end users.

Network Processing Engine (NPE)

Routing engine for the Cisco Universal Broadband Router

Nonvolatile Memory

A type of memory whose contents are not lost or disturbed if operating electrical power is lost.

Off-Line Programming

The ability to program computer operational parameters during operations so as to not stop production, but can be used as changes to the operation or as a back-up.

Ohm

A unit of measurement for resistance.

Open

A condition within a circuit without a complete pathway for current flow.

Open Shortest Path First (OSPF)

Link state routing protocol (LSRP) that uses the Shortest Path First (SPF) algorithm for the shortest connection path between devices

Order Picking

Order picking or order selection is the process of retrieving individual items (from storage locations) for the purpose of fulfilling an order for a customer.

Orthographic Projection

A drawing of a machined part or other object showing the vertical (frontal) plane, the horizontal (top) plane, and the profile (side) plane.

OSHA (Occupational Safety and Health Administration)

OSHA is an agency of the United States Department of Labor. OSHA's mission is to assure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance.

Parallel

A type of electrical circuit that has more than one pathway for electrical current flow.

Personal Protective Equipment (PPE)

Refers to protective clothing, helmets, goggles, or other garments or equipment designed to protect the wearer's body from injury.

Perspective Drawing

This type of drawing nearly presents an object as it appears to the eye or is seen in an actual picture.

Photoelectric

The development of electrical energy from a light source.

Photoelectric Sensor

A device which detects a visible or invisible beam of light and responds to a change in received light intensity to detect the presence or absence of a physical object.

Pick and Place Robot

A type of robot that moves parts from one place to another.

Pneumatic

The operation or powering of devices with the use of a gas.

Pneumatic Hoist

A motor driven hoist whose power is derived from pneumatically (compressed air or gas) powered motors. These hoists are often used in areas where electrical sparks are undesirable due to the possibility of explosion of fumes or materials.

Point-To-Point Motion

The user specifies points for the robot to follow along the path. The movement is point to point as opposed to a continuous motion.

Pressure

Hydraulic or pneumatic force developed by a pump and normally applied to a device.

Pressure: Maximum Rated

The maximum pressure at which a component should be operated on a continuous basis, usually the relief valve setting at maximum flow rate.

Preventative Maintenance

Periodically inspecting and repairing motors, conveyors, switches, forklifts, weight scales, etc. to insure these items are operational and accurate.

Procedure

A set of instructions to help guide activities and avoid harmful or dangerous situations.

Programmable Logic Controller (PLC)

industrial computer adaptation for manufacturing processes control; a solid-state control device that can be programmed to control process or machine operations. It consists of five basic components: the processor, memory, input/output modules, the power supply, and the programming device.

Proximity sensor

An electronic device that detects and signals the presence of a selected object. When used in association with a radio frequency identification system, the sensor is set up to sense the presence of a tagged or a transponder carrying object when it enters the vicinity of the reader/interrogator so that the reader can then be activated to effect a read.

Proximity Switch

This switch completes the circuit when a target comes close to the switch. It works over a short distance.

Pump

A device which converts mechanical energy into hydraulic energy to create pressure or movement of liquids. They may be either fixed or variable displacement.

Quality Control

The process of ensuring that the finished product, service, or system meets the specified criteria and constraints.

Queue

A wait or line of production.

R&D

Research and development

Radio Control

A communication medium through which motors, drives and controls receive direction over radio waves emitted from hand-held and equipment mounted transmitters.

Radio Frequency Identification (RFID)

A communication medium by which motor and controls are directed by means of high and low frequency radio transmission directives. RFID tags are labels with electronic chips embedded to allow for identification.

Radio Frequency Interference (RFI)

Interference caused by electromagnetic radiation at radio frequencies to sensors or to other sensitive electronic circuitry.

Random Access Memory (RAM)

A volatile, alterable memory that provides storage for the application program and data.

Receiving

The incoming process for supplied items from suppliers.

Refraction

The "bending" of light rays as they pass through a medium having one refractive index into a medium with a different refractive index. For example, as from air into water or from air into glass or plastic.

Reliability

A measure of the ability to perform similar operations multiple times based on similar operating conditions.

Repeatability

The variability of the position and orientation as the operation makes the same moves under the same conditions.

Reservoir

A container which stores the liquid in a fluid power system.

Resistance

The opposition to electrical current flow.

Respirator

Personal protection device used to filter breathing air of impurities.

Routing Information Protocol (RIP)

Protocol with hop count limit to prevent routing loops by implementing a limit on the number of hops allowed in a path from source to destination

Safeguard

Protects workers from hazardous situations through physical barriers or guidelines to follow.

Safety Procedure

A set of instructions to help avoid harmful or dangerous situations.

Sectional View

A drawing of a machined part or other object showing a cut-away view from inside the part.

Secure Shell (SSH)

Cryptographic protocol for operating secure operations over an unsecured network

Self-Guided Vehicle

A Self-Guided Vehicle (SGV) is an autonomous, self-directed robotic delivery system for the movement of product in diverse environments. An SGV operates independently to navigate around fixed and moving obstructions without the need for an external guide path network or sensors, such as buried wires or mounted magnetic or optical strips. Instead, an SGV uses on-board sensory inputs and navigational software to dynamically plot a path as the robot moves to each goal or task destination.

Semiconductor

Solid state device that is used in the application of electronics.

Sensor

An electronic device designed to detect a specific phenomenon, such as the presence or absence of a physical object, and used to affect control over a designated process.

Series

A type of electrical circuit that has a single pathway for current flow.

Server

A server is a computer program that provides services to other computer programs in the same or other computers. A computer running a server program is also frequently referred to as a server. In practice, the server may contain any number of server and client programs.

Shelf

A storage surface located above the floor level and usually contained in shelving systems or rack systems.

Shelf Life

The amount of time an item may be stored before it is unusable.

Shock

A physical condition where a person is traumatized by the effects of an injury.

Short

A condition within an electrical circuit that allows current flow through a faulty or accidental connection between two points of different potential.

Side Loader truck

An industrial lift truck with capabilities that can deliver a load to a storage rack in a sideways movement in each direction allowing for narrow aisles to save floor space.

Simple Network Management Protocol (SNMP)

Protocol for obtaining information about devices on IP networks and changing that information to change device operation.

Six Sigma

A process improvement initiative that troubleshoots operation concerns, locates problems, finds solutions, and reduces costs.

Smart Card

A card with a magnetic stripe to capture and present information.

Solenoid

A coil containing a moveable iron core that is used for transforming electrical energy to mechanical movement. The core moves as the electrical current moves through the coil.

Simple Network Management Protocol (SNMP)

Protocol for obtaining information about devices on IP networks and changing that information to change device operation.

Sprocket

The device that drives or is driven by a chain.

Standard

A collection of voluntary rules developed through consensus and related to a particular trade, industry or environment.

Stock (Storage)

Items that are held in inventory.

Storage

The process or act of positioning and placing items (cartons, packages, pallet unit loads, etc.) in area set aside for holding these items or staging these items for shipment.

Strain

The amount of deformation or flex a material undergoes with the application of load.

Strapping

A load stabilizing and securing method where a variety of materials can literally be used to wrap or tie down a load or individual item for movement and protection.

Stress

The load or force applied to a material.

Stretch Wrapping

Unitizing a load by stretching and wrapping a plastic sheet tightly around and over the load.

Supervisory Control and Data Acquisition (SCADA)

Computer control system architecture for network data and graphical user interfaces (GUI) for process management, including peripheral devices such as programmable logic controllers (PLC) and discrete proportional-integral-derivative (PID)

Supply Chain Management

Supply Chain Management is the integration and coordinated execution of all the business processes used to plan and execute the flow of material, goods, products and related information between the many sources and points of use throughout the supply chain.

Surface Hardness

The hardness of the outside surface of a material.

Surface Roughness

This is height value of the surface finish. Values range from 1 (super fine) through 1000 (extremely rough).

Symbols

Pictures or diagrams used to represent a function or component.

Teach Mode

The control state that allows the generation and storage of positional data points within a robotic operating system.

Tensile Strength

The maximum stress a material will withstand prior to failure.

Tensile Stress

The force per unit area that results in the application of tension forces.

Tension

The application of forces in opposite directions.

Three-way Valve

A 3 port valve (in, out and work) normally used with a single acting cylinder or uni-directional motor.

Time and Motion

A work measurement process that takes into consideration the time it takes to perform a task in a normal or variant effort or pace. The time and effort needed to accomplish a task.

Tool Safety

The proper procedures used when operating tools to minimize risks to personnel and equipment.

Torque

Twisting power or force.

Tracking Software

Software programs developed specifically to enhance the "tracking" or location of product, returnable containers, pallets and merchandise.

Transducer

A device used to convert physical parameters, such as temperature, pressure, and weight, into electrical signals.

Transistor

Three wire electrical semiconductor that allows voltage to flow through the circuit when a signal is received.

Transmission Control Protocol/Internet Protocol (TCP/IP)

TCP (transmission control protocol) and IP (Internet protocol) combination

Troubleshooting

The process of determining the basic cause of a failure so repairs can be accomplished.

Unshielded

An inductive proximity sensor configuration that requires a metal-free zone around the sensing face.

V – Belt

A flexible power transmitting device used with pulleys that is placed to drive a motor, pump, or other rotating motion device.

Valve

A device which controls fluid or gas flow rate, direction, or pressure.

Variable Frequency Drive (VFD)

An AC electrical input control that converts the 60 hertz (cycles) to both higher and lower cycles which increases and decreases motor RPM.

Viscosity

Thickness or resistance to flow of a fluid.

Voice Headset

Earphones and an attached microphone used by operators to interact with computer systems while keeping both hands free to simultaneously perform other tasks.

Voice Recognition

The ability to receive, recognize and/or understand voice commands. Usually associated with computer directed systems utilized for process control and data collection.

Volt

Unit value that represents voltage.

Voltage

Electrical pressure.

Walking Stacker

A power operated device controlled by an operator standing behind it, which lifts, stacks, and transports pallets.

Wattage

The unit value for power.

Waveform Audio File Format (WAVE or WAV)

File format for audio bitstream on PCs.

Welding

Any method of joining two materials by a cohesive fusion of the materials.

XYZ Coordinates

A reference to the most common names given to the lines forming a three dimensional solid. These coordinates are used for programming robots and other machine tools.

Yield Strength

The guaranteed minimum yield point stress of a material as specified by the supplier.