

## A comprehensive review on mechanical conveyor systems: evolution, types, and applications

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### Abstract

Mechanical conveyor systems are essential components in various industrial sectors, acting as the backbone for efficient material transportation from one location to another. This paper provides a comprehensive review of the development, classifications, design considerations, and applications of these systems. It delves into the different types of conveyors, including belt conveyors, roller conveyors, chain conveyors, screw conveyors, and overhead conveyors. Each type is explored in detail, highlighting their unique features and operational benefits. The paper also examines the innovations and advancements in conveyor technologies, discussing their significant impacts on enhancing efficiency, productivity, and sustainability in industrial operations. By illuminating the significance of these conveyor systems and their role in improving industrial efficiency, productivity, and sustainability, this paper aims to offer valuable insights into the field of materials handling and logistics.

**Keywords:** mechanical conveyor systems, industrial conveyors, belt conveyors, roller conveyors, chain conveyors, screw conveyors, overhead conveyors

### Introduction

Mechanical conveyor systems are fundamental components in a multitude of industrial sectors, serving as essential tools for the efficient transportation of materials from one location to another. The importance of these systems is profound, as they ensure the smooth movement of goods, raw materials, and finished products within manufacturing plants, distribution centers, and various other industrial settings. Over the years, mechanical conveyor systems have undergone significant transformations, evolving to meet the diverse needs of different industries. They have become integral to manufacturing, material handling, and processing industries by minimizing manual handling, reducing human error, and enhancing productivity [1]. The origins of mechanical conveyor systems can be traced back to ancient times when simple, manual methods were employed to move materials. Early conveyors were rudimentary devices, often powered by human or animal labor. These early systems were limited in their capacity and efficiency, but they laid the groundwork for future innovations. The industrial revolution marked a significant turning point in the development of conveyor systems. The introduction of steam power and later, electric power enabled the creation of more robust and efficient conveyors [2]. In the late 19th and early 20th centuries, conveyor systems became more widespread in industrial applications, particularly in manufacturing and mining. Innovations such as the assembly line, popularized by Henry Ford, further underscored the importance of conveyors in enhancing production efficiency. In the mid-20th century, the advent of automation and computer control revolutionized conveyor technology. Automated conveyor systems, equipped with sensors and control systems, could perform complex material handling tasks with minimal human intervention. These advancements not only improved efficiency but also enhanced safety and reduced labor costs [3]. Mechanical conveyor systems can be broadly classified into several types, each designed to meet specific industrial requirements. The primary types include Belt Conveyors, Roller Conveyors, Chain Conveyors, Screw Conveyors, and Overhead Conveyors. Belt conveyors are the most common type, consisting of a continuous belt that moves between two pulleys and are widely used in various industries due to their versatility and ability to handle a wide range of materials. Roller conveyors, using a series of rollers to transport materials, are particularly effective for handling heavy loads and are commonly used in warehouses and distribution centers. Chain conveyors, utilizing chains to move materials, are ideal for heavy-duty applications and are often employed in automotive and heavy manufacturing industries. Screw conveyors, consisting of a helical screw blade that rotates within a tube, moving materials along its length, are

commonly used in agricultural and food processing industries. Overhead conveyors transport materials via a track suspended from the ceiling and are used in various industries, including automotive assembly and dry cleaning. Each type of conveyor system has unique advantages and limitations. For instance, belt conveyors are suitable for long-distance transportation, while screw conveyors are ideal for moving granular materials. Understanding these differences is crucial for selecting the appropriate conveyor system for a given application [4]. The field of conveyor technology has witnessed remarkable innovations driven by advancements in engineering and material science. Modern conveyor systems are designed to be more efficient, reliable, and adaptable to diverse industrial environments. One significant advancement is the development of intelligent conveyor systems equipped with sensors and control systems. These systems can monitor their operation in real-time, detecting and addressing issues such as blockages or mechanical failures. Intelligent conveyors enhance operational efficiency and reduce downtime, contributing to increased productivity. Material advancements have also played a crucial role in the evolution of conveyor systems. The use of high-strength, lightweight materials have improved the durability and performance of conveyors. For example, the development of advanced polymer belts has led to more efficient and reliable belt conveyors. Additionally, the integration of automation and robotics with conveyor systems has transformed material handling processes. Automated conveyors can seamlessly interface with robotic arms and automated guided vehicles (AGVs), creating highly efficient and flexible material handling systems. These advancements have significant implications for industries such as manufacturing, warehousing, and logistics [5]. The ongoing innovations in conveyor technology have profound impacts on industrial operations. Improved efficiency and productivity are among the most notable benefits. Modern conveyor systems can handle higher volumes of materials with greater speed and accuracy, reducing the time and labor required for material handling tasks. Enhanced sustainability is another critical impact of advanced conveyor systems. Energy-efficient motors and control systems reduce power consumption, contributing to lower operational costs and a reduced environmental footprint. Additionally, the use of recyclable and eco-friendly materials in conveyor construction supports sustainability initiatives. The reduction of manual labor and associated risks is a significant advantage of modern conveyor systems. By automating material handling tasks, companies can minimize the risk of workplace injuries and improve worker safety. This shift also allows human workers to focus on more complex and value-added tasks, enhancing overall operational efficiency [6].

**Conclusion:** Mechanical conveyor systems have evolved from simple manual devices to highly sophisticated, automated technologies that are integral to modern industrial operations. Their transformative journey, driven by innovations in power sources, automation, and material science, has enabled industries to significantly improve efficiency, reduce labor costs, and enhance safety. Conveyor systems, such as belt, roller, chain, screw, and overhead conveyors, each serve unique functions and are designed to meet the specific needs of diverse industrial applications. The continued advancements in intelligent systems, materials, and integration with automation technologies have further optimized performance, allowing conveyors to handle larger volumes of materials with increased speed and accuracy. Moreover, modern conveyor systems contribute to sustainability efforts by reducing energy consumption and supporting eco-friendly practices. As industries continue to embrace automation, the role of conveyors in improving productivity, ensuring worker safety, and advancing sustainable practices will remain essential to the future of manufacturing, logistics, and other sectors

### Literature Review on Recent Advances in Conveyor Belt Systems

Recent advancements in conveyor belt systems have focused on optimizing performance through innovative control methods, efficiency studies, sensor integration, and material handling techniques [7]. propose an optimized robust control method for precise speed control in belt conveyors, addressing nonlinear disturbances such as friction, mass, and stiffness. They develop a fuzzy model to represent these uncertainties and design a robust controller that stabilizes the system, demonstrating superior effectiveness compared to LQR control, particularly in reducing speed discrepancies and preventing belt breaks [8]. In a similar vein, Tsunazawa et al. (2024) investigate conveying efficiency using experiments and discrete element method (DEM) simulations, analyzing factors such as inclination angle and belt speed. Their study highlights the critical role of the inclination angle, revealing that higher angles lead to increased particle loss and reduced efficiency, providing insights for optimizing conveyor system design [9].

Furthermore, Gao et al. (2024) introduce a combined detection and segmentation method to address conveyor belt deviations, incorporating machine learning and image processing techniques. This system

significantly enhances maintenance efficiency by detecting deviations accurately, thus ensuring more reliable conveyor operations in complex environments [7]. In the context of energy efficiency and sustainability, Ra et al. (2022) propose an IoTE conveyor system, which integrates triboelectric sensors and electromagnetic generators for self-powered, real-time monitoring of product transportation. This system eliminates the need for an external power source, offering a sustainable solution for smart, off-grid conveyor operations, particularly in environmentally conscious manufacturing [10].

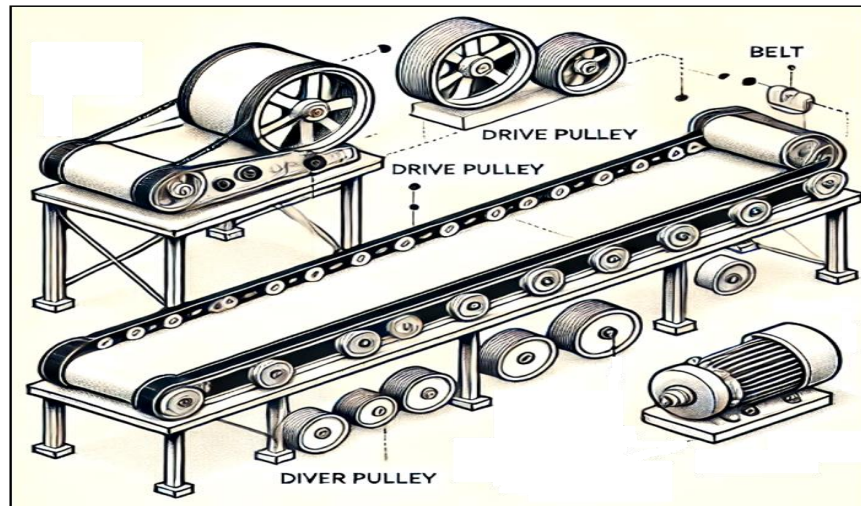
Hrabovský et al. (2023) explore a specialized conveyor design capable of handling bulk materials at steep inclination angles, introducing a cover belt mechanism to maintain material stability. Their findings provide critical data for the design of pressing mechanisms, enhancing conveyor system efficiency and reliability, especially for bulk materials like maize and gravel [11]. Piatkowski (2024) discusses a novel modeling approach for positioning cuboidal objects along conveyor belts using driven oblique rollers, incorporating dynamic friction models like LuGre to simulate interactions during the positioning process. This modeling framework improves understanding of frictional forces during material handling and aids in enhancing conveyor alignment [12].

The study by Vasić et al. (2020) on idler roller bearing failures provides valuable insights into the wear and damage mechanisms in belt conveyor systems, emphasizing the need for improved idler design to prevent premature failures. Their analysis using fault tree analysis (FTA) has practical implications for engineers in specifying new idler requirements [13]. Lastly, Ma et al. (2024) address the challenges faced by scraper conveyors in underground coal mining, focusing on load and speed variations. Their DEM-MBD model provides critical insights into optimizing scraper conveyor components and transport state monitoring, leading to enhanced energy efficiency and conveyor lifespan [14]. These studies collectively demonstrate the ongoing advancements in conveyor belt systems, from improving speed control and efficiency to integrating sustainable technologies and advanced monitoring techniques. The integration of fuzzy models, real-time data analytics, and self-powered systems showcases the future potential of conveyor belt systems in optimizing industrial operations across diverse sectors.

## **Classification of Mechanical Conveyor Systems:**

### **Belt Conveyors**

The concept of conveyor systems dates back to ancient civilizations, where crude methods of material transportation were employed. However, the modern belt conveyor system we are familiar with today began to take shape during the Industrial Revolution in the late 18th century. It was in the early 19th century that flat belts made of leather or fabric were first used to transport bulk materials within factories. The conveyor technology continued to evolve through the 20th century, with the introduction of various innovations such as rubber belts, steel belts, and modular belting systems. These advancements significantly improved the efficiency and reliability of belt conveyors, making them indispensable in various industries (Figure 1). Currently, belt conveyors hold a significant share in the bulk material handling industry due to their elevated efficiency in transporting materials over short to medium distances [2]. Despite their renown, conveyor systems often experience poor economic performance, either due to being oversized or operating inadequately [2,3]. A belt conveyor consists of several key components designed to work together harmoniously to ensure efficient material handling. The core component of any belt conveyor is the belt itself, which can be made from various materials, including rubber, fabric, or metal, depending on the application's requirements. The belt's width, length, and thickness vary based on the material being transported and the conveyor's capacity [4]. Pulleys, also known as drums or rollers, support and guide the conveyor belt, with powered pulleys driving the belt and idler pulleys maintaining tension and alignment. The drive system, comprising an electric motor, gearbox, and coupling mechanisms, provides the necessary power to move the conveyor belt. Additionally, the support structure ensures stability and alignment, while idlers reduce friction and maintain proper belt tension. Various belting accessories, such as cleats, sidewalls, and scrapers, can be added to meet specific material handling needs. Modern belt conveyors often feature advanced control systems that enable precise speed and direction control, integrating with sensors, switches, and programmable logic controllers (PLCs) for seamless operations [1].



**Figure 1: Block diagram of Belt Conveyors**

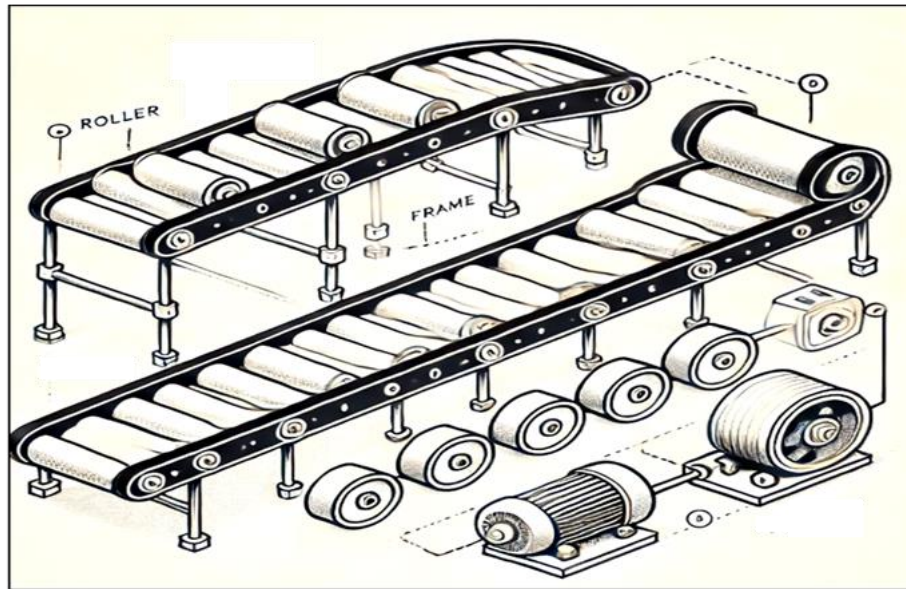
The operation of a belt conveyor is a well-defined and systematic process involving several phases: loading, conveying, unloading, and maintenance. Materials are loaded onto the conveyor belt at the loading point, ensuring even distribution to prevent spillage. Once the materials are on the belt, the drive system activates to move the conveyor belt, with the belt carrying the materials along its length, guided by the pulleys and idlers. At the unloading point, materials are transferred to their destination using mechanisms such as diverter gates or chutes. Regular maintenance is crucial for ensuring the conveyor's reliability and longevity. This includes cleaning, lubricating, inspecting, and replacing worn components, as well as monitoring belt tension and alignment [4]. Belt conveyors are incredibly versatile and find applications across a wide range of industries. In mining, they transport bulk materials like ore, coal, and minerals from extraction sites to processing plants or storage areas. In manufacturing, conveyors facilitate the movement of raw materials, work-in-progress, and finished products between various production stages. Food processing facilities use belt conveyors to move ingredients, packaging materials, and finished food products efficiently and hygienically. Warehouses and distribution centers rely on conveyor systems for sorting, packaging, and shipping goods. In agriculture, belt conveyors assist in loading and unloading grain, transporting feed, and sorting produce. The automotive industry employs belt conveyors for assembly line processes, including transporting car parts and vehicles. Airports use conveyor belts for baggage handling; ensuring passengers' luggage reaches the correct destination. Retail stores utilize conveyor systems for moving clothing items from storage to display areas and managing inventory in distribution centers. The popularity of belt conveyors can be attributed to their efficiency, versatility, reliability, safety features, cost-effectiveness, and ability to integrate into automated processes [5, 6, 15, 16].

In conclusion, the belt conveyor system has evolved from its early use in ancient civilizations to become a crucial component in modern material handling. Its efficiency, reliability, and versatility have made it indispensable across various industries, including mining, manufacturing, food processing, and logistics. Despite challenges in optimizing economic performance, advancements in materials and design have greatly improved its functionality. Regular maintenance and efficient system design ensure long-term reliability and performance. The belt conveyor system continues to play a vital role in streamlining operations, contributing to the automation and efficiency of industries worldwide.

### **Roller Conveyors:**

The history of roller conveyors can be traced back to ancient civilizations that utilized rudimentary forms of rollers to move heavy objects. However, the modern roller conveyor system, as we know it today, has its

roots in the Industrial Revolution of the 18th and 19th centuries. During this period, innovations in manufacturing and transportation led to the development of more efficient conveyor systems. One of the earliest roller conveyors used wooden rollers to facilitate the movement of materials in factories. Over time, these wooden rollers were replaced by metal rollers, which improved durability and load-carrying capacity. As technology advanced, the design and applications of roller conveyors continued to evolve, leading to the sophisticated systems in use today [17, 18].



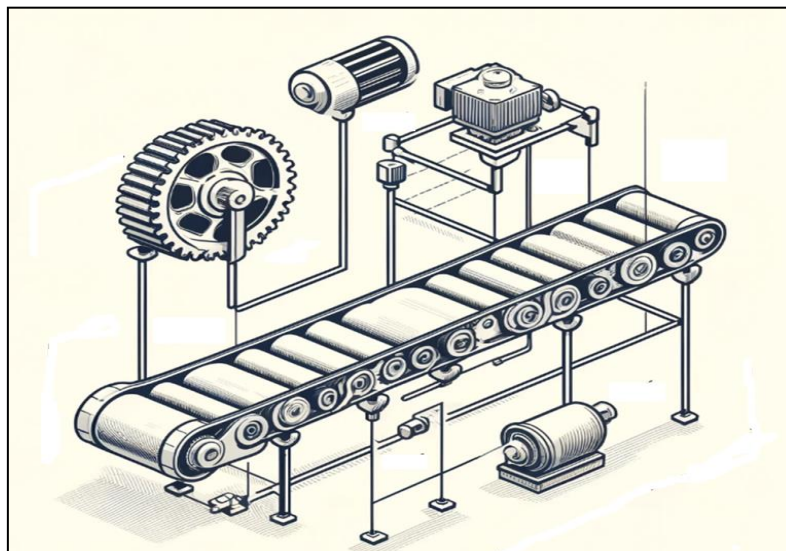
**Figure 2: Block diagram of Roller Conveyors**

A roller conveyor consists of several essential components designed to work in tandem (Figure 2). Rollers, which are the core elements, are cylindrical components typically made of materials like steel or plastic. These rollers rotate on their axles and support the weight of the transported materials. The spacing and diameter of the rollers can vary to accommodate different types of loads. A sturdy frame or support structure provides stability to the conveyor system, housing the rollers and ensuring proper alignment and load distribution. Roller beds, sometimes referred to as roller decks, are the surfaces on which materials rest as they move along the conveyor. These beds can be driven by external mechanisms or free-spinning (gravity rollers) to allow for different modes of operation. Roller conveyors can be powered or gravity-driven. Powered roller conveyors use external motors or internal drives to move the rollers, while gravity roller conveyors rely on the force of gravity to transport materials. The choice of drive mechanism depends on the application's requirements. Modern roller conveyors may also incorporate advanced control systems for precise speed and direction control. Automation technologies, such as sensors and programmable logic controllers (PLCs), enable seamless integration into material handling processes [1, 2]. The operation of a roller conveyor follows a systematic process, including loading, conveying, unloading, and maintenance. Materials or products are placed onto the rollers at the loading point, ensuring even distribution so that the conveyor can efficiently move the load. Once loaded, the rollers are activated either through a powered drive or by gravity, causing the materials to move along the conveyor. The rollers support and guide the materials as they progress. At the unloading point, materials are transferred from the conveyor to their intended destination, which can involve various mechanisms such as chutes, diverters, or additional conveyors. Regular maintenance is essential to ensure the conveyor's reliability and longevity, including tasks such as cleaning, lubrication, inspection, and the replacement of worn component[19,20]. Roller conveyors find applications in diverse industries due to their versatility and efficiency, including material handling in factories, automated assembly lines, package sorting in logistics, agricultural product handling, airport baggage handling, automotive manufacturing, and food and beverage processing. Roller conveyors offer several advantages, such as high efficiency, versatility, low maintenance, cost-effectiveness, space optimization, and modularity, making them a popular choice in material handling applications [1].

In conclusion, roller conveyors, which have evolved from their rudimentary origins in ancient civilizations to the modern systems of today, continue to play a crucial role in material handling across various industries. The advancements in design, materials, and control systems have significantly enhanced their efficiency and versatility. Roller conveyors are widely used in sectors such as manufacturing, logistics, food processing, and automotive industries, offering benefits like low maintenance, cost-effectiveness, and modularity. Their robust performance, combined with ease of integration into automated systems, makes them an essential part of modern material handling operations. Additionally, the adaptability of roller conveyors to various load requirements and operational conditions ensures their continued relevance in diverse applications.

### Chain Conveyors

The history of chain conveyors can be traced back to the Industrial Revolution of the late 18th century, coinciding with the development of chain-driven mechanisms used in steam engines and locomotives to transmit power[1]. Initially serving industrial applications, chains gradually found their way into material handling systems, leading to the advent of chain conveyor technology. Among the earliest adopters were coal mining operations, where chain conveyors revolutionized the transport of coal from mines to processing facilities, marking a pivotal application that underscored their efficiency and reliability.



**Figure 3: Block diagram of Chain Conveyors**

Over time, advancements in materials science and engineering have enhanced the design and functionality of chain conveyors. Modern chain conveyors comprise several essential components that work synergistically to ensure efficient material handling (Figure 3). Central to their operation is the conveyor chain itself, typically constructed from materials such as steel, stainless steel, or plastic, chosen based on durability and application-specific requirements. This chain is driven by sprockets connected to a robust drive mechanism, often comprising an electric motor, gearbox, and coupling mechanisms tailored to varying load capacities and operational speeds[20,21]. Critical to the conveyor's stability and performance is its support structure, providing a solid foundation for mounting components like chains and sprockets. Proper tensioning mechanisms, such as adjustable idlers or screw tensioners, maintain optimal chain tension, essential for smooth operation and prolonged chain life. Chain guides strategically placed along the conveyor's length ensure the chain remains on its intended path, preventing deviations that could disrupt material flow [22,23].

Incorporating a chain lubrication system further reduces wear and friction, enhancing conveyor longevity and minimizing maintenance requirements[5]. Modern chain conveyors often integrate advanced control systems, including sensors, switches, and programmable logic controllers (PLCs), enabling precise control over speed, direction, and material flow for seamless operations across diverse industrial settings. The operational cycle of a chain conveyor involves systematic stages: loading, conveying, unloading, and maintenance. Materials are loaded onto the conveyor chain at designated points, ensuring even distribution

and secure attachment. Once activated, the chain conveys materials along its path, guided by the conveyor's design to facilitate efficient material movement. At the unloading point, mechanisms such as chutes or additional conveyors facilitate the transfer of materials to their intended destinations[17,23].

Chain conveyors find extensive use across diverse industries due to their robustness, adaptability, and high load capacity. They are integral in mining and quarrying operations for transporting bulk materials like coal and ore over rugged terrain. In automotive manufacturing, chain conveyors support assembly and painting processes, while in agriculture, they handle grains, seeds, and fertilizers efficiently. Bottling and packaging industries utilize chain conveyors for moving bottles and packages through production and packaging lines, ensuring smooth and continuous operations[24].

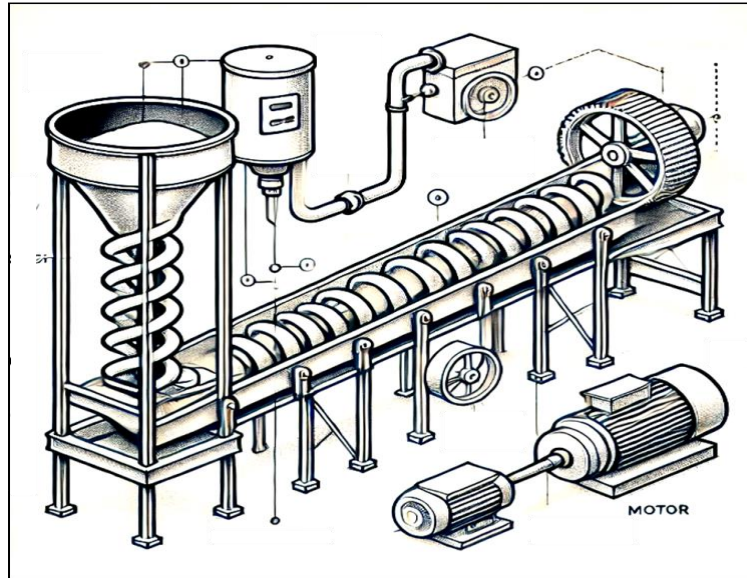
The advantages of chain conveyors further underscore their widespread adoption: high load capacity suitable for heavy materials, durability in harsh environments, and versatility in handling various shapes and sizes of items. Customizable configurations allow for tailored solutions to meet specific application needs, enhancing reliability and operational efficiency over extended service life spans. Some chain conveyors are designed for vertical or inclined transport, facilitating seamless material flow across different levels within manufacturing and distribution facilities [25]. In alignment with modern industrial sustainability initiatives, chain conveyors contribute to energy efficiency by optimizing power consumption during operation. They minimize material waste and spillage, supporting resource conservation efforts, and many of their components, such as steel or plastic chains, are recyclable at the end of their lifecycle. Equipped with safety features, chain conveyors prioritize worker protection and accident prevention, promoting both safety and environmental stewardship in industrial operations [26].

In conclusion, chain conveyors have evolved from their early industrial applications to become integral to various sectors due to their robustness, adaptability, and high load capacity. Their design and functionality have advanced significantly with improved materials, control systems, and enhanced performance features. Widely used in industries such as mining, automotive, agriculture, and packaging, chain conveyors offer advantages like durability, versatility, and customizable configurations. Additionally, their role in promoting energy efficiency and sustainability, combined with safety features, further underscores their importance in modern industrial operations.

### **Screw Conveyors**

The history of screw conveyors can be traced back to ancient civilizations where simple screw mechanisms were used for tasks like raising water or transporting grain. However, the modern screw conveyor as we know it today has its roots in the industrial revolution of the 18th century. The development of screw conveyors was closely linked to the burgeoning industries of mining and agriculture, where they initially facilitated the transportation of coal and minerals from mines to processing facilities[1]. Over time, advancements in screw conveyor technology led to their widespread adoption across various industries, including agriculture, food processing, chemical manufacturing, and beyond.

A screw conveyor comprises several essential components that work in harmony to facilitate material transport. At its core is the screw or auger, a helical structure that rotates within a trough or tube, effectively moving materials along its length. The design of screws can vary in terms of helix angles, pitches, and diameters, tailored to specific application requirements. The trough or tube, housing the screw, is typically constructed from materials such as carbon steel, stainless steel, or plastic, chosen based on the material being handled and environmental conditions. The rotation of the screw is powered by a drive mechanism consisting of an electric motor, gearbox, and coupling mechanisms, configured to meet varying load capacities and operational speeds[1,2,3].



**Figure 4: Block diagram of Screw Conveyors**

Supporting the structural integrity of the conveyor system is a sturdy frame or support structure, ensuring proper alignment and stability of the screw (Figure 4). Hanger bearings are strategically placed along the length of the screw to reduce friction and facilitate smooth rotation. Inlet and outlet points facilitate the loading and unloading of materials, equipped with features like feeders or valves to control material flow. In some applications, a cover or lid may be added to the trough or tube to enhance safety and prevent contamination. The operation of a screw conveyor follows a systematic process that includes loading, conveying, unloading, and maintenance. Materials are fed into the conveyor at the inlet point, utilizing chutes, hoppers, or feeders to ensure even distribution. Once activated, the screw rotates, propelling materials along the trough or tube to the discharge point, where they are unloaded using mechanisms such as chutes or valves. Regular maintenance, including cleaning, lubrication, inspection, and component replacement, is essential to ensure the conveyor's reliability and longevity [26-28].

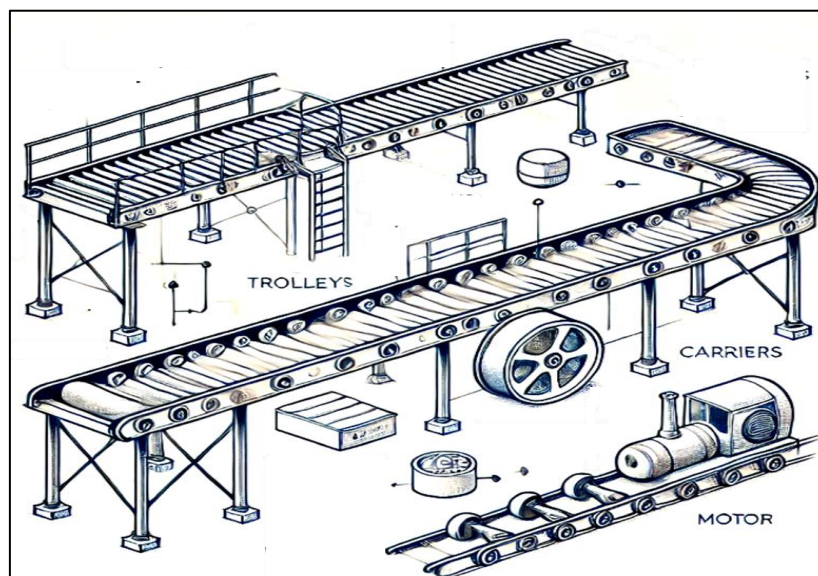
Screw conveyors are highly versatile and find applications across diverse industries. In agriculture, they transport grains, seeds, and feed, while in food processing, they handle cereals, flour, and bulk ingredients. Chemical and pharmaceutical industries use screw conveyors for conveying various chemicals, powders, and pharmaceutical products. They also play crucial roles in mining and quarrying operations for transporting minerals, ores, and aggregates, as well as in construction for moving cement, sand, and building materials. The advantages of screw conveyors contribute to their widespread adoption in material handling applications. They are efficient in moving materials with high moisture content or irregular shapes, offering versatility and customization in terms of length, diameter, pitch, and material. The helical design of the screw provides gentle handling, making them suitable for fragile or delicate materials, while their compact design proves space-efficient in facilities with limited space. Cost-effectiveness further enhances their appeal, providing good value for their capabilities [29]. In alignment with modern industrial sustainability initiatives, screw conveyors contribute to energy efficiency by optimizing power consumption during operation. They minimize material spillage and degradation, reducing waste and the need for reprocessing, while many components are recyclable at the end of their lifecycle. Equipped with safety features, screw conveyors prioritize worker protection and accident prevention, aligning with both safety and sustainability goals in industrial operations [2,30].

In conclusion, screw conveyors have evolved from simple mechanisms to essential systems in diverse industries, offering efficient, versatile, and cost-effective material handling solutions. Their design allows for the transport of a wide range of materials, including those with high moisture content or irregular shapes, while ensuring gentle handling of fragile products. Widely used in agriculture, food processing, chemical manufacturing, and mining, screw conveyors contribute to operational efficiency, energy savings, and sustainability. With their adaptability, safety features, and minimal maintenance needs, screw conveyors remain integral to modern industrial processes.

## Overhead Conveyors

The history of overhead conveyors can be traced back to the early 20th century when they were developed to streamline material handling processes in industrial settings. Initially, these conveyors were simple manual systems utilizing ropes or chains to move materials within manufacturing facilities[1]. As industrialization advanced, the demand for more efficient and automated solutions grew, prompting significant advancements in overhead conveyor technology. These developments included various conveyor types, materials, and control systems, evolving overhead conveyors from basic manual setups to sophisticated automated systems that offer enhanced efficiency and versatility. Essential components of overhead conveyors work synergistically to facilitate efficient material transport. The track system, typically consisting of rails, beams, or tracks installed overhead, guides carriers or trolleys along a defined path. These carriers, suspended from the track system, hold materials and are available in diverse designs to accommodate different types of loads, from hook-type carriers to specialized attachments[31,32]. The movement of carriers along the track system is powered by a drive mechanism, which can be manual, electric, pneumatic, or a combination thereof, with electric drives commonly used in automated setups.

Modern overhead conveyors feature advanced control systems that enable precise control over carrier speed, direction, and timing. Integrated sensors, switches, and programmable logic controllers (PLCs) automate material handling processes and monitor system performance, ensuring efficient operations and timely responses to operational conditions[33]. Load and unload stations along the track system facilitate the ingress and egress of materials, equipped with devices like hoists, cranes, or manual labor depending on the application's requirements.



**Figure 5: Block diagram of Overhead Conveyors**

The operational cycle of an overhead conveyor includes loading materials onto carriers at designated stations, conveying them along the track system, and unloading them at their intended destinations. Maintenance tasks such as lubrication, inspection, and component replacement are crucial for maintaining reliability and longevity. Overhead conveyors find widespread use across various industries due to their efficiency and adaptability. They are integral in automotive manufacturing for transporting vehicle components throughout assembly processes and in paint and finishing lines for moving products through coating and finishing stages. Distribution centers and warehouses utilize overhead conveyors for handling garments, hanging garments, and cartons, while food processing facilities rely on them for transporting meat, poultry, and baked goods between processing stages [33].

Advantages of overhead conveyors include maximizing floor space utilization by transporting materials overhead, customization to accommodate diverse load sizes and shapes, and enabling continuous material flow that enhances productivity. Safety features such as emergency stops, anti-derailment devices, and

protective guards ensure worker safety and prevent accidents. They also integrate seamlessly with automation technologies, reducing manual handling, labor costs, and the risk of injury. In alignment with sustainability goals, overhead conveyors contribute by optimizing energy consumption through efficient operation and control systems. They minimize material handling, reducing the risk of product damage and waste, and many components, such as steel or aluminum structures, are recyclable at the end of their lifespan. Their compact design helps maximize space within facilities, reducing the need for larger buildings and land use while enhancing safety and operational efficiency.

In conclusion, overhead conveyors have become vital components in modern industrial settings, evolving from simple manual systems to highly efficient automated solutions. Their ability to maximize floor space, customize for different load types, and ensure continuous material flow enhances productivity across industries like automotive, food processing, and warehousing. With their integration of advanced control systems, safety features, and energy-efficient design, overhead conveyors contribute to both operational efficiency and sustainability. Their versatility, cost-effectiveness, and minimal environmental impact make them an essential part of modern manufacturing and material handling systems.

Each conveyor type offers distinct advantages that suit different industrial applications. However, maintenance needs, capacity limitations, and initial installation costs can be significant factors to consider in choosing the appropriate conveyor system.

Table 2.1: Types of conveyors, their key features, applications, and limitations

Conveyor Type	Key Features	Applications	Limitations
<b>Belt Conveyors</b>	<ul style="list-style-type: none"> <li>- Made from rubber, fabric, or metal.</li> <li>- Powered by electric motor, gearbox, and coupling.</li> <li>- Can include accessories like cleats, sidewalls, and scrapers.</li> <li>- Versatile, cost-effective, and safe.</li> </ul>	<ul style="list-style-type: none"> <li>- Mining (transporting bulk materials like ore, coal)</li> <li>- Manufacturing (raw materials, finished products)</li> <li>- Food processing (ingredients, packaging)</li> <li>- Airports (baggage handling)</li> <li>- Warehouses (sorting, packaging, shipping).</li> </ul>	<ul style="list-style-type: none"> <li>- Can suffer from poor economic performance if oversized or underperforming.</li> <li>- Requires regular maintenance (cleaning, lubricating, inspecting).</li> </ul>
<b>Roller Conveyors</b>	<ul style="list-style-type: none"> <li>- Consists of rotating cylindrical rollers.</li> <li>- Can be powered or gravity-driven.</li> <li>- Uses external motors or gravity to move materials.</li> <li>- Can include automation with sensors and PLCs.</li> </ul>	<ul style="list-style-type: none"> <li>- Factories (material handling, assembly lines)</li> <li>- Warehouses (sorting packages)</li> <li>- Agricultural product handling.</li> <li>- Airport baggage handling.</li> <li>- Automotive manufacturing (assembly).</li> </ul>	<ul style="list-style-type: none"> <li>- Gravity-based systems can only be used where the terrain is level.</li> <li>- Limited to flat, smooth surfaces.</li> <li>- Requires space for rollers and supporting frames.</li> </ul>
<b>Chain Conveyors</b>	<ul style="list-style-type: none"> <li>- Uses steel, stainless steel, or plastic chains.</li> <li>- Driven by sprockets connected to an electric motor.</li> <li>- Features tensioning systems and chain guides for stability.</li> </ul>	<ul style="list-style-type: none"> <li>- Mining (coal, ore transport)</li> <li>- Automotive manufacturing (assembly line)</li> <li>- Agricultural product handling (grains, seeds)</li> <li>- Packaging and bottling industries.</li> </ul>	<ul style="list-style-type: none"> <li>- Can be bulky and take up more space than other systems.</li> <li>- Requires heavy-duty maintenance for chain lubrication and tension.</li> </ul>
<b>Screw Conveyors</b>	<ul style="list-style-type: none"> <li>- Features a rotating helical screw (auger) inside a trough or tube.</li> <li>- Powered by electric motors and gearboxes.</li> <li>- Customizable in terms of screw diameter, pitch, and</li> </ul>	<ul style="list-style-type: none"> <li>- Agriculture (grains, feed)</li> <li>- Food processing (bulk ingredients, flour)</li> <li>- Chemical/pharmaceutical (powders, chemicals)</li> <li>- Mining and construction (coal, cement, sand).</li> </ul>	<ul style="list-style-type: none"> <li>- May not be suitable for long-distance transport.</li> <li>- Can be prone to clogging with certain materials.</li> <li>- Requires regular cleaning to avoid material</li> </ul>

	length.		build-up.
<b>Overhead Conveyors</b>	<ul style="list-style-type: none"> <li>- Suspended above the ground on tracks, often with electric drives or pneumatic systems.</li> <li>- Can transport materials overhead, maximizing floor space.</li> <li>- Uses specialized carriers or trolleys.</li> </ul>	<ul style="list-style-type: none"> <li>- Automotive manufacturing (vehicle components)</li> <li>- Paint and finishing lines (coating processes)</li> <li>- Distribution centers (garments, cartons)</li> <li>- Food processing (meat, poultry).</li> </ul>	<ul style="list-style-type: none"> <li>- Installation can be complex and expensive.</li> <li>- Requires significant ceiling height for track installation.</li> <li>- Not suitable for transporting large, heavy items.</li> </ul>

Table 2.1 outlines the key features, applications, and limitations for each type of conveyor system, helping to identify the most suitable system for specific material handling needs in various industries.

### Evolution and Advancements

The evolution and advancements of mechanical conveyors have significantly shaped modern industrial processes, revolutionizing material handling and contributing to increased efficiency, productivity, and safety. Over the years, these ingenious systems have undergone continuous development, transitioning from rudimentary and manual mechanisms to highly automated and specialized conveyor solutions, each tailored to meet specific industry demands. The journey of mechanical conveyors can be traced back to ancient civilizations where rudimentary systems consisting of wooden rollers or sleds were used to transport heavy loads. The innovation primarily served as a means to reduce physical labor and streamline the movement of goods within agricultural, construction, and mining contexts. These early conveyor systems laid the foundation for subsequent advancements that would redefine the industrial landscape. As industrialization gained momentum during the 18th and 19th centuries, there was a growing need for more efficient material handling solutions. This era witnessed the emergence of conveyors featuring basic belt and chain mechanisms, which significantly improved the speed and capacity of material transport. The simple design of these conveyors made them accessible and adaptable across various industries. The next pivotal development came in the form of screw conveyors, which originated in the early 20th century. These innovative systems utilized rotating helical screws to move bulk materials within troughs or tubes. Screw conveyors were especially beneficial in industries such as agriculture, mining, and food processing, where the gentle handling of materials was essential. The mid-20th century marked a transformative period in the evolution of mechanical conveyors with the introduction of overhead conveyors. These systems utilized a track-mounted configuration, suspended from overhead structures, to transport materials efficiently [5,25,34]. Overhead conveyors were widely adopted in industries like automotive manufacturing and warehousing, where space optimization and continuous material flow were critical. Simultaneously, advancements in manufacturing techniques, such as the use of stainless steel and other durable materials, led to the development of conveyors capable of handling corrosive or hygienic materials. This expanded the application of mechanical conveyors to industries like pharmaceuticals and food processing, where strict cleanliness and material integrity were paramount. The latter half of the 20th century saw the integration of automation technologies into conveyor systems, transforming them into highly sophisticated and customizable solutions. Programmable Logic Controllers (PLCs) and sensors allowed for precise control over conveyor speed, direction, and material flow. This automation revolutionized industries like logistics, distribution, and e-commerce, enabling efficient sorting, routing, and tracking of packages[22]. The advent of modular conveyor systems further accelerated the evolution of mechanical conveyors. These systems featured standardized components that could be easily configured and adapted to meet specific application requirements. The modular approach reduced lead times, simplified maintenance, and facilitated the expansion or modification of conveyor systems as needed. Additionally, advancements in conveyor belt technology led to the development of specialized belts designed to handle various materials and environments. Heat-resistant, flame-resistant, and anti-static belts became essential in industries like mining, construction, and manufacturing, where extreme conditions posed significant challenges. The 21st century ushered in a new era of innovation in mechanical conveyors, with a focus on sustainability and energy efficiency. Conveyors were designed to minimize energy consumption, reduce material waste, and enhance safety. Smart conveyor systems integrated with data analytics and remote monitoring capabilities allowed for

real-time performance optimization and predictive maintenance [26]. Furthermore, the emergence of Industry 4.0 and the Internet of Things (IoT) brought about the concept of "smart factories," where conveyor systems played a central role in the seamless flow of information and materials. Conveyors were equipped with sensors and connected to centralized control systems, enabling real-time tracking of materials, quality control, and production optimization. Today, the evolution of mechanical conveyors continues with the integration of emerging technologies like artificial intelligence, machine learning, and robotics. Conveyor systems are becoming increasingly autonomous, capable of making real-time decisions and adjustments to optimize material flow and energy consumption. Robots and automated guided vehicles (AGVs) are often integrated with conveyors to facilitate material loading, unloading, and sorting. Innovations in conveyor design have also focused on sustainability and environmental impact. Conveyors are now designed to be more energy-efficient, using regenerative braking systems and variable speed drives to reduce power consumption. Additionally, conveyor components are being manufactured using eco-friendly materials, and recycling initiatives are being implemented to minimize waste [17].

In conclusion, the evolution of mechanical conveyors has been pivotal in transforming industrial processes, enhancing material handling efficiency, and contributing to increased productivity and safety. From their origins in ancient civilizations to their present-day integration with cutting-edge automation, conveyors have continuously advanced to meet the evolving needs of various industries. Innovations such as modular systems, smart technologies, and energy-efficient designs have made conveyors more adaptable, cost-effective, and environmentally sustainable. As industries continue to embrace automation and sustainability, the future of mechanical conveyors promises even greater efficiency, further optimizing material flow and reducing environmental impact. The ongoing advancements in conveyor systems underscore their vital role in shaping the future of industrial operations.

#### Design Considerations:

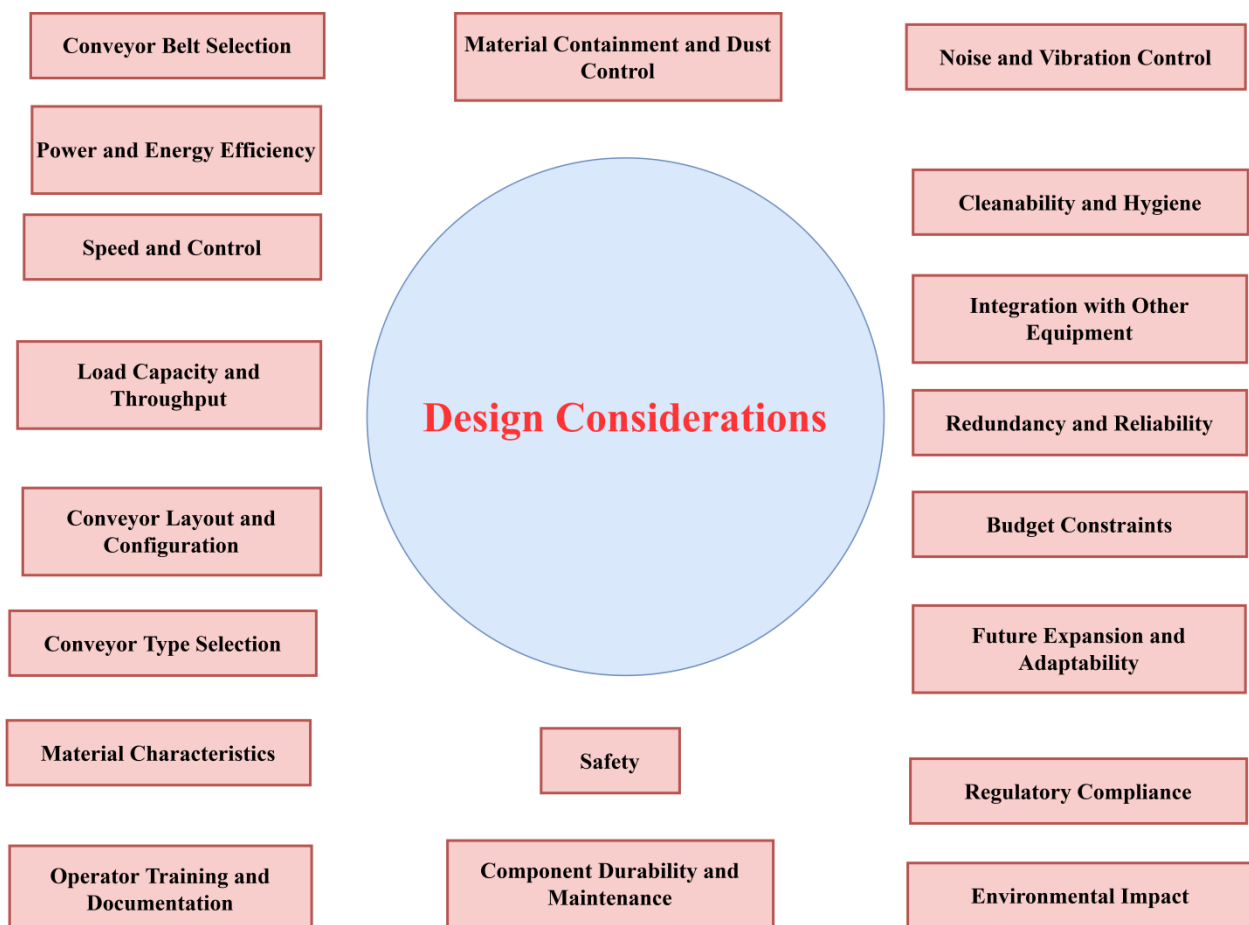


Figure 6 : Design Considerations of mechanical conveyor systems

Designing mechanical conveyor systems necessitates considerations on various factors including material properties, environmental conditions, operational requirements, and economic constraints. Selecting appropriate conveyor types, materials, and configurations are critical in ensuring operational efficiency and longevity. Designing a mechanical conveyor system is a complex and critical process that requires careful consideration of numerous factors to ensure optimal performance, efficiency, and safety as shown in figure 6. From the choice of conveyor type to the selection of materials and components, each decision plays a significant role in determining the conveyor's effectiveness for its intended application. In this comprehensive exploration, we will delve into the key design considerations of mechanical conveyors, shedding light on the essential aspects that engineers and designers must take into account [11,25,26].

**Material Characteristics:** One of the foremost considerations in conveyor design is the nature of the materials to be transported. The material's properties, such as size, weight, shape, abrasiveness, temperature, and moisture content, dictate the type of conveyor best suited for the task. For example, abrasive materials may require conveyor components made of wear-resistant materials, while high-temperature materials necessitate heat-resistant conveyor systems.

**Conveyor Type Selection :** Choosing the appropriate conveyor type is a fundamental design decision. Common types include belt conveyors, roller conveyors, screw conveyors, chain conveyors, and overhead conveyors, each with distinct advantages and limitations. The selection should align with the material handling requirements, space constraints, and desired throughput of the application.

**Conveyor Layout and Configuration:** The layout of the conveyor system should be designed to optimize material flow and space utilization. Factors like the path of travel, elevation changes, merging and diverging of material streams, and accessibility for maintenance must be carefully considered. Additionally, designers should account for any potential bottlenecks or congestion points in the layout.

**Load Capacity and Throughput:** Determining the conveyor's load capacity and throughput requirements is essential to avoid overloading and ensure efficient material transport. Factors such as the size and weight of materials, the desired flow rate, and peak loading conditions must be considered during the design phase.

**Speed and Control :** Conveyor speed plays a critical role in material handling processes. Designers must strike a balance between maximizing throughput and maintaining safe and controlled material flow. Advanced control systems, such as variable frequency drives (VFDs) and programmable logic controllers (PLCs), allow for precise speed control and automation, enhancing conveyor performance.

**Safety:** Ensuring the safety of operators and maintenance personnel is paramount in conveyor design. Guarding, emergency stop systems and anti-derailment mechanisms should be incorporated to minimize the risk of accidents. Additionally, conveyor systems should comply with relevant safety standards and regulations.

**Material Containment and Dust Control:** In applications where materials may spill or generate dust, designers should implement containment measures and dust collection systems to maintain a clean and safe working environment. Proper sealing, hoods, and ventilation are critical considerations.

**Conveyor Belt Selection:** For belt conveyors, selecting the appropriate conveyor belt is crucial. Factors like belt material, carcass type, surface texture, and thickness should be chosen based on material properties, operating conditions, and wear resistance requirements [4]

**Component Durability and Maintenance:** The durability and maintenance requirements of conveyor components, such as rollers, pulleys, bearings, and chains, are vital considerations. Components should be selected for their resistance to wear, corrosion, and fatigue, as well as ease of maintenance and replacement.

**Environmental Conditions:** Conveyor systems may operate in a variety of environmental conditions, including temperature extremes, humidity, and exposure to chemicals or corrosive materials. Designers must select materials and coatings that can withstand these conditions to ensure long-term reliability.

**Power and Energy Efficiency:** The energy consumption of a conveyor system is a significant cost consideration. Designers should optimize the drive system's power requirements, incorporate energy-efficient motors and variable speed drives, and implement regenerative braking systems where applicable.

**Noise and Vibration Control:** Excessive noise and vibration can be disruptive and potentially harmful. Designers should consider measures such as vibration isolation, damping materials, and noise-reducing conveyor components to minimize the impact on workers and equipment.

**Cleanability and Hygiene:** In industries like food processing and pharmaceuticals, conveyors must adhere to strict cleanliness and hygiene standards. Conveyor design should facilitate easy cleaning, with features like open frameworks, removable components, and sanitary conveyor belts.

**Integration with Other Equipment:** Conveyor systems often interface with other equipment, such as packaging machinery, sorters, and robotic systems. Designers must ensure seamless integration by coordinating conveyor specifications with the requirements of adjacent equipment.

**Redundancy and Reliability:** In critical applications where downtime is costly, redundancy and reliability are paramount. Designers can incorporate redundant drive systems, backup conveyors, and robust maintenance plans to minimize disruptions.

**Budget Constraints:** Designers must work within budget constraints while aiming to achieve the desired conveyor performance. Careful cost-benefit analysis should guide decisions regarding materials, components, and automation features.

**Future Expansion and Adaptability:** Consideration should be given to the potential for future expansion or modifications of the conveyor system. Designers can incorporate flexibility into the system to accommodate changes in production volume or product types.

**Regulatory Compliance:** Compliance with industry-specific regulations and standards is essential. Designers should be aware of relevant guidelines, codes, and safety standards and ensure that the conveyor system adheres to them.

**Operator Training and Documentation:** Once the conveyor system is designed and installed, operators must be trained to operate and maintain it safely and efficiently. Comprehensive documentation, including operation manuals and maintenance procedures, should be provided.

## **Applications:**

### **Manufacturing:**

In manufacturing, mechanical conveyors play a pivotal role in enhancing efficiency, streamlining production processes, and ensuring the seamless flow of materials throughout various stages of manufacturing. These versatile and reliable systems find wide-ranging applications across different industries, each tailored to specific production needs. One of the primary applications of mechanical conveyors in manufacturing is the transportation of raw materials to production lines. Whether it's the delivery of bulk materials like grains, plastics, or metals, or the precise handling of small components and parts, conveyors efficiently transfer materials from storage or supply areas to where they are needed in the manufacturing process. This not only reduces manual labor but also minimizes the risk of material contamination or damage, critical in industries like food processing, automotive, and electronics manufacturing. Manufacturing processes often involve intricate assembly lines where conveyors are integral components. Mechanical conveyors aid in the continuous movement of work-in-progress items, components, and subassemblies between workstations. In automotive manufacturing, for example, conveyors seamlessly transport vehicle bodies through various assembly stages, allowing for precision work like welding, painting, and component installation [19]. The pharmaceutical industry heavily relies on conveyors for the safe and hygienic handling of sensitive materials. Conveyors in pharmaceutical manufacturing are designed with sanitary features to meet stringent regulatory requirements. They are used for the transportation of ingredients, blending processes, tablet and capsule filling, and packaging, all while adhering to strict cleanliness and contamination control standards. Another critical application lies in the realm of logistics and warehousing within manufacturing facilities. Conveyors

assist in the efficient sorting, storage, and distribution of finished products, ensuring timely delivery to customers or subsequent manufacturing stages. Automated conveyor systems in distribution centers have become indispensable for industries ranging from e-commerce to consumer goods manufacturing, helping streamline order fulfillment and reduce lead times. In the context of lean manufacturing principles, conveyors enable just-in-time (JIT) production, reducing inventory levels and associated carrying costs. JIT manufacturing relies on precise coordination, and conveyors are instrumental in synchronizing material movement to match production demand. This minimizes waste, lowers storage expenses, and increases overall operational efficiency. Furthermore, mechanical conveyors have applications in specialized manufacturing processes. In the semiconductor industry, conveyors are used in cleanroom environments to transport delicate components, wafers, and microelectronics, minimizing the risk of contamination. In the textile industry, conveyors assist in the handling of fabrics, textiles, and garments throughout the production, dyeing, and finishing processes [5].

### **Food Processing:**

In the realm of food processing, mechanical conveyors are indispensable tools that ensure the safe, efficient, and hygienic handling of a wide range of food products throughout various stages of production. These specialized conveyor systems are tailored to meet the stringent requirements of the food industry, playing a critical role in maintaining product integrity, quality, and safety. One of the primary applications of mechanical conveyors in food processing is the transportation of raw ingredients and materials. From the delivery of bulk grains, fruits, vegetables, and meats to the precise movement of delicate food components, conveyors enable the seamless transfer of these materials from receiving areas to processing units. This reduces the need for manual handling, which can introduce contamination risks, and ensures consistent material flow into production processes. Conveyors are essential in the sorting and inspection of food products. Automated conveyor systems transport fruits, vegetables, and packaged goods through inspection stations equipped with sensors and cameras to detect defects, foreign objects, or irregularities. This real-time quality control ensures that only safe and high-quality products proceed through the processing line, minimizing the risk of subpar or contaminated items reaching consumers. Within food processing facilities, conveyors are integral to the various stages of food production. They facilitate the movement of products through washing, peeling, cutting, cooking, and packaging processes. For example, in the meat processing industry, conveyors are used to transport cuts of meat to cooking or packaging stations, maintaining a consistent and controlled flow of product. Hygiene is paramount in food processing, and conveyors are designed to meet strict sanitary standards. They are often equipped with features like easy-to-clean stainless steel surfaces, removable components, and hygienic belting materials that resist bacterial growth. In environments where cleanliness is paramount, such as meat processing and dairy production, these features are essential. In the packaging phase, conveyors play a pivotal role in efficiently moving packaged food products to labeling, weighing, and sealing machines. Automated packaging lines benefit from the continuous and synchronized movement provided by conveyors, allowing for precise filling, sealing, and labeling processes. This is particularly important in industries like snack foods, beverages, and frozen foods. Conveyors also contribute to food safety by enabling the rapid cooling and freezing of perishable products. Spiral conveyors and blast freezers efficiently move food items through temperature-controlled environments, reducing the risk of bacterial growth and ensuring food products meet safety standards while maintaining their quality and taste. Moreover, in the bakery and confectionery industry, conveyors are utilized for dough handling, baking, cooling, and packaging. These systems are designed to handle various dough consistencies, ensuring the precise shaping and baking of bread, cookies, pastries, and other baked goods. In the context of ready-to-eat and convenience foods, mechanical conveyors are instrumental in the assembly and packaging of meal components. Conveyor systems transport individual food items, such as sandwiches, salads, and snack packs, through assembly stations, where they are arranged, sealed, and prepared for distribution to consumers [28,29].

### **Mining:**

In the mining industry, mechanical conveyors are indispensable tools that serve a multitude of critical functions, facilitating the extraction, transportation, and processing of valuable minerals and materials from mines and quarries. These robust and versatile conveyor systems play a pivotal role in improving operational efficiency, reducing manual labor, and enhancing safety in mining operations. One of the primary applications of mechanical conveyors in mining is the transport of bulk materials. Conveyor belts, for

instance, are commonly used to move large volumes of minerals, ores, coal, gravel, and other mined materials from the extraction point to processing and storage facilities. These conveyors are engineered to handle heavy loads over long distances, ensuring a continuous and reliable flow of materials, even in challenging terrains and adverse weather conditions. Within mining operations, mechanical conveyors also contribute to material sorting and processing. They are utilized to transport raw ores and minerals to crushers, screens, and separation equipment. For instance, in open-pit mining, conveyors transport excavated materials to crushing stations, where they are reduced in size for further processing. This process streamlines the material handling process and minimizes the need for manual intervention[1,28]. Conveyors are instrumental in conveying mined materials from underground mining operations to the surface. In underground mining, where access is restricted and hazardous conditions prevail, conveyors provide a safer and more efficient means of material transportation compared to traditional haulage methods, such as trucks or railcars. They navigate through narrow tunnels and steep inclines, ensuring the timely delivery of ore to processing facilities. Moreover, mechanical conveyors are vital in the processing and refining of minerals. Conveyors transport materials to crushers, mills, and beneficiation plants, where minerals are extracted, refined, and prepared for further use or distribution. These conveyors are equipped with specialized components to withstand the abrasive and corrosive nature of mined materials, ensuring long-term reliability. Safety is a paramount concern in mining, and conveyors play a crucial role in enhancing worker safety. They reduce the need for manual material handling and minimize the risk of injuries associated with heavy lifting and transportation. Conveyor systems can also be equipped with safety features, such as emergency stop switches and anti-rollback mechanisms, to prevent accidents and protect personnel. Conveyors assist in material stockpiling and storage, a critical aspect of mining operations. Overland conveyors are often used to transport mined materials to storage areas or to create stockpiles for future use. These stockpiles help manage fluctuations in demand and provide a buffer for uninterrupted production. Additionally, mechanical conveyors are employed in the transportation of waste materials and tailings away from mining sites. In environmentally sensitive mining operations, conveyors are used to transport waste materials, reducing the environmental impact and potential contamination of surrounding areas [2,5, 28].

### **Warehousing:**

In the context of warehousing, mechanical conveyors are essential tools that streamline the storage, retrieval, and distribution of goods within large storage facilities, such as distribution centers, logistics hubs, and fulfillment centers. These versatile conveyor systems play a pivotal role in enhancing operational efficiency, reducing manual labor, and improving inventory management in warehousing operations. One of the primary applications of mechanical conveyors in warehousing is the movement of goods from receiving areas to storage locations. Conveyors efficiently transport incoming shipments, whether they are palletized goods, cartons, or individual items, from loading docks to storage racks. This reduces the need for manual handling and expedites the process of bringing inventory into the warehouse. Conveyors are instrumental in optimizing the storage of goods within the warehouse. Automated storage and retrieval systems (AS/RS) often incorporate conveyors to transport items to and from storage locations. These systems efficiently utilize vertical space by stacking pallets or bins in high-density storage configurations, allowing for increased storage capacity while minimizing the footprint of the warehouse. In the context of order fulfillment, conveyors play a central role in the efficient processing of customer orders. They transport items from storage areas to picking stations, where workers or automated systems can quickly assemble orders. Conveyors synchronize the flow of items, ensuring that the right products are available for picking and subsequent packing, reducing order processing times and increasing accuracy. Moreover, conveyors contribute to the efficient loading of outbound shipments. They transport picked and packed items to loading docks, where they are loaded onto trucks and containers for distribution. The continuous flow provided by conveyors ensures that products are readily available for loading, reducing loading times and minimizing the risk of shipping errors. Safety is a paramount concern in warehousing, and conveyors help enhance worker safety. By reducing the need for manual material handling, conveyors mitigate the risk of injuries associated with heavy lifting and repetitive tasks. Additionally, safety features like emergency stop switches and protective guards are often integrated into conveyor systems to prevent accidents and protect warehouse personnel. Conveyors are also instrumental in managing returns and reverse logistics processes within warehousing. They transport returned items to designated areas for inspection, restocking, or refurbishing. This efficient handling of returns streamlines reverse logistics operations, allowing for quicker processing and reducing the impact on inventory levels [32].

### **Some practical applications of conveyor system in industry**

Amazon has revolutionized its e-commerce fulfillment process with automated conveyor systems integrated with robotics and AI, optimizing product sorting and delivery to reduce processing times and enhance efficiency in its fulfillment centers. BMW employs overhead conveyor systems in its manufacturing plants, transporting vehicle parts above the assembly floor, which improves space utilization and scalability while enhancing productivity with integrated automated tools and robots. Cargill utilizes customizable screw conveyors in its grain handling and processing operations to efficiently transport bulk materials while minimizing spillage and ensuring hygiene, thus improving throughput and product quality. In food processing, Nestlé's flexible conveyor systems allow quick reconfiguration to accommodate different product requirements, reducing downtime and enhancing production efficiency while adhering to food safety standards. Zurich Airport has implemented smart conveyor systems for baggage handling, integrating RFID technology and real-time data analytics to track and reroute luggage, reducing mishandling and improving efficiency during peak hours. In mining, Rio Tinto uses automated conveyor systems, combined with AI, autonomous trucks, and drones, to transport mined materials over long distances, improving operational efficiency, worker safety, and reducing energy consumption. Finally, Pfizer uses vacuum conveyors to handle delicate pharmaceutical powders in a contained and hygienic environment, ensuring high product quality and sterility while improving manufacturing throughput. These innovations across various industries highlight the critical role of automated conveyor systems in enhancing operational efficiency, reducing labor costs, and improving safety and product quality[7-8].

### **Sustainability and Environmental Considerations:**

The utilization of mechanical conveyors in various industrial applications is pivotal, enabling the seamless and efficient movement of materials from one point to another. When exploring the environmental and sustainability considerations of mechanical conveyors, it's imperative to assess their impacts and benefits holistically. Mechanically-driven conveyors, as opposed to pneumatically-driven ones, generally exhibit lower energy consumption, hence mitigating the overall carbon footprint. Optimizing energy efficiency is crucial, and this is often achieved through the incorporation of advanced technologies and designs, such as energy-efficient motors and optimal belt designs, reducing friction and energy loss. The material selection for conveyor components plays a vital role in determining environmental impact. Employing materials with lower embodied energy and a smaller environmental footprint, like aluminum or recycled steel, contributes to sustainability. Furthermore, many conveyors are designed to be modular and adaptable, allowing components to be reused or reconfigured, thus extending the system's life cycle and reducing waste. This modularity and adaptability are crucial in adapting to varying operational needs without necessitating the complete overhaul or replacement of systems. The production process and operation of conveyors are also underlined by considerations of noise and pollution. Manufacturers are inclined to implement designs that minimize noise pollution, reducing the overall environmental impact, and contributing to a healthier workplace. Additionally, employing closed conveyors can contain dust and particulate emissions, which is crucial in mitigating air pollution and maintaining air quality, especially in industries dealing with bulk materials. Consideration of the location and the ecosystem surrounding it is another aspect that needs attention when deploying conveyors. Proper environmental assessments ensure that the local flora and fauna are not adversely affected due to the installation and operation of the conveyor systems. Eco-sensitive design considerations like green belts and buffer zones are often integrated to preserve the local biodiversity [5,7]. Lifecycle assessment (LCA) and end-of-life management of mechanical conveyors are pivotal. The LCA involves evaluating the environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). The implementation of recycling and proper disposal methods for worn-out conveyor components is essential in reducing environmental impact and promoting sustainability [7,32].

In conclusion, the environmental and sustainability considerations of mechanical conveyors highlight their crucial role in promoting efficient and eco-friendly industrial operations. By focusing on energy efficiency, material selection, and modular designs, conveyors can significantly reduce energy consumption, waste, and carbon footprints. The integration of noise reduction, pollution control, and eco-sensitive design further contributes to minimizing environmental impacts. Lifecycle assessments and proper end-of-life management practices ensure that conveyors continue to support sustainable industrial practices throughout their lifespan.

Ultimately, these efforts help strike a balance between operational efficiency and environmental responsibility, advancing sustainability in material handling systems.

### **Challenges and Future Trends**

Mechanical conveyors, being integral components in material handling across diverse industries, face numerous challenges and are concurrently evolving due to emerging trends. A significant challenge is the consistent need for enhanced energy efficiency and reduction in operational costs. Industries are perpetually seeking innovative solutions that can decrease energy consumption, thereby reducing environmental impacts and operational expenses. Maintaining optimal functionality and reducing downtime are persistent challenges, necessitating regular maintenance and monitoring to prevent wear and tear of components like belts and rollers, which could lead to operational disruptions and losses. Another challenge is the adaptation of conveyor systems to the rapidly changing and diverse needs of different industries. The need for greater flexibility, adaptability, and scalability in conveyor designs is more pronounced than ever, with varied materials, processing requirements, and operational environments necessitating bespoke solutions[2,5]. In this context, the advent of Industry 4.0 is reshaping conveyor technologies, integrating automation, IoT, and data analytics to enhance operational efficiency, predictive maintenance, and real-time monitoring. The future trends in mechanical conveyors are prominently steered by technological advancements and sustainability considerations. There is an increasing trend towards the integration of green technologies, aiming for minimal environmental impact through the utilization of eco-friendly materials and energy-efficient designs. Advanced materials that are lightweight, durable, and sustainable are becoming a focal point in conveyor design, contributing to energy conservation and reduction in carbon emissions. Concurrently, digital transformation is another pivotal trend shaping the future of mechanical conveyors. The integration of smart technologies like sensors, automation controls, and AI enables real-time monitoring and analysis, which is crucial for predictive maintenance and operational optimization. These technologies enable conveyors to adapt to varying operational needs dynamically, optimizing energy consumption, and improving overall productivity. Moreover, the convergence of robotics and conveyor technologies is expected to drive innovations, facilitating seamless material handling, sorting, and processing, further elevating operational efficiency and precision. The escalating need for customization is pushing the development of modular and reconfigurable conveyors, allowing industries to modify and scale their conveyor systems in accordance with evolving needs [33,34].

### **Conclusion**

In conclusion, mechanical conveyor systems have evolved significantly, becoming essential in a wide range of industrial applications. From their origins with simple wooden rollers to the modern, highly automated systems in use today, conveyor technology has continuously adapted to meet the changing demands of industries worldwide. As industries embrace digitalization, automation, and sustainability, conveyors remain at the heart of innovation in material handling. The future of conveyor systems holds immense potential for further advancements. A key area of focus is optimizing control strategies for improved system stability and precision. Research into robust control methods and advanced modeling techniques could lead to more adaptable and efficient conveyor systems, capable of real-time adaptive control to adjust to changing load conditions. This would enhance reliability and reduce downtime, ensuring continuous material flow even in dynamic operational environments.

Another promising direction is enhancing the efficiency of conveyor systems, particularly in handling challenging materials. Simulation-based approaches, such as the Discrete Element Method (DEM), can optimize conveyor design and provide insights into system performance under varying environmental conditions. Integrating real-time monitoring and sensor technologies will also enable operators to make immediate adjustments, improving system performance and preventing inefficiencies. Sustainability remains a key consideration for future conveyor developments. The creation of self-powered conveyor systems, utilizing technologies like turboelectric sensors or electromagnetic generators, could reduce energy consumption and operational costs, especially in remote or off-grid locations. Additionally, advancements in specialized conveyors for bulk material handling, such as those designed for steep inclinations, will further expand the versatility of conveyor systems in industries like mining and manufacturing. Incorporating machine learning and artificial intelligence will revolutionize maintenance practices, enabling predictive maintenance and real-time issue detection, extending system lifespans, and reducing costs. As these

technologies continue to evolve, conveyor systems will become smarter, more efficient, and more sustainable, optimizing material handling, reducing costs, and contributing to the advancement of industrial processes.

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