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Chapter 5: Autonomous logistics and intelligent material flow in large-scale manufacturing facilities

5.1. Introduction

The emergence of Cyber-Physical Systems (CPS) promises updates to the functionalities of large-scale manufacturing facilities. Herein, changes in equipment, transport, and communication capabilities will give rise to further automation and self-organization of the respective production processes and flows. Benefits will be found in high-level equipment and transport, as well as the connection to higher-level systems. Together with the integration of logistics and production, these developments will deliver greater responsiveness and efficiency to these facilities (Oliveira et al., 2021; Keung et al., 2023; Pop, 2024).

Within this chapter, we specifically address logistics at the transport and flow level. When discussing transport to- and inside-workstations, we are particularly interested in Automated and Autonomous Guided Vehicles for the transport of pallets and racks. Recent developments allow the expansion of these systems far beyond traditional subsystems for storage and feeding with bulk-materials. The increased collaboration of transport and non-logistic equipment in the above take place at a very low cost should also be highlighted. As for transport systems, we focus on new approaches to unload and load AGVs. This aspect is key to reducing the granularity of the directed flow of items and addresses the so-called high-event problem: The incapacity of large-scale production systems to deliver a simultaneous number of pieces larger than the number of workstations. Additionally, we consider the problem of automatic recognition of items entering the logistic processes and respective storage, particularly in the context of Heavy Load Logistics. Herein, automatic video recognition and reservation in the areas are finding increasing interest as well as parallelization of logistics and production processes (Törngren et al., 2021; Zhang et al., 2022).

5.2. Overview of Autonomous Logistics

Logistics involves the transport and storage of resources at different manufacturing lifecycle stages. The substantiating goal of production logistics is to ensure a smooth flow of physical inputs and outputs on the shopfloor.

Fig 1 : Overview of Autonomous Logistics

Essentially, this translates into appropriate material flow conditions, i.e., ensuring that the required materials are available at the required locations and in the right quantities at the right point in time. This means the differentiation of logistics branches into many specific logistics variants, for instance, sales logistics, patient logistics, after-sales support logistics, and others, indicating the substantial economic importance of logistics activities. The logistics field has evolved into a new discipline of its own, and to understand the rationale behind the terms. Using the terms "autonomous" or "intelligent" in this context, we briefly elaborate on the terms.

The term "autonomous system" can mean anything in between fully human-controlled and remotely operated and fully machine-controlled. While this offers some freedom of interpretation, we wish for a more specific and operational definition, containing only few requirements. First, such systems typically not only accomplish many tasks within a specified domain but also do so without any human involvement. This is the ultimate goal set by enabling fully unattended operation for any domain and for any combination of functioning intelligence components. In this sense, autonomous systems are characterized by both their operational domain and by not requiring human guidance.

5.2.1. Definition and Importance

The industrial world is moving quickly toward the autonomous operation of its production facilities. Approach to achieve this outcome aims to autonomously undertake the logistics tasks performed in factories. In this context, the field of autonomous logistics, at the crossroads of logistics and autonomy, forms a critical part of the industry 4.0 concept that includes such paradigms as predictive maintenance, digital twin, smart factory, big data, cyber-physical systems, distributed intelligence, control tower, etc. The aim of this chapter is to provide a formal definition of the autonomous logistics discipline, as well as its applications in large-scale manufacturing environments. The main research issues and open problems requiring future work will be stated. Within this context, autonomy is defined as the ability to perform tasks without relying on humans or other agents in the environment to monitor or direct actions. Such capabilities are an important step toward augmenting human capabilities in the workplace, freeing humans of tasks that can be successfully accomplished by machines, as long as such tasks are not too random, require situational awareness, learning from experience or social interaction. In this way, autonomy is a natural way to grow the level of automation in humans' environments around the globe reducing the influence of errors due to humans, such as variability decrease, risk assessment and scheduling.

Indeed, all of the deskilled and poor contrast tasks that any other agent can perform are the logical way today to develop smarter factories. In this perspective, the logical way to improve manufacturing is to provide automated systems with the capability to perform their main tasks without constant supervision. So, in this vision toward autonomous logistics, the work of intelligence is to improve the behavior of automated agent, helping them to decide the best action to undertake in time. The autonomous factory would also be able to optimize production scheduling by evaluating variability, risk, and productivity, giving the responsibility to machines of routing products and of all transfer activities between the different cells composing the factory.

5.2.2. Historical Context

Since antiquity, humans have searched for ways to make our burden carry out to make our existence easier. For early humans, it was necessary to tame animals and employ them to carry loads. In the twenty-first century, technological progress allows us to conceive and develop robots in advanced and autonomous systems capable of performing these functions through the use of various sensors and algorithms for detecting and avoiding obstacles. This was possible thanks to technological advances such as miniaturization, optimization of the motors, miniaturized electronic controllers, navigation and sensor systems, laser-ranging sensors, sensors by vision and artificial intelligence. These systems have become a practical reality and used in factories, hospitals, commerce, houses, etc. The self-guided systems became a standard in the industry through the work of several manufacturers and later by the implementation of systems called Automated Guided Vehicles (AGV) that modify the environment of the factory. This serves for material handling, generally for fragile components in assembly lines. In the offices that support the operations of production systems, the bulk document manipulation had been benefited by the systems to supply papers for printers and faxes, among others. These have also reached the community becoming a valuable tool in collective systems of people transport. For everything mentioned previously, it is desirable to develop autonomous systems in the assembly and disassembly lines of any type of components.

5.2.3. Current Trends

In recent years, there has been a shift towards adopting autonomous logistics to improve supply chain competitiveness, especially with the rise of digitalization. Extended and distributed production, as well as a new network structure across borders, regions, and industries, has created a need for just-in-time delivery, open communication channels, and quick response to higher volatility demands. It is expected that by 2025, a significant percentage of plants will be integrated in a digital ecosystem, with a portion adopting a fully connected and engaged digital ecosystem to implement advanced or autonomic logistics management and create significant savings, the majority with AI applications. Such digital twins are a value creation which creates real-time visibility. These new digital models have built simulations that help visualize events and measure costs. The integrated and real-time visibility of products and resources as well as manufacturing processes are real core advantages that AI allows and that are mandatory for autonomic logistics. As a foundation, these digital twins are connected with equipment providing performance and status data and with their surrounding system environment.

On the shop floor, advanced technologies are supporting this development, such as connected sensors and cloud platforms that are allowing real-time factory operations. Digital twins share necessary information and allow the establishment of react and proactive processes, required for the implementation of AI logic processes. Interfacing with vendors, customers, and logistics providers and their ordering and status information allows realizing new levels of autonomous logistics implementation in the supply chain. Together with autonomous vehicles, an increased level of structure becomes apparent from smart factories to smart highways and smart cities. Cybersecurity is a main challenge of these new digital structures because the significance of autonomic processes relies on the transition towards external service providers.

5.3. Intelligent Material Flow Systems

Intelligent material flow systems represent a specific connection bridge between autonomous, intelligent transport and logistic devices and manufacturing or corporate information systems. Autonomous logistic systems, incorporated in advanced workplace and corporate business processes, constitute important productivity growth factors. Using autonomous unit handling or transport systems, owning distinct intelligent features, in the material flow and internal product transport areas should provide manufacturing facilities with a needed competitiveness superiority. Intelligent material flow systems can function using logistic and transport devices with different technical features, like mobile robots equipped with various end-effector tools, such as grippers, vacuum systems, robotic manipulators; automatic fork-lift trucks; automatic vehicles; AGVs; lactating technologies using technological equipment of varying complexity; virtual units of distinct logistic or transport features, for example, in a multi-agent environment.

Realization of scheduled transport operations inside large-scale logistic environments will be fulfilled upon special task scheduling tables, written earlier in the material flow system creation phase. Tables are based on products and routing parameters. For products of various structure but from similar or identical material are transported to different or identical routings can be executed or realized with dissimilar transport devices equipped with different tools. Intelligent material flow system operation efficiency depends on both hardware and software means that compose the system, reducing to the utmost extent the use of resources with maximum use of capacity potential both in routine and transport systems or devices. Therefore, designing is started from scheduling algorithms creation that will base the operation process control system for task collecting, distributing described earlier. The algorithm structure assumes a centralized flow of information on scheduled transport activity and transferring necessary data for solving transport tasks.

5.3.1. Conceptual Framework

Intelligent Material Flow Systems as a subclass of Material Flow Systems are defined and discussed together with examples. Selecting a two-dimensional ordering principle, it is shown that higher automation degrees and higher information degrees are all contained in the class of intelligent material flow systems. Furthermore, the contradiction "Intelligent versus Autonomous" is discussed, and it is shown that Intelligent Material Flow Systems, because of the additional information processing layer, allow for higher degrees of autonomy than classical Autonomous Material Flow Systems. Presenting the IMaFS-Levels Notation, a method for the formal representation of Material Flow Systems is presented, the use of which is shown with practical examples. "We can have intelligent Material Flow Systems, but they can be even more intelligent with a degree of autonomy.

Thinking about the future of manufacturing and of Material Flow Systems in existence or structures to be built, the question comes to mind: What do we want to achieve? What will intelligent Manufacturing mean? It is said that intelligent Manufacturing will mean to have machines that operate without human interaction. Such systems will be autonomous and will have a high degree of autonomy. But do we want actual structures of manufacturing and Storage to become autonomous? Do we really want, for example, that an Autonomous Storage System operates on its own? From the experiences we make with our existing Autonomous Storage Systems, it seems, in many cases, that the interaction with the surrounding environment cannot be neglected. Even a very well operating Autonomous Retrieval System will need information from outside like "What do I have to do? When do I have to do the action? When do I have to do it?" to be fully productive. Should systems be built that are more autonomous than our existing autonomous systems?

5.3.2. Components of Intelligent Systems

Modern complex industrial systems require long-range horizons, a high degree of automation, and intelligent on-line decision making and flexibility. An intelligent system must have a variety of entity features that enable it to perceive its own and its environment states, to have a reliable decision making capability, and to execute its decisions within a variety of time constraints. These entities perform special tasks in coordination with other entities and general systems. Each intelligent system, and usually its components, has a special organizational structure; but they also can be implemented as a distributed system. Intelligent Control Systems, Hierarchical Intelligent Control Systems, and Intelligent Mixed Control Systems can be identified. The intelligent material flow system integrates the functions of storage, transportation, and processing of materials in a large-scale flexible manufacturing facility. Various advanced algorithms and supervisory control functions enable the planning and control of the manufacturing operation. Identifying the intelligent control system architecture is the first step. It is a hierarchy defined by the scope and the time scale. The intelligent material flow system itself is also a specially defined work within the intelligent factory, and it is usually implemented as a distributed system with on-line decision making capability.

5.3.3. Integration with Existing Systems

The concept of intelligent IMFS involves the development of new robotized technology-based systems, as well as the integration of existing ones. The latter can have a scope problem – what part of the IMFS we want to be intelligent? It may happen that a second category of existing systems does not obey the same transition gap dictated by various concepts: artificial intelligence, soft systems, intelligent behavior, information, and knowledge. Each application will indeed have to develop a transition roadmap indicating how to intelligently evolve the existing systems.

All the industrial robots that are not used in cells were originally developed for specific tasks. Their programming is preferably off line or teaching, both unsuitable for the applications because of the high inaccuracies of the robot controller. They brake during work, when the material flow speed is higher than the transfer speed of the manipulator. Originally, these robots had limiters on the rise of the torque which made the attachment safety devices unusable. These robots, when put back in use with functional improvement, can serve various tasks for various tool mounting, as well as eventually be mounted in various points of the plant and, at the end of their life time, be adapted again to the original cell or another cell. The introduction of innovations will serve a short industrial life of these infrastructures. The more expensive the old manipulators are, the more delays will arise, which will limit the possible applications of these systems.

5.4. Technologies Enabling Autonomous Logistics

The advancement of autonomous logistics from concept to reality is largely dependent on the wide acceptance of robotics, especially mobile and collaborative robots. With increasing capabilities, lower costs, ease and safety of use in human-centric environments, robots are being increasingly accepted in roles traditionally carried out by human labor. These include ordering, transport, storage, assembly, handling, picking, placement, service, and supply of materials. Therefore, robotic applications in warehouses, distribution centers and factories to assist or automate logistic tasks have been popular in recent years and will continue to grow in the future. Mobile Autonomous Robots, including Automated Guided Vehicles, Automated Mobile Robots, drones and Unmanned Ground or Aerial Vehicles, are becoming increasingly autonomous and are therefore able to carry out tasks that previously required human assistance or oversight. These robots have improved abilities, including autonomy, collaboration, flexibility, reliability, safety, intelligence, navigation, perception, security, sensing, and transport efficiency.

Mobile and collaborative robots are combined with suitably designed electronic and information technologies such as middleware, battery technology, devices, connectivity, identification, localization, communications, real-time data management, security, telemetry, and simulation. Applications in logistics, including transport, storage, and material management, support the efficient, flexible, and safe movement of goods, components, materials, and finished products around the factory as well as between the factory and external suppliers and customers. Co-pilots and collaborative robots work alongside people to assist with dangerous, strenuous or repetitive logistic tasks, particularly in challenging indoor or outdoor environments, including healthcare, hospitality, manufacturing, and warehousing. Robotic mobile manipulators mounted on Mobile Autonomous Robots or service robots, supplemented with effective grippers or end-effectors, are flexible, adaptable and smart tools that efficiently carry out specialized logistical tasks in factories or other environments.

5.4.1. Robotics and Automation

The rise of advanced automation technologies, especially robotics, allows for new concepts of automated logistics. Autonomous guided vehicles (AGVs), applied for several decades to transport materials in factories, have evolved from being driven by wires, magnets, or lasers to navigation using built-in cameras and artificial intelligence, allowing them to operate more flexibly at lower cost and at higher safety levels. An advanced concept of automated logistics is allowing mobile collaborative robots (cobots) and AGVs to cooperate in warehouses and shops to pick, carry, and deliver physical goods. While cobots are becoming commonly used for material-handling operations, AGVs, however, are still applied only for non-physical goods.

To make robots more autonomous, they are equipped with adequate sensors, cameras, and advanced AI algorithms supporting perception functions and decision-making processes. It can be expected that in-plant transport logistics will be largely automated in the next decade. Robots will be able to efficiently deliver to a shop or a cell varying numbers of units, especially shelf-ready containers or trays with subassemblies and parts. Automated under-manned shops will use robots for relief of workers in carrying manufacturing operations. The role of a logistician will mostly be performing material flow control tasks, especially adjusting time schedules for supply and distribution of components and products.

5.4.2. Artificial Intelligence Applications

Artificial intelligence (AI), and in particular its branch deep learning, has achieved significant success in implementing computational systems capable of human-supervised and human-augmented capabilities such as visual perception, speech recognition, natural language, and text generation; as well as in-game scenarios. Those capabilities enable the automation of a large number of tasks currently done by human agents in a variety of application domains. For instance, visual perception can enable the automation of assembly operations currently performed by workers in high-mix, low-volume manufacturing environments. On the other hand, natural language and text generation can enable interfaces masking the complexity levels of the advanced systems presently used by many companies in logistics planning and operations, ideally increasing the accessibility of those systems.

Beyond that, AI techniques, like reinforcement learning and deep reinforcement learning, can be applied to train and optimize the behaviors and decision-making loops of the many robotic and automation solutions available at the base of the autonomous logistics ecosystem. These capabilities include, but are not restricted to, path and trajectory planning for both mobile and manipulation robots; mission planning, dispatching, and execution monitoring of mobile and manipulation robots and automation systems, optimization and flexible operation of manufacturing and logistics systems, among many others. Due to the unpredictable nature of manufacturing and logistics requirements throughout the day, week, and year, these robotics and automation systems need to be capable of adjusting their behavior, and that is the role of decision-making and planning systems utilizing AI and, in particular, machine learning and deep learning algorithms that learn and adapt from the real-world situation and context. These systems need to be operated in a mission mode aimed at logistics excellence.

5.4.3. Internet of Things (IoT) in Logistics

Indeed, there is a growing focus on the innovative applications of new technologies in Logistics and Manufacturing. Advanced technologies are being applied to Logistics and Manufacturing, to enhance capabilities, accelerate Development, and optimize supply chain networks. Internet of Things (IoT) is playing a major role in Logistics and Manufacturing rate of disruption and is already having profound effects on Logistics and Manufacturing, increasing visibility in product flows, and having a significant ramification for efficient use of space and reduction in warehousing times. The total investment for Smart Supply Chain Technologies in the Americas is projected to be significant by 2025. With such investments, the transformational and disruptive role of IoT technologies will only increase.

Efficient Logistics streamlining and Optimization relies on LMIS providing proper access to and sharing of total demand and process resource and component supply. Such information must be constantly updated in real-time to be meaningful. Proper audit trails of all material flow processes taking place in the Logistics System are also necessary, so that inconsistencies can be detected and rectified. This implies that LMIS must constantly check the actual status of processes (in-process inventory levels) and resources (required capacities) in systems, subsystems, and/or components against currently expected levels. RFID technology plays an essential role in constantly tracking in-process inventories of components required to fulfill customer demand, in systems, subsystems, and/or components, at the intelligent, material handling, routing, and control functions, orchestrated by the LMIS.

5.5. Benefits of Autonomous Logistics

Logistics plays a key role in the manufacturing process, as it is the flow channel of different products in each production step. Current logistic systems in manufacturing are not efficient enough due to their high cost associated with an increased number of operators, as well as potential causes of down-times. Thus, logistics also contributes to increase the cost associated with the entire factory. Autonomous logistics can significantly help to decrease the overall cost of a manufacturing system. With regards to costs, autonomous logistics is a competitive solution because automated guided vehicles are generally less expensive in terms of long-term operational costs than human operators. Autonomous logistics also contributes to efficiently manage material flow and minimize logistics down-times caused by human fatigue, availability, and safety restrictions. This is crucial, especially in mass manufacturing processes that may require 24-hour operation. Additionally, autonomous logistics allows to overcome the recent shortage of manual labor, particularly in developing countries.

During the last two decades, rapid and dramatic technology development pushed forward the implementation of SA and FA, making autonomous logistics the preferred alternative in different sectors, primarily material handling operations. Research and industrial implementation of autonomous logistics has shown that it can bring substantial benefits. Indeed, the impact that autonomous logistics may have on the overall system efficiency is one of the most significant in a manufacturing system. Essentially, automation of logistic processes contributes to increased efficiency because the time consumed to perform logistics operations is lower than the one associated with different human activities. Furthermore, it has direct implications on production activities by minimization of material flow lead times, thus contributing to better overall coordination and optimization of the entire production process. Another benefit of autonomous logistics is associated with safety considerations. Automation contributes to eliminate the duration, frequency, and severity of accidents in the logistics cell.

5.5.1. Cost Reduction

Logistics is and will remain a major cost factor in any manufacturing business. Systematic cost reduction in logistics systems is therefore a major motivation resulting in efforts to automate logistics tasks, including autonomous logistics systems. Potential contributors to cost reduction are the increased flexibility of the automated systems versus more traditional fixed systems, enabling to shift the extent of the logistical function to the counterpart in the supply chain. This way, inventories are reduced on the manufacturing side, resulting in reduced working capital. Some of the logistics tasks and their automation are partly driven by easy to achieve risk reductions. Computerized management systems for production logistics create the potential for increasing the forecasting accuracy of logistical processes and the coordination of its different phases, flagging exceptions and taking care of them in a predefined way, such as manufacturing cycle disruptions or order delays stemming from the supply side of the chain. In addition, manufacturing scheduling and production control is enabled to focus on decision nodes and boundary conditions that are critical for the success of the physical product flow, increasing the success rate of the logistical operations. Other cost reduction potentials stem from increased efficiency in the performance, such as reduced cycle times encompassing task scheduling and load transfer, lower transfer cost per unit of transported loads, reduced level of waiting times, or increased accuracy rates resulting in fewer losses from product damages.

Some logistical tasks are faster, more reliable, and more accurate with the help of machines than when performed by humans. Others can be automated in a more economical way if a certain level of Takt time steadiness can be guaranteed. Despite the seemingly high initial investments in technology for time and operational cost duration, autonomous logistics systems contribute to time reductions on the same level that were so far obtained through advanced manufacturing technologies. This way, total time and operational time, the duration of manufacturing, such as those for plant set-up or shut-down can be reduced, contributing to direct labor reductions during manufacturing execution. Consequently, product costs and contribution margins can be reduced. This reduction in production costs can be used to gain market shares through price weakening, supporting the company’s reaction in case of a sudden demand slump as experienced due to the current economic situation.

5.5.2. Increased Efficiency

Large manufacturing facilities, such as factories, distribution areas, and large retail stores, are very expansive. In order to have an optimal material flow that enables the facility to run as efficiently as possible, inventory, in particular raw material and finished products, need to be kept in strategic locations. However, limiting the amount of raw material and finished products stored within these facilities, in favor of streamlined material flow, requires intelligent replenishment and dispatching systems that allow for proper scheduling of incoming raw material transports and outgoing product orders. If either of these elements is overlooked, inadequate stock levels required for operation are created. This results in inefficiencies, which negate the benefits and strengths of a high-throughput integrated system.

Cost and delays attributed to the overhead of transporting material and products cannot be removed from the equation. However, they can be significantly reduced through planning such transports based on the requirements of the system. Autonomous mobile robots, equipped with AI technology, can play a critical role in this regard. These intelligent mobile robots can be programmed with power management systems that allow them to recharge, and resume operations when the requirement for transport has been eliminated. Furthermore, they can be outfitted with flexible loading and unloading systems that enable them to automatically respond to fluctuations in demand. Together these complementary software and hardware components allow autonomous mobile robots to operate without the highly skilled human laborers needed to support normal manual operations within a facility. By filling these gaps in operations, productivity of both the facility operating at peak capacity and the human workers undertaking other operations is optimized. More importantly, the introduction of autonomous mobile robots requires initial or ongoing investments in labor for supervision, maintenance, and key support operations. Labor investment for these robots in many low-margin industries is widely seen as a cost prohibitive factor.

5.5.3. Enhanced Safety

Even before the pandemic, physical safety in the workplace was a matter of much discussion, and unfortunately due to the widespread rise of incidents, it is a concept that could no longer be taken for granted. The measures that companies were driven to take included the reduction of physical contact between people while working, and if possible the substitution of humans from boring and dangerous positions. Due to these abusive demands, globalization, which was once seen as a lever of development, became reversed, generating a completely different problem that put safety at the edge of risk. Autonomous logistics can play an important role in alleviating this situation. The proliferation of work and social safety standards to which industries are subjected can now be understood in the broader picture of the business being part of the local people. This aspect has not been well understood yet, and it is for sure that upon the introduction of autonomous technologies in all processes of a manufacturing facility, both effective incident reduction and tangible business benefits will occur.

The introduction of autonomous logistics in manufacturing is not aimed at removing jobs from the local workforce, but engaging that workforce in more qualified and productive tasks while minimizing the risks relevant to safety of work events. Encumbrance and dangers introduced by carrying materials and components, typical of work-related accidents, can largely be absorbed by autonomous logistics. Any work station can have its own material and component feeding managed by autonomous vehicles, and the same system can also be used for removed product in processing stages. Autonomous vehicles can also replace manually driven forklifts in warehouses, even disaster prone, where the large amount of traffic has safety-related problems.

5.6. Challenges and Limitations

It would be overly optimistic to assume that technology can solve the problems of sustainable logistics within a system that incentivizes consumption irrespective of its ecological consequences. While we can expect an increasing contribution from innovation in logistics technology, we should not overlook the substantial challenges facing its implementation. Two sets of issues have been identified: technological barriers and regulatory obstacles. Part of these hurdles lies with the technology itself; major hurdles have more to do with the political and regulatory environment. Currently, these issues are more pronounced in the context of interesting new trends concerning urban mobility than within logistics in the manufacture-to-demand context.

It is relatively easier to motivate investments in the upgrade and further development of facilities, as well as in the automation of intra-company transport within a single firm by a clear-cut logistics cost-benefit analysis. Although these advantages can be quite significant over time in the business-to-business context, compelling companies and investors to engage in these costly long-term investments among themselves is a big hurdle due to negative spillover effects of any single company investing alone in foregoing the short-term flexibility that make these cost-savings realizable. Besides the problem of split incentives, companies engaging in such investment cycles face the danger of those missing out will gain a crucial competitive edge in the short term. Considerable time lags are also required before paybacks from these investments materialize.

5.6.1. Technical Barriers

Concepts such as autonomous vehicle, fleet management, production control, automated guided vehicle system, intelligent transportation system, industrial automation, and manufacturing decision support system are ubiquitous in the context of autonomous logistics. Autonomous logistics is approaching the current hype cycle and has the potential to automate the physical material flow in manufacturing which according to some perspectives has not received substantial investments yet in comparison to other fields. Case studies of major manufacturers are paving the way towards an increased technological maturity within the next decade. Emerging capabilities of autonomous logistics address large-scale flow complexity, dynamism, uncertainty, and variability as well as enable seamless unaided interactions between all supply chain stakeholders. Autonomous logistics is the result of an artificial intelligence-based fusion of autonomous vehicle technology, logistics and production process knowledge, and fleet management control functions towards a product-oriented component of an intelligent manufacturing system. Intelligent material flow, appearing from an industrial manufacturing perspective, is a techno-physical system that provides new services for internal customers within large-scale manufacturing facilities.

Potential technical barriers are identified, being the demand for standardization efforts, sensor systems for partially structured environments, AI methods for partially formalized situations, the communication colonization of wireless technologies, the unknown desire for collateral markets, and the anticipated challenges with heights and speeds. These barriers prevent or delay a latent market potential of intelligent material flow in large-scale manufacturing facilities and transiently hinder industry investment in the dialog between logistics and AI providers. The ongoing trend driving such inquiries is the vision of autonomous sensor-based logistics with a rapid development of commercial sensor technologies for increasing throughput and cheaper costs. Simultaneously, AI-supported process control concepts within peer-to-peer networks are facilitating decentralized logistics decision-making mechanisms based on dynamic pricing methods. It is assumed that these locally optimized logistics processes organize themselves autonomously and will eventually lead to an economically sustainable distribution strategy.

5.6.2. Regulatory Issues

As a new-high-tech industry, automated logistics and intelligent material flow technologies, especially logistics robots, have great development potential and broad industry prospects. However, related laws and regulations are not yet perfect, for example, the laws and regulations relevant to the extensive application of logistics robots such as safety and environmental protection, traffic regulations, and insurance clauses are unclear, the connection between relevant laws and regulations is not close enough, which brings difficulties for the development of automated logistics and intelligent material flow systems. Therefore, the Government needs to perfect relative laws and regulations as soon as possible. First, they may carry out relevant law enforcement in advance to ensure that uni-order robots can safely execute relative mission. Second, establish economic incentives to promote construction, operation, and transportation coordination, guide and promote the development of automated logistics and intelligent material flow industry. Third, they need to offer feasibility suggestions for the automated logistics and intelligent material flow system from the perspective of liability compensation and insurance clauses.

Moreover, the development and applied technology are still too early, and different businesses have different requirements, resulting in relative applied function and performance can't satisfy market demand. On one hand, the applied technology of machine vision is still immature, and the positioning and safety protection of logistics robots and AI technology recognition of photosensitive color demand continue to be strengthened. On the other hand, further optimization is needed in the core power and information system of logistics robots, the design process of robot body structure and arm, collaborative control strategy between robots and people, or robot equipment management system.

5.6.3. Workforce Implications

Advances in autonomous logistics could once again prompt the public and sectors representing workers to demand restrictions on automation. First, conventional arguments against automation led workers to conclude that new investments in more automated systems will result in fewer, not more, new manufacturing jobs. Anti-automation forces can marshal practical arguments against claims that new investments in autonomous systems will create more jobs for existing workers. For example, if technology reduces the labor time necessary to produce a given amount of products, and some of those products must be produced, prices can be reduced to stay competitive with lower-cost imports in world markets, and manufacturing output can be expanded. Because an increased scale of production depends on the business decisions of firms and not on any labor law or product and labor time limitation, it is entirely possible for a firm to invest in new, more autonomous systems and proceed to lay off workers at the same time. Some have argued further that, in the context of selective “deindustrialization,” workers will not have industries waiting to expand into which they can transfer. Although labor-saving advances in autonomous systems lead to losses in employment, large sectors of the labor force must look to lower wage sectors for their future employment. These arguments could easily form the basis for future labor mobilization against autonomous systems.

Skeptics point to a missing link between increasing automation and rising productivity. Many caution that it will take years before the potential productivity gains multiplier effect begins to operate. Skeptics caution that past experiences suggest that the short-run effects of reducing the share of value-added accounted for by labor has been to encourage manufacturers to use their profits for share price inflation, mergers, and acquisitions. Demands from workers opposing job losses in large sectors of assembly manufacturing will not be satisfied by promises from capitalists and technology boosters of future productivity and economic growth that will never arrive. One potential response of capitalists to worker anger may be to call for some ethic of sacrifice.

5.7. Case Studies of Large-Scale Manufacturing Facilities

The design and control of material flow in large-scale manufacturing facilities, such as those found in automotive, electronics, and consumer goods industries, is a crucial area of research because of the centralized, hierarchical nature of the organization, the compositional structure of the product development and production allocation process, and the expense of the initial investment and inevitable error costs. The production layout in these facilities incorporates multiple parallel production resources, which can substantially ease bottleneck removal and enhance productivity, and is subject to congestion. The resource allocation and sequencing involves specific jig, tooling, and job assignment, which can affect production flexibility and expense, as well as product quality and production speed. The logistics task assigns the part transfer to automated guided vehicles and overhead transporters. The product flow optimization problem concentrates on the processing precedence relations based on product architecture considerations, product technology characteristics, quality concerns, and equipment reliability. The case studies of three industrial sectors are presented below, as varied examples of automation technology applications in manufacturing operations globally.

There is ongoing research across the world about development of autonomous production systems in vehicle manufacturing. Industry groups around the globe have been creating pilot plants for years, where all levels of motion are largely automated; usually linked with parts producers in low-wage regions who do the same. These regions receive part drawings designed with advanced technology, offer inexpensive labor, and patiently wait for orders to build the parts to be sent to the automaker for final assembly. This comment would descriptive capabilities in steady environment and this would assist realization of what are every automakers hope for, perfect quality and instant delivery of parts for assembly.

Electronic firms worldwide want their products made with the latest technology. Hence, they wish to identify and pay for development, production, and deployment of the next generation of automation solutions. They need an extensive variety of sensors, including vision, ultrasonic, and laser; integrated circuits such as application specific integration circuits for synchronous manufacturing needs; robots or Automatic Guided Vehicles; Application Specific Integrated Circuits for synchronous manufacturing needs. These sensors, integrated circuits, and automatic guided vehicles can offer great value: demand is for flexible, reliable, functional, and inexpensive automation solutions that ensure perfect quality and fast delivery of products certain to work the first time – every time.

5.7.1. Automotive Industry

In the automotive industry, domain specific knowledge is paramount to comprehend and structure the potential of autonomy in the development and production of products and manufacturing systems of that industry. The implementers of logistic processes and material flows in the innovative and creative product development process possess great knowledge and experience. Their technical and operative interaction with the production plants is vital for its successful implementation. Pre-series production and problem solving in serial production with contained volumes are tied to the competence of specialized logistic service providers.

Although world leading automotive manufacturers have initiated a wave of innovation through the introduction of new technologies, the working volumes of the classic automotive services providers are still of high importance for producers and suppliers alike. Further implementation of external logistics whose project scope is urged by a high pressure to innovate should adhere to the indirect and specific interfaces under which the logistics are provided in a rather high variety production environment. Flexible approaches through modular ancillary agreements state the key for further improvement without damaging the innovative product development. The formation of competence centers in the producer's periphery might be a first step towards a more efficient handling of the risk divided logistic function. Visibility concepts in anticipation of peaks in demand will become a fallback strategy in spite of the complex environment.

5.7.2. Electronics Manufacturing

Electronics manufacturing encompasses a wide range of production activities involving components, assemblies and systems. Almost all contemporary electronics manufacturing use highly automated processes and systems such as surface mount technology in printed circuit board assembly. Many different types of electronic products are manufactured, from small run special purpose items to millions of consumer products, all with a very high level of automation. Today's manufacturing environments range from factories with simple test operations and few resources to highly engineered cleanroom installations which require large capital investments. A large assortment of robot types and sizes are used for electronics assembly including those that are manufactured by well-known robotics companies as well as companies that specialize in electronics assembly. Advancements in actuators and camera-based vision systems now allow robotics companies to provide smaller, lighter, and faster robots at lower prices.

Differentiation of the subtasks within electronics assembly often determine the use of robots in completing the assembly function. For example, large-area electronics assemblies, such as displays for flat panel televisions or screens for computers, require special purpose, high-throughput, pick-and-place operations that utilize large robots provided by companies whose sole focus is high-speed assembly. But there also exist companies that specialize in pick-and-place assembly for surface mount devices, such as integrated-circuit chips, capacitors, and resistors. These devices are extremely small and delicate. Placing them correctly on a printed circuit board often requires special purpose assembly machines. The electronic product and industry profiles for surface-mounted devices and for large-area displays are representative of many unique subtasks associated with electronics assembly.

5.7.3. Consumer Goods Production

The methods of autonomous logistics and intelligent material flow described in this book are not just applicable to industrial facilities producing discrete products. Examples have sought to team parts-transfer autonomous mobile robots with product-flow conveyor systems to form more integrated product distribution systems. Such combinations are especially useful in the consumer goods manufacturing sector of large-scale mass production, which includes branch and seasonal or single-period production operations, such as drinks, baked goods, butter/margarine spreads, snack foods, pre-cooked/processed foods.

These are unlike those of the industrial segments generally discussed. In the former, product variety and changes in consumer preferences can be rapid. This requires that such manufacturing processes be flexible enough to support not only high production levels, but also frequent and sudden adjustments to product type, size, volume, weight, and other characteristics. However, even so, the basic practical difficulties of supporting integrated autonomous logistics and intelligent material flow can be similar for the vegetable oil and snack food industries as they are for automotive. The product types produced are similar. The money involved in getting it wrong is substantial in each case. Solutions that work are therefore likely to be similar.

They are explored in this section through a pair of case studies. The first describes the uses and workings of the company's Robotic Satellite technology in a snack food plant. The second presents a model for a joint conveyor-Robotic Satellite system that adaptive optimally controls production and logistics operations for a baked goods production-distribution facility, with and without the associated joint operation of warehouse, feeder, and shipping facilities. These case studies reveal how consumer goods mass production can be adapted using the methods and techniques of integrated autonomous logistics and intelligent material flow.

5.8. Future Trends in Autonomous Logistics

In the previous chapters of this work, we primarily discussed technological enabling of logistics automation and its impact on modern manufacturing facilities and factories. With the huge contemporary investments into robotic, autonomous, sensor-based and machine learning technologies, as well as into robotic and logistics service potential become available, the present creation and utilization of large scale logistic and material flows, supporting the production and use of mass-products, is rapidly changing and emerging in the multi-shored and globalized environments. In this chapter, we shall discuss what are the possible future logistic solutions with respect to novel automation technologies on one side, and modern society requirements on the other side, demanding more sustainability of everyday life and slowing down of the pace of the constantly evolving world.

Emerging Technologies

Possibly the largest logistic concept change regards the efficiency of massive systems and their productivity around the world. With the decline of people costs in world manufacturing capabilities and with it the relative decrease in productivity for the labor-intensive low-cost world areas, shipping, transport, logistic system and material flow times and costs gain on importance. This means that possibly within the next few decades, on a global scale, the modularization and homogeneity of made products will increase, shipping routes for such products become optimized for the minimum shipping time, with the emergence of a bipolized production world. In this bipolized, globalized manufacturing, recurring need and emergency products would be produced in states with lazy population and would require short shipping time to the end consumer markets. The Autonomy in smart logistic and material flow systems will come from the combination and integration of the haulage and service robots, augmented by a wireless sensor-detecting world for the operation area, as well as the synergy of innovative and optic logistic methods for emergency delivery and service planning. The sensing and communication elements will link the existing transport, robotics, and building technologies into a concept for responsive logistics solutions. In this sense, logistics would be guided by the combination of sensor webs and planning mechanism into smart systems and operations which could react and optimize active flows, as well as processes.

5.8.1. Emerging Technologies

The transportation of goods around the world is often taken for granted but is made possible by a multitude of networked logistics systems that make and move all things in a coordinated manner. Logistics is defined as the planning and executing of demand and supply activity processes, including transportation, maintenance of movement capabilities, warehousing, inventory, packaging, communications, and integration of these activities. With an eye toward the future, autonomous logistics systems that employ new or emerging technologies will be explored, paying particular attention to how those technologies relate to the continued movement of goods in and around large industrial facilities, including the changing roles of humans. Logistics and technological development outside manufacturers' gates affect what happens inside the factories. Likewise, the role of logistics service suppliers reacting to development is increasingly important for the company's competitiveness.

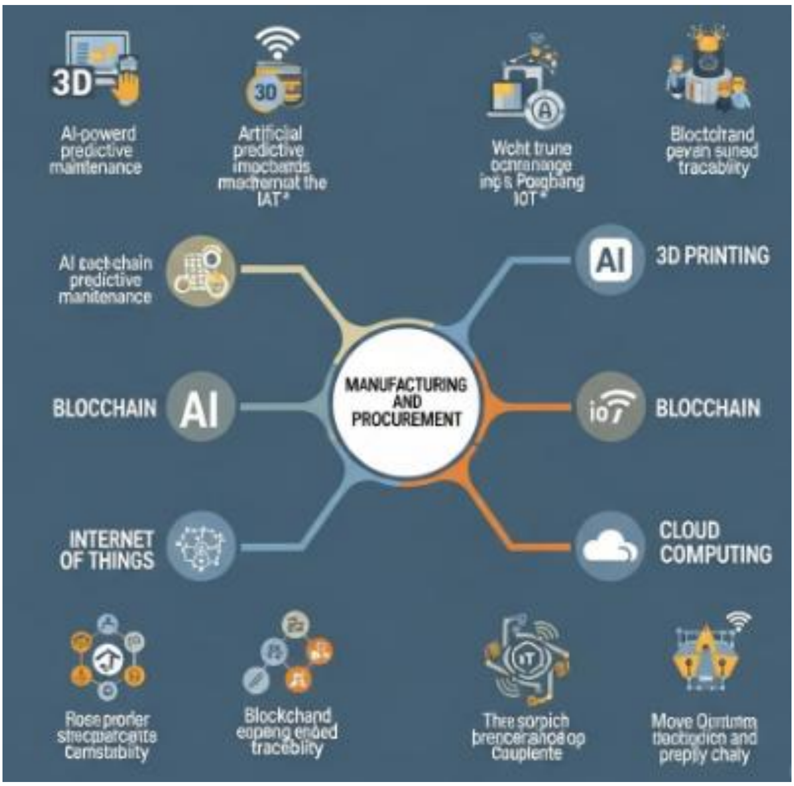

Fig 2 : Emerging Technologies

Advanced driver-assistance systems are enhancing logistics methods in road transport systems, such as lane-keeping assistance and obstacle avoidance for tractor-trailer vehicles. Freight-making systems also are becoming more autonomous with automatic lapping of delicate circuit components, such as a fragile flextape extension to an electronic touch screen used in smartphones. Roadway systems development is likely to soon permit full autonomy over long distances, especially for trucks. Scaled-down equivalents are already developed for larger cargo robots, and prototypes for packages have been shown. Thus far, however, mobile logistics robots are becoming the transport method of choice for in-plant usage, relocating boxes on the same dolly route in warehouses or delivery boxes to clerks for distribution. In addition, automated guided vehicles are being introduced driven by saturation logistics demand. These vehicles use magnetic, laser, or vision navigation for full autonomy over their route carpeted with tagged affinity destinations. The naked path over which baggage flows, however, is not carpeted.

5.8.2. Sustainability Considerations

The extreme rise in consumerism during the last decades has enabled the evolution and growth of business driven by the so-called “cheap society” concept, based on low costs and practices contrary to sustainability. It is true that there has been an increasing consciousness of the big and negative impact that the manufacturing industry has on global warming through pollution and energy consumption, as well as through the non-reusing of materials. But it is also true that twisted realities such as the pandemic, followed by the outbreak of the conflict with its consequences on energy prices, are forcing a rethinking of priorities. In the face of economic uncertainty and social instability, the temptation for just focusing on economy tends to overcome that of sustainability. Sustainability has become a borderline between maintaining a more expensive and of jagged quality level or tending toward the lowest price and, consequently, lower-quality products.

By fostering transparency in the global supply chain and closely cooperating with key stakeholders, manufacturers can assess and continuously monitor the environmental footprint of their products and processes. There is emerging technology to help businesses understand the impacts define, measure, and iterate on innovative approaches that strive to balance price and sustainability. Methods such as digital twins can help manufacturers test out these ideas. Manufacturers can also develop and audit sustainable manufacturing management systems, along with roadmaps and key performance indicators to track and measure their overall sustainability. These approaches can govern all activities, including resource use and conservation, energy use and conservation, emissions, waste, recycling, product development, supply chain selection and management, and social responsibility, so that they also support economic objectives.

5.8.3. Global Impacts

Logistics is an important part of the global economy and, currently, any delays in material and parts inventory transferring in the production process, leads to an important financial loss of producers, as well as reduces product availability to the customers. In

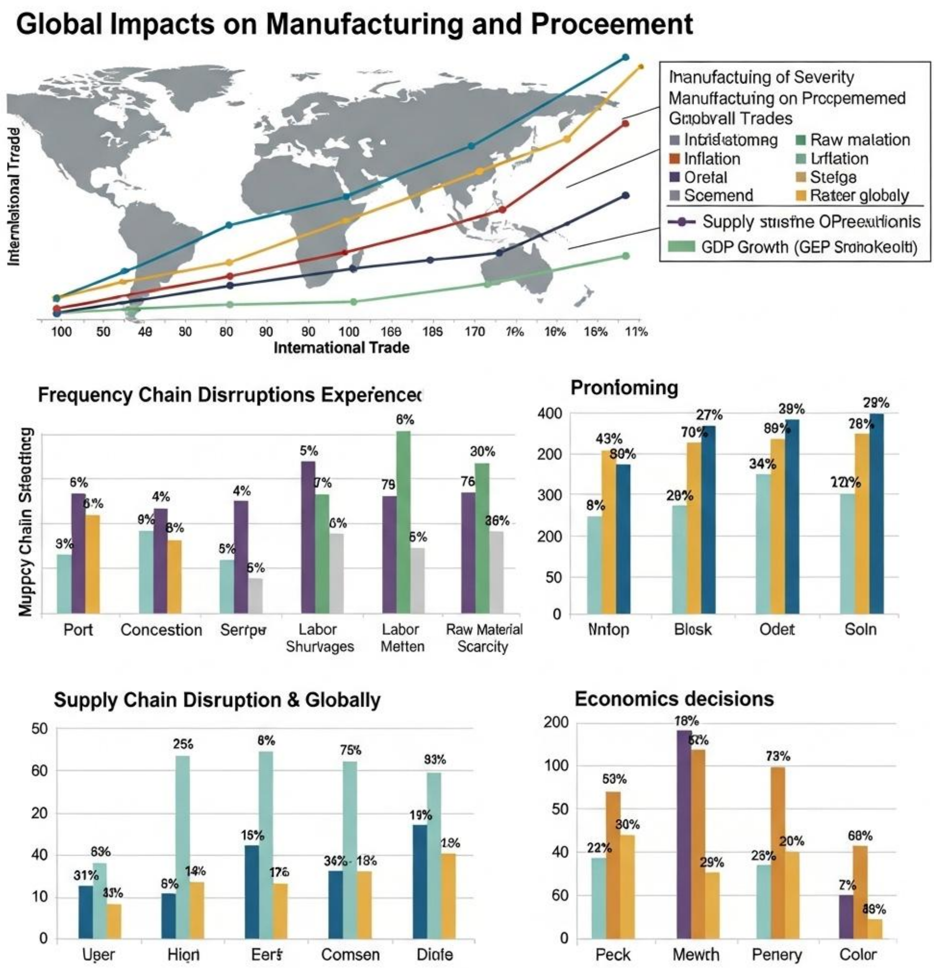

Fig : Global Impacts

addition to losses at the producer side, potential information breaches and commodity demand losses at the retailer side can also be generated. Such failures escalate to the job loss issues. Current observed increases in wages, the need for safe working environments, and livable retirement plans air for logistics and supply chain advances to return competitive manufacturing back to the western world and the need for increased flexibility, availability, and predictability in inter-company relations push these advances of automation that make logistics operations in huge manufacturing locations more reliable and less costly. Hence, by enabling prolonged exemption of logistic processes from human labor, autonomous logistics can help increase demand and the availability of outsourced jobs, and act towards job replacement on tasks that traditionally were performed manually and are not needed to be sparked by creativity. Advanced logistic systems such with learning capabilities can allow the major interruption of logistics having material flow between often not physically connected enterprises, which has reduced dependency on single local production locations.

The increase in utilization of intelligent autonomous vehicles and systems pushes back production cost fractions directed by logistics, supply chain, and distribution operations. This is opening space for the consideration of manufacturing site location, allowing traditional high-cost locations to stay attractive to pursue business at a small-margin level as these low costs-per-item or delivery-order products that are supported by strategies.

5.9. Conclusion

The autonomous flow of goods is an important, but previously neglected, aspect of production management research. It serves to relieve production employees in various possible ways. Furthermore, it prevents costly losses due to stressed and demotivated personnel or a lack of qualified workers. Fulfilling logistic tasks with autonomous transport robots represents a considerable challenge for the technical systems. Unknown environments and changing requirements as well as feedback and interaction with other employees must be considered. At the same time, research and development activities on the technical solutions for the autonomous logistic flow of goods are continuously increasing. The union of autonomous transport robots, sensor capabilities and on-board planning intelligence will pave the way towards the implementation of self-organized and driverless flexible transport systems.

The original idea and proposal of a vision-driven special multi-sensor framework for the guidance of autonomous transport machinery has led scientific researchers from the area of technical systems and production automation as well as production management to focus their motivations and resources on the domain of vision-based systems and applying computer as well as car vision algorithms for the recognition of vital transport problem-specific information in order to assist and enhance the performance of driver-controlled transport units by means of a feedback operation. The main advantage of an intelligent automation system is the capability of self-planning, self-scheduling, and decision-making to accommodate changing requirements or conditions in dynamic manufacturing environments. However, there are many challenges for computational intelligence for approaching these tasks, especially in an industrial environment. In the end, the design, development, and deployment of manufacturing intelligent systems will be a promising field between new advances of technologies from both manufacturing systems approaches and intelligent systems.

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