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The Role of Artificial Intelligence in Optimizing Logistic Activities

A Case of Sabena Engineering

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Abstract

This research aims to provide answers to the following question*: **To what extent does AI allow the optimization of the crisis management supply chain?*** The research is divided into two parts: a literature review on logistic and AI, and an empirical study based on interviews with 15 employees of our reference company, Sabena Engineering

Artificial intelligence is emerging as an essential technology in logistics. Its use in supply chains can revolutionize the planning, production, management, and optimization of activities in this field. By processing large amounts of data, predicting trends, and performing complex tasks in real time, AI can improve decision-making and operational efficiency in the supply chain. Moreover, AI-powered supply chain systems help companies optimize routes, streamline workflows, improve purchasing processes, minimize shortages, and automate end-to-end tasks.

Our research shows that while it is important to embrace AI, it is also imperative to understand all the benefits and challenges it can bring before introducing a new system into a supply chain. Sabena Engineering must take the necessary steps to prepare its supply chains for AI systems and understand that optimization of this magnitude requires time and resources. Indeed, AI technology represents a major change that requires training, patience, and a plan. Since employees must learn to work with AI, open communication is essential for its successful implementation.

Keywords: AI, supply chain, optimization, logistics management, Sabena Engineering

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General Introduction

The supply chain represents a competitive advantage that companies strive to maintain. Its goal is to optimize the exchanges, or flows, that the company has with its suppliers and customers. These flows can be of different types. They can be information flows (supplies or product design), financial flows (purchases), or even goods flows (raw materials and assembly parts to finished products) (Chakir et al., 2020). In particular, crisis management supply chain is increasingly being talked about.

Crisis management is not limited to the application of a crisis management procedure when a triggering event occurs. It consists of an organization, techniques and means that must allow a company or institution to deal with the unexpected. In short, the preventive dimension of crisis management is essential; downstream, the improvement of procedures resulting from feedback must be systematic in order to modify the business continuity plan (Roberts & Yeager, 2023).

For these crisis management supply chain, where it is never very easy to anticipate changes in the environment, the forms of changes undergone are varied and rapid (Detzer et al., 2016). Indeed, logisticians' decision-making involves actions that take place in a constantly changing environment. Furthermore, when responding to an emergency call, they cannot predict what will happen (Chakir et al., 2020). A crisis management supply chain can be disrupted at any time by delivery delays, inaccurate consumption estimates, cargo losses, spontaneous consumption peaks, and a variety of other unforeseeable events. All these unforeseen events are likely to result in stock shortages at any point in the supply chain, which can have disastrous consequences, including human losses. Because these extreme situations are not acceptable, it is necessary to develop a tool that simulates real and/or probable logistics situations, with the goal of observing the behavior of the various zones in place and determining the best strategies to employ in response to crisis situations (Chakir et al., 2020). This research, conducted in collaboration with Sabena Engineering's logistics department, aims at providing answer to these challenges.

A Multi-Agent System (MAS) is made up of multiple agents who interact in the same environment. Some of these agents could be humans, their representatives (avatars), or even mechanical machines (Ferber, 1997). They are particularly requested in the implementation of such applications because of their adaptation for the behavioral representation of the entities that make up the system and for the dynamic study of their interactions. The flow management problems addressed are considered both at the global level between several actors in the chain, and within the activities of one of the actors. Thus, optimization problems ranging from the positioning of crisis management logistics zones to those of decision-making within each zone are part of our issues addressed. In this sense, the question we will try to answer is the following: ***To what extent does AI allow the optimization of the crisis management supply chain?*** In order to provide some answers to our problem, we will devote the first part of this research work to a literature review, and the second to an empirical study, in particular the case of Sabena Engineering.

PART 1: LITERATURE REVIEW

Chapter I: Advanced Distributed Logistics

I.1. Introduction

This thesis focuses on the optimization of the crisis management supply chain, and in particular the optimization of planning and management activities of logistics flows, taking into account constraints such as cost, time and quality of service. In this first chapter, we start by defining the concepts of logistics and supply chain management. Then we focus on the specificities of certain supply chains. This is followed by a presentation of the strengths and weaknesses of the different existing approaches in terms of modeling and management of supply chains. This will allow us to define, on the one hand, the methodological needs specific to supply chain management, and on the other hand, to justify our motivation for adopting the research stream that focuses on the decentralization of logistics decision-making and crisis management.

Then we present the industrial partner with whom we are conducting our work, which allows us to situate the industrial need and formulate the research proposal that we bring to cover this need.

I.2. Logistics and Supply Chain Management

I.2.1. Logistics - Definitions

The original military definition is often cited: "Logistics consists in bringing what is needed, where it is needed and when it is needed." (Christopher,1992). The word "logistics" first appeared in France in the 18th century, with the emergence of military support problems (resupply of weapons, ammunition, food, etc.) (Chakir et al., 2020). This term then spread, particularly in the industrial environment, to mainly refer to the handling and transport of goods. Until the 1970s, logistics had little importance in business management, considered a secondary function, limited to execution tasks in warehouses and on shipping docks. However, logistics is understood as an operational link between the various activities of the company, ensuring the consistency and reliability of material flows, with a view to the quality of service to customers, while allowing the optimization of resources and the reduction of costs (Colin, 1996).

Logistics became, in the mid-90s, a globalized function of physical flow management in a complete vision of the Customer/Supplier chain and truly constitutes a new discipline of business management. "Global logistics" thus refers to all the company's internal and external activities that add value to its products and services for customers (Mangan & Lalwani 2016). Colin et al. (1998) proposed the following definition: “Logistics is the strategic process by which the company organizes and supports its activity. As such, it is possible to determine and manage the related material and information flows, both internal and external, both upstream and downstream.”

Thus, the logistics function would be responsible for managing both physical flows of raw materials and products, as well as information flows, such as transportation, warehouses, and information technology (Belmokaddem et al., 2014). There are several types of logistics that we must explain in this part. Supply logistics which allows the stocks of companies and factories to be supplied with raw materials, components and subassemblies necessary for production. Supply logistics plays a fundamental role in the smooth operation of a company's production chain. It comprises all the operations necessary to supply plant and company stocks with the raw materials, components and sub-assemblies required for the manufacture of finished products. Its effectiveness directly affects the overall performance of the supply chain, as well as the competitiveness of the company in its market. Procurement is the first step in the supply chain. This is a complex process that requires fine coordination between several internal and external actors, as well as rigorous management of information and material flows. The planning of requirements for components and raw materials is generally based on production and sales forecasts, which must be regularly reassessed to take account of fluctuations in demand, supply delays or transport disruptions (Calleja et al., 2018).

The primary objective of supply logistics is to ensure the availability of inputs required for production, at the right time, in the right quantity, and at the lowest cost. This search for performance implies a permanent arbitrage between the stock level, the service rate and the logistic costs. Too much stock leads to high storage costs and risks of obsolescence, while insufficient stock can lead to very costly production disruptions (Farahani et al., 2011). Within this framework, companies have gradually adopted "just-in-time" approaches aimed at minimizing stocks and synchronizing supply flows with production rates. This logic has developed particularly in capital-intensive industries, such as the automobile or electronics. It requires a high level of supplier reliability, integrated information systems, and highly responsive logistics processes (Colin, 1996).

The organization of supply logistics is based on several key functions: supplier selection and qualification, order management, upstream transport, delivery tracking and reception management. The choice of suppliers is strategic because it directly influences quality, delivery times and costs. It is based on technical, economic and logistical criteria as well as social and environmental criteria, in a logic of global responsibility. Once suppliers are selected, the company must establish a collaborative relationship with them based on trust and transparency. Extensive research shows that strategic logistics alliances optimize flows, reduce costs and better manage risks (Bowersox, 1990). Pooling planning tools, sharing production forecasts and automating orders are all levers that can improve supply performance.

Transport also plays a critical role in this logistics. The choice of mode of transport – road, rail, sea, air – depends on the nature of the products, the distance, the time required and economic or ecological constraints (Dablanc, 2017). The development of information systems and traceability tools now makes it possible to track goods in real time, anticipate delays and react quickly in case of hazards. In addition, the current logistics environment is marked by high uncertainty and increasing complexity of supply chains. The globalization of trade, geopolitical tensions, health crises and climate change require proactive risk management (Ho et al., 2015).

Companies must identify vulnerabilities in their chain, assess potential impacts and implement business continuity plans. This approach is at the heart of Supply Chain Risk Management (SCRM), which combines quantitative and qualitative approaches (Lavastre & Spalanzani, 2010).

In this context, procurement logistics is increasingly relying on digital technologies. Integrated information systems (ERP, APS, WMS), connected sensors, artificial intelligence and blockchain offer new capabilities for controlling, predicting and securing flows (Feng & Ye, 2021). For example, advanced warehouse management systems allow raw material inputs to be dynamically managed, reduce receiving errors and optimize storage space (Farahani et al., 2011).

In addition, the "smart logistics" approach promotes reactivity and agility of operations through better visibility across the entire chain. It allows us to move from a reactive logic to a proactive or even predictive logic, anticipating needs, disruptions or variations in demand (Feng & Ye, 2021). This approach is part of a broader transformation from supply chains to cyber-physical systems, in which the physical (material flow) and digital (information flow) dimensions are fully interconnected (Aldana et al., 2017). Supply logistics is also concerned with environmental and societal issues. It must integrate the requirements of sustainable development, optimizing transport, reducing CO_2 emissions or promoting the circular economy. The concept of "green logistics" or "responsible logistics" is gaining ground, prompting companies to rethink their practices in order to reduce their ecological footprint while guaranteeing economic performance (Bano et al., 2019). It is important to emphasize that supply logistics cannot be thought of in isolation. It is part of a systemic logic and must be aligned with the other components of the supply chain: production, distribution, reverse logistics. Therefore, its performance depends on a smooth coordination between the different links in the chain, but also on a corporate culture oriented towards cooperation, innovation and continuous improvement (Siurdyban, 2014).

There are also production logistics which consists of making the materials and components necessary for production available at the foot of the production lines. It aims to ensure that materials, components and sub-assemblies required for the manufacture of finished products are available at the right time and in the right place. Unlike supply logistics, which focuses on the flow-to-business entry, production logistics manages internal flows from receiving or storage areas to workstations and production lines. It acts as a key link in flow synchronization and production process optimization. One of the main goals of production logistics is to supply manufacturing lines with components continuously and smoothly, while minimizing intermediate stocks and unnecessary travel. It is based on precise planning of needs, rigorous management of physical flows and perfect coordination between logistics teams and production operators (Farahani et al., 2011). The role of production logistics is to avoid supply disruptions at workstations, which can result in line shutdowns and consequently productivity losses and high costs.

In traditional industrial models, workshops often had large stocks to prepare for any eventuality. However, this logic of overstocking has proved to be inefficient and costly. Therefore, companies have gradually moved towards models of production in flows drawn, particularly inspired by lean manufacturing, where the objective is to produce only what is needed, when it is necessary, reducing wastage (Colin, 1996). In this context, production logistics becomes a driver of performance, ensuring the delivery of components on demand, often within very short deadlines. This logic has been implemented in particular through the kanban system, a visual tool that allows replenishment to be triggered based on actual consumption at workstations. Kanban allows to control the flows autonomously, avoiding overstocking and ruptures. It is a fundamental element of the just-in-time approach, which aims to align logistics with the actual pace of production (Calleja et al., 2018).

Production logistics must also take into account the physical constraints of the plant: line layout, storage area capacity, circulation routes and production cycle times. In this context, the design of an efficient internal logistics system is based on a fine analysis of flows, often using simulations and modelling (Calleja et al., 2018). The objective is to optimize journeys, minimize load failures and ensure smooth operations. Internal transport, or "intralogistics", is an essential aspect of this organization. It includes handling equipment (trucks, AGVs – automated guided vehicles, conveyors), tracking information systems, and real-time control devices. The development of digital technologies now allows for the automation of many logistics' tasks, while ensuring complete traceability of component movements (Feng & Ye, 2021). These technologies improve not only responsiveness, but also reliability and security of flows. The digitalization of production logistics is more broadly in line with the emergence of the smart factory. In this model, production equipment and logistics systems are interconnected within a cyber-physical system, which makes it possible to synchronize operations, anticipate needs, and adjust flows in real time according to hazards (Aldana et al., 2017). This integration is based on robust digital architectures, capable of processing large amounts of data and making fast decisions.

People also play a key role in production logistics. Operators, truck drivers, planners or maintenance technicians must work in perfect coordination. Logistics effectiveness is often based on collaborative practices, good communication, and a shared understanding of goals (Siurdyban, 2014). The introduction of decision support systems, intuitive human-machine interfaces or specific training helps to strengthen this collaboration. Production logistics is also a lever for continuous improvement. The analysis of logistics performance through key indicators (feed time, failure rate, reliability rate of internal deliveries) allows to identify bottlenecks and implement corrective actions. The Kaizen approach, widely used in industrial environments, encourages the permanent search for optimizations, even modest, but repeated over time. Production logistics is increasingly part of a sustainability approach. Reducing travel, optimizing packaging and reusing containers are all part of a strategy to reduce the carbon footprint of logistics activities. Growing awareness of environmental issues is pushing companies to develop green logistics logics, including within their sites (Bano et al., 2019). The integration of circular economy principles, such as waste sorting or the return of by-products to recovery channels, is also encouraged in internal production practices.

In other area, we have distribution logistics which consists of transporting the products they need to the end customer or consumer. It includes all the operations necessary to transport finished products from warehouses or factories to the place of consumption, on time, at a controlled cost and in the expected quality conditions. The primary role of distribution logistics is to ensure product availability at the right place, time and condition. This mission is made complex by the ever-increasing expectations of customers in terms of responsiveness, flexibility and personalization, especially in the context of online commerce and home delivery. It requires rigorous logistics and the ability to manage increasingly fragmented and rapid flows (Dablanc, 2017). The distribution process usually starts with order preparation in warehouses or logistics platforms. This step includes picking, packaging and palletizing the goods. It is often automated in high volume centers, notably through warehouse management systems (WMS) that optimize picking routes, storage locations and loads (Farahani et al., 2011).

Once prepared, orders are transported to their final destination via adapted transport networks: trucks, trains, planes or ships depending on the distance, nature of the goods and the time requirements. The choice of transportation mode is a strategic issue as it influences both logistics costs, environmental footprint and customer perceived quality of service (Arentze et al., 2011). In urban environments, where density and congestion pose many challenges, specific urban logistics solutions are implemented, such as night deliveries, clean vehicles or relay points (Dablanc, 2017). These schemes aim to reconcile logistics efficiency and environmental sustainability, while responding to the growing regulatory constraints in large cities. The organization of distribution is also based on the quality of demand forecasts and the planning of delivery routes. Poor anticipation can lead to costly overstocking or, on the contrary, service disruptions. That's why companies are investing in predictive management systems that rely on sales data, history and artificial intelligence algorithms to adjust flows in real time (Feng & Ye, 2021).

Military logistics aims to transport the forces and resources necessary to ensure their operational implementation and maintain their support to a theater of operations. It is a fundamental pillar of any military maneuver, because without effective logistical support even the best trained and equipped forces are quickly paralyzed. The military logistics function covers a wide range of activities from the procurement of equipment, ammunition, fuel, food and medical care to the maintenance of equipment, transport, storage and distribution of these resources. It is based on principles similar to those of civil logistics, such as planning, reliability of flows, traceability and optimization of resources, but with specific constraints: the environment is often unstable, time-critical and high logistical risks (Detzer et al., 2016). One of the particularities of military logistics is its ability to operate in areas where infrastructure is absent or destroyed, such as conflict zones or humanitarian crises. This requires great agility, a modular organization, and often autonomous and mobile logistics solutions. Military convoys, cargo planes, logistics vessels or helicopters are all means used to supply troops, often under extreme conditions (Detzer et al., 2016).

The military supply chain is divided into several levels: strategic logistics (organization of flows between home country and theatre of operations), operational logistics (coordination between rear bases and deployed units) and tactical logistics (direct field support). Each of these levels requires rigorous synchronization and constant adaptation to the evolving mission (Bowersox, 1990). Military logistics also relies on increasingly sophisticated technological tools: logistic information systems, planning software, real-time geolocation, and automated command platforms. These devices help to improve the responsiveness of supply chains, anticipate needs and manage inventory with precision (Feng & Ye, 2021). The cyber-physical dimension, now crucial in civil energy systems, also finds an echo in military logistics, where cybersecurity and interconnection have become important (Aldana et al., 2017).

Reverse logistics, which consists of taking back products that the customer does not want or that they want to have repaired, or products to be treated as industrial waste, is another kind of logistic (Viguier-Williams, 2019). Reverse logistics refers to all the logistical operations related to the return of products from the end customer to the producer, distributor or processing center. It occurs when the delivered products are defective, not in accordance with expectations, or at the end of their life, whether for repairs, recycling or disposal of industrial waste (Viguier-Williams, 2019). This logistics responds to growing economic, environmental and regulatory challenges. It requires a specific organization to manage the flows in reverse, with processes of sorting, diagnosis, reintegration into stock, or treatment of waste. These operations require rigorous traceability, close coordination between after-sales services, carriers and logistics platforms (Farahani et al., 2011). Increasingly integrated into companies' strategies, Reverse logistics relies on information systems capable of tracking returned products, analyzing their causes and optimizing their reuse or recovery. It is thus part of a circular economy logic, aimed at extending the life of products and reducing the environmental footprint of supply chains (Feng & Ye, 2021).

Therefore, there are many different logistics until the concept of supply chain comes to bring a certain unity in this area.

I.2.2. The Concept of the Supply Chain

I.2.2.1. Supply Chain (SC)

This is a relatively recent concept, even if the military has been using the same expression for much longer. The supply chain is often defined as “The sequence of stages involved in the production and distribution of a product, from the suppliers' suppliers to the end customers' customers.” (DeWitt et al, 2001).

In order to better understand the concept of Supply Chain, we propose to review the definitions of this term used in the literature. Christopher (1992) defines the supply chain as “the network of companies that participate, upstream and downstream, in the various processes and activities that create value in the form of products and services provided to the final consumer.” In other words, a supply chain is composed of several companies, upstream (supply of materials and components) and downstream (distribution), and the final customer”.

Stevens (1989), for his part, defined the supply chain as “the network of entities through which the material flow passes. These entities include suppliers, carriers, assembly sites, distribution centers, retailers, and customers." A more general definition is that proposed by Poirier and Reiter (1996): “A supply chain is the system through which companies bring their products and services to their customers.”

However, Calleja et al. (2018) distinguish two approaches: those that define the supply chain of a company, that we have already explained, and those that define the supply chain of a product. The supply chain of a finished product is defined as “the set of companies that intervene in the processes of manufacturing, distribution and sale of the product, from the first supplier to the final customer.” (Bel et al., 2001)

I.2.2.2. Supply Chain Management (SCM)

There is a distinction between "supply chain" and "supply chain management". Indeed, supply chain management brings together the approaches, processes, and functions essential for reducing the costs of a supply chain and increasing its flexibility in order to optimize its performance. Here again, there are several definitions of supply chain management (DeWitt et al. 2001).

Many authors emphasize the difficulty of defining SCM. According to Naslund and Williamson (2010), SCM is “the art and science of creating and enhancing synergistic relationships between partners in the same supply chain with the common goal of delivering, just in time, the right products and services to the right customer, with the best quantity.” Johnson and Kopczak (2003) propose the following definition in their work: "SCM is a strategy that aims both to reduce overall costs, allowing a more competitive position for all the different parts of the supply chain, and to optimize the satisfaction of the end customer through greater adaptability of production and distribution systems".

For Croxton et al. (2001), Doing SCM entails integrating all internal and external resources to meet customer demand. The goal is to optimize all logistics processes at the same time rather than in sequence. SCM aims to enhance industrial competitiveness by minimizing costs, ensuring customer satisfaction, efficiently allocating activities among production, distribution, transport, and information actors, and preventing antagonistic local behaviors from affecting overall performance (Daknou et al., 2008).

In short, the concept of supply chain is considered as a strategic lever. This concept implies an effort by all the actors in the network in order to have a better profitability of the chain and that of its actors. To achieve this, companies in the same supply chain collaborate in order to establish lasting partnership relationships. These relationships are generally formalized by contracts determining the terms of physical, financial and possibly informational exchanges.

I.2.3. Decision-Making in Logistics: A Hierarchical Process

For any type of supply chain, decision-making is divided into three levels: strategic, tactical and operational, corresponding respectively to long, medium- and short-term horizons (Chakir et al., 2020).

I.2.3.1. Strategic Level

This level, also known as Strategic Management or Strategic Planning, brings together all strategic decisions (Chakir et al., 2020). These are directives and lines of action over the long term (from 6 months to several years), such as the search for new industrial partners, the selection of suppliers and subcontractors, but also decisions to establish or relocate intervention zones in the case of military logistics, the allocation of a new supply zone to a distribution center (warehouse), the development of a new product, the configuration of the supply chain, its operating mode, as well as the financial objectives to be achieved (Llerena et al., 2004).

I.2.3.2. Tactical Level

The tactical decision-making level is concerned with medium-term decisions (from a few weeks to a few months) that must be carried out in order to implement the company's strategy (Chakir et al., 2020). These decisions concern problems related to the management of the company's resources, in particular the planning of activities based on the resources available over a fixed horizon (Llerena et al., 2004).

I.2.3.3. Operational Level

Decisions at the operational level are more limited in scope and time (Chakir et al, 2020). At this level, tactical decisions generate a detailed production or scheduling plan, applicable at the level of a workshop or a logistics area (Llerena et al., 2004).

I.2.4. Performance

Supply chain management seeks to improve the overall production system. To achieve this objective, we often use a certain number of performance indicators. These indicators, which can be difficult to quantify, include customer satisfaction, delivery time compliance, chain flexibility, information sharing, risk management, traceability improvement, and so on (Bakkoury et al, 2019). They are built from inventory monitoring and make it possible to set the thresholds of the objectives to be achieved.

According to Chakir et al., (2020), three major supply chain performance indicators are commonly used, each corresponding to a different type of flow:

- ***"cooperation" indicators*** *for information flow performance.*
- ***costs*** *for financial flow.*
- ***delivery times*** *for physical flow.*

The first step in performance monitoring is to "measure performance." (Chakir et al., 2020). Several performance criteria are possible. Tangen (2005) divides these into two types:

- ***qualitative performance measures*** *(customer satisfaction, flexibility, integration of physical and information flow, financial risk management, etc.).*
- ***quantitative performance measures*** *(delivery delays, customer response time, etc.).*

Then, reengineering decisions must be made, and the system and model should be adjusted through decision variables in order to achieve the desired results. Implementing a high-performance system reflects the need for supply chain control and performance improvement (Chakir et al., 2020).

The aim of logistics systems management is to develop optimization models and methods to provide effective decision support. Indeed, logistics systems constitute particularly complex socio-technical organizations and present complex modeling and optimization issues. The logistics systems concerned are mainly those relating to production, transport, and crisis management. Such systems are often dynamic, distributed and extended on large-scale networks and generally take the form of autonomous entities in interaction. The processes resulting from these systems are complex, due to their large dimensions (very large number of variables), the nature of their dynamic relationships, and the multiplicity of constraints to which they are subject (productivity and safety constraints for humans and the environment).

Logisticians working with these systems face increasingly complex problems, such as how to improve, secure, and optimize logistics flows. How can flows be better synchronized in distributed systems such as the global multimodal transport supply chain, multi-site production networks, and multi-zone crisis management? What new information and communication technologies should be adopted, and how should they be implemented in accordance with the specific activities of these logistics systems? This research work is intended to be a response to these challenges.

I.3. Transport Logistics

Transport logistics covers two main categories:

- ***passenger transport systems****, related to city management and urban planning.*
- ***goods transport systems****, also called distribution logistics.*

I.3.1. Multimodal Transport

A multimodal transport network, in the case of passenger transport systems, is characterized by the simultaneous presence of different modes of transport (Arentze et al., 2011). The connection between these modes is established at the level of interchange hubs or transfer nodes. Compared to the monomodal case, traffic planning in a multimodal network is more difficult, given the complexity of the trips. Indeed, this process requires the scheduling of vehicles in order to assign them trips, and also the scheduling of personnel to assign them services.

Knowing that information in transport is a key element, it is necessary to choose between the multiple information systems intended to make the best use of the network. (Marakas & O'brien, 2006).

I.3.2. Regulator-Side Information Systems

These Regulator-Side Information Systems (RSIS) are also called Operator-Side Information Systems (OSIS). Indeed, the operation of a transport network mainly involves two key phases: a planning phase and a regulation phase. Therefore, we find Operating Support Systems (OSS) and Decision Support Systems (DSS) used to carry out these two phases. The first phase is the planning phase carried out upstream of the network commissioning. It consists of designing, planning and scheduling transport resources. This is an important phase for operators (Marakas, & O'brien, 2006).

The problem of planning is directly linked to scheduling algorithms and particularly to vehicle routing algorithms (Vehicle Scheduling Problem VSP) (Baita et al., 2000). Currently, several transport companies rely on planning tools, software and systems to generate timetables and driver service sheets (Caris et al., 2013). The second phase occurs after the transport service is set up. This is the regulatory phase, in which timetables and the number of vehicles at peak times are refined in order to improve service quality and optimize network use (Khorbatly, 2018).

I.3.3. Customer-Side Information Systems

The second type of information system links the customer and transport. These are Travel Assistance Information Systems (TAIS). The main objective of this type of information system is to help in the planning phase by proposing the shortest or least expensive route. Currently, customer information systems are generally single-modal and in the case where these systems are multimodal, they only concern a single operator and are then single-operator. These systems are presented in the form of a website. In addition to the usual information (timetables, station layout on a map), they offer an internal route calculator. This is a route search engine that accesses the local data of a single operator. Therefore, it provides single-modal routes.

All these systems remain single operator. More and more projects are being set up with the aim of integrating data from several operators. The work carried out has mainly followed two strategies, the first aims to centralize the data of all operators in a huge data deposit and then exploit it, the second tends to exploit remote data by creating a mediating system between existing systems.

I.3.4. Transport of Goods

The transport of goods covers the functional areas of distribution and supply logistics. It generally entails making quality products available to customers in sufficient quantity, on time, and at a reasonable and competitive price (Khorbatly, 2018). Distribution logistics is a cross-functional function. The definition of Dablanc (2017) includes:

- *the choice of transport mode: road, air, waterway, combined.*
- *the choice between clean, outsourced, hybrid transport.*
- *the type of packaging, standard.,*
- *the management of storage, handling, location of depots.*
- *after-sales service.*

This activity covers traffic carried out by road, rail, waterways and sea, air and oil pipelines. Road represents the largest share of land transport.

I.3.4.1. Participants

- ***The own-account carrier or "private carrier"***

This is generally a company or an individual who transports their own goods with their own vehicles or rented vehicles and most often with their own drivers. These private carriers are opposed to public carriers.

- ***The public carrier***

Public carriers, often referred to as couriers or express couriers, provide transportation services for a variety of shipment types, including single packages, transport of industrial batches, etc. A distinction is made between sending parcels to individuals, sending express parcels by companies to other companies for parcels not exceeding 31 kg, and express courier which allows parcels to be sent on pallets with a maximum weight of up to 3 tons (Nikolic-Doric, & Stojanovic, 2014).

- ***The sender or "loader"***

This is the person who calls on a carrier. They are often better known as the principal.

- ***The recipient***

The recipient is an important participant in road transport. It has obligations concerning the unloading of goods, the conditions for receiving goods and the possibilities of making a claim in the event of problems.

- ***Road transport vehicles***

There are several types of vehicles: van, 6x4 flatbed, 6x4 tipper, carrier, semi-trailer, trailer truck or road train. Loading assistance software packages can optimize the layout of packages, pallets and various materials inside the vehicle in question, taking into account the order of deliveries on a tour, ease of unloading and maximum weight.

I.3.4.2. Distribution Network Configuration Parameters

According to Aldana et al. (2017), the definition of the physical architecture of a distribution network must take into account a significant number of parameters, including:

- *characteristics, volume, variety and value of products.*
- *number, location, stability of delivery points.*
- *level of service set in terms of deadlines, reliability of deliveries, responsiveness to contingencies, traceability.*
- *impact of packaging on the types of means of transport used and the physical organization of storage points.*
- *different costs: transport, storage, immobilization.*

I.4. Optimization of the Crisis Management Supply Chain

The multiplication of stakeholders, the divergent performance criteria in terms of deadlines, costs, compliance with standards and certifications, are all risk factors identified by the authors in the smooth running of logistics operations, whether physical or immaterial as reported by Farahani et al. (2011). Through their work on an analysis of the most cited articles dealing with the issue of risks in the SC, they carried out a synthesis of the typologies of risks in the supply chain in thirty-seven types, if we omit the simplified typologies. These include factors such as:

- *increased outsourcing to suppliers.*
- *Globalization.*
- *compressed time-to-market.*
- *rapid and massive increase in demand at the beginning of product life cycles, and limited production capacity.*
- *reduction in the supplier panel.*
- *increasingly intertwined processes between companies, internal risks to the company (processes, control).*
- *risks external to the company but internal to the network that constitutes the SC (upstream, downstream).*

Therefore, it seems essential to focus on the points that we can consider critical, and which appear most often during the transition from one actor in the chain to another. Mastering this handover between the different actors must lead researchers but also specialists to question themselves and focus on this stage. Indeed, it seems that this is when risks are likely to appear, and that mastering this stage can allow them to be reduced, because many of the typologies identified and cited above focus on the risks themselves rather than the factors creating them as reported by Feng and Ye (2021). This is even more interesting since when a new actor is integrated into the supply chain, it is with its organizational typology, its methods but also its information system that it enters the organizational loop of the logistic chain. Thus, as authors emphasize, although information systems are identified as a potential risk for SCs, the authors refer to them as "collaborative" tools to "counter the risks of the SC". We must also understand here that the entry of a new actor must be considered with its organizational, methodological or procedural and informational heritage. It then appears essential for our research to first define the notion of risk in the supply chain. We will see that this is not a simple exercise. This will then lead us to identify the risk management methodologies that we find in the literature.

The evolving configurations of the supply chain have led the various actors to rethink the nature of inter-organizational relationships. Indeed, the purely competitive vision that prevailed a few years ago has now given way to the development of increasingly present partnership relationships, in whatever form. We thus find ourselves in the framework of what Bowersox (1990) called an “extended organization” and which assumes a continuous relationship as opposed to the series of separate transactions occurring in a traditional subcontracting relationship. According to Siurdyban (2014), a partnership is a tailor-made business relationship based on mutual trust, openness, risk and benefit sharing, and the goal is to provide a competitive advantage through better business performance than the partners could have obtained individually. It is important to note here the sharing of risks within the supply chain. However, Jacyna-Golda et al. (2014) define the concept of risk related to the chain logistic as “any unforeseeable incident or malfunction impacting one or more links in the supply chain in a negative way and consequently its ability to achieve its performance objective both at the level of the companies involved and the service provided.”

This gives us a first element of understanding the concept of risks in the SC. Risk is an element that extends over the entire chain, its impact generally affecting several links in it (Hansali et al., 2024). Defining risk for the supply chain is then not easy. The literature dealing with this topic also offers us an interesting spectrum. Indeed, as noted by Comes et al. (2015), only a few authors explicitly define supply chain risk. Thus, if we wanted to define risk, it would be appropriate to approach the issue more generally at first, based on the work of Stone and Yates (1992) for whom risk is defined according to three criteria, namely "the extent of the loss (elements of loss), its importance (significance of loss) and its probability of occurrence (uncertainty associated with loss)". The work presented by Dickson et al. (2015) at a conference in Dubai on engineering and industrial operations management, define risk according to the following elements:

- *“Potential losses in case of realization of risk”, which are the potential losses in the event of the risk occurring.*
- *“Probability (likelihood) of the occurrence of an event that leads to realization of the risk”, or the probability of the occurrence of an event leading to the realization of the risk.*
- *“Significance of the consequences of losses”, which is the importance of the consequences of the losses caused by the risk.*

Dickson et al. (2015) also explains that “the supply chain risk is characterized by both the probability of an event and its severity given that an event occurs”. In other words, the supply chain risk is characterized by both the probability of an event and its severity when it occurs.

Among the first authors to propose a definition of supply chain risk, March and Shapira (1987) defined SC risk as “potential disruptions in the flow from one link to another that could impact the supply chain; these flows could be of different natures (physical, information) and have an impact on the use of resources that will result.” Ho et al. (2015) proposes the following definition: "supply risk is defined as the probability of an incident associated with inbound supply from individual supplier failure or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety". In other words, the probability of an incident related to a supplier failure or the supply market occurring will results in the purchasing firm being unable to meet customer demand or endangering the life and safety of the customer. As we noted previously, the transition from one actor to another in the chain represents a strategic issue for logistics; it is at this precise moment that collaboration or partnership relationships materialize.

It is also at this moment that risks can appear, through the possible loss of a flow. Another particularity, fundamental in the understanding of risk for the SC, is the frequency of occurrence of an event considered as such. Some specialists agree that a minor risk that is repeated too often will be more serious than a risk deemed more important, but occurring only very rarely. Taking up the aforementioned definition, Wallenburg and Wieland (2013) draw the conclusion that if the probability of a risk occurring is high, then the risk is no longer a risk but a certain event to come; if it is too low, it will only be a chimerical and unfounded fear that managers should not try to manage.

It is also important to try to understand the factors that can promote the emergence of a risk in the supply chain. Bano et al. (2019) have identified five categories of risk sources:

- *environment.*
- *demand.*
- *supply.*
- *processes.*
- *control.*

These different explanatory elements remain fairly theoretical. To have a more operational approach, we can rely on nine categories of risks identified and described by Lavastre and Spalazani (2010). Among these, we can cite:

- *delivery delays.*
- *stock shortages.*
- *machine breakdowns.*
- *delivered products not having the desired quality.*

- *problems related to the use of information systems relating to the integrity of the data used or by the system becoming out of service.*

Finally, the work of Amri and Ouabouch (2014) put forward three hypotheses that seem essential to us in our analysis:

- *The risks of failure (related to the upstream process) upstream of the CL will have a negative impact on the performance of the CL.*
- *The risks of operational failures (related to operational processes) will negatively influence the performance of the CL.*
- *The risks of failure downstream of the chain logistic will have a negative impact on its performance.*

Thus, it seems clear that risk in the context of a supply chain is a factor whose consideration is fundamental and that it is necessary to question the means available to companies to be able to manage it when it appears, or in the best case, prevent it. Through the architecture of current logistics networks, where extended organizations involve a large number of actors, and which are increasingly managed by external service providers, the probability of a risk appearing is even more important as the outputs and inputs are important. Therefore, defining a risk within the framework of a SC is a first step in establishing a management and prevention strategy.

I.5. Crisis Management Logistics: Key Issues

On average, 40,000 to 50,000 people are affected by natural disasters each year (Ritchie et al, 2023). Therefore, humanitarian and military organizations must often set up complex supply chains in an extremely volatile environment. These supply chains have many particularities that differentiate them from their counterparts usually encountered in traditional industry. If we exclude certain terms specific to corporate logistics, such as customer or store, the concept of SCM (Supply Chain Management) is consistent with the objectives of crisis impact management. The concept of SCM applied to relief, supply and support operations is called crisis management.

A crisis, whether natural or man-made, is a situation that local governments cannot cope with their own resources. Crises can be caused by several causes: natural disasters (such as earthquakes, floods, etc.), political conflicts or industrial accidents. Some crises will cause thousands of deaths, others will affect a limited number of the population. Some will last a few weeks, as in the case of heat waves, others can last for years. The main types of crises are presented in the appendices (see appendix 1: The Different Types of Crisis).

Each crisis situation pushes operations beyond their normal boundaries. Therefore, it is essential to set up a methodology that allows a rapid return to a normal situation before the crisis escalates further. This is called crisis management. Crisis management and the deployment of a crisis management supply chain depend on the location of the disaster, its intensity, its nature and the actors affected by the disaster. It is composed of three types of activities:

- ***Crisis prevention****: aims to bring the risk of crisis to an acceptable threshold and, when possible, to prevent it from actually occurring.*
- ***Operational response capacity****: includes advanced strategic planning, training and simulation in order to ensure the availability, speed of mobilization and deployment of the resources necessary to manage potential emergencies.*
- ***Declared crisis management****: this is the response, including evacuation, search and rescue, at the time of the crisis, and the recovery of the situation from this crisis, minimizing its effects, limiting the impacts on the environment and the local population.*

In the longer term, the objective is to return the systems to normal, whether environmental, economic or other (Khodarahmi, 2009).

I.5.1. Characteristics of the Crisis Supply Chain

Khorbaty (2018) has attempted to identify the characteristics of such an environment. He has retained five main categories:

- ***The life cycle of the operation****: The life cycle of the operation is composed of 4 main phases, in which the duration of each varies depending on the type of crisis (rapid or slow evolution):*
  - *prediction and analysis of risks.*
  - *preparation of action plans.*
  - *immediate intervention.*
  - *dismantling.*
- ***The environment****: The crisis management supply chain is governed by several constraints such as neutrality, impartiality, etc.*
- ***The nature of the flows****: The distribution channels manage the traditional types of flows with however some specificities:*
  - *Physical flows are composed of materials and units constituted.*
  - *Information flows (transmission of orders, monitoring and coordination of physical flows) are highly structured and hierarchical.*
- ***Logistics network****: The logistics infrastructure can be fixed and can be created in operation. The road network can often be subject to multiple and unplanned disruptions.*
- ***Dynamics****: The dynamics of a crisis management supply chain are very specific since they try to meet certain urgent needs. These dynamics are accentuated in the case of a sudden crisis, where needs arise unexpectedly after the crisis has occurred. In most cases, the crisis management supply chain will have to:*
  - *Estimate urgent and vital needs, but also uncertain ones.*
  - *Coordinate supplies, urgent and uncertain as well.*
  - *Work in emergency conditions, consider unpredictable events, all with very short deadlines.*
  - *Take into consideration the lack of transparency and the unstable climate in which it may have to operate.*

I.5.2. Flow Management

Several types of flows exist, depending on the management method.

I.5.2.1. Push Flows

The push flow relates to production based on estimated needs, intended to supply or supplement a stock. In this case, supplies are "pushed" as far as possible towards the consumer. In the context of crisis management, the push flow corresponds to the delivery of a resource estimated to be sufficient for the field operator (or customer). In the event of under-consumption, these caused stocks would handicap the stockholders; in the event of over-consumption, the lack of responsiveness would be noticeable due to a lack of visibility.

I.5.2.2. Pull Flows

The pull flow corresponds to upstream production driven by downstream needs, where the supplier supplements the need of its customer on request. In the context of crisis management, this corresponds to the request for replenishment made by the consumer according to their needs, while staying within the limits set by the order constraints. This principle takes into account the forecast of needs and the concept of safety stock, necessary to compensate for a shortage or an unwise action. This method theoretically ensures the permanent adequacy of support to the real need.

Generally, in the event of a crisis, we use both methods, with a preference for the push flow in the upstream areas, and the pull flow in the downstream areas. Indeed, the pull flow in the downstream areas aims to really adapt the shipments to the demand, to be able to stick closely to the requirements on the ground and avoid stock shortages. But an upstream pull flow operation presents a risk of delay of resources, because the delivery time from one area to another is not negligible. This is why the push flows are used in the upstream area.

1.5.3. Modeling

There are various supply chain models. The model we choose is directly related to the type of problem and structure we want to study (Hodgson et al, 2004).

I.5.3.1. Analytical Model

Analytical models allow the system to be described by a set of mathematical equations. For an analytical model (deterministic or stochastic) to be viable, it must be relatively simple. Therefore, a certain number of assumptions and simplifications must be made. This may explain why analytical models typically focus on distribution aspects within a dyadic structure (Huang et al., 2003).

I.5.3.2. Simulation Model

The simulation model is typically used when there is no relationship between the system's variables and thus cannot be represented by an analytical model (Khorbatly, 2018). Simulation models are both stochastic and dynamic models. There are many studies on the analysis of decision-making processes by simulation model. Kleijnen (2005) proposes to classify the different supply chain simulation techniques into four main parts:

- *spreadsheet simulation.*
- *the system dynamics approach.*
- *the discrete event approach.*
- *business games, which allow to educate and train users in certain aspects of supply chain management.*

I.5.4. Optimization

The optimality of logistics service quality implies user satisfaction with the proposed system's integration of the functionalities required for effective supply chain management (Lambert et al, 2002). In this sense, the concept of optimization has retained all our attention. Optimization was introduced in a concern to improve the services provided regardless of the field to which they apply. An optimization problem concerns the execution of specific methods in search of an optimum. The latter can be a value maximizing or minimizing a function f, called objective function or cost function; it is also called optimization criterion (Chen et al., 2024).

Depending on the case, and whether it is a monovariable or multivariable problem, continuous or discrete, etc., an adequate optimization method is chosen to solve the problem posed. Between exact, meta-heuristic, hybrid or other methods, researchers and practitioners have at their disposal a wide range of choices of optimization methods that they can adopt. Not all of them are appropriate for the optimization problem they face, and a choice must then be made. Otherwise, the expected optimization and efficiency will be hampered.

I.5.5. Decision Support

Decision support techniques aim to accurately model an expert's preferences. This modeling will then allow us to design and build appropriate tools that can assist or replace a decision-maker on complex issues. Decision support formalizes the knowledge gained from an interview with the decision-maker and the interactions between the decision-maker and his surroundings. Given that we are primarily interested in decision-makers' logistics expertise, the model used must be adaptable and detailed enough to represent the various decision-making behaviors most commonly encountered in crisis management supply chain management (Azghandi et al, 2020).

I.6. Centralized Management vs. Distributed Management

We devote the first part of this section to presenting the evolution of centralized systems. The latter, initially of the MRP (Material Requirements Planning) type, have evolved and given rise to APS (Advanced Planning and Scheduling) systems. We will see that these systems are mainly based on the centralization of decision-making and that their development is mainly marked by the increasing number of functions included. Note that the research work associated with this type of centralized systems is still as numerous as ever, and that these correspond to the systems more widely implemented in industry. Companies had installed this type of system mainly for cost reasons, but also because of their inability to obtain detailed information, in real time, from the different entities making up their supply chain. Then, we present the research stream that focuses on intelligent distribution or logistics systems. The vision of logistics decision-making at the level of these new systems (at the beginning of 1990) has shifted dramatically from the traditional centralized to the distributed perspective. This shift in perspective is driven by new needs for flexibility and responsiveness. Thus, these new systems aim to address issues such as distributivity, re-configurability, interoperability, and reusability (Azghandi et al, 2020)

I.6.1. Definition of Management

Managing a supply chain composed of multiple entities is a function that allows the exploitation of the resources that are available in this supply chain (Chakir et al, 2020). This function is materialized in two organizational elements: the information system and the decision-making system. The information system allows the storage, adaptation and provision of data on which the decision-making centers are based. The role of the information system is to provide each decision-making center with the necessary and sufficient information for adequate decision-making (Kaminsky et al., 1999).

I.6.2. Conventional Centralized Systems

I.6.2.1. MRP Systems

MRP (Manufacturing Resource Planning) is defined by APICS (International Association for Operations Management) as an “effective planning method for all the resources of an industrial company.” MRP systems offer several services, the most used of which are operational schedules, financial plans and especially decision support through scenario analysis. This method consists of a large number of functions all linked together: Strategic Plan (SP), Industrial and Commercial Plan (ICP), Master Production Program (MPP), calculation of needs, planning of capacity needs and monitoring of the execution of plans (Khorbatly, 2018).

I.6.2.2. ERP

Based on the technological foundations of MRP, ERP (Enterprise Resource Planning) software packages allow the management of the transactional functions of the company. ERP systems cover several functions such as manufacturing, distribution, accounting, human resources management, finance, project management, inventory management, maintenance and transport (Khorbatly, 2018). Seddon and Shang (2000) present the advantages commonly promoted by companies that develop ERP systems:

- *Allow access to reliable information (common database, data consolidation and improved reports).*
- *Avoid redundancy of operations and data (modules access the same data in the central database).*
- *Avoid multiple update and data entry operations.*
- *Offer e-commerce functions (Internet commerce and collaborative culture).*
- *Offer additional modules such as customer relationship management and SCM.*

Other advantages can be identified such as reduction of cycle and delivery times, minimization of costs and adaptability, but they are still debatable to this day.

The most noted disadvantages of these systems are the time spent on implementation, the cost of the system, and above all the rigidity regarding the complexity of the company's different processes (Seddon & Shang, 2000).

I.6.2.3. Advanced Planning Systems

The idea behind APS (Advanced Planning and Scheduling or Advanced Planning Systems) is the use of technics and algorithms that allow obtaining optimized solutions at different decision levels (Meyr et al., 2015). APS software packages ensure the planning and optimization of flow circulation along a supply chain. These are techniques that fall within the framework of the analysis and planning of production and logistics in the short, medium and long terms. They are presented as the advanced version of ERP, since they provide a solution that optimizes collaborative work based on objectives such as the service rate and margins on activities. The main components of an APS system are production planning, production scheduling and distribution and transport planning. Some disadvantages should be mentioned, in particular those related to flexibility, reconfigurability, robustness, agility, responsiveness or reuse. In fact, these problems are still far from being solved by this type of system due to the complexity generated.

I.6.2.4. Some Criticisms

The combinatorial nature of most problems in distribution systems, such as the resource allocation problem, leads to the simplification of the complexity inherent in such systems. Indeed, the information needed to obtain decisions at different levels is aggregated information and in this aggregation process, important relationships between the different components of the system can be neglected. A second weakness of centralized approaches is the lack of real feedback from lower levels of the supply chain, which reduces responsiveness and flexibility to possible disturbances.

I.6.3. Intelligent Distributed Systems

I.6.3.1. Fractal Systems

Fractal systems were proposed based on the work of Warnecke (1993). These systems take up the characteristics of self-similarity and recursion used in fractal geometry, for the design of a system structure. This system is built by ensuring the coherence between the global and local objectives of the entities that compose it. The objective is to provide the system structure with the reactivity and flexibility necessary to withstand changes in the environment.

I.6.3.2. Multi-Agent Systems

Beyond the models taking into account, in an analytical model, the entire supply chain, these approaches consist in highlighting the distributed aspect of the chain by creating links with more or less autonomy. These models are based on object-oriented concepts and result in a distributed architecture based on actors (agents). The paradigm of multi-agent systems appears as a response to the problem of modeling large-scale distributed systems.

I.6.3.3. Holonic Systems

Based on the concepts expressed by Alfred Koestler (1968), the HMS (Holonic Manufacturing Systems) consortium proposed holonic production systems. A holonic entity has a recursive structure of societies. Holons have properties such as autonomy and cooperation and the preservation of dynamic flexibility at the distributed level. Each holon in the system has the same characteristics as the whole and has a specialty. Since their application in manufacturing systems, holonic systems have been extended to many other areas such as transportation systems (Galland et al., 2020).

I.6.3.4. Product-Controlled Systems

A product-controlled system evolves the previous vision into a more interoperable and intelligent system. Indeed, the product becomes the controller of the company's resources. This is called an intelligent product. Product-controlled systems have generally been perceived as a special class of holonic systems. The fundamental idea is the change of perspective from a classical hierarchical and aggregated vision of the production planning and control function to a distributed perspective of decision-making. In this sense, part of the decision is made locally and throughout the product life cycle.

I.6.4. Motivations for the Decentralization of Control in the Case of the Crisis Supply Chain

Mookherjee (2006) proposes several motivations for the decentralization of control:

- ***Feasibility***

In some cases, distributed decision-making is the only possible automated solution. For instance, in supply chains where entities are competing with each other and shared information is scarce due to security concerns, decentralization is a more systematic and automated strategy to replace existing ad-hoc practices.

- ***Robustness and flexibility***

This advantage allows performance improvement for different scenarios. It is one of the most important characteristics to justify the use of agent-based systems. Specifically, it means that the system has the following properties: robustness to failures or disruptions of plans, online reorganization and effective response to external disruptions.

- ***Reconfigurability***

Agent-based solutions strongly support a plug and play approach. This allows to change, add or remove hardware and software modules, online whenever it is necessary. It also makes the maintenance of the system significantly cheaper. This change is the result of either equipment failures or in a change of plan. Migration from old technology to new ones can evolve slowly without disrupting the operation.

Chapter II. AI

II.1. Attempt at a Definition

The name "Artificial Intelligence" was proposed in 1956 by McCarthy (Andresen, 2002). It covers the sciences and technologies that allow us to imitate, extend and/or increase human intelligence with machines. This term, still subject to debate on its semantics, was more a declaration of intent for the creation of a new discipline that wanted to differentiate itself from more formalized fields such as mathematics or computer science, than a true accomplished science.

Indeed, the field of artificial intelligence calls upon many disciplines that have helped to shape its theoretical and practical aspects. This first observation on the heterogeneity of the origins of artificial intelligence gives an overview of the complexity in drawing its contours which makes any attempt at a single definition futile.

We can see that the field is so broad that different systems of reflection and then of thoughts have been built in parallel to answer this question.

Depending on the angle taken, the disciplines will have varying importance. One, however, will always be at the heart of the implementation and practical architecture, computer science, whose rise was the main catalyst for the production of algorithms, some of which were imagined as early as the 1960s. However, some authors, pillars of the field, have tried to define this concept. According to Norvig and Russel (2020), four types of thought systems make it possible to circumscribe the problem posed by the definition of the field of artificial intelligence. Indeed, the problem is to define what intelligence covers and what can be considered as an imitation of this intelligence.

The first system is the one that considers that artificial intelligence must lead to human thinking. The goal is to give computers the ability to think like a human. It is also called the cognitive approach, which amounts to giving machines the ability to think in the full and literal sense by drawing inspiration from human thought. This requires determining how humans think and so calls upon cognitive science. Thus, this interdisciplinary approach to cognitive science brings together computer models from artificial intelligence and experimental techniques from psychology in order to construct precise and verifiable theories of how the human mind works. (Norvig & Russell, 2020).

The second system is that of the law of thought or how to think rationally. This system originally formulated by Aristotle (Aristotelian Logic and Formal Thought) deals with the form of reasoning, independently of its contents or the objects on which it bears. These laws of thought are supposed to govern the operation of the mind and lay the groundwork for logic (Norvig & Russell, 2020). The development of formal logic provided a precise notation for formulations on all sorts of topics in the world and their interrelationships. As early as the 1960s, there were programs that could, with enough time and memory, describe a problem in logical notation and find the solution to the problem, However, if no solution existed, the program could continue searching indefinitely without halting. (Norvig & Russell, 2020).

The third system is that of the rational agent (acting rationally). Indeed, the field of artificial intelligence includes the study and construction of "intelligent agents". What we call an "intelligent agent" is a system that is able to perceive its environment and make decisions that optimize its chances of success in performing a task (Norvig & Russell, 2020). An agent can be represented/defined by a function (F), which accepts a perception of the world and decides on an action to take

To be considered an intelligent agent (i.e., artificial intelligence), the following elements must be taken into account:

- *Perception,*
- *Knowledge representation,*
- *Reasoning,*
- *Planning,*
- *Learning.*

Elements 1, 2 and 3 are the minimum prerequisites to be able to succeed in a task. Therefore, an agent perceives its environment and encodes this perception using a particular representation (for example a vector) that it will then compare with a knowledge base (of the same representation). Then, it reasons before deciding on the action to perform. But, without learning, the agent will not be able to adapt or improve in its environment and will be limited to a few rules codified by a human being on a purely deterministic model. Similarly, without planning, it will not be possible for it to have a long-term vision.

In addition, when we talk about "success" in a task, we can speak more specifically of a loss/error function (to be minimized) or performance (to be maximized). It is crucial - but not always obvious - to define the task according to our intuitions and our morals. Whatever happens, the human must stay behind the intelligent agent to understand its decisions.

The fourth system is the one that proposes to the computer to act humanly. This vision leads to the study of computers to do things that, at present, are better done by humans (Norvig and Russel, 2020).

This school of thought began with Turing in 1950, when he published his paper "Computing Machines and Intelligence" in which he defined what we call the Turing Test or the Imitation Game. Turing (1950) defined intelligent behavior as "the ability to match human performance in all cognitive tasks, sufficient to fool an interrogator." However, to achieve this goal, the computer must have the following capabilities in its programming:

- *Natural language processing (NLP) to enable it to communicate successfully.*
- *Knowledge processing and knowledge representation to store what it knows or hears.*

- *Having an automated representation, that is, automated reasoning to use the saved information to answer questions and draw new conclusions.*
- *Managing machine learning to adapt to new situations and to detect patterns.*

If the computer is to interact with the examiner, it must have two additional characteristics:

- ***computer vision**, which must allow it to recognize objects.*
- ***robotics**, which allows it to manipulate and move objects.*

These six disciplines constitute most of the fields studied in artificial intelligence. However, this Turing test is not often proposed. The question of acting like a human arises mainly when artificial intelligence programs must interact with humans, such as when an expert system explains how it arrived at its diagnosis, or when a natural language processing system engage in a dialogue with a user (Indira Gandhi National Open University, 2003).

II.1.1. Data Science

Since the early 2000s, two other components have evolved significantly, the exponential mass of data and the increasing computing power (Moore's law), which has given a much larger share to learning on large quantities of data. This field of study, which we call data science, although being a sub-part of artificial intelligence itself, is partly at the origin of the craze for data. (Mitchell, 1999).

Data science involves human expertise and visualization to improve learning. It often uses elements of artificial intelligence to improve the highlighting of rules and regularities, this is the role of data mining (in particular statistical, mathematical and computer science techniques). This interdisciplinary field shares machine learning with artificial intelligence but also relies on human expertise to analyze large amounts of data, and extract knowledge that a human alone could not see (Mitchell, 1999).

Data science is at the crossroads of expertise, computer science and mathematics. The goal of data mining is to extract knowledge from available databases. In practice, this corresponds to the use of exploratory techniques, with the aim of discovering relationships within the data studied (rules, correlations, dependencies) after cleaning and preprocessing them (Mitchell 1999).

II.1.2. Machine Learning

Machine learning methods are one of the most important approaches to artificial intelligence. Machine learning is at the heart of data science. According to Professor Mitchell (1999), it consists of creating computer programs that improve with experience. In this context, the task is to build an algorithm based on the available data and predict a class at the output.

To achieve this result, the main components of machine learning are:

- *a database,*
- *a loss function or objective function (the definition of the goal for the agent),*
- *a model (or, how we will represent the problem),*
- *an optimization method (how we will do the learning).*

Also, the "actions" to be taken are specifically to choose a label to place on each entry (perception of a data). With the different combinations of this recipe, when the database is annotated by experts, meaning that we already have a label to train the algorithm, we speak of supervised learning.

Depending on the type of data, we can carry out either regressions (quantitative class or prediction) or classifications (qualitative class or prediction). It is also possible to carry out unsupervised learning to bring out new groups of classifications within the data thanks to clustering or data reduction techniques.

In short, artificial intelligence is not a new discipline because it uses concepts discovered in the 18th century, and the research itself began in the 1950s until today with periods of plateau. Even the famous "deep neural networks" have been known for decades. Nevertheless, it is certain that artificial intelligence has attracted/renewed interest since the early 2000s, thanks to successes that are revolutionizing both the industrial world and the daily life of citizens and as a result, it attracts billions of euros in funding for research and its ubiquitous implementation (Iqbal, 2009). There is almost no industry or sector that remains unaffected by this change. The logistics sector is obviously no exception. These techniques can also be used at the organizational level to optimize customer journey management.

However, there are risks associated with its use and deployment that the current craze should not make us forget. Indeed, in the past, artificial intelligence has already experienced some moments of euphoria followed by disappointments and disinterest. To avoid this again, we must keep in mind that the unknowns are even greater than the discoveries and progress made in recent years. Its deployment must be carried out cautiously and must be accompanied by experts in the field to ensure the explainability of the algorithms, guaranteeing its acceptability, and above all to maintain its role of helping to optimize logistics activities.

The integration of artificial intelligence (AI) in the logistics sector has brought about a revolution, fundamentally transforming the way goods are transported from the point of production to the last consumer. At the heart of this transformation, the crucial phase of logistics has become the ultimate innovation ground (Boute & Udenio, 2022). It has indeed become a focal point of attention due to the rise of e-commerce, where customers demand fast, flexible, and seamless deliveries. This supply chain, however, is riddled with complex challenges, ranging from urban congestion to inventory management and delivery times (Beamon, 1998). This is where AI comes in with the promise of optimizing every aspect of logistics. As customers around the world increasingly place orders online, delivery expectations have become more demanding than ever. They demand fast delivery times, increased flexibility, and frictionless experiences. This has exacerbated the challenges of logistics, creating a complex operational landscape (Garcia & You, 2015).

In this context, artificial intelligence has emerged as a major transformative force. It provides solutions to complex logistics problems and optimizes end-to-end delivery operations. AI is thus the backbone of the logistics revolution, enabling companies to rethink route planning, inventory management, customer experience personalization, and environmental sustainability (Garcia & You, 2015).

Within the scope of logistics and planning, this evolution refers to route optimization. AI analyzes a range of data, including traffic conditions, customer preferences, and delivery schedules in real time to design optimal routes (Braganza et al., 2022). This reduces travel times, fuel costs, and greenhouse gas emissions, while increasing customer satisfaction. In real-time inventory management, AI-based systems transcend simple route planning. They also predict customer demand and adjust inventory levels in real time. This allows businesses to avoid costs associated with excess inventory and avoid losses due to stockouts. AI enables customer experience and personalization by offering flexible delivery schedules and anticipating customer needs (Ejimuda et al., 2024).

Chatbots and virtual agents improve communication with customers, providing real-time support and resolving issues quickly. In addition to improving operational efficiency, AI contributes to environmental sustainability by optimizing routes to minimize carbon footprint. It also encourages the adoption of electric vehicles and other eco-friendly solutions.

However, this logistics revolution is not without its challenges. Data security, customer privacy, and regulatory issues require constant attention.

II.2. Smart Logistics

Artificial Intelligence (AI) has emerged as a major player in the transformation of logistics. In the era of increasingly populated and connected cities, efficiently managing delivery operations within these complex urban environments has become a key challenge for logistics and transportation companies. AI provides innovative solutions to address these challenges by optimizing various aspects of logistics. One of the key areas where AI is having a significant impact is delivery route optimization. AI algorithms are able to take into account a multitude of factors in real-time (Veluru, 2023), such as traffic, customer preferences, delivery constraints, and weather conditions to plan more efficient routes. This helps reduce travel times, operational costs, and greenhouse gas emissions, while improving customer satisfaction.

In addition, AI is also being used for vehicle fleet management. By monitoring the condition of each vehicle, planning preventive maintenance, and optimizing resource allocation, companies can maximize the utilization of their fleet while minimizing downtime. This has a positive impact on the profitability and reliability of delivery operations. Demand prediction is another area of application of AI in urban logistics (Cho et al., 2020), by analyzing historical data and using predictive models, demand fluctuations, allowing them to better plan their operations and reduce work peaks.

According to Cho et al. (2020), AI technologies help to efficiently manage local warehouses, collection points, and delivery methods, ensuring a seamless delivery experience for customers. Overall, AI has become a key driver of efficiency, sustainability, and innovation in urban logistics, providing significant benefits to companies while helping to reduce the environmental impact of delivery operations.

II.3. What Is the Connection Between Artificial Intelligence and Logistics?

Artificial intelligence and supply chain are two closely related elements that have revolutionized the way products are delivered to customers.

To understand this complex relationship, it is essential to delve into the challenges faced by logistics. Traditionally, it is a step that requires careful planning, effective coordination, and great attention to detail. Complexities include managing deliveries, the variability of customer schedules and preferences, issues related to traffic congestion, and the need to ensure a satisfactory delivery experience for the customer (Abreu et al., 2022).

This is where AI comes in. Advances in these areas have fundamentally transformed supply chain management. AI offers solutions to optimize delivery routes, allocate resources more efficiently, anticipate customer needs, and improve real-time traceability of goods. In short, AI has transformed the supply chain into a space of innovation and efficiency. This connection demonstrates the critical importance of AI in supply chain management, highlighting its role in optimizing delivery processes, improving customer experience, and reducing operational costs. This relationship continues to evolve and redefine the way products reach customers' hands.

II.4. Emerging Trends

We have already mentioned in the previous sections that new technologies have revolutionized logistics, transforming the way companies plan, execute, and optimize their delivery operations. The rapid advances in AI are paving the way for emerging trends that are profoundly redefining logistics and delivery management. These trends are not only improving operational efficiency, but they are also reinventing the entire delivery process, offering significant benefits to both companies and consumers. Emerging trends in last-mile logistics and conversational AI to interact with customers, autonomous robotics that ensure fast and flexible deliveries, advanced warehouse optimization and demand prediction, these developments are pushing the boundaries of what is possible in supply chain management. The integration of AI into the supply chain promises to reduce costs, increase delivery speed, improve accuracy and reduce environmental impact.

Also, we can say that work on artificial intelligence (AI) has experienced a real explosion in recent years, as it is true that it is profoundly transforming the commercial, industrial and logistics processes of most private and public organizations. AI refers to computer systems that can perform complex tasks that only a human could previously accomplish like reasoning, making decisions, solving a problem and more (Global Online Electronic International Interdisciplinary Research Journal, 2025).

Very few specialists in organizational management and information systems doubt that the use of AI in supply chains will radically transform the way products will be stored, handled and transported in the near future. Let us also note the extraordinary prescience of Fabbe-Costes (1990), who, 35 years ago, anticipated such changes. Since then, an abundant literature has taken up the subject, as evidenced by a quick detour via Google Scholar and the examination of the literature reviews, but very often, by proposing a sort of "catalogue" of probable applications. Even if these works are of real interest, particularly in highlighting how all logistics processes – or almost – will be affected by AI, they lack a reading grid to better understand the holistic and systemic nature of the revolution underway.

Indeed, even a quick analysis of the use of AI in the context of trade highlights that the dream of efficient downstream flow management, mentioned in the 1970s by Heskett (1977), is becoming a tangible reality. In other words, AI places final demand at the heart of the operation of supply chains, breaking with the logic of pushed flows resulting from planning approaches in the materials requirement planning (MRP) movement. Knowing that final demand is expressed in different product reception points, the performance of regional hubs in ensuring distribution becomes a key element of a responsive supply chain, also giving rise to highly innovative AI applications. They are important@ for ensuring rapid and reliable delivery to reception points.

II.5. Significantly Improve Downstream Flow Management

A rapid response to customer demand is a source of competitive advantage, as quick response (QR) approaches have been indicating since the early 1990s (Choi & Sethi, 2010). QR refers to a management approach whose objective is to shorten the time between receiving an order and making it available in order to improve available cash flow; the success of a company like Walmart is a perfect illustration of this, associated with the implementation of innovative information systems, including the famous *Retail Link* (He, 2023).

However, AI algorithms have the capacity to analyze large quantities of historical and real-time data, taking into account numerous factors such as customer behavior, market trends and even weather conditions. AI-based procurement systems use this data to optimize inventory levels and reduce the number of stockouts (Soni, 2022).

Indeed, stockouts are one of the main challenges facing large retailers. A study conducted in the United States indicates that they cost between 15 and 20 billion US dollars per year in lost sales, not to mention the negative impact on the customer experience. When they result from calculation errors in registering products or in anticipating demand, AI can optimize the management of flows downstream in the supply chain in order to reduce the probability of this costly problem occurring. As explained by the Boston Consulting Group in a report published in April 2023 and entitled Amid uncertainty: AI gives retailers a path to resilience, AI algorithms far surpass human capabilities because they are able to predict demand using a multitude of inputs and provide solid use cases in merchandising and inventory management. This clearly contributes to reducing stockouts, an endemic problem for decades (Biggs et al., 2023).

This is probably where the most significant developments will be in the medium term. The doctoral research conducted by Clarke et al. (2008) had early highlighted that the major issue for improving downstream flow management would be, for distributors, to know how to process and interpret billions of data. Some AI projection tools in terms of big data and neural networks are precisely designed to bring out information and knowledge from many sources, including past sales records, real-time customer purchases, mentions on social networks and dominant economic and geopolitical indicators. In addition, AI projection tools can be used to facilitate better collaboration between the links in the supply chain, by allowing data to be shared, in particular between the store and its regional hub.

Since the 1980s, large distributors have set up supply systems based on warehouses and platforms, in other words regional hubs (Corbett, 1996). As a result, direct deliveries are no longer common, except for regional products whose customers are local. The interface between the product reception points and the industrial supplier is thus a sort of "logistics node" whose more or less efficient operation determines the success of downstream flow management.

It is indeed understandable that effective management of sales data by AI risks being completely destroyed by recurring failures in the management of logistics operations on regional hubs. This is why AI is increasingly used to automate a series of tasks, including receiving, putting into storage and preparing orders.

II.6. Better “Perform” the Operation of the Regional Hub

A regional hub, except when it is a simple transit platform, has the main mission of activating the warehousing of products (operational dimension) and the management of product inventories (managerial dimension) as well as possible. In both cases, AI constitutes an important reserve of productivity for large distributors, and the multiplication of publications on the intelligent hub and hub 4.0, highlighted by the literature review of Burciu et al. (2022), provides an excellent indicator.

Concerning warehousing, intelligent robots with computer vision and machine learning perform operations by automating tasks such as sorting and packaging, taking the example of the JD.com case study conducted by Carlsson et al. (2022). These robots can work alongside employees, thus reducing the errors that they could make. More broadly, AI-based systems optimize product allocation, leading to faster order preparation and increased satisfaction of receiving points with a higher level of service quality.

Autonomous mobile robots are becoming a tool used in a growing number of warehouses, as they are able to operate independently: by integrating AI, they efficiently perform complex tasks related to the extreme splitting of deliveries in a context of the disappearance of full pallet supply in favor of composite pallets. In addition, these robots have the ability to adapt to changing configurations of regional hubs and operational requirements. In environments where AI leads to an intensified human/woman-machine interaction (Ardichvili, 2022), the synergy allows humans to focus on more complex tasks that require a strong dose of creativity and specific problem-solving skills, while AI focuses on repetitive tasks.

Using Walmart as an example, the company aims to automate all of its regional hubs within a decade as part of an expanded partnership with AI specialist Symbotic. The scalable AI-powered system includes a fleet of fully autonomous robots to accelerate throughput while increasing the warehouse's capacity to unload, sort and store products. Symbotic's technology leverages palletized loads sorted by family, allowing Walmart to get products onto its North American store shelves faster. Symbotic says regional hubs help modernize the retailer's supply chain by speeding up store order fulfillment, improving inventory accuracy and increasing the capacity to receive and ship products to stores. Other benefits include simplified and safer material handling and the creation of new technology jobs (Redman, 2022).

If we look at inventory management at the regional hub, it is clear that it has been an ongoing challenge for logistics professionals for decades. Here too, AI can provide real-time data on inventory levels, customer habits and delivery times, allowing large retailers to streamline operations and cut costs (Soni, 2022). AI systems can use machine learning algorithms to predict optimal inventory levels, reduce excess inventory and even automate replenishment processes, a key dimension of a responsive supply chain (Kalusivalingam et al., 2022). Such intelligence-based inventory management, in a pure knowledge management logic, promotes better demand satisfaction by increasing the level of customer service and improves cash flow by drastically reducing working capital requirements.

II.7. Optimizing (Sustainably) the Delivery Process

If the regional hub, as a point of origin of the products, has the function of ensuring the interface between the point of destination of the products, then it is impossible to ignore the routing activity. Even if the model of delivery in a few hours (the "same-day delivery"), as initiated by Amazon, implies the presence of small depots, from which the products travel a few hundred meters, the most common case remains that of transports that are deployed over several tens of kilometers, since the regional hubs need a large space far from cities. In a context of climate crisis that highlights the environmental issues associated with the transport of goods, widely highlighted by researchers (Bagreeva et al., 2021), it is clear that large distributors must urgently think about sustainable deliveries.

In this sense, the question that arises is the following: What are the prospects offered by AI in this area? The most frequently cited examples, particularly in the professional press, concern optimized route planning, which also refers to issues addressed in logistics in the early 1970s, particularly in the work of Kolb (1972). AI algorithms can indeed optimize delivery route planning by taking into account various factors such as traffic conditions (traffic jams during peak hours), fuel costs, and delivery windows imposed by the receiving point.

AI can identify the most efficient routes, recommend alternative modes of transportation, and even optimizer vehicle loading based on historical and real-time data (Soni, 2022). These intelligent logistics technologies minimize CO_2 emissions, while increasing the level of agility demonstrated by the delivery process (Caldeira et al., 2011).

What is now called smart mobility increasingly relies systematically on the Internet of Things (IoT) with sensors to track and trace deliveries in real time. For example, if a vehicle deviates from its route, breaks down or exceeds the maximum speed, the system will send an immediate alert. The next challenge is to plan the route of each of these delivery vehicles by combining IoT and AI within an Artificial Intelligence of Things (AIoT) platform. By combining IoT sensor data with AI analytics, economic, operational and energy factors will be taken into account to increase the operational efficiency of deliveries. When assigning them to different vehicles and determining the best route, AI takes into account parameters such as the mix of products to be delivered, delivery times, product characteristics, load volume and vehicle type (Coronado Blazquel, 2022).

But AI will certainly not stop at optimizing routes between the regional hub and product reception points. On the contrary, it should have a major impact on food and non-food retail in the use of new means of traction. Without falling into science fiction, even if it can have virtues in management, it is very likely that the use of autonomous vehicles will develop rapidly in the very near future. One of the explanatory factors is that the technology is progressing rapidly, while there is a shortage of qualified drivers. According to Bendiab (2023), the technology will become an attractive option for large distributors as it becomes more reliable, knowing that it is impossible to determine precisely when autonomous vehicles will be in common use given the safety standards to be respected and that an ad hoc law on robots still need to be built, even if McKinsey & Company takes the risk of projecting 2027 as the year of the generalization of autonomous vehicles.

Partial Conclusion

Writing that AI is about to revolutionize the functioning of most supply chains is not really a "scoop". Indeed, regardless of their sector of activity and size, companies are looking for new sources of flow optimization, factors of renewed cost- and price-competitiveness, and even when the positioning is that of differentiation through the service offered to customers, logistics plays an essential role, for example with high levels of responsiveness to sometimes volatile demand. Large distributors, both online and offline, are not immune to this structuring trend, and by exploiting the algorithmic power of AI, they have understood that the possibilities of improving downstream flow management, optimizing inventory management, automating warehousing operations and delivering their stores, drives and relay points as best as possible have never been greater. In other words, the future of the supply chain will undoubtedly consist of the intelligent integration of AI technologies, opening the door for a more agile, resilient and sustainable ecosystem (Artifical Engine, n.d.). This optimism is reiterated by Roschelle and Rotenberg (2022) who do not hesitate to speak of a "magical relationship" with AI.

However, we should not recklessly deify AI, one of whose main limitations is the existence of biases constituted by the existence of incomplete or deliberately truncated data, coupled with complex algorithms (such as neural networks), factors of significant informational asymmetries. A biased AI system can thus be deliberately designed to give priority to certain logistics parameters, leading to an underuse of resources in certain areas, for example an optimization of the delivery process contrary to that of product storage and order preparation in a regional hub. More broadly, AI's complex algorithms can undermine teams' "power to act," as Liu (2018) points out, and ultimately generate powerful resistance to the adoption of a major innovation that undoubtedly requires a change in mindset and organizational culture. Therefore, logistics employees must be trained to work with AI, and senior management must be prepared to implement decision-making based on the data that we have just indicated may be incomplete or truncated.

Ensuring data quality throughout the supply chain can be extremely difficult when the supplier network is complex, with multiple levels of decomposition (rank 1 to rank n) and geographical locations scattered over large scales, as is the case for global value chains. Not to mention the fact that developing and integrating AI into the existing architecture of a supply chain can be time-consuming and costly.

It will indeed be a question of investing heavily in infrastructure, employee training and maintenance activities to take full advantage of the potential benefits of AI. Such dimensions should not be underestimated, at the risk of opting for a purely instrumental vision of AI, while its political dimension in the sense of Morgan (2006), that is the fact that the supply chain refers to an assembly of subsets and objectives that sometimes oppose each other in the way they project the dynamics of flows, is of crucial importance that no one will dispute. Nothing surprising in essence when we look at older processes of adoption of an information-based innovation, which were also confronted with a clearly "political" logic.

PART 2: EMPIRICAL PART

Chapter I: Presentation of Sabena Engineering and the Study Framework

In this chapter, we present Sabena Engineering, a key company in the logistics and aeronautics sector, highlighting its main activities and its role in optimizing logistics processes. We will also detail the study framework, which allows us to analyze the impact of artificial intelligence in the company's operations, exploring the issues and objectives of this technological transformation. This framework will serve as a basis for understanding the specific contexts in which these technologies are deployed and the challenges associated with integrating them.

I.1. Presentation of Sabena Engineering and its Logistics Environment

I.1.1. History and Activities of Sabena Engineering

Founded in 1923, Sabena Engineering is a company specializing in aeronautical maintenance. It offers a wide range of services for civil and military operators. With decades of expertise, the company has established itself as a key player in the aircraft engineering and maintenance sector, offering tailor-made solutions adapted to the specific needs of its customers. Its headquarters are located in Brucargo, Steenokkerzeel, a strategic location close to Brussels airport, which facilitates the logistics and management of maintenance operations. Sabena Engineering's activities cover several key areas of aeronautical support, including the maintenance, repair and overhaul of commercial and military aircraft, the management of aeronautical components and equipment, and the maintenance of engines and avionics systems. Thanks to its expertise, the company helps to ensure the safety and performance of aircraft, in compliance with the most stringent international standards in the sector (Sabena Engineering, n.d.).

Sabena Engineering's logistics environment is marked by specific requirements linked to the very nature of its operations. The company has to manage complex logistics flows, from the supply of spare parts and components to the distribution of repaired or replaced equipment. One of the major challenges lies in optimizing stock management and storage space, particularly for aeronautical parts, which require specific packaging and rigorous traceability. As part of the digital transformation of the logistics sector, Sabena Engineering is implementing artificial intelligence-based solutions to optimize its operations (Sabena Engineering, 2024). The company relies in particular on innovative technology of Modula, which automate stock management and the picking of spare parts. This tool is designed to improve operational efficiency by reducing the time needed to identify, locate and retrieve components, while optimizing storage space. In logistics, the ability to maximize available space is a key competitive factor, as it enables storage capacity to be increased and, consequently, revenue opportunities to be maximized (Modula, n.d.).

In addition to optimizing storage, the company is relying on artificial intelligence to improve other aspects of its supply chain, including transport planning and flow management. Efficient management of delivery routes, based on the use of real-time data such as traffic conditions, delivery times and customer preferences, is a major challenge for ensuring the responsiveness and profitability of operations. However, the adoption of new artificial intelligence technologies at Sabena Engineering is not without its challenges. Thanks to the implementation of the new systems, in particular the Modula cabinets, the company expects to see benefits in the medium and long term. Among the challenges identified are the high initial cost of investing in AI and the need for employees to adapt gradually to the new working methods. IT support is essential in the initial phase of the project to ensure successful integration (Sabena Engineering, 2024).

As part of its ongoing innovation strategy, Sabena Engineering aims to take advantage of artificial intelligence to optimize its logistics and strengthen its operational efficiency. The aim is to make maintenance and parts flow management processes more efficient, reducing labor costs and increasing the flexibility of operations. Ultimately, this digital transformation should enable the company to improve its competitiveness in the aeronautical maintenance market by reducing turnaround times and improving the quality of service provided to its customers (Sabena Engineering, n.d.).

I.1.2. Organization of Logistics and the Supply Chain

Logistics management at Sabena Engineering is based on a structured organization designed to optimize the flow of resources and equipment required for aeronautical maintenance operations. As a company specializing in aircraft maintenance, repair and overhaul, Sabena Engineering has to manage a complex logistics network integrating several levels of players, from spare parts suppliers to end customers, including storage and distribution platforms (Sabena Engineering, 2024).

Sabena Engineering's logistics organization is based on an optimized supply chain to meet the requirements of its aeronautical maintenance activities. This organization is based on the management of physical and information flows, taking into account the imperatives linked to delivery times, stock management and coordination with suppliers and customers. The company has introduced automated a storage system that is Modula, which improve the management of spare parts and optimize the space available in its warehouses. This technology makes parts more accessible, reducing preparation and distribution times. One of the major logistics challenges facing Sabena Engineering is the management of resources and infrastructure. The storage of spare parts and maintenance equipment represents a constant challenge due to the volumes to be handled, space constraints and traceability requirements. The company seeks to maximize the use of its logistics infrastructure while reducing the operational costs associated with the storage and management of spare parts flow (Sabena Engineering, 2024)

In this constantly changing environment, the ability to optimize the management of stocks and distribution flows is an essential factor in ensuring the continuity of maintenance operations and customer satisfaction. The gradual integration of new technological solutions based on artificial intelligence, such as automated storage systems and algorithms for optimizing logistics flows, is part of this drive for continuous improvement. This modernization not only increases the speed and reliability of deliveries, but also reduces the costs associated with storage and resource management. By integrating systems such as Modula, Sabena Engineering is seeking to meet the challenges posed by the growing complexity of aeronautical logistics, in particular the efficient management of spare parts stocks, the optimization of storage space and the acceleration of picking and distribution processes. These advances are part of a wider drive for digital transformation aimed at increasing the company's operational efficiency and competitiveness in a constantly changing market (Sabena Engineering, n.d.).

I.1.3. Logistical Issues and Challenges Facing Sabena Engineering

Sabena Engineering operates in a sector characterized by high requirements in terms of precision, responsiveness and compliance with safety standards. Logistics management in this field is particularly complex due to the quality, lead time and traceability requirements that must be met to ensure the availability of parts and equipment needed for aeronautical maintenance operations. One of the main challenges facing the company is the optimization of logistics flows, particularly in terms of stock management and picking. The increasing volume of operations and the diversity of parts to be stored mean that space and resources have to be managed efficiently. The constant quest to reduce costs is driving Sabena Engineering to rationalize its storage and distribution process, in order to maximize the use of space and optimize order processing time (Sabena Engineering, 2024)

Another major challenge lies in the planning and organization of transport. Sabena Engineering's logistics relies heavily on the availability and punctuality of deliveries, particularly due to the critical nature of aircraft maintenance operations. The management of transport routes is subject to unforeseen events such as delivery delays, variations in demand, or logistical hazards linked to the flow of components and spare parts. Any disruption can have a significant impact on maintenance operations and, by extension, on aircraft availability. The integration of artificial intelligence into Sabena Engineering's logistics process is part of an optimization approach designed to meet these challenges. However, the company faces a number of obstacles in its digital transformation strategy. These include employee resistance to change, the need for adequate training in the new technologies and the high initial cost of investment. The adoption of solutions such as Modula cabinets is part of a continuous improvement project, but its impact has yet to be measured, particularly in terms of reducing costs and optimizing workflows (Sabena Engineering, 2024).

Despite these challenges, AI offers promising prospects for optimizing a company's logistics activities. It is a strategic lever for reducing labor costs, improving stock management and increasing transport efficiency. Employee acceptance of these technologies is also a key issue, requiring specific support and training to ensure their adoption and maximize their impact on optimizing logistics operations.

I.2. The Integration of Artificial Intelligence at Sabena Engineering

I.2.1. Motivations for the Implementation of AI in Logistics

I.2.1.1. Company Objectives

Sabena Engineering operates in an environment where competitiveness is largely based on logistical efficiency and operational cost control. The company, which specializes in aeronautical maintenance, has to manage flows of spare parts and equipment in a context where supply and delivery times are crucial. The need to improve the performance of its operations while reducing costs has led to the gradual adoption of solutions based on artificial intelligence. The main aim of integrating these technologies is to reduce logistics-related costs, in particular by reducing the working hours spent on repetitive tasks such as picking and stock management. By automating these operations using advanced storage and retrieval systems such as Modula, companies can optimize the use of their workforce, freeing up time for higher value-added activities. Reducing labor costs over the long term is a key motivation in this digital transition, as it increases profitability while maintaining a high level of quality and compliance with aeronautical safety standards (Sabena Engineering, 2024).

Then there is storage optimization. The space available to store spare parts and components is a strategic factor, as it directly influences the company's ability to respond to maintenance needs. By optimizing stock organization through AI and automation, it is possible to maximize storage space, reduce warehousing costs and improve the accessibility of parts for technicians. Improved stock management also makes it possible to limit the risk of stock outs, avoid over-accumulation of materials and ensure smoother management of logistics flows. Optimizing distribution and transport flows is another major lever for improvement. AI makes it possible to plan transport routes more efficiently, taking into account a number of parameters, such as real-time traffic conditions, vehicle availability and customer needs. This data-driven approach aims to minimize delivery times, better allocate resources and guarantee a more responsive service. Greater precision in planning logistics flows helps to limit the costs associated with delays, delivery errors and unnecessary expenditure on fuel or temporary storage (Sabena Engineering, 2024).

Through this logistical modernization, the company is seeking not only to improve efficiency, but also to position itself as an innovative player in the aeronautical maintenance sector. The introduction of AI is part of a drive to move towards a more agile logistics model, capable of anticipating fluctuations in demand and continuously optimizing internal processes. The aim of this transformation is to ensure better management of resources and reduce costs, while maintaining a quality of service in line with customer requirements and strict aviation regulations (Sabena Engineering, n.d.).

I.2.1.2. Global Context of Digital Transformation in Logistics

Digital transformation in the logistics sector is part of a global drive to modernize and optimize supply chains. Faced with increased competition, growing demands for rapid and reliable deliveries, and constant pressure to reduce costs, companies in the aeronautical maintenance sector, including Sabena Engineering, are turning to artificial intelligence and automation to improve their competitiveness. The growth of global trade, the increasing complexity of supply chains and the need to optimize logistics operations have led companies to seek advanced technological solutions. Artificial intelligence, combined with tools such as the Internet of Things, predictive analysis and robotics, offers unprecedented opportunities to manage stocks, logistics flows and human resources more efficiently. As a major player in aeronautical maintenance, Sabena Engineering must guarantee a fluid and responsive supply of parts and equipment, while controlling costs and reducing response times. The gradual implementation of new technologies is part of a strategy to adapt to the profound changes taking place in the sector (Sabena Engineering, n.d.).

The company has undertaken to implement automated storage and retrieval systems for spare parts, in particular Modula. However, we must add that other companies use Kardex and Rotomat solutions. These technologies enable better management of storage space and optimization of picking processes, reducing the time needed for order preparation operations. By improving the accuracy of logistics flows and limiting human error, these systems contribute to better resource management and lower long-term operating costs (Modula, n.d.). The introduction of artificial intelligence into logistics processes is also part of a wider drive to optimize transport and distribution. AI enables real-time analysis of data relating to routes, delivery times and transport conditions, facilitating better decision-making in flow planning. For a company like Sabena Engineering, whose operations require precision logistics, this digital transformation becomes a strategic lever to ensure a faster and more efficient service.

However, the transition to AI-based systems is not without its challenges. Implementing new technologies requires significant investment, and the economic benefits are only perceptible in the medium to long term. Furthermore, adopting these tools requires support for employees, particularly in terms of training, to ensure successful integration and greater acceptance of the new practices. The involvement of IT teams is essential to support the implementation and maintenance of digital infrastructures, particularly those linked to automated storage systems and AI-based logistics flow management solutions.

I.2.2. AI Technologies Generally Used in Companies: The Case of Kardex, Modula and Rotomat

I.2.2.1. Functioning and Specific Features of the Technologies

Among the most widely used innovative solutions are the Kardex, Modula and Rotomat technologies, each of which has its own specific features and its own way of integrating AI to improve the efficiency of logistics operations.

- ***Presentation of Kardex Technology (Kardex, n.d.)***

Kardex is an automated storage management system based on vertical storage and automated goods movement technologies. It is designed to maximize space utilization while improving the speed of product retrieval. AI technologies built into Kardex systems enable intelligent inventory management, optimizing the placement of items based on demand, product turnover frequency and historical trends. The system can also predict future stock requirements through data analysis, enabling more accurate replenishment planning. The robots and conveyors used in these systems are controlled by AI algorithms that optimize the path of each product to make it available more quickly.

Kardex is a major player in the field of automated logistics, renowned worldwide for its innovative storage and goods flow management solutions. Over the years, the name ‘Kardex’ has become almost synonymous with automated vertical storage systems. Behind this name lies a company with a long industrial history, a capacity for continuous adaptation to technological developments, and a strong ambition: to optimize logistics operations through automated and intelligent solutions. The history of Kardex dates back to the early 20th century. Founded in the United States as Remington Rand Kardex in 1898, the company initially developed physical filing and archiving systems, mainly for business documents and files. The name ‘Kardex’ was originally an abbreviation of ‘card index’, an innovative system at the time for filing manual data efficiently. As logistics needs evolved and industrial technologies developed, the company gradually broadened its scope, moving into automated logistics and warehousing.

It was in the second half of the 20th century that Kardex really came into its own in the field of industrial storage. In Europe, particularly in Germany and Switzerland, the company gained new momentum. Today, the Kardex group is mainly divided into two divisions: Kardex Remstar and Kardex Mlog. Kardex Remstar specializes in dynamic storage solutions such as automated vertical storage systems (VLM) and horizontal carousels, while Kardex Mlog focuses more on complex intralogistics systems and large-scale warehouses. The technologies developed by Kardex are based on a fundamental principle: the product comes to the operator, not the other way round. This working paradigm is revolutionizing warehouse management by considerably reducing journey times, human error and the costs associated with picking operations. Among Kardex's most emblematic solutions are vertical storage systems such as the Kardex Shuttle XP. These machines resemble large, automated cabinets in which goods are stored on mobile trays. When an operator calls up a product via an interface, the system identifies where the product is stored, mobilizes the appropriate tray and automatically transports it to an opening at an ergonomic height. This process not only saves space (up to 85% less floor space) but also improves the viability of the warehouse.

With the advent of artificial intelligence and robotics, Kardex has been able to incorporate the latest innovations into its solutions. Modern systems no longer simply store and return goods on demand. They analyze usage data, order histories, seasonal demand peaks and product turnover rates to anticipate future needs. For example, a frequently used item will automatically be placed in a more easily accessible area of the system, reducing the time needed to retrieve it. This functionality is based on machine learning algorithms, which continually adjust the parameters of goods placement and access. Automated conveyors, robotic arms, vertical lifts and visual control interfaces are all components integrated into the Kardex system. They interact under the supervision of centralized software that manages goods-in, goods-out, locations, stock levels and replenishment requirements in real time. The software is often connected to an ERP (Enterprise Resource Planning) system to ensure complete synchronization with the company's other functions, such as production, accounting or customer order management. Thanks to this interconnection, the company can adopt a fluid, agile logistics strategy that is responsive to unforeseen market events.

A further aspect of Kardex solutions is traceability and security. Every product movement is recorded, so you can always know where an item is, when it was stored, by whom and for what purpose. This traceability is crucial for certain highly regulated sectors, such as the pharmaceutical industry, aeronautics and military logistics. In addition, systems are often equipped with access security levels, limiting the handling of certain products to authorized personnel, which is an advantage in terms of quality control and compliance. In terms of evolution, Kardex has made continuous integration a pillar of its strategy. The company collaborates with logistics researchers, automation research centers and emerging technology companies to enrich its ecosystem. For example, it is developing augmented reality solutions to assist operators when interacting with machines, and intelligent touch interfaces to enhance the user experience.

With sustainable development in mind, Kardex is also investing in energy-efficient technologies. Its systems consume less energy than traditional warehouses because they limit unnecessary movement, reduce the lighting required (storage areas are often closed and lit only when open), and can be coupled with renewable energy sources. Furthermore, by reducing storage and picking errors, they indirectly help to reduce the waste of resources. Adaptability is another strength of Kardex systems. Whether an SME needs a compact storage solution, or a large industrial group is looking for complete automation of its logistics flows, Kardex offers tailor-made configurations. The machines can be installed on mezzanine floors, in controlled environments, in combination with AGVs (Automated Guided Vehicles), or in multi-site installations.

In human terms, Kardex is also transforming warehouse work. By automating the most arduous tasks, the company is reducing musculoskeletal disorders (MSDs) and improving working conditions. Operators are becoming supervisors, quality controllers and even maintenance technicians, fundamentally changing the nature of their jobs. The training on offer supports this transition to a more technical and technological logistics environment. The COVID-19 pandemic acted as a catalyst for the adoption of Kardex systems. Many companies, faced with the need to maintain their business while limiting human contact, turned to automation. As a result, Kardex has seen significant growth in 2020-2022, with installations in healthcare, food retail, e-commerce and industrial manufacturing. The resilience provided by automated solutions has proved its relevance in times of crisis.

Today, as the digital transformation of businesses intensifies, Kardex is positioning itself as a leader in logistics 4.0. By combining robotics, AI, data analytics and flexibility, it is offering a vision of the warehouse of the future: intelligent, connected, autonomous and eco-responsible. Warehouses are no longer simply storage facilities, but nerve centers for commercial activity, capable of responding instantly to customer requests, managing complex flows and providing strategic added value to the company. Kardex embodies the evolution of modern logistics. From its beginnings as a manual filing system to its latest innovations incorporating artificial intelligence and robotics, the company has successfully adapted to technological and industrial change. Its management software and equipment no longer simply meet the needs of businesses: they anticipate and shape them, propelling them into a new era of logistics performance. For any company seeking to optimize stock management, improve team productivity and reduce costs while increasing customer satisfaction, Kardex is an essential partner.

- ***Presentation of Modula Storage System***

Modula is an automated storage and retrieval system that works with a dynamic stock management process. Artificial intelligence in Modula enables the optimal arrangement of items in the warehouse to be calculated on the basis of a number of criteria, such as real-time demand and delivery priorities. Thanks to AI, the system adapts to fluctuating needs and constantly optimizes the organization of the warehouse, reducing human error and waiting times. Predictive analysis is also used to anticipate replenishment needs, enabling smoother, more efficient stock management (Sabena Engineering, 2024).

The Modula story began in the early 2000s, when the Italian company Modula Srl was founded. Initially, the company's aim was to offer solutions to improve the management of storage space in warehouses, maximizing the use of vertical space. Modula's initial solutions focused mainly on automated vertical storage systems, similar to those developed by other market players such as Kardex. However, Modula quickly distinguished itself by its innovative approach and early use of artificial intelligence to optimize stock management in its automated systems. One of the great advantages of the Modula system is its ability to integrate dynamic stock management. Unlike traditional warehousing systems, where products are stored statically and access to items often requires complex physical movement, Modula offers automated management that enables rapid, error-free retrieval. At the heart of this solution is an automated logistics management process, which relies on the system's ability to adjust the layout of items in real time according to user requests, delivery priorities and order volumes (n.d., 2020).

Modula's design is based on a simple concept: items are stored on mobile shelves that can be moved vertically or horizontally as required. When an operator wants to retrieve a product, they simply enter an order in the system's management interface. Modula's intelligent software then selects the optimum location to retrieve the item, based on its availability and location in the system. This automated system reduces the time spent searching for and retrieving items, significantly improving warehouse productivity. What sets Modula apart from other automated stock management systems is the introduction of artificial intelligence into its operation. The system is equipped with software that continually analyses data relating to stocks, orders and consumer trends. Artificial intelligence is used to calculate the optimal layout of items in the warehouse in real time, taking into account factors such as current demand, delivery priorities, expiry dates and even seasonal fluctuations in demand. Using these criteria, the system adjusts the position of items on shelves and optimizes routes to maximize efficiency (Vanas Engineering, 2024).

Modula's software goes beyond simple real-time management. Using sophisticated predictive analysis algorithms, it can anticipate future replenishment needs. For example, if a category of items starts to experience high demand due to an emerging trend or an anticipated event, Modula's AI can predict the increase in requirements and recommend adjustments to inventory or the ordering of new stock. This enables companies to anticipate stock shortages and maintain a high level of service for their customers. Predictive intelligence and real-time adjustments enable Modula to considerably reduce human error. In traditional warehouses, stock errors are often due to manual input errors or confusion over the location of items. The Modula system eliminates these errors by ensuring continuous and dynamic stock management, with complete traceability of product movements. Each item is tracked throughout its journey through the system, guaranteeing total transparency of processes and enabling stock integrity to be checked at any time (Vanas Engineering, 2024).

Modula's dynamic adaptation process also makes it easier to manage fluctuations in demand. Whether it is an e-commerce company that has to deal with a sudden increase in orders during a promotional period, or a distribution company that has to manage large volumes of orders during peak periods, Modula adjusts its operations to meet these needs. This dynamic management system not only reduces the costs associated with surplus stock but also optimizes the use of space. The system can be installed in smaller storage spaces, while offering storage capacity equivalent to that of much larger traditional storage systems. Another major advantage of Modula is its intuitive user interface, which simplifies day-to-day warehouse management. Operators can easily interact with the system via a touch screen or a central computer. This interface enables them to view stock levels in real time, carry out quick item searches, place replenishment orders and optimize picking tasks according to priorities. In addition, integration with other warehouse management software (WMS) and the company's ERP systems ensures consistency of information throughout the supply chain, from production to distribution (Vanas Engineering, 2024).

Another important aspect of the Modula system is its ability to adapt to different sectors and logistics needs. The system can be used in a variety of applications, from pharmaceuticals and retail to automotive logistics and consumer goods distribution. Each sector has particular requirements in terms of product storage and retrieval, and Modula offers a flexible, customized solution to meet these specific needs. For example, in the pharmaceutical industry, where the management of drug stocks is particularly critical, the Modula system can be configured to meet strict safety and traceability standards, ensuring compliance with health regulations. Modula's evolution has also been marked by a particular focus on reducing its ecological footprint. The system uses less energy than traditional warehouses, as it minimizes movement and reduces the use of lighting and heating in unused areas. In addition, more precise stock management helps to reduce waste, by avoiding overproduction and surplus products (Vanas Engineering, 2024).

The scalability of the system is also a key factor in its success. As technology advances, Modula continues to develop new functionalities. For example, the integration of robotics and automated guided vehicles (AGVs) completes the automation of logistics processes. These robots can transport items from one point to another in the warehouse without human intervention, increasing the speed of operations and further reducing the risk of errors. In addition, connectivity to the Internet of Things (IoT) enables data to be collected and analyzed in real time, providing companies with detailed information to fine-tune their stock management. Therefore, the Modula system is much more than just an automated storage system. It represents a global, intelligent solution for managing the warehouse and optimizing the supply chain. Thanks to its constant evolution and the integration of artificial intelligence and advanced technologies, Modula enables companies to meet the contemporary challenges of modern logistics: cost reduction, increased productivity, flexibility and customer satisfaction. Its success is testament to the way in which technological innovations are transforming logistics processes, paving the way for a new era of efficiency and performance in inventory management (Modula, n.d.).

- ***Presentation of Rotomat Storage System (Hanel, n.d.)***

The Rotomat system, another major player in the field of warehouse automation, is based on vertical and horizontal rotating cabinets. These cabinets are used to store and retrieve small parts and products quickly and efficiently. The AI used in Rotomat calculates and adjusts storage and retrieval routes to reduce product search times. The system also adapts to warehouse conditions in real time, optimizing movements and preventing malfunctions through continuous analysis. By combining vision technologies and AI algorithms, Rotomat can also detect and report anomalies or products that no longer meet storage criteria.

These three technologies, while differing in their specific approach, share a common feature: they all exploit AI algorithms to improve inventory management, optimize logistics flows and ensure maximum efficiency. These systems enable companies to improve their warehouse management performance, reduce operating costs and offer greater responsiveness to customer demand. The Rotomat is an automated storage system that is one of a number of innovative solutions developed to meet today's logistical challenges. Used primarily for the storage and retrieval of small parts and components in industrial, medical and distribution environments, the Rotomat system is based on vertical and horizontal rotating cabinet technology. This technology, combined with intelligent management software and artificial intelligence algorithms, enables dynamic and efficient stock management.

The origins of the Rotomat system date back to the end of the 20th century, a period marked by growing interest in the automation of logistics processes. Inspired by the concepts of the Ferris wheel and manual rotating storage systems, the Rotomat was initially designed as a compact solution for optimizing vertical space in workshops and warehouses. Its modular design quickly won over industries looking to improve productivity while reducing the floor space dedicated to storage. With the advent of industrial computing in the 1990s, the Rotomat underwent a major transformation. The integration of stock management software enabled the physical system to be linked to a centralized digital database, facilitating real-time tracking of stored items. The user could now, via an IT interface, automatically control the rotation of the cupboards so that the bin containing the desired item appeared at an ergonomic height. This feature considerably reduced search times and human error when handling products.

The most striking development of the Rotomat is undoubtedly its association with artificial intelligence (AI). With the increasing digitalization of logistics, the system's developers have introduced algorithms capable of analyzing flow data, picking frequency, periods of high demand and replenishment cycles. Thanks to these algorithms, the Rotomat can autonomously optimize the arrangement of items in the cupboards according to their turnover rate. The most frequently used items are placed in easily accessible areas, while slow-moving items are relegated to less busy locations.

Rotomat also uses predictive analysis to anticipate stock requirements. For example, by cross-referencing historical consumption data with current orders and sales forecasts, the system can alert the warehouse manager to impending replenishment requirements. This feature prevents stock-outs and allows stock levels to be adjusted in line with actual demand, resulting in better cost management and greater customer satisfaction. Another notable advance is the integration of artificial vision technologies. Using high-definition cameras and intelligent sensors, the Rotomat system can carry out automated visual checks when items are taken out or put in. This enables it to detect damaged, incorrectly labelled or incorrectly placed products. This continuous check reinforces the reliability of the system and helps to reduce errors in the supply chain.

In terms of adaptability, the Rotomat also stands out for its ability to be integrated into environments with a wide range of constraints. Whether in refrigerated warehouses, medical cleanrooms or highly automated production units, the system can be customized to meet very specific requirements in terms of temperature, humidity, safety or ergonomics. The system is also renowned for its compatibility with Warehouse Management System (WMS) and Enterprise Resource Planning (ERP) software. This compatibility ensures perfect synchronization between warehousing operations and other corporate functions such as purchasing, production and distribution. Furthermore, the dashboards provided by the Rotomat software offer a real-time view of logistics performance indicators, such as fill rate, picking times and stock rotation, making it easier to take decisions.

From an environmental point of view, the Rotomat system also contributes to more sustainable logistics. By reducing unnecessary movement, optimizing storage space and cutting lighting and air conditioning requirements through better stock compaction, it significantly reduces the energy footprint of warehouses. The Rotomat is much more than just a mechanical storage device: it is an intelligent, scalable logistics solution. Its development is a perfect illustration of the transition from traditional warehouses to intelligent logistics centers, capable of self-regulation, adapting in real time and supporting a company's global strategies. Its ability to harness data, interact with other digital systems and automate complex tasks makes it an indispensable tool in the modern supply chain. With ever-increasing demands for speed, reliability and sustainability, the Rotomat is a strategic tool for effectively meeting the new logistics challenges of the 21st century.

I.2.2.2. Objectives and Expectations of These Systems

The objectives and expectations of automated warehouse management systems, such as those offered by Kardex, Modula and Rotomat, are manifold and are primarily aimed at improving the efficiency, speed and flexibility of logistics operations. These technologies are designed to meet specific needs in the areas of stock management, order preparation and warehouse space optimization (Modula, n.d.).

One of the main objectives is to increase productivity by reducing products handling times and optimizing storage space. By automating the process of retrieving items, these systems reduce the need for manual movements, which not only reduces human error, but also the time needed to locate and prepare products. Space optimization is also a key expectation, as automation systems allow items to be stored in a more compact and organized way, maximizing warehouse capacity without the need for physical extension of facilities (Modula, n.d.).

Then there is real-time stock management. By integrating artificial intelligence into these systems, stock levels can be monitored with greater precision, replenishment requirements can be anticipated, and stocks can be adjusted in line with fluctuating demand. The aim is to minimize stock outs and avoid overstocking, thereby contributing to better cost control and smoother resource management. Thanks to intelligent algorithms, these systems can also adapt to demand forecasts, thereby optimizing stock rotation. Another expectation of these technologies is improved responsiveness to customer needs. By making the order management process faster and more accurate, companies can offer a faster, more reliable service, thereby increasing customer satisfaction. The ability of these systems to adapt to changes in warehouse requirements, such as a variation in demand or a sudden need for reorganization, is also a key objective. Flexibility and the ability to integrate these technologies into existing working environments are key requirements to ensure a smooth transition without major disruption (Modula, n.d.).

The overall aim of these systems is to reduce operational costs. By optimizing resources, improving process efficiency and minimizing errors, these technologies enable companies to make significant savings over the long term. This includes not only the costs associated with physical stock management, but also indirect costs such as reduced labor requirements, fewer errors in order preparation and shorter delivery times (Modula, n.d.).

I.2.3. Challenges Encountered When Integrating AI Into Logistics

Integrating artificial intelligence into logistics processes involves a number of challenges, both technical and human. These obstacles are often linked to financial constraints, internal resistance and implementation difficulties, as shown by the results of the interviews conducted with the players involved. One of the main challenges identified is the financial constraint associated with implementing AI technologies in logistics. The purchase of expensive automated systems, the installation of suitable infrastructures and the training of personnel all require substantial investment. These costs can be a major obstacle, especially for companies with limited budgets. The integration of artificial intelligence (AI) into enterprise storage systems represents a major technological revolution, particularly in sectors where precision, speed and security are fundamental requirements. However, this transformation is not without cost. The investment required to integrate AI into warehouses, particularly in aeronautical maintenance and other high-tech industries, is considerable. It is essential to understand the various components of these costs in order to justify their scale and strategic relevance.

First of all, the costs associated with the acquisition of specific hardware are among the most visible. AI systems do not operate autonomously but are integrated into an ecosystem made up of sensors, servers, communication networks, automated storage systems (such as Kardex, Modula or Rotomat), robots and intelligent conveyors. This equipment often has to be tailor-made to suit the specific needs of each company. For example, in the field of aeronautical maintenance, where each part has regulated traceability, the storage system must be able to identify each component with absolute precision, which requires sophisticated RFID sensors, machine vision cameras and integrated weighing devices. This equipment alone can cost several hundred thousand euros, or even more (Modula, n.d.).

Second, the integration of AI requires powerful IT infrastructures. Real-time data processing, machine learning, predictive analytics and image recognition require high computing power. This involves the acquisition of high-performance servers, the deployment of low-latency communication networks (such as 5G or Wi-Fi 6), and sometimes the implementation of secure cloud computing systems. The cost of such a deployment varies according to the size of the company, but it can reach several million euros for complete installations. These infrastructures must be maintained and updated regularly, which also generates significant recurring costs. Another cost factor often underestimated is software development. AI is not limited to universal algorithms downloaded online. In a logistics environment, you need to create machine learning models that are tailored to the specific data of the company, configure inventory management rules, integrate demand forecasts and design a user-friendly interface. This process requires the involvement of data scientists, industrial computer engineers, developers and specialized consultants. To illustrate this, take the example of Sabena Engineering, a company specializing in aeronautical maintenance. In order to automate its spare parts storage system and streamline the internal distribution process, it had to develop customized software capable of identifying critical parts, prioritizing them according to aircraft maintenance cycles, and automatically trigger replenishment orders. This software solution took more than a year to develop, with a team of eight engineers, at an estimated cost of over 500,000 euros (Sabena Engineering, 2024).

Moreover, the implementation of AI in logistics requires a significant training phase. Employees need to be trained not only in the use of new tools, but also in understanding decisions made by smart systems. In regulated sectors such as aeronautics, where safety is paramount, it is essential that operators be able to supervise and interpret AI decisions. This training must be continuous, due to the rapid evolution of technologies. It can be costly, especially if it involves travel, simulators or sessions on specialized platforms (Sabena Engineering, 2024). Another cost is cybersecurity. AI integration means more access points to the company's systems. Connected warehouses become potential targets for cyber-attacks. Therefore, it is becoming essential to strengthen firewalls, intrusion detection systems, data encryption, and invest in regular security audits. For a company like Airbus, for example, which has an international logistics network and automated warehouses, the protection of logistic data and maintenance schedules is a strategic imperative. The cybersecurity budget can represent up to 10% of the total cost of the AI integration project. Indirect costs associated with disruptions must also be taken into account during integration. Transitioning to an automated and intelligent system often requires temporary suspension of operations or reorganizing logistics flows. This may result in delays, temporary subcontracting costs or penalties for failure to deliver on time. These operational impacts must be anticipated and integrated into the overall budget (Airbus Protect, n.d.)

Finally, do not forget about maintenance and continuous improvement. An AI-based system is never frozen. It must evolve with new data, regulatory requirements, changes in business or the availability of new technologies. This involves a scalable maintenance contract with suppliers or the constitution of an internal technology watch team. The annual cost of this maintenance can be 15 to 20% of the initial installation cost. Despite these high costs, companies that invest in logistics AI will reap significant long-term benefits. These benefits include reduced human error, better inventory management, faster response to fluctuations in demand, enhanced traceability and lower operating costs through flow optimization. Sabena Engineering, in the previous example, saw a 30% improvement in productivity of its logistics operations and a significant reduction in aircraft downtime. This has enabled the company to offer more competitive services and expand its client portfolio (Sabena Engineering, 2024).

Furthermore, the long-term profitability of these investments is sometimes uncertain, which complicates the decision-making process. According to the interviews, although these technologies can improve operational efficiency, the return on investment is not always immediate, and it can take several years before the gains made in terms of productivity and cost reduction justify the initial outlay. The late profitability of an intelligent storage system is explained by several factors: the magnitude of initial costs, the time required to learn and adapt AI tools, the complexity of integrating them into systems already in place, as well as the organizational changes necessary to accompany change. All these elements contribute to the long-term extension of the operational, economic and strategic benefits associated with implementing these technologies. Take the example of Sabena Engineering, a Belgian company specializing in aeronautical maintenance. This company, which is committed to maintaining a high level of performance in its logistics operations, has recently invested in an intelligent automated storage system. The objective was twofold: to optimize the organization of its spare parts and streamline the recovery process of technical material. The AI system chosen allowed, on paper, to predict future needs, automate stock movements and optimize storage space (Sabena Engineering, 2024).

However, upon implementation, several hurdles hampered the immediate profitability of the project. First, the initial investment was substantial: purchase of equipment, system setup, recruitment of specialized consultants, and staff training. To this were added indirect costs related to the restructuring of internal flows to adapt to the new requirements of the automated system. Sabena Engineering, like other players in its sector, had to take into account the latency period during which performance remained stable, or even slightly decreased, as long as the system reached its optimum level of efficiency. This phenomenon is partly explained by the need for AI algorithms to rely on a sufficient volume of relevant data to become efficient. In the case of aircraft maintenance, the flows of parts are extremely varied, and sometimes incomplete histories. Therefore, it takes several months or even years for the algorithms to arrive at reliable forecasts. During this time, the return on investment remains low, which can be problematic for companies that need short-term results (Sabena Engineering, 2024).

On the other hand, long-term profitability requires organizational stability and a sustainable strategic vision. However, in a volatile market such as aeronautics, where customer needs, standards and economic conditions are changing rapidly, it is sometimes difficult to predict whether a technological investment will remain relevant in five or ten years. The risk of technological obsolescence is real, especially in an area where innovation advances at high speed. Another compelling example is a pharmaceutical logistics company that has invested in an AI solution to optimize the cold chain. After a successful technical deployment, the company had to face unforeseen additional costs: specialized maintenance of equipment, frequent software updates, and recurrent need for staff retraining. Here again, the economic benefits were only apparent after three years, a time-frame difficult for an SME operating in a context of increased competition.

It is also worth mentioning that the transition to smart logistics requires digital acculturation by teams. Resistance to change is common, and its impact on productivity should not be underestimated. During the first few months of implementation, human errors may even increase due to misunderstanding of the system. This has been observed in several French aeronautical subcontractors who, despite a strong commitment to digital transformation, have seen their performance drop temporarily after the installation of AI tools in warehouses. Faced with these findings, some experts point out that long-term profitability is certainly achievable, but under certain conditions: rigorous project management, a long-term vision well anchored in the corporate strategy, as well as operational flexibility to adapt to the unexpected. The challenge is not only technological, but also human and organizational.

It is also important to emphasize that companies must make informed choices about the nature of AI solutions to be adopted. Not all structures are suitable. For example, systems designed to forecast demand must be distinguished from those focused on optimizing handling or managing critical inventory. Poor alignment between the tools chosen and the actual needs of the business can amplify costs without guaranteeing the expected ROI. The business models of technology providers are also evolving. The SaaS (Software as a Service) model, although advantageous in terms of flexibility, can generate significant recurring costs, weighing on overall profitability. Many companies that chose this model for their intelligent warehouse management ended up with higher subscription costs than originally expected, making it more difficult to break even. Finally, regulatory constraints, especially in sensitive sectors such as aeronautics, agri-food or pharmaceuticals, make the process of implementing AI more cumbersome. Certification, compliance with international standards and cybersecurity add layers of complexity that further extend the time to full project profitability.

Employee resistance is another major challenge, particularly regarding fear of job losses and apprehension about technology. Many employees are reluctant to see automated processes replace tasks they usually perform. According to interview results, this resistance can manifest itself in the form of decreased motivation or a feeling of insecurity among staff, which can hinder the adoption of new technology. Management support and adequate guidance from the IT department are essential to overcome this resistance. Employees need reassurance about the impact on their work and must be trained on how to use the new tools so they can adopt them with confidence. The integration of artificial intelligence (AI) in storage systems represents a major turning point for many industrial, logistics and technological companies. However, despite the undeniable benefits that this technology offers in terms of efficiency, reduction of errors, optimization of resources and improvement of overall performance, it often encounters resistance from employees. This opposition to change, although it may seem irrational in the face of apparent benefits, is rooted in several psychological, social, economic and organizational factors. The analysis of this resistance, through concrete examples in the field of aeronautical maintenance, allows to better understand the obstacles to the adoption of AI and to consider adapted solutions.

The first resistance factor is the fear of losing your job. Automation, and in particular artificial intelligence, is often seen as a direct threat to human employment. In traditional warehouses, many employees are responsible for the manual management of products, their inventory, storage or stock verification. When an AI system is in place, with robots able to manipulate products, algorithms that analyze data in real time and make decisions about optimal article disposition, some employees worry they will be made obsolete. This phenomenon has been observed for example at Safran Aircraft Engines, a major company in the aeronautical maintenance sector (Safran, 2019). When introducing automated inventory and predictive parts management systems, some technicians expressed concerns about the removal of positions or redefining their responsibilities, perceived as a loss of value or competence. Second, another source of resistance is the fear of the unknown and technological complexity. AI is based on concepts that are still poorly understood by many employees. The opacity of algorithms, machine learning models, or decisions made by intelligent systems without direct human intervention can create a form of misunderstanding or even mistrust. This mistrust can turn into active rejection, especially when employees have not been trained or involved in the implementation process. In some aircraft maintenance hangars, for example at Lufthansa Technik, the introduction of AI-based decision support systems for fault analysis has caused discomfort among technicians, used to rely on their experience and professional judgment rather than the recommendations of a computer system (Google Cloud, n.d.).

At the same time, artificial intelligence challenges established practices and profoundly changes working patterns. This transformation can be seen as a loss of landmarks. When a storage facility has been operating on proven routines for years, the sudden introduction of technology that redistributes roles, rearranges storage channels and automates processes can create a sense of insecurity. This insecurity is often reflected in withdrawal behavior, gradual disengagement, or even passive acts of sabotage such as refusal to cooperate, voluntary slowing down of work, or the spread of negative rumors within the organization. Another important factor is the lack of support for change. When a company decides to implement an intelligent system, it may tend to underestimate the importance of internal communication and training. Employees feel excluded from the process, which reinforces their opposition. The case of Air France Industries is a good example. When deploying intelligent storage solutions for aircraft parts, some technicians expressed frustration at the lack of prior training, which hindered the appropriation of the tool. It is essential that companies anticipate these needs by setting up appropriate training programs and enhancing the human skills which are still needed for the supervision and maintenance of automated systems.

It is also important to mention that some employees have a strong attachment to their expertise, developed over the years, and they perceive artificial intelligence as a tool that challenges it. This particularly affects experienced technicians or warehouse managers who have built their legitimacy on the fine knowledge of products, locations or logistics procedures. AI can be seen as unfair competition, a tool that makes decisions without human experience but nevertheless imposes its choices. This sense of dispossession can create a divide between generations, with younger people generally more open to technology. In some cases, the refusal to change takes on a collective dimension. Trade unions or employee representatives may oppose the integration of AI on the grounds of de-humanization of work, increased surveillance, and growing internal inequality. Technology, in fact, can accentuate the divide between employees who are skilled at using these tools and those who are not, thus creating tensions. A study at Boeing, in its maintenance units, found that employees who received continuing training were much more likely to accept AI, while those left behind showed growing hostility.

The rapid pace of technological change poses a constant challenge for adaptation. When a company invests in an AI solution, it is often forced to regularly update its systems, integrate new functionalities, or modify its internal processes. This imposes a continuous learning effort on employees, which can be experienced as pressure or overload. This digital fatigue is a major barrier to acceptance of change, especially if the benefits of technology are not immediately visible. Faced with these multiple forms of resistance, it becomes clear that the integration of artificial intelligence into storage systems cannot be achieved without rigorous and human change management. It is not just about introducing technology, but about transforming an organizational culture. This involves involving employees from the earliest stages, communicating clearly on the objectives, valuing existing skills, offering adapted training and building a shared vision of the expected benefits. Companies like Rolls-Royce have made this transition by establishing a constant dialogue with their teams, setting up pilot phases before massive deployment, and involving technicians in the performance assessment of AI systems (Solberg, 2024).

The challenges associated with implementing and deploying new technologies are also significant. Integrating AI into an existing logistics environment requires restructuring processes and adapting existing systems. Compatibility issues between legacy infrastructure and new technologies can complicate integration. According to interviews, IT teams often face technical challenges adapting systems to the specifics of the business and the requirements of new solutions. This process can lead to significant delays and additional costs, particularly in ensuring a smooth deployment and avoiding disruptions to logistics operations. Managing the transition from legacies to automated systems is a challenge in itself. The time required to train employees, adjust processes, and ensure a smooth transition can also lead to temporary business disruptions. This phenomenon can be exacerbated by unforeseen technical issues or malfunctions during the deployment phase.

Before any implementation, a company must have or adapt facilities capable of supporting AI. This includes not only warehouses with robust internet connections, but also IoT (Internet of Things) sensors, programmable controllers, optical reading devices (such as RFID readers), human-machines, and sometimes even autonomous mobile robots. If these are not available or compatible with AI software, the potential productivity gains are significantly reduced. Take the example of a company like Sabena Engineering, a major player in the field of aeronautical maintenance. Aeronautical maintenance involves a rigorous and secure management of spare parts, diagnostic tools and equipment specific to each type of aircraft. The implementation of intelligent systems for managing these stocks could significantly accelerate operations. However, if the hangars and storage areas are not equipped with AI-enabled automated systems – such as dynamic racks, connected conveyors or automated vertical storage units – the AI alone will not be able to fulfill its role (Sabena Engineering, 2024).

In many cases, the storage architecture is still manual or semi-automated. This means that the data collection necessary for the proper functioning of the algorithms is partial or even absent. AI depends on the quality, quantity and consistency of the data it processes. Without sensors to track inventory movements in real time, or integrated systems that can transmit this data to a processing platform, AI becomes ineffective. The system cannot learn properly or adapt to usage trends or peak demand. Another challenge of adaptability: management software already in place. A company may use an outdated Enterprise Resource Planning (ERP) system that is not compatible with new AI solutions. The synchronization between different tools becomes difficult, causing problems of double entry, loss of information, or worse, decisions made on the basis of incorrect data. This is a common problem in historic industrial enterprises, where the IT infrastructure has not evolved as fast as technological innovations.

Another relevant company that one of the staff interviewed mentioned is Lufthansa Technik, an aircraft maintenance giant. Lufthansa Technik has invested heavily in the digitalization of its processes. However, this transformation did not happen overnight. It was necessary to modernize the warehouses, install sensors, train staff and above all ensure that the different systems could interact harmoniously. Lufthansa Technik's AVIATAR program, which combines predictive maintenance and intelligent inventory management, could not have been implemented without this infrastructure upgrade. On the other hand, lack of adaptability can generate additional costs. When a warehouse is too old or too specific to accommodate modern technologies, the company is faced with two costly choices: either completely transform the physical space (renovation, installation of new devices), or opt for tailor-made AI systems, often more expensive and less scalable. In all cases, this delays the commissioning of the system and compromises the expected return on investment (Google Cloud, n.d.).

The lack of adaptability is not only a matter of hardware or IT. It can also be organizational. Some companies operate according to very rigid or highly hierarchical processes, which makes it difficult for information to flow smoothly. For an AI system to make intelligent decisions, it needs a constant flow of data from different departments: purchasing, production, maintenance, etc. When these services do not communicate effectively or are not interconnected, AI operates in an informational vacuum, reducing its usefulness to nothing. In addition, the integration of AI requires continuous maintenance and regular hardware and software updates. Infrastructures must be designed to accommodate these developments without causing major disruptions in the supply chain. A warehouse with static or unscalable facilities may block future integration of improvements or new artificial intelligence modules. This rigidity can become a major handicap in a context where flexibility and logistics agility are key factors of competitiveness.

It is also important to stress the impact of a lack of adaptability on cyber security. Older infrastructures are often less protected against digital threats. AI, as a connected technology that in many cases depends on the cloud, increases the surface area for exposure to cyber-attacks. If existing systems do not have adequate protection (firewalls, encryption protocols, network segmentation), the integration of AI could expose sensitive data, compromise operations or even lead to partial business paralysis. A case in point is that of an aerospace SME, subcontractor to a major manufacturer, which wanted to automate the management of its stock of critical parts in order to reduce production lead times. As the infrastructure was too old, the AI system it had installed could only operate in degraded mode. As a result, the expected gains in accuracy and speed were minimal, despite the considerable initial investment. The company had to revise its strategic plan and gradually modernize its installations over three years.

To overcome these challenges, some companies are opting for a gradual, phased approach to integration. They start by auditing the state of their infrastructure, identifying priority areas and implementing hybrid solutions. For example, they may start by introducing predictive analysis tools in a single warehouse, testing their compatibility, and then gradually extending the technology to other sites. This type of approach limits the risks while ensuring that internal skills are built up. The lack of adaptability of infrastructures is one of the biggest obstacles to the successful integration of artificial intelligence into storage systems. Whether it is a lack of connectivity, an obsolete ERP, an unsuitable warehouse or a rigid organizational culture, each factor contributes to limiting the potential benefits of AI. That is why every company, especially those in critical sectors such as aeronautical maintenance, needs to consider this transition not as a simple technological upgrade, but as a genuine structural and strategic transformation.

Chapter II: The Effects of AI on Optimizing Logistics Processes at Sabena Engineering

This chapter focuses in particular on an exposition and analysis of the different information obtained during field surveys within the company Sabena Engineering. The aim is to take into account the various contributions made by employees in order to clearly identify what they think of artificial intelligence and everything that stems from its integration into logistics. To carry out these investigations, we interviewed 15 of the company's employees. Each of them was able to give their position on the issue of AI and its impact within the company. Therefore, after presenting and analyzing the results of the interviews, we will take a look at the challenges and issues encountered by these employees before concluding with a study of the prospects of Artificial Intelligence for Sabena Engineering in the field of logistics.

II.1. Interview Results and Analysis

The 15 employees questioned all had to give relevant answers to the various questions asked, which can be found in the appendices (see appendix 5: Summary of questions and answers from the 15 respondents).

II.1.1. Sabena Engineering Employees' Perceptions of AI

II.1.1.1. Level of Knowledge of AI Before Implementation

Before the introduction of solutions based on artificial intelligence in the company's logistics, employees' level of knowledge on this subject was relatively limited. Although some had already been in contact with automated systems like Modula, Kardex or Rotomat, their understanding of artificial intelligence as a lever for logistics optimization remained partial. The majority of employees had no technical training in emerging technologies, which influenced their perception of these tools and their appropriation of the new working methods. The interviews revealed that workers mainly perceived these solutions as automated storage and retrieval systems, without necessarily making the connection with the advanced capabilities of AI, such as flow optimization, intelligent stock planning or predictive analysis of supply needs. For many, artificial intelligence was still an abstract concept, often equated with traditional automation rather than a technology capable of learning and progressively improving the performance of logistics operations.

This relative unfamiliarity raised challenges in the initial phase of implementation, particularly in terms of adoption and adaptation to the new technologies. Some employees expressed reservations about the impact of these tools on their working methods and responsibilities, stressing the need for support and progressive training to help them better understand the benefits of AI in their day-to-day work. As a result, the company has had to plan awareness-raising and integration initiatives to ensure a smoother transition and facilitate the acceptance of technological innovations within logistics teams.

II.1.1.2. Employee Acceptability of AI

The interviews conducted with Sabena Engineering employees shed light on their acceptance of artificial intelligence in the context of logistics operations. Overall, the feedback gathered shows a gradual acceptance of these new technologies, although some initially expressed doubts about the consequences of implementing AI on their work. Initially, one employee revealed that the introduction of artificial intelligence into the company's logistics management has elicited varied reactions among employees. A majority of them admitted that they were not familiar with the concept of AI applied to logistics. And this was well before the implementation of automated system of Modula. Some saw these technologies simply as automated warehousing tools, without immediately perceiving their impact on optimizing workflows and stock management. For others, artificial intelligence evoked more abstract notions, often associated with robotics or predictive algorithms, without them really understanding the practical implications for their day-to-day work.

Analysis of the interviews shows that acceptance of AI within the company has been gradual and staged. Initially, curiosity played a decisive role. Several employees said they were intrigued by these new technologies and wanted to understand how they could improve their work. For them, AI represented an opportunity for development and a way of lightening certain repetitive tasks, in particular picking management and stock monitoring. The practical demonstrations and initial test phases of the new logistics solutions helped to reassure these employees, enabling them to see first-hand the benefits of AI on their workload and process efficiency. However, not all employees welcomed these changes with the same enthusiasm. Some were more skeptical, expressing reservations about the implications of artificial intelligence, particularly in terms of its impact on employment and worker autonomy. A significant number raised concerns about the possibility of automation replacing certain human tasks, leading to a reduction in manual intervention and, potentially, a reduction in the need for staff. This concern was reinforced by the fact that AI, by optimizing processes, makes it possible to reduce the time spent on certain activities, which could be perceived as a problem.

The interviews also highlighted another aspect of the initial reluctance: the fear linked to the complexity of the new technologies. Several employees said that they felt unprepared to use these tools, and that they feared that the transition would be too abrupt, requiring technical skills that they did not necessarily master. Therefore, the introduction of automated systems based on AI required specific support to enable employees to familiarize themselves with these new working methods. The training courses put in place by the company were decisive in the acceptance process, helping employees to understand the benefits of AI and overcome their apprehension when faced with these innovative tools.

Those who initially expressed doubts gradually recognized the usefulness of artificial intelligence in their day-to-day work. Several employees testified that, far from replacing them, AI enabled them to improve their efficiency by reducing tedious and time-consuming tasks. They also stressed that these new technologies were saving them a great deal of time, enabling them to concentrate on more strategic and decision-making aspects of their work. One employee interviewed explained that the use of Modula cabinets had considerably simplified access to spare parts, reducing the time spent searching for and retrieving components. Before the implementation of these systems, the picking process required more manual intervention, with the risk of errors in the selection of parts. With artificial intelligence and automation, these operations have become smoother and more precise, which has improved the overall productivity of logistics teams. Others also mentioned that the optimization of transport flows thanks to AI had made it possible to better plan deliveries and avoid certain frequent delays in the routing of goods.

Despite these positive aspects, the interviews show that the acceptance of artificial intelligence has not been without difficulty. Some employees admitted that they remained vigilant about the future development of these technologies and hoped that their integration would not lead to a reduction in the workforce. This fear underlines the need for the company to support this transition by highlighting the collaborative benefits of AI rather than its strictly automated dimension. The interviews show that the technical support provided by these teams has played a key role in helping employees to overcome the difficulties encountered during the transition phase. Several participants expressed their satisfaction with the availability of the IT teams to resolve technical problems and provide follow-up tailored to their needs.

At the end of these investigations, it appears that artificial intelligence has been accepted by the majority of employees, even if this acceptance has been gradual and not without initial resistance. The process of appropriating the new technologies was facilitated by training, practical demonstrations and personalized support. In the end, employees recognized that AI represented an asset for improving their working conditions, while remaining attentive to future developments and the impact that these innovations could have on their jobs in the long term.

II.1.2. Main Impacts of AI on Logistics Activities

II.1.2.1. Optimization of Storage and Space

In interviews with Sabena Engineering employees, a number of aspects relating to the optimization of storage and space using artificial intelligence (AI) were discussed. The responses highlight the various benefits that AI technologies have brought in improving space and inventory management. Employees highlighted how AI has made stock management more efficient, reduced warehouse congestion, and maximized the use of available space, contributing to smoother, more cost-effective resource management. Using machine learning algorithms, AI can analyze the frequency of movement of items in the warehouse and dynamically adjust their placement according to demand. For example, products that are frequently in demand are placed closer to the picking zones, while those that are less in demand are stored in zones further away. This organization reduces employee travel time and improves the speed of operations, as items are more easily accessible. Employees have expressed their satisfaction with this improvement, as it allows them to work more fluidly and reduces the time they spend searching for items in the warehouse.

Employees have observed that artificial intelligence enables spaces to be better organized by maximizing the use of storage areas. AI is able to predict and recommend the optimum arrangement of items based on their size, frequency of rotation and volume, minimizing underutilized areas and freeing up space for other products. This type of organization is particularly relevant in large warehouses, where space management is a constant challenge. AI can also anticipate future replenishment needs, avoiding excessive stock build-up and ensuring that space remains functional and flexible. Prior to the integration of AI, warehouse space management relied heavily on manual methods, which sometimes led to errors in item placement, increased the risk of stock outs and created imbalances in warehouse organization. AI-driven automated systems have made it possible to replace these obsolete methods and ensure more accurate and faster stock management. For example, the AI system can recommend adjustments to the layout of products based on changes in demand, ensuring that space is always used optimally. Automation also helps to reduce human error, which is crucial in an environment where precision and accuracy are essential.

Optimizing storage using AI goes hand in hand with improved management of movements in the warehouse. Employees mentioned that AI enables better planning of the routes to be taken by forklift trucks or picking robots, reducing unnecessary movements and improving work efficiency. The AI system can calculate in real time the shortest route to move a product from one area to another, which not only saves time, but also reduces energy consumption and the operational costs associated with transporting goods. This translates into an overall increase in productivity, as employees spend less time moving items from one place to another and can concentrate on higher value-added tasks.

Employees also highlighted the positive impact of AI on managing peaks in demand. When demand for certain products increases unexpectedly, AI enables resources to be reallocated quickly and efficiently, in particular by optimizing the use of available space to meet urgent needs. For example, in the event of high demand for a particular product, AI can recommend freeing up space to store an additional quantity of that item without disrupting the overall organization of the warehouse. This flexibility in adapting to market needs is another benefit that employees have greatly appreciated, as it allows the company to react quickly to fluctuations in demand without compromising efficiency.

AI can use historical data to anticipate fluctuations in demand and recommend optimal stock levels. This enables Sabena Engineering to avoid having too many products in stock, which can lead to additional costs for managing surpluses. By avoiding these unnecessary costs, the company can save resources and reallocate storage space more cost effectively. Stock optimization, combined with intelligent space management, enables companies to better manage their resources and limit the risk of wastage. In terms of implementation, employees stressed the importance of training and support in adopting these new technologies. They mentioned that the transition to intelligent systems was not immediate and that the process required support from the IT and logistics teams. The provision of training for employees was crucial if they were to understand how the new tools worked and use them effectively. Technical support from the IT teams also played a key role in resolving the technical problems encountered when integrating these technologies into the company's day-to-day operations.

II.1.2.2. Automation of Picking and Reduction of Processing Time

In interviews with Sabena Engineering employees, several points were raised regarding the impact of artificial intelligence (AI) on order picking automation and the reduction of processing time. Employee responses showed that the integration of AI has significantly improved the efficiency of logistics operations, notably by optimizing order management, automating picking processes and reducing order processing times. Prior to the adoption of AI-based technologies, order picking was a manual process requiring a lot of time and human resources. This included searching for items in stock, gathering products into picking areas and preparing them for dispatch. Employees reported that errors were common at this stage, and that processing times were often long due to the need to travel long distances in the warehouse to locate products.

With the integration of AI, order management has been considerably simplified and improved. One of the main changes brought about by these technologies have been the automation of item search and collection. Thanks to automated systems, AI analyzes incoming orders and defines an action plan for preparing each order in real time. For example, automated robots or trolleys, guided by AI algorithms, are responsible for going directly to the specific locations where products are stored, retrieving them and bringing them to the preparation areas. This automation has helped to reduce unnecessary journeys and has greatly contributed to a reduction in order processing time. Furthermore, employees have pointed out that this reduction in movements has also reduced the risk of errors in order picking, as the robots are able to follow optimized routes and precisely identify the items to be retrieved.

AI has also helped to manage priorities and optimize tasks. Employees mentioned that, thanks to intelligent systems, order preparation is now carried out more efficiently, as algorithms are able to prioritize orders according to their urgency, size or destination. For example, an urgent order can be processed first, while less urgent orders can be prepared later. This ability to prioritize tasks has made it possible to optimize the organization of workflows and better manage the human and material resources available. Employees have found that this efficient distribution of tasks has speeded up the entire order preparation process, reducing processing times.

Before the introduction of AI, picking errors (i.e. the incorrect preparation of orders) was relatively common. These errors could be the result of misreading order forms, product mix-ups or incorrect location in the warehouse. With the automation of order picking, AI has made it possible to significantly reduce these errors. Picking robots are equipped with vision systems or scanners that enable them to check the conformity of items with the order before transporting them to the preparation area. This real-time verification reduces the risk of human error, while ensuring that the right references are sent to customers. Employees also pointed out that AI enabled better real-time stock management, which had a direct impact on reducing processing times. Thanks to AI, the system can anticipate replenishment needs and adjust stock levels according to demand trends. This not only helps to maintain an optimal inventory but also ensures that items are available and ready to be dispatched immediately when an order is placed. As a result, the time needed to check stocks and prepare orders has been significantly reduced. This smoother, more reactive stock management helps to avoid stock outs and ensures that orders are processed quickly.

Automation has also enabled product returns to be managed more fluidly. Employees mentioned that, in the past, returns management was a time-consuming and complex task, requiring manual coordination and constant updating of management systems. Thanks to AI, returns management is now automated, enabling better tracking of returned items and quicker reintegration of products back into stock. Returns are recorded automatically by the system, and items are returned to the appropriate areas according to their condition. This has not only saved time, but also reduced errors in the processing of returns, ensuring better organization of stock and better availability of products for future orders.

AI-based systems enable real-time monitoring of every stage of the order-picking process, from receipt of the order to dispatch of the products. Thanks to AI, all actions are tracked, and employees can access detailed information on the status of orders at any time. This traceability has improved visibility of workflows, enabling any anomalies or delays in order processing to be identified quickly. The ability to intervene quickly to resolve problems has reduced lead times and improved customer satisfaction. Prior to automation, order preparation was a repetitive and often exhausting task, particularly at times of peak demand. Automation has freed employees from these time-consuming and physical tasks, allowing them to concentrate on higher value-added tasks, such as quality control or improving logistics processes. Employees have noted that this development has also had a positive impact on their motivation and well-being, as they have been able to concentrate on more varied and less exhausting activities.

II.1.2.3. Improvement of Transportation Planning and Flow Management

Sabena Engineering employees highlighted the significant impact of artificial intelligence on transport planning and flow management. Using advanced technologies, AI has optimized logistics by improving route management, resource allocation and forecasting transport requirements. These advances have not only contributed to more efficient operations but have also had a positive impact on reducing costs and improving customer satisfaction. Before the introduction of these technologies, route planning was mainly carried out manually, which could lead to inefficiencies, delays and additional costs. Now, artificial intelligence algorithms analyze a multitude of factors in real time, such as road traffic, weather conditions, vehicle availability and order priorities, to determine the most optimal routes. Employees have found that this automation has reduced delivery times by avoiding congestion and choosing the shortest and fastest routes. Furthermore, these systems are capable of adapting in real time to unforeseen circumstances, such as an accident or a closed road, by instantly recalculating an alternative route.

Before the introduction of AI, allocating transport vehicles and drivers was a complex task, often carried out empirically. Now, intelligent systems take into account various parameters, such as lorry capacity, the nature of the goods being transported and the deadlines to be met, in order to allocate resources in the best possible way. This more efficient allocation has maximized the use of vehicles and avoided empty runs, thereby reducing operating costs. Employees have pointed out that this optimization has also had a positive environmental impact, reduced fuel consumption and lowering the company's carbon footprint. AI has also led to better synchronization of logistics flows. One of the major problems encountered by Sabena Engineering before adopting these technologies was the lack of synchronization between the different stages of the supply chain. For example, a delay in receiving raw materials could disrupt the entire production and delivery process. Thanks to intelligent systems, transport flows are now coordinated more precisely. Algorithms analyze data in real time and automatically adjust schedules to avoid bottlenecks. Employees noted that this improved synchronization operations and reduced waiting times, both at warehouses and at delivery points.

AI's predictive capability was also mentioned as a major asset for transport planning. Employees explained that AI technologies are able to analyze past trends and variations in demand in order to anticipate future transportation needs. For example, during periods of high activity, such as seasonal peaks, AI can accurately forecast order volumes and adjust the available transport fleet accordingly. This anticipation has made it possible to avoid vehicle shortages and ensure that deliveries are made on time. In addition, this predictive approach enabled the company to optimize inventory management, ensuring that goods were dispatched at the right time and in the right quantities. Improved visibility across the entire supply chain was also a key point mentioned by employees. Thanks to AI tools, it is now possible to track the location and condition of transported goods in real time. Employees pointed out that this increased traceability has made it easier to manage shipments and quickly identify any problems, such as a late delivery or an incident in route. This transparency has not only improved the efficiency of internal operations, but it has also boosted customer satisfaction, as they can now follow the progress of their shipments in real time.

By optimizing routes, better allocating resources and anticipating needs, they have significantly reduced expenditure on fuel, vehicle maintenance and personnel. In addition, AI has helped to limit human errors, which could previously lead to additional costs, such as incomplete deliveries or unnecessary journeys. By reducing these inefficiencies, the company was able to improve its profitability and allocate its financial resources to other strategic aspects of its development. Employees also mentioned improved management of returns and faulty goods. Before the introduction of AI, returns management was a laborious task requiring complex manual tracking. Now, thanks to intelligent systems, it is possible to optimize return circuits by identifying the fastest and least costly routes for repatriating faulty or non-compliant products. This automation has enabled us to reduce returns processing times and improve inventory management by ensuring the rapid reintegration of recoverable products.

In a logistics environment, hazards are frequent: vehicle breakdowns, strikes, bad weather, sudden variations in demand, and so on. Thanks to artificial intelligence, Sabena Engineering is now able to react quickly and efficiently to these situations. AI systems analyze data in real time and propose alternative solutions within seconds. For example, if a vehicle is unavailable, the system can immediately reassign another resource and inform the teams concerned. This enhanced reactivity has minimized interruptions and ensured optimum continuity of logistics operations.

II.1.2.4. Efficiency and Reduction of Labor Costs

Sabena Engineering employees unanimously emphasized the impact of artificial intelligence on improving operational efficiency and reducing labor-related costs. According to their testimonies, the integration of AI into logistics processes has made it possible to automate a number of repetitive tasks, optimize human resources management and promote better allocation of personnel to higher value-added missions. Prior to the introduction of AI, many logistics operations required constant human intervention, resulting in significant manpower mobilization and an increased risk of human error. Now, thanks to intelligent algorithms and automated systems, many tasks such as inventory management, order picking or even optimizing transport routes are handled by AI-based solutions. As a result, employees have seen a reduction in the time spent on administrative tasks, and greater fluidity in the processing of daily operations. This automation has not only speeded up work, but also limited errors, reducing the costs associated with corrections and rework.

Another fundamental aspect noted by employees is the reduction in labor requirements for certain logistics operations, thanks in particular to the use of advanced technology of Modula. This automated warehousing technology, coupled with artificial intelligence algorithms, have improved warehouse management by reducing the need for constant human intervention. For example, the search and retrieval of parts is now managed by automated systems that identify the required items and deliver them directly to operators. As a result, employees have observed a reduction in physical effort and time wasted searching for goods, leading to an overall increase in productivity. In addition, several employees pointed out that AI has contributed to a better allocation of human resources. Before its integration, many workers were assigned to low value-added tasks, often repetitive and unstimulating. With automation, these same employees have been able to be redeployed to missions requiring more expertise, such as logistics data analysis, quality control or internal process improvement. Not only did this redeployment enhance staff skills, but it also improved job satisfaction by offering more rewarding and motivating tasks.

Employees also emphasized the impact of AI on scheduling and work planning. Thanks to intelligent tools, it is now possible to optimize schedules according to peaks in activity and the real needs of the business. For example, AI systems can analyze past trends and predict periods of high demand, enabling the number of workers on site to be adjusted accordingly. According to testimonials, this flexibility has prevented situations of over- or understaffing, reducing unnecessary labor costs while ensuring optimal coverage of operations. Before the introduction of AI, data entry errors, oversights or poor decisions in inventory and transport management led to considerable financial losses. Now, intelligent systems take charge of data analysis and propose optimized solutions, minimizing the risk of error. For example, predictive algorithms can flag up insufficient stock before a shortage occurs, thus avoiding costly production delays. This increased reliability has made logistics operations safer and reduced the financial losses associated with human error.

Thanks to AI-based solutions, training processes have been optimized, enabling new arrivals to acquire the required skills more quickly. For example, some systems use machine learning to guide new operators through intuitive interfaces, reducing the learning curve and increasing productivity in the first few weeks on the job. Some employees did mention, however, that the integration of AI raised initial concerns, particularly with regard to the fear of mass job cuts. However, they found that automation did not necessarily lead to a drastic reduction in staff, but rather to a transformation of roles and responsibilities. Indeed, rather than cutting jobs, AI has enabled workers to be refocused on higher value-added tasks, contributing to a better balance between automation and human intervention. A number of employees have even pointed out that the increased efficiency brought about by AI has made the company more competitive, leading to an expansion of its activities and, consequently, the creation of new specialist positions.

Employees highlighted the impact of AI on reducing indirect costs related to workforce management. For example, reducing overtime through better planning, reducing the need for temporary recruitment during busy periods and optimizing material resources have all contributed to an overall reduction in expenditure. AI has also made it easier to manage leave and absences by intelligently redistributing tasks between teams, thus avoiding work overloads and inefficiency.

II.2. Analysis of the Issues and Challenges Encountered

Despite the fact that employees have benefited from a number of IA advantages in the field of logistics, they have also encountered problems and challenges. Therefore, it is a question of analyzing them in terms of their response contributions.

II.2.1. Challenges Related to AI Implementation

Before studying the different sort of challenges, we must take into account the answers of the employees questioned. The integration of artificial intelligence (AI) into Sabena Engineering's logistics processes has led to many advances in terms of automation, optimization and inventory management. However, several employees expressed concerns about the challenges they faced throughout this integration process. These difficulties range from resistance to change, to more technical challenges related to systems adaptation, and concerns about costs and training. An Inventory Manager shares his perspective on the challenges of adapting AI systems to existing infrastructure: "*The integration of AI into our storage systems, especially Modula solutions, has been more complicated than we had anticipated. Our equipment was already performing* *well, but their evolution to integrate AI involved complex technical adjustments. Some of the solutions offered by suppliers required changes that we did not anticipate in our initial plan, resulting in additional costs and delays*."

Modula system used for storage is very specific and sophisticated technologies. According to several employees, reconfiguring processes to make them compatible with new AI-based solutions has not been an easy task. An Information Systems Engineer explains that: "*The technical challenges have been many. Each storage system has its own specificities, and to integrate AI, we had to review every process to make sure it runs smoothly. For example, there were interoperability issues between inventory management software and new AI platforms which slowed the implementation of the solution*." Delays in integration and unforeseen costs have sometimes created tensions between teams, particularly between the logistics and IT departments. The IT Project Manager adds that: "*It has been difficult to adapt some of our old infrastructures to the new technical requirements of AI systems. Our IT teams have faced unforeseen challenges, especially in terms of compatibility and data processing capacity. One of the biggest challenges was managing the massive volumes of data generated by AI, which put additional pressure on our servers*."

Problems related to employee training and adaptation to new systems were also mentioned several times. Human Resources Lead, recognize that the transition to AI has been perceived as a major change by many employees: "*We have faced strong resistance to change, especially from employees who are less comfortable with new technologies. The feedback was often negative, as many of them were afraid that automation would lead to their jobs being cut. Our main challenge has been to reassure them and provide them with the necessary training so that they feel more comfortable with the new tools.*" Lack of preparation for changing skills has created a gap between the needs of the company and the skills of employees. A Storage Operator says that: "*There is some skepticism among us. We feel that AI is going to replace our work. But it is not, the idea is to help us be more productive. However, training to master these new tools has been insufficient and this has caused frustration. More in-depth training sessions would have been beneficial."*

The Logistics Manager said that the reluctance was sometimes exacerbated by a lack of visibility on short-term results: "*Employees want immediate results, but AI requires time to adapt. While the gains are clear in the long run, the learning curve is a challenge. In addition, there have been misunderstandings about the objectives of AI, including that it does not replace employees but helps them to better manage logistics operations*." Sabena Engineering has had to invest substantially in integrating AI systems into its logistics operations, and some employees feel that the economic benefits are not immediately obvious. The company's Purchasing Manager points out, "*The investment costs were considerable. While AI offers us optimization potential, adoption has led to unforeseen expenses for equipment upgrades and staff training. We had to review our financial plan and find solutions to offset these additional costs. The return on investment is not as fast as we had hoped*."

The cost of maintaining new AI systems is also a recurring topic. A Maintenance Technician expressed concern: "*We have had failures at times and even though AI systems are supposed to be more reliable, their maintenance is expensive and requires specific skills that we did not have in-house. We had to bring in external experts, which increased the cost*." Issues related to change management and team adaptability also raised questions. It is in this context that the Operations Manager comments: "*Adapting our internal processes to new technologies has been a challenge. Our processes were well established, but the integration of AI changed these habits and resulted in a delicate transition. Some people struggled to understand why certain tasks were now automated and how they could work with the new solutions*."

The last challenge raised by employees is data management. AI is based on real-time data collection and analysis, and some employees have expressed concerns about managing the massive volumes of information generated. The Data Analyst says, "*One of the biggest challenges is data management. The amount of data we need to collect, store and analyze has exploded. Even if AI allows to process these data, the implementation of an infrastructure capable of managing them without generating delays has been a major constraint. We must constantly improve our systems to ensure a smooth flow of information.*"

II.2.1.1. Technical Constraints and Need for IT Support

Sabena Engineering employees have largely highlighted the technical challenges associated with integrating artificial intelligence into their logistics processes. While AI has made it possible to optimize many tasks, its implementation has also created constraints that require constant adaptation and increased technical support. According to their testimonials, a number of factors explain why IT support has become essential to their day-to-day operations. Unlike traditional methods, AI technologies used in stock management, order automation or transport planning require a thorough understanding of algorithms and digital interfaces. A number of employees admitted that, at the start of integration, they felt a certain confusion when faced with these advanced tools, particularly due to the lack of appropriate initial training. Adopting these technologies then required a gradual learning curve, sometimes punctuated by mistakes and successive adaptations.

Sabena Engineering already had a logistics infrastructure with specific software and IT equipment before the new technologies were introduced. However, the integration of AI tools sometimes led to compatibility problems with existing systems. A number of employees have reported difficulties in getting these different platforms to communicate, which has slowed down certain operations. For example, discrepancies between databases sometimes led to errors in stock management, requiring manual intervention to rectify anomalies. The reliability of AI systems has also been a major concern. While these technologies offer considerable potential for optimization, they remain dependent on the quality of the data they use. Many employees mentioned that AI algorithms sometimes generated erroneous recommendations due to incomplete or poorly informed data. For example, some employees observed that demand predictions based on sales history were biased when anomalies in the input data were not detected in time. These errors required manual adjustments and constant monitoring to avoid stock outs or oversupply.

System maintenance was another technical challenge frequently highlighted by employees. Unlike traditional tools, AI solutions require regular updates and ongoing monitoring to ensure that they work properly. Several employees reported that technical interruptions sometimes occurred at critical times, disrupting the smooth running of logistics operations. In some cases, these breakdowns required the rapid intervention of IT teams to restore systems functionality. The growing dependence on these tools has highlighted the need for IT support to be available at all times. The limited autonomy of some employees with regard to new technologies has reinforced the need for increased IT support. Some acknowledged that they did not always have the technical skills required to fully exploit the functionalities of AI systems. For example, difficulties were encountered in interpreting the predictive analysis and reports generated by the algorithms. This situation led to a certain reticence among some workers, who feared making mistakes or not making proper use of the tools made available to them.

Employees also mentioned that IT support was crucial because of the rapid evolution of technologies. AI systems are not set in stone and require constant adjustments to adapt to new business constraints. Some employees expressed difficulties in keeping up with these developments, particularly when an update made significant changes to the interface or the operation of the tools. This perceived instability sometimes led to resistance to change, necessitating training sessions and increased supervision by the technical teams. With the integration of connected systems and the massive use of digital data, the protection of sensitive information has become a priority for Sabena Engineering. Employees have expressed concerns about the risk of cyber-attacks and potential security breaches that could affect logistics systems. Some have reported incidents where attempted intrusions or anomalies in data access have required rapid intervention by cyber-security specialists. Faced with these threats, the company has had to strengthen its protection protocols and raise awareness of good IT security practices among its teams.

In other ways, several employees spoke of the importance of human support in the transition to AI. While these technologies bring efficiency gains, their adoption must not be at the expense of the relationship between the teams and the IT department. Some employees pointed out that the first few months following the integration of AI tools had been particularly stressful due to a lack of communication between operators and IT experts. Gradual support and the introduction of discussion sessions helped to overcome these difficulties and establish a more fluid collaboration between the various departments.

II.2.1.2. Investment Cost and Expected Return on Investment

It was pointed out that integrating artificial intelligence into their logistics processes represents a considerable financial investment. While the expected benefits are promising, the initial costs, as well as the time needed to observe a real return on investment, are major challenges. Employees interviewed expressed concern about the long-term profitability of these new technologies, as well as about how these costs affect their daily lives and working methods. The solutions implemented at Sabena Engineering, such as automated storage and flow management systems, require adapted infrastructures and high-performance software, which entails significant expenditure right from the initial phase. Several employees pointed out that these tools require not only an investment in hardware but also costs associated with the installation and adaptation of existing systems. Some reported that this transition required the involvement of external experts and specialist consultants, adding to the overall cost.

In addition to the acquisition of technologies, employees also highlighted the recurring costs associated with the upkeep and maintenance of AI systems. Unlike traditional equipment, these tools are constantly evolving and require regular updates to operate effectively. Some employees have observed that these updates can sometimes cause temporary interruptions to operations, impacting productivity and requiring rapid intervention from IT teams. In addition, technical support and the management of any breakdowns involve additional costs, which must be taken into account when assessing the profitability of these technologies. Staff training also represents a significant proportion of the costs involved in integrating AI. According to employees, the implementation of these new solutions has required intensive training sessions to enable teams to adapt to the new working methods. Several employees pointed out that this training, while beneficial in the long term, had an impact on initial productivity, as the time spent learning the new tools temporarily reduced the efficiency of operations. In addition, some expressed difficulty in assimilating the new skills quickly, requiring ongoing coaching and refresher sessions, adding further costs to the business.

Although the automation and optimization of logistics processes have improved many aspects of operations, some employees have expressed doubts about how quickly these benefits translate into tangible financial gains. In their view, it is difficult to measure the economic impact of these changes immediately, as cost optimization is based on multiple factors, including reducing errors, improving stock management and reducing order processing time. Some employees mentioned that assessing the profitability of these tools requires in-depth analysis and specific performance indicators, which adds further complexity to managing the investment.

Employees also mentioned the challenge of justifying costs to the various stakeholders in the company. The adoption of new technologies often involves discussions about budget priorities and the need to allocate resources to these projects rather than to other initiatives. Some employees have found that management has had to make strategic investment choices, sometimes to the detriment of other business needs. This may have created tensions, particularly among teams who feel that certain aspects of the business could have benefited from more immediate funding.

Another factor influencing the return on investment is the need for a phase of adaptation and adjustment following the implementation of AI technologies. Employees reported that the first few weeks following the integration of the new systems were marked by operational difficulties, unforeseen errors and technical adjustments. Although these problems were gradually resolved, they temporarily reduced the expected gains and required additional efforts to stabilize operations. Some employees mentioned that this adaptation period sometimes generated stress among the teams, who had to master new tools while maintaining the production targets set by the company. Several employees stressed the need for a long-term strategy to maximize the return on investment from AI technologies. In their view, the company needs to adopt a gradual and considered approach in order to exploit the full potential of these tools. Some stressed the importance of regular monitoring of system performance, in order to identify areas for improvement and optimize processes on an ongoing basis. They also mentioned the need for constant dialogue between the company's various departments to ensure smooth integration of AI solutions and avoid organizational silos that could undermine their effectiveness.

II.2.1.3. Infrastructure Adaptation and Process Reconfiguration

Sabena Engineering employees spoke of a number of challenges associated with integrating artificial intelligence into their logistics operations, including adapting infrastructure and reconfiguring work processes. The implementation of Modula automated storage systems has profoundly changed the organization of warehouses and workflows, requiring both physical and structural transformation of facilities. This transition, although beneficial in the long term, raised a number of difficulties that employees had to overcome to ensure effective integration of these technologies. Prior to the implementation of Modula, stock management was based on traditional methods using static racks and manual access to parts. With the introduction of these automated solutions, the warehouse layout had to be completely redesigned to maximize the available space and ensure the smooth flow of materials. Several employees reported that this reconfiguration involved structural changes to the facilities, including the removal or reorganization of certain storage areas, which temporarily disrupted day-to-day operations. The reorganization process also required careful planning to avoid prolonged interruptions and ensure business continuity.

In addition to space constraints, employees highlighted the challenges of integrating the Modula systems with existing technology infrastructures. These automated solutions run on advanced software that has to be compatible with the inventory management systems already in place at Sabena Engineering. Some employees mentioned that this integration phase was complex, as it required adjustments to ensure perfect synchronization of the databases and avoid any inconsistencies in inventory management. Communication errors between the systems were reported at the start of the roll-out, leading to delays in retrieving parts and difficulties in updating stock information in real time. With the adoption of Modula, the way employees interact with stock has changed radically. Previously, staff accessed parts directly by moving around warehouses and manually retrieving the necessary items. These automated systems now retrieve and present parts on demand, changing the role of employees and requiring them to adapt to new working methods. Several of them pointed out that this transition has required in-depth training to understand how the machines work and optimize their use. Order management, shipment preparation and even stock checking processes had to be rethought to adapt to the new technologies.

Employees also mentioned that automation has led to a redefinition of tasks and responsibilities within logistics teams. Some tasks that previously required manual intervention are now handled by the Modula system, which has changed the division of labor and created a need for support to help employees adapt to these changes. Some expressed concern about the need to develop new skills to remain relevant in an increasingly automated environment. Although training was provided to facilitate this transition, some employees reported initial difficulties in getting used to the new software interfaces and associated work protocols.

In addition, the integration of the Modula system has raised concerns about maintenance and reliability. Unlike traditional storage methods, these solutions require regular maintenance and constant monitoring to avoid breakdowns or malfunctions. Several employees mentioned that technical incidents occurred during the first few months of use, requiring interventions from the IT and maintenance teams to restore the equipment to working order. This increased reliance on technology has also led to concerns about the resilience of the system in the event of a prolonged outage or software update problem. Although the Modula system offer advanced automation, its effectiveness depends largely on the parameters configured by the company. Several employees reported that the initial algorithms did not always perfectly match Sabena Engineering's specific needs, resulting in adjustments to improve the speed and accuracy of storage and retrieval operations. This optimization phase was sometimes lengthy and required successive trials to find the configurations best suited to the company's requirements.

In addition, during the interviews, some employees expressed concerns about the flexibility of the new systems in the face of future changes in the company's logistics requirements. The integration of Modula required considerable investment in terms of infrastructure and process re-engineering, making it difficult to make major changes in the short term. Some employees have pointed out that the rigidity of these systems could pose problems if Sabena Engineering were to adopt its logistics model or expand its storage capacity in the coming years. Therefore, it is crucial to anticipate these changes now to ensure that the company can continue to take full advantage of integrated technologies.

II.2.2. Strategies and Recommendations for Successful AI Integration

II.2.2.1. Steps to Follow before Adopting an AI System in Logistics

The adoption of AI in logistics requires a structured approach to ensure an effective transition and optimal integration of new technologies. In the case of Sabena Engineering, where the Modula systems is already in place, it is essential to follow a number of steps before introducing or enhancing AI in warehousing and logistics management processes. These steps will ensure smooth adoption, minimize internal resistance and maximize the expected benefits. Before implementing an AI solution, it is crucial to analyze the weak points of existing systems, identify the tasks that could be automated or optimized, and define the expected objectives. In the case of Sabena Engineering, this analysis could include the study of bottlenecks in stock management, parts retrieval times, potential errors in order preparation or the limits of current storage capacities. This assessment must be carried out in collaboration with the operational teams who interact directly with Modula in order to obtain precise feedback on the problems encountered on the ground.

Once the requirements have been identified, it is essential to carry out a technical and financial feasibility study. Introducing AI often involves significant investment in hardware, software and training. Therefore, it is important to assess the total cost of implementation and compare it with the expected gains in terms of productivity, efficiency and error reduction. Sabena Engineering must ensure that the investment in AI will bring real added value and will not be a burden disproportionate to the expected benefits. This study must also take into account indirect costs, such as updating IT infrastructures, acquiring new equipment or maintenance costs.

The third step is to select the technologies best suited to the needs identified. There are several AI solutions that can be integrated into automated storage systems, such as Kardex, Modula and Rotomat. Therefore, it is crucial to choose those that best match Sabena Engineering's constraints and objectives. AI can be used to optimize stock organization, forecast demand levels, automate parts retrieval and improve item traceability. It is advisable to work with specialist suppliers and carry out tests on pilot solutions before deploying them on a large scale. This trial phase enables us to assess the compatibility of new technologies with existing infrastructures and to anticipate any adjustments that may be required.

Once the technology has been selected, planning the implementation becomes a crucial stage. It is important to define a detailed timetable and plan a gradual transition to avoid any major disruption to logistics operations. Sabena Engineering could adopt a phased approach by first integrating AI in a single warehouse or part of the process, then gradually extending its use according to the results obtained. This approach also makes it possible to limit the risks and make the necessary adjustments as the project progresses.

The next stage is employee training and change management. The adoption of AI entails a transformation of working methods and may give rise to internal resistance. Therefore, it is essential to make teams aware of the benefits of AI and to provide them with appropriate training so that they can master the new technologies. In the case of Sabena Engineering, this could include training sessions on the use of stock optimization algorithms, the management Modula system control interfaces, or the interpretation of recommendations generated by AI. Involving employees from the start of the process helps them to accept the change more readily and anticipate any difficulties they may encounter.

Once AI has been deployed, it is essential to put in place rigorous monitoring and an ongoing evaluation process. It is not enough to install an intelligent system so that it works optimally from day one. It is necessary to measure performance in real time, identify any anomalies and make the necessary adjustments. Therefore, Sabena Engineering will need to define key performance indicators (KPIs) such as reducing processing times, improving stock accuracy or reducing operational costs. Regular audits will ensure that AI is delivering the expected benefits and identify areas for improvement.

One of the aspects often neglected in the integration of AI is the management of technical problems and the maintenance of new systems. Sabena Engineering will have to ensure that its IT teams are sufficiently prepared to intervene in the event of malfunction or necessary adjustments. Responsive technical support and ongoing employee training will be essential to ensure the longevity and effectiveness of the new AI solutions. It is also advisable to work with the suppliers of the Modula systems to benefit from regular updates and technical support when needed.

Finally, the last stage involves anticipating future changes in logistics requirements and ensuring the flexibility of the solutions adopted. As the logistics sector is constantly evolving, it is important that the integrated AI can adapt to the company's new requirements. Therefore, Sabena Engineering must provide scalable and modular solutions, capable of handling new storage volumes, integrating other complementary technologies or continuously optimizing processes based on feedback. AI must be seen as a dynamic tool that requires regular adjustments to maintain its effectiveness.

II.2.2.2. Importance of Technological Support and Employee Training

The integration of artificial intelligence into logistics represents a powerful lever for optimizing processes and improving operational efficiency. However, to guarantee the success of this transformation, it is essential to ensure adequate technological support and ongoing staff training. In the case of Sabena Engineering, which uses automated storage systems like Modula, these two elements are of important. A well-supported technological transition enables the full capabilities of new AI solutions to be exploited while minimizing internal resistance and operational disruption. Implementing AI often involves upgrading equipment and IT systems to ensure optimal compatibility. At Sabena Engineering, Modula technology already offer advanced automated storage capabilities but integrating it with AI solutions requires technical upgrades and fine-tuning. For example, artificial intelligence can be used to analyze storage data in real time, forecast replenishment requirements and optimize space management. For these improvements to be fully effective, companies need to ensure that their IT infrastructures and software interfaces are adapted to these new technologies.

AI must be able to communicate effectively with Modula or automated systems such as Kardex and Rotomat to optimize part retrieval and logistics flow management. This means integrating specific software capable of processing and exploiting the data from these systems. Therefore, technological support is not limited to the supply of high-performance tools but also includes the implementation of a robust and scalable IT architecture. It is essential to ensure regular maintenance and to anticipate any breakdowns or technical incompatibilities that could slow down operations. At the same time, staff training is a key success factor. The adoption of AI is transforming working methods and requires an increase in employee skills to fully exploit the new technologies. At Sabena Engineering, operators using the Modula systems not only need to master the functionality of the equipment but also understand how artificial intelligence can improve their day-to-day efficiency. With the right training, employees gain a clear understanding of how algorithms, data analysis systems and automated management tools work.

One of the challenges of training is to support change. When a company adopts new technologies, employees often express reluctance for fear of losing their role or being overwhelmed by technological developments. Therefore, it is crucial to adopt an educational approach that highlights the benefits of AI while valuing human skills. In the case of Sabena Engineering, it is possible to show employees how artificial intelligence can facilitate their work by reducing repetitive tasks, improving the accuracy of operations and limiting stock management errors. Well-structured training should include theoretical and practical sessions, adapted to the different skill levels of employees. For example, technicians responsible for maintaining the Modula systems will need to acquire in-depth knowledge of the new interactions between these technologies and AI. Operators, meanwhile, will need to be trained in how to use AI-enhanced interfaces, interpret automated storage recommendations and manage alerts in the event of malfunctions. It is also a good idea to organize interactive workshops where employees can experience the new systems' functionalities at first hand, to increase their understanding and buy-in.

Technology support and staff training need to be seen as an ongoing process rather than one-off actions. Artificial intelligence is constantly evolving, and logistics solutions need to adapt accordingly. At Sabena Engineering, it is recommended that a regular training program is put in place to enable employees to familiarize themselves with system updates and acquire new skills as technology advances. This program can include refresher sessions, online training modules and practical demonstrations led by experts. The company must set up a helpdesk capable of answering users' questions and intervening quickly in the event of a problem. This can be dedicated IT support or a team of technicians specialized in managing Modula system. This support is essential to ensure smooth adoption and avoid frustration caused by malfunctions or misunderstandings about how the new technologies work.

It is also relevant to encourage feedback from employees on the use of AI in their daily tasks. Sabena Engineering could, for example, organize regular meetings where operators share their observations, suggest improvements and express their needs in terms of training or technical assistance. This participative approach encourages better appropriation of the technologies and enables the rapid identification of any adjustments that need to be made to optimize the efficiency of the system.

II.3. Towards a Sustainable Transformation of Logistics Through AI

II.3.1. Outlook for the Evolution of AI Technologies in Logistics

Artificial intelligence continues to transform the field of logistics, offering innovative solutions to improve efficiency, reduce costs and optimize the management of goods flows. The rapid evolution of AI technologies points to a future in which logistics processes will become increasingly automated, intelligent and interconnected. In the coming years, several major trends are expected to shape the development of AI systems in logistics, incorporating advances in robotics, machine learning, data optimization and connectivity. Today, systems such as Kardex, Modula and Rotomat are already improving the storage and retrieval of goods through vertical automation. However, advances in artificial intelligence are taking this a step further by introducing autonomous robots capable of interacting with these systems to optimize workflows. Collaborative robots, also known as cobots, are set to play a central role in this development, taking on handling, sorting and packaging tasks with greater precision. Thanks to machine learning algorithms, these robots will be able to adapt their behavior to the specific needs of warehouses and improve their efficiency over time.

Furthermore, AI will continue to revolutionize stock management by integrating increasingly sophisticated predictive models. One of the major challenges facing logistics companies is to maintain an optimum balance between supply and demand, while minimizing storage costs and the risk of stock outs. Thanks to artificial intelligence technologies, companies will be able to analyze huge quantities of data in real time from different sources, such as market trends, consumer behavior and weather data, to proactively adjust their stock levels. Demand forecasting algorithms will become even more accurate, enabling companies to reduce surpluses and optimize their inventory investments. Artificial intelligence is already being used to improve delivery management by analyzing complex variables such as traffic, weather conditions and customer preferences. In the future, these technologies will become even more powerful thanks to the integration of connected sensors and autonomous vehicles. Autonomous trucks and delivery drones could become commonplace in the supply chain, reducing transport times and operational costs. By combining AI with the Internet of Things (IoT), companies will be able to track the location and condition of goods in real time, guaranteeing a more efficient supply chain.

Improving interoperability between different logistics technologies is also a key issue for the future. Today, many companies use several independent systems that are not always perfectly synchronized. Artificial intelligence is expected to enable more seamless integration between inventory management platforms, transportation optimization tools and automated storage systems. This increased interconnectivity will facilitate the coordination of logistics operations and reduce inefficiencies related to information transfers between different stages in the supply chain. Logistics equipment, whether automated storage systems such as Kardex, Modula and Rotomat or transport vehicles, are subject to constant wear. Outages can cause costly disruptions and disrupt operations. Thanks to artificial intelligence, it will be possible to monitor the condition of machines in real time and anticipate breakdowns before they occur. On-board sensors will collect vibration, temperature and wear data, allowing algorithms to detect early warning signs of malfunction and proactively plan maintenance interventions.

Artificial intelligence will also play a key role in improving the sustainability of logistics operations. Faced with growing pressures to reduce the sector’s carbon footprint, companies will need to adopt more environmentally friendly and efficient solutions. AI will optimize energy consumption in warehouses by automatically adjusting lighting, heating and air conditioning to actual needs. In addition, optimizing transportation routes will help reduce fuel consumption and CO_2 emissions. Intelligent logistics flow management systems will also be able to offer more environmentally friendly alternatives, such as increased use of rail or maritime transport instead of roads. In the near future, AI should also enhance the personalization of logistics services. Customer expectations are changing, and the demand for faster, more flexible deliveries is growing. With real-time data analytics capabilities, companies will be able to offer tailor-made solutions tailored to the specific needs of each customer. For example, AI algorithms will be able to automatically adjust delivery times based on individual preferences and offer alternative options in the event of an unexpected event. This increased personalization will help improve customer satisfaction and strengthen the competitiveness of companies in the sector.

Despite these promising advances, some barriers will have to be overcome in order to fully exploit the potential of artificial intelligence in logistics. One of the main challenges remains the initial investment required to adopt these new technologies. The implementation of AI solutions requires significant financial resources, especially for infrastructure modernization, employee training and integration of different systems. To encourage this transition, it is essential that companies can benefit from financial incentives and appropriate support. AI is based on the exploitation of large amounts of information, but the quality and reliability of the data used are crucial to ensure the effectiveness of the algorithms. Therefore, it will be essential to improve data collection, processing and security capabilities to avoid bias and ensure optimal decision-making.

The evolution of regulations and standards surrounding artificial intelligence in logistics will need to be closely monitored. The increasing integration of these technologies raises ethical and legal questions, particularly with regard to liability in case of malfunctioning of autonomous systems. Clear and appropriate regulation will provide a framework for the use of AI while promoting innovation and competitiveness in the sector.

II.3.2. Limitations and Future Challenges for Sabena Engineering

Sabena Engineering has taken an important step in integrating artificial intelligence into its logistics processes, particularly through the use of Modula system. These technologies have helped to optimize storage, improve flow management and reduce order processing times. However, despite these remarkable advances, several limitations remain, and many challenges remain to be addressed in order to maximize the effectiveness of AI in corporate logistics., Modula is an advanced automated storage solution, but its interoperability with other logistics management technologies is not always optimal. There are still challenges in ensuring seamless communication between these systems and warehouse management software (WMS) or enterprise resource planning (ERP) systems. This partial interconnection can lead to data processing inefficiencies and limit the ability of AI to provide accurate, real-time analysis on inventory status and logistics flows.

The effectiveness of artificial intelligence algorithms is based on the collection and analysis of a large volume of reliable, up-to-date data. In practice, however, Sabena Engineering still faces barriers related to the quality of information used by its systems. Errors in data entry, inconsistencies in updates and integration issues between different data sources can affect the accuracy of AI-generated predictions and recommendations. Without effective standardization of data collection and processing protocols, AI may not reach its full potential. The company also faces cybersecurity challenges. The increasing integration of artificial intelligence into logistics operations is accompanied by an increased risk of cyber-attacks. Automated inventory and flow management systems are connected to networks that can be the target of intrusion attempts, data theft or malicious manipulation. Therefore, Sabena Engineering must strengthen its IT security devices to protect its logistics infrastructures and guarantee the integrity of its data. The implementation of advanced encryption protocols, threat detection solutions and regular backup mechanisms is essential to ensure that systems are resilient to cyber threats.

Another important challenge is the cost of investing in artificial intelligence. Although the adoption of technology of Modula has improved operational efficiency, these systems require continuous investment for maintenance, updating and optimization. The acquisition of new advanced AI solutions also represents a significant cost that Sabena Engineering must anticipate in its development strategy. The return on investment (ROI) of these technologies is not always immediate, and the company must find a balance between adopting new innovations and making its operations cost-effective. Employee resistance to change is another limit on the expansion of AI in Sabena Engineering's logistics. The introduction of new technologies is profoundly changing working methods and may cause concern among teams. Some employees may perceive automation as a threat to their jobs or have difficulty adapting to new digital tools. To overcome this obstacle, the company must implement appropriate training programs and support its employees in the appropriation of AI technologies. A phased approach, combined with awareness sessions and effective technical support, will mitigate resistance to change and promote smooth adoption of new solutions.

Artificial intelligence in logistics is constantly growing, and new innovations are emerging regularly. Therefore, the company must ensure a permanent technological watch and be able to quickly adapt its infrastructures and processes to the advances of the sector. The integration of more advanced machine learning solutions, the use of intelligent sensors for more precise inventory management and the optimization of flows through predictive AI are all areas of improvement that Sabena Engineering will have to explore in order to remain competitive. The issue of regulation and compliance is also an issue for the future of AI in corporate logistics. The growing use of artificial intelligence technologies is framed by regulations that evolve according to data protection, system security and environmental impacts. Sabena Engineering will have to ensure that its AI solutions comply with current standards and anticipate legislative developments to avoid any risk of non-compliance.

The environmental impact of AI technologies is another limitation to be considered. Although the logistics optimization enabled by artificial intelligence can contribute to reducing energy consumption and CO_2, the operation of digital infrastructures and automated systems generate a significant carbon footprint. The company will have to seek solutions to minimize the environmental impact of its operations, including by adopting sustainable logistics practices, Optimizing the use of energy resources and exploring green alternatives to current technologies. Sabena Engineering will have to face the challenge of adaptability and flexibility in the evolution of its logistics processes. Artificial intelligence enables more efficient flow management, but it also requires greater responsiveness to market fluctuations and unforeseen events. The company will need to strengthen its adaptive capacity to adjust its logistics strategies in real time and fully exploit the potential of AI in an ever-changing economic and technological environment.

General Conclusion

Artificial intelligence (AI) is gradually transforming the logistics landscape, offering innovative solutions to optimize operations, improve efficiency and reduce costs. As companies seek to adapt to new market requirements and meet increasingly complex challenges, AI is positioning itself as a key asset. However, while many companies have begun to integrate AI into their logistics processes, the idea of fully integrating these technologies remains a matter of debate. Could the future of logistics really be made entirely by AI? To answer this question, it is necessary to explore the current impacts of AI, its future prospects, as well as the obstacles that still hinder a full adoption. With intelligent systems that can collect, analyze and process data in real time, companies can now better manage their inventory, optimize transport routes, predict demand and reduce human error. Automated storage systems such as Kardex, Modula and Rotomat, used in companies like Sabena Engineering, are concrete examples of integrating AI into inventory management. These technologies optimize space, reduce order processing time and improve flow management, while providing accurate product tracking at every stage of the logistics process.

Another key area where AI plays a critical role is transportation management. AI enables companies to plan routes more efficiently by taking into account a wide range of factors such as weather, traffic, fuel costs and delivery times. The use of predictive algorithms maximizes vehicle utilization, reduces distance traveled and optimizes transportation costs. In addition, autonomous vehicles such as driverless trucks and drones represent a futuristic perspective of logistics where AI could manage the entire delivery process from planning to execution. Artificial intelligence can also strengthen decision-making through advanced analytical tools. AI platforms can analyze massive volumes of historical data, market trends and demand forecasts to provide informed recommendations on supply chain optimization. This allows companies to adapt more quickly to fluctuations in demand, anticipate stock shortages and adjust logistics strategies in real time, increasing the responsiveness and flexibility of operations.

Despite the obvious benefits of AI in logistics, there are still a number of challenges and obstacles before full integration. First, interoperability of systems remains a major issue. Many companies use diverse logistics technologies, which must be able to communicate with each other to optimize operations. AI systems must be designed to integrate with existing infrastructure and interact seamlessly with other supply chain management software. Poor integration can lead to inefficiencies and limit the potential of AI. Second, data quality is another important constraint. The effectiveness of AI systems is based on accurate and up-to-date data. Input errors, database inconsistencies and incomplete information can distort analyses and compromise decision-making. For AI to be fully effective, companies need to put in place rigorous mechanisms for data collection, validation and updating, which is a significant investment of time and resources.

Another obstacle to the full integration of AI in logistics is resistance to change, especially among employees. The introduction of AI changes work methods and can lead to fears about automation of tasks, especially with regard to job losses. While some employees welcome AI as a way to improve their work, others may perceive it as a threat. Supporting staff through appropriate training and communicating the benefits of AI is essential to reduce this resistance and foster acceptance of new technologies. The initial investment cost in AI technologies also remains a constraint for some companies, especially SMEs. Advanced automation, supply chain management and transport management systems require significant investments in hardware, software and infrastructure. In addition, maintenance and optimization costs are also important. While these investments can result in long-term savings and efficiency, the return on investment (ROI) is not always immediate, which is a challenge for some companies.

Cyber security is a key issue in the adoption of AI. Automated logistics flow management systems, as well as autonomous vehicles and other smart technologies are vulnerable to cyber-attacks. Therefore, the security of data and infrastructure is essential to avoid risks related to information manipulation and disruption of operations. Companies must implement rigorous security protocols and invest in protective technologies to avoid major incidents. The environmental impact of AI in logistics is also a growing issue. While AI can improve the energy efficiency of logistics operations and reduce CO_2 emissions, the use of advanced technologies such as data centers that host AI systems can have a significant environmental impact. The carbon footprint of AI systems must be factored into companies' sustainable development strategies, and efforts must be made to make these technologies more environmentally friendly.

The future of logistics looks promising, but it is clear that full integration of AI requires a number of challenges. Companies must invest in appropriate infrastructure, implement robust security systems, ensure data quality and support employees in this technological change. If these obstacles can be overcome, AI could well redefine the contours of logistics, creating a fully automated and interconnected system, capable of responding in real time to market demands and revolutionizing the way goods are stored, transported and delivered globally. Therefore, the full integration of AI in logistics is not a distant dream, but an achievable goal, provided that current challenges are overcome and continued investment in innovation.

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