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Research Article

The AI-Driven Supply Chain: Optimizing Engine Part Logistics For Maximum Efficiency

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ABSTRACT

The world operates at a pace that is always too fast and too much for its good. The industry supply chains are no exception to that trend. With the high speed often necessary for industry and parts manufacture, the logistics of parts delivery are a critical but often overlooked area for potential improvement. The manufacturing company in this case study is a large automobile engine plant, which has slowly evolved into a pretty complex manufacturing and delivery system with many different teams and systems involved. The focus here will be upon a specific sub-process: the delivery and movement of individual engine components between a system of on-site 'supermarkets'. The current process relies heavily on a few employees' knowledge and experience. It needs metrics and data, making it easier to measure efficiency. Many different part types have specific packaging and storage requirements, leading to mistakes and damage. AI tools are being considered to improve logistics operations, and OptQuest is being used to determine its suitability. This will be compared to established statistical methods.

Keywords: Engine, Supply Chain, Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Smart Manufacturing (SM)

1. Introduction

The Malaysian automotive industry is rapidly growing and aims to become a regional hub for auto production. To support this growth, GE collaborated with Proton in a three-year project called EPSC to improve engine part logistics. The project began in 2012 and aimed to optimize logistics processes using GE's supply chain tools and methods. This research focuses on the challenges faced by the industry and the goal of improving quality and cost efficiency in line with future expectations.

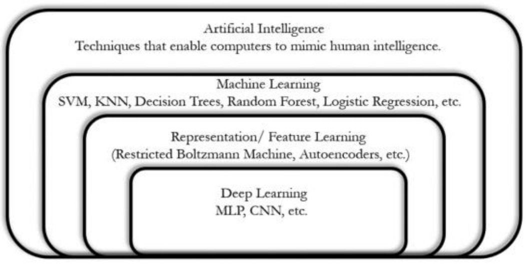

FIGURE 1. Introduction to AI Categories

1.1. Background

Managing inventory in the aerospace sector is complex due to strict regulatory environments and controls for part provenance and certification. This results in a complex supply chain network with multiple tiers of customers and suppliers. Obtaining genuine parts from the OEM or authorized distributors is crucial, as non-authorized parts are closely regulated. Counterfeit parts and questionable originality must be reported. Part provenance information must be maintained. Actions involving part movements and information transfers must be considered when optimizing the supply chain. The concept of a virtual centralized warehouse can improve inventory sharing. However, any changes made must be carefully considered for their implications.

1.2. Problem Statement

The globalization of the manufacturing industry has led to changes in its business environment. Information technology has allowed companies to improve supply chain management (SCM) through closer customer linkages. AI is an SCM enhancer that can further enhance company efficiency. Engine parts logistics is an important industry that can benefit from advanced SCM systems. Optimizing this industry can lead to increased profits and cost savings for consumers. The complexity and varying methods of part movement make it an industry that could benefit from an intelligent SCM system.

1.3. Research Objectives

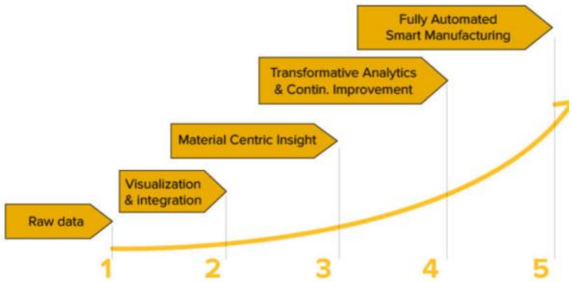

FIGURE 1.3. AI driving the smart supply chain management

- The first research objective is to develop a model to allow Eagle Aviation's client to manage the inventory of engine parts by partitioning the supply chain to extract the optimal stocking levels for a range of parts over several serviceable groups and different types of aircraft, each with differing demand. Additional issues that will be addressed include optimization of inventory levels under supply uncertainty and repair times, and the control of component cannibalization.
- The second research objective is to determine the feasibility and benefits of managing the entire best-case inventory system using a centralized national inventory in place of the current system, which is characterized by centralized pooling of resources.

The final research objective is to develop a decision support system to dynamically revise part stocking levels based on changes in operational scenarios and resource constraints. This is important as operational scenarios change frequently during conflict and peacekeeping missions, and Eagle Aviation's client often has little control over the duration and location of such missions. The system should be capable of determining the demand for parts and repairing components from partially observed data.

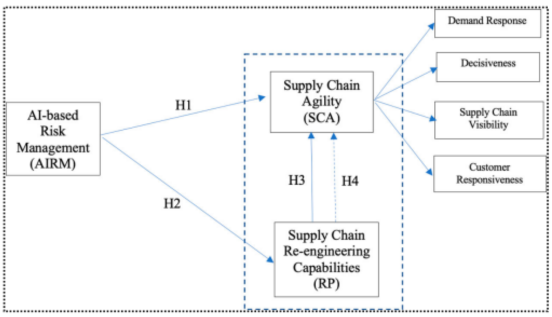

FIGURE 2. Conceptual model

2. Literature Review

From 2001 to 2006, there was a 42% increase in the use of AI technologies in business, showing the growing relevance of AI in supply chain management. Value-added services have become a company focus, leading to increased responsibility for 3PL providers. Both manufacturers and retailers have turned to 3PL providers for technology-enabled services. The complexity of supply chains has increased, resulting in more interest in technology-based SCM solutions. AI is applied in decision support systems, providing information for managers to make decisions. It also focuses on automating complex tasks to reduce labor and determine the best level of automation for processes. AI aims to match supply chain processes to human implementation for maximum value added.

2.1. Overview of AI in Supply Chain Management

FIGURE 2. Impact of AI

AI-based systems streamline decision-making, reducing reliance on consultants, cutting costs, and ensuring accurate decisions. Human decision-making can be emulated using cognitive mapping, which has ample potential. AI can revolutionize logistics and supply chain management for companies.
This is a classic optimization problem with multiple suppliers. A business wants to assign purchases or partial purchases of supplies from multiple suppliers. IBM solved this using CP Optimizer for over 15K optimization runs. The tool increases efficiency and reduces costs, which is a primary goal for every organization.
AI automates parameter settings for shipments based on client importance and shipment relevance. Studies show overspending on premium shipments despite ground shipments needing to be increased. The lack of a well-documented process and excessive options contribute to high opportunity costs. AI finds optimal shipment methods, learns, and adapts to preferences. IBM's Sterling TMS has the AI-Driven Smart Sourcing tool as an example.
AI advancements have improved logistical and supply-chain predictions, aiding better decision-making and inventory reduction. AI and machine learning analyze inventory levels and their relationship with consumer habits and sales trends. Accurate predictions can be made about product demand, enhancing capital allocation. AI takes various forms, from algorithms to machine learning. Traditional AI uses algorithms, while machine learning applies complex calculations to big data for decision-making. It offers an advantage in problem-solving compared to traditional computing methods.

2.2. Applications of AI in Logistics

FIGURE 2.1. Applications of AI in Logistics

The purpose of AI in logistics is to analyze data and make decisions. AI systems automate tasks that require human functions. The concept of an intelligent agent is fundamental for AI applications in logistics. AI is suitable for complex decision-making and logistics planning tasks. It can provide near-optimal solutions to problems. AI systems are fast, accurate, and unaffected by tiredness. AI can learn from data and react to environmental changes, which is helpful in supply chain management.

2.3. Challenges and Limitations

Automation can harm decision-making processes, leading to the deskilling of employees and a lack of human oversight. It can also result in inefficiencies and job losses. Critics argue that AI is often used for cost-cutting and profit-making, disregarding employee well-being.
Challenges in AI logistics include complex data and human intervention for exception cases. AI is commonly used for transportation optimization and well-defined problems with flexibility for rule changes.

3. Methodology

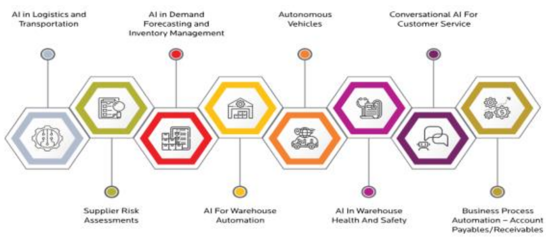

FIGURE 3. Use Cases of AI in Supply Chain Management

Step 1: Data Collection

We will begin by obtaining detailed information on the layout of a factory(s) in which engine parts are produced. Information regarding the locations, line of sight, and type of part to be transported will be recorded in a database. A specific example of a factory will be used, in which we have direct access to decide the best method of moving the part. This ensures a clear understanding of the problem to be addressed. Simulation data from a different Honeywell project will provide a cost function for transporting parts. This data will be translated into the simulation to evaluate the success of the transportation methods developed.

Step 2: Simulation Development

This step involves using the data collected to solve a specific transportation-based problem for the AI. Engine parts will be represented as specific objects with known destination points. A method of tracking the part location will be implemented, and the success of part transportation must be recorded. Different methods of moving the part will be represented as different actions to the AI. An example of a simple problem would be moving from a conveyor belt to a nearby storage location. A more complex problem would involve moving apart through several areas to get it to a location that changes dynamically.

The objective is to develop a system for optimizing engine part logistics. It will simulate different methods of moving parts within a factory. First, data on current methods within Honeywell will be collected. This data will validate the simulation. The simulation will use AI search techniques to find the best method of moving parts. It will be validated against real-world data and suggest improvements to transportation methods.

3.1. Data Collection

Data was collected from the Rolls-Royce facility in Germany, which assembles Trent series jet engines. The study focused on the electrical harness assembly (EHA), a complex and high-value part used to transfer power within the engine and to other aircraft systems. The EHA is constantly moved around the facility, making it an ideal system to study the reasons behind item movement. Before observing and analyzing the current state of part logistics, meetings were held with individuals knowledgeable about the EHA to understand its movement and value better.

3.2. AI Algorithms and Techniques

AI techniques like and integer programming is widely used in supply chain network design. They optimize the objective function by deciding on the values of decision variables with constraints. Mahmoud et al. (2008) used integer programming to minimize the total cost of resource allocation. However, these techniques can be time-consuming for complex and large-scale problems. This has led to research on using AI techniques for optimization.

Today, AI-based techniques are preferred mainly due to their ability to adapt to dynamic environments. AI techniques are broadly classified as soft computing methodologies and complex computing methodologies. The latter consists of methods and techniques that can provide an exact solution, whereas the former robustly provides a satisfactory solution.

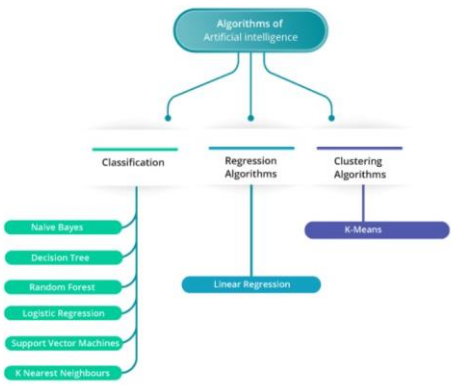

FIGURE 3.1. AI Algorithms and Techniques

3.3. Experimental Design

The AI system determines part delivery based on available parts at the workstation, eliminating the need for fuzzy part demand tracking and subjective decision-making. The system uses a set point and error equation like controlling a plant. Part deliveries are simulated and moved to the destination when predicted to be needed, simplifying control.

The AI control system considers the system's part demands and simplifies system control. Compared to a traditional kanban system, it addresses uncertain part demands and prevents late or early deliveries.

This study analyzed Rolls-Royce PLC's engine part logistics system. A simulation model assessed the impact of an AI-driven control system on part delivery time. The model compared the performance of an AI-driven system to a traditional kanban-based system. Three operating environments were tested: random demand fluctuations, low uncertainty, and limited shop floor space.

4. Findings and Analysis

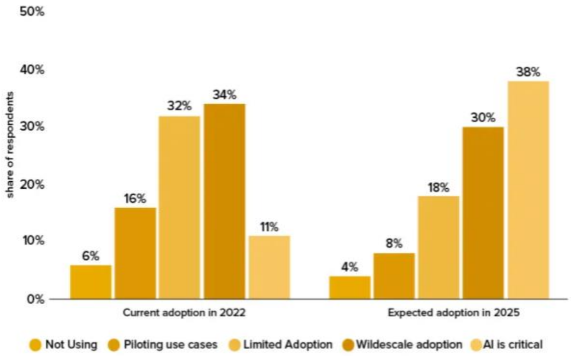

FIGURE 4. AI Adoption Rate in Supply Chain Globally 2022-2025.

Using the auto manufacturing supply chain as a model in the airline industry improves supply chain activities. Airlines can introduce high-margin services like in-flight internet or leather seats, similar to the auto industry. Airlines can improve efficiency and deliver more value to the consumer by focusing on high-margin superiority. The auto manufacturing supply chain has successfully increased value and reduced costs through standardization and efficient purchasing. However, airlines sometimes must catch up in the supply chain and develop premium products. Research shows that logistics providers should understand the nature of the parts they ship, and Rolls-Royce has centralized part attribute data to optimize logistics. This initiative matches customer needs and reduces costs.

4.1. Optimization of Engine Part Logistics using AI

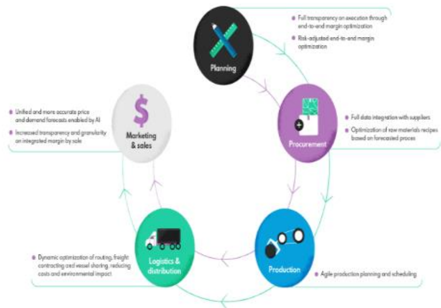

FIGURE 4.1.Logistics of AI

This text focuses on the feasibility of using AI to manipulate supply chain inventory levels. It discusses how AI can model and optimize demand for parts, providing a new method for matching aircraft build with part supply. AI has proven effective in the semiconductor industry, but further research is needed on the aviation supply chain. AI also benefits engine manufacturers by dealing with fuzzy constraints and competitive design. AI can potentially improve engine part logistics, but the industry is still in the early stages of data analysis and supply chain methods.

4.2. Efficiency Gains and Cost Reductions

An AI-based simulation with dynamic resource routing was used to optimize shipping routes and reduce time and cost in the supply chain. Further details will be discussed later.

The optimization model was created using ILOG OPL CPLEX with constraint programming and a sliding time window. It determined the delivery dates and storage location of parts at Honda. A successor model would determine a detailed shipping and storage schedule for each day within the time window. Data came from various suppliers and was implemented using real-time consulting. The solution significantly reduced shipment frequency and lowered logistics costs. Implementing the tool would result in a 25% reduction in inventory and a 20% reduction in logistics costs for the supplier.

Transport and distribution costs in the supply chain are high due to suboptimal resource allocation. FIFO inventory management strategies lead to wastage and excess inventory, which causes confusion and delays in production and delivery and damaged parts. Constraint-based optimization methods helped develop an intelligent resource allocation tool for suppliers.

The distribution of engine parts is complex. AI optimizes transport schedules while considering production rates and disruptions.

4.3. Impact on Supply Chain Performance

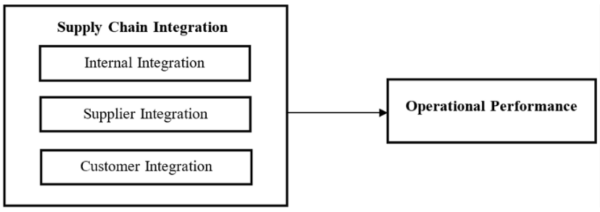

FIGURE 4.3. Research Model.

AI has a significant impact on supply chain performance. It improves scheduling, inventory allocation, and customer service levels. AI can prevent stock-outs and line stoppages by determining the right stocking level for each part based on demand and criticality. This results in leaner resource allocation, inventory reduction, and the freeing up of capital. AI also enhances the speed and reliability of complex decisions, such as order promising. However, there are instances where AI masks underlying system problems, leading to inefficiency in the long run. It can sometimes prioritize creating stock buffers instead of addressing the root causes of stock-outs. AI is still developing in its ability to navigate highly complex systems and distinguish between global and local optima.

5. Conclusion

This paper discusses several operational issues concerning original engine manufacturers and Tier 1 suppliers. This includes planning and scheduling, inbound logistics, inventory management and distribution, information exchange, and customer synchronization. It was argued that artificial intelligence systems and information exchange, planning, and scheduling techniques significantly improve current practices. The case study on planning and scheduling showed that soft computing techniques offer an effective method of obtaining a sound engine build schedule and rescheduling production when unexpected disturbances occur. Furthermore, an artificial intelligence model was provided for a typical inbound logistics problem, and it was shown to be superior to the current method used by an automotive company. These techniques offer significant cost reductions for the supply chain and thus should be pursued further to obtain better methods than the current complex computing techniques. A secure information exchange model for inventory management and customer synchronization was also shown to improve current internet exchange and electronic data interchange practices significantly. As IT and AI technology is rapidly improving at a substantial pace, these models could be implemented shortly.

5.1. Implications for Supply Chain Management

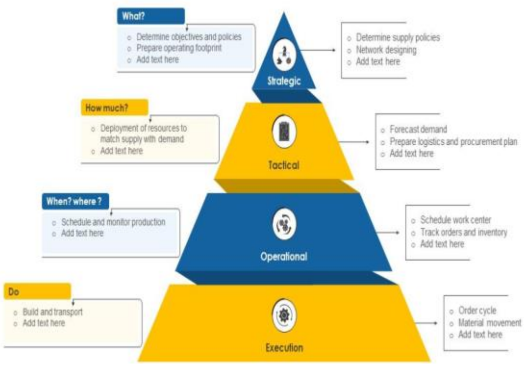

FIGURE 5. Supply chain management with strategy

The "Organization Name" Engine Alliance project uses AI technologies to optimize supply chain decisions in the aerospace industry. Implementing AI tools can determine the impact of Engineering Change Orders (ECOs), making it easier to alter sourcing decisions. These tools offer a compelling business case for changing current practices in the industry. They provide evidence for cost savings and more intelligent decision-making processes. The global nature of the aerospace industry also benefits from AI diagnostic tools, as they can help make optimal decisions that benefit all parties involved. This includes situations where suppliers may no longer be sourced, and surplus parts can be sold to customers. These new decisions can minimize cargo logistics and improve supplier location.

5.2. Future Scope

In the future, it will be easy to visualize this network extending to multiple companies (tier-one suppliers to a car manufacturing company, other parts distributors to a single supplier). Sharing the information between these companies allows for an even more complex web of retrieval and delivery. We can now form a more realistic view of a nationwide or global-level supply chain network. This development will reduce the complexity of the problem, as suppliers will have more diverse part orders to fulfill. Thus, fewer part deliveries must be made before the part is allocated to its end location. However, retrieving information about which parts are being ordered from which location will be vastly more complex, with several customers entering orders of different priorities for the same parts destined for different locations. This is the true strength of the AI-based system: the ability to rationally sift through many possibilities and choose the cost-effective path. A global supply chain network can be optimized at the highest level to reduce worldwide part inventory costs and streamline part delivery across seas and continents. Currently, a project of this magnitude is far beyond the resources of a team of academic researchers. However, ongoing AI research in the private sector has the potential to make this a reality within a few decades. At this point, the AI-driven supply chain will reach its full circle, being integrated into every level of logistics and planning for the companies involved.

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