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Ai-Based Optimisation Of Inventory Transshipment-Lateral For Competitive Supply Chain Management In Tunisia

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Abstract
Objective : Lateral transshipment refers to the transfer of inventory between warehouses, points of sale, or distribution centers of the same level (for example, between two stores of the same brand), without passing through the main distribution center. Its aim is to balance inventory levels and avoid stockouts or localized overstocking.
Methods : This research paper aims to combine qualitative and quantitative analysis to highlight the influence of artificial intelligence integration on Transshipment-Lateral and on the competitive position of Safran-Tunisia at both the national and international levels.
Results: In Tunisia, logistics and distribution are closely linked, as distribution performance depends directly on the efficiency of logistics flows, warehouses, and transportation. With the rise of digitalization, the application of artificial intelligence improves these processes by optimizing demand forecasting, inventory management, and transportation routes. In this context, Safran Tunisia, which operates several industrial sites, particularly benefits from AI solutions to enhance the visibility and coordination of its internal flows.
Conclusion : In Tunisia, logistics and distribution are highly interconnected, as the competitiveness of companies depends on their ability to efficiently manage the flow of goods between sites and to their customers. Artificial intelligence enhances this performance by optimizing demand forecasting, inventory planning, and transportation coordination. AI can also support lateral transshipment, a strategy that involves transferring inventory between sites of the same size to reduce stockouts and minimize costs. Thus, the combined integration of logistics, AI, and lateral transshipment allows Safran Tunisia to improve its operational flexibility and supply chain reliability. At Safran Tunisia, these technologies are particularly useful for supporting Vendor Managed Inventory (VMI), where suppliers directly manage inventory levels to ensure the continuous availability of aerospace part.
Keywords : Lateral Transshipment Optimization, Artificial Intelligence in Supply Chain, Inventory Management, Logistics Optimization and Mathematical Modeling.

1. Introduction

A green supply chain aims to reduce the environmental impact of all stages of production and distribution. It begins with the selection of environmentally responsible suppliers, prioritizing sustainable and recyclable materials. Production is optimized to consume less energy and generate less waste. Transportation and logistics are organized to reduce carbon emissions, for example, by consolidating deliveries or using eco-friendly vehicles. Inventory management promotes efficiency to limit waste. At the end of the cycle, the chain integrates the recycling, reuse, or recovery of products to sustainably close the life cycle. Finally, the green supply chain involves continuous monitoring and evaluation to constantly improve environmental practices (Antheaume et al., 2018).

A green supply chain is designed to minimize environmental impact throughout a product's life cycle, from production to distribution. It begins with the selection of environmentally responsible suppliers, favoring sustainable, recyclable, and ethically produced materials. Product design incorporates ecological criteria, such as reducing polluting components and ensuring ease of recycling (Ansi et al., 2023).

First, the collaboration between artificial intelligence (AI) and the green supply chain has become a major strategic challenge of our time.

This collaboration optimizes sustainable practices at every stage of the process. AI can analyze massive amounts of data to identify the most environmentally responsible suppliers and the most sustainable materials. It also enables accurate demand forecasting, thereby reducing

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overproduction and waste. It contributes to efficient inventory management by automatically adjusting stock levels to prevent overstocking and product degradation. AI can monitor the carbon footprint of each stage, providing real-time reports to support decision-making. In production, it helps reduce energy consumption and identify the most polluting processes. AI also facilitates the sorting and recycling of end-of-life products by predicting their reuse or recovery. It enables the detection of anomalies and inefficiencies in the supply chain, contributing to continuous improvement. Through predictive analytics, AI helps anticipate the need for sustainable resources and plan their procurement. It promotes transparency and traceability, making the supply chain more responsible and reliable for consumers. Finally, the collaboration between AI and green supply chains creates a virtuous circle, combining economic performance, reduced environmental impact, and sustainable development. (Baniket et al., 2022). Secondly, it can result in optimized stock levels, as AI rebalances inventory between different locations (stores, warehouses) through lateral transshipment.

Finally, this cooperation can lead to dynamic optimization of transshipment decisions, as AI can predict shortages or surpluses in real time using data on sales, weather, promotions, etc., identifying overstocked points of sale or warehouses and those with potential shortages. It can also recommend (or automate) lateral stock movements to avoid stock shortages or obsolescence (**Calvin et al 2023**).

The importance of transshipment continues to grow, especially following the emergence of a strategy called Vendor Managed Inventory (VMI). VMI, in French, translates to shared supply management. According to this strategy, the supplier manages the product inventory at the distributor, and thus the supply decision is made by the supplier, not the customer. This will be illustrated in figure1. (**Li et al., 2025**).

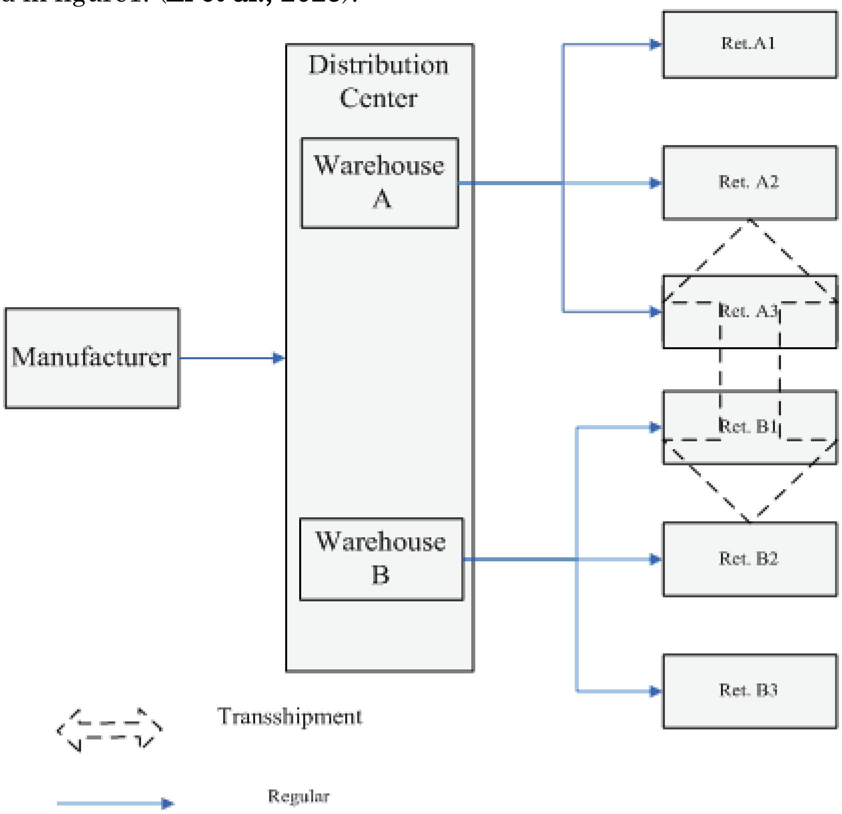

Figure 1: Representative diagram of Lateral Transshipment in a supply chain

First, There are indeed two main approaches to lateral transshipment in supply chain management. These approaches differ depending on when the transfer decision is made and the underlying inventory management logic. (**Dehghani and Abbasi, 2018**).

This first named : reactive transshipment is triggered after an inventory imbalance has been observed, such as: one point of sale is out of stock, another has excess stock. A transfer is then carried out to rebalance the situation.. The research work of (**Dong et al., 2012**) analyzed this lateral transshipment approach.

The second approach is that of preventive transshipments; these occur when retailers adjust and balance their inventories or prevent future stockouts. Among the studies that have studied this approach, we can cite, for example, that of (**Ekren and Sunderesh, 2008**).

In the literature, studies that have studied emergency transshipment are the most common. Therefore, we summarize, in the following,

In the literature, there are two lateral transshipment policies: "complete pooling" and "partial pooling."

These two policies define how inventory is shared or transferred between different locations (stores, warehouses, points of sale) within a logistics network.

• Partial-pooling: transshipment is carried out while maintaining a targeted stock level. According to (**Mishra and Tripathi, 2021**), the retailer accepts transshipment up to the excess stock at its reorder point.

• Complete-pooling: The Complete Pooling policy involves freely sharing all available stock between the different sites in the network. In other words, any excess stock can be used to meet any demand within the network, as long as this reduces the total cost (or the risk of stockouts) (**Yi et al., 2020**).

The Complete-Pooling policy assumes that all available inventory within the network can be pooled and freely redistributed. It aims to maximize product availability and customer service levels by utilizing the entire network inventory as a "common stock."

This is achieved by eliminating local stockouts, because if one site experiences a stockout, another site can immediately transfer stock to meet demand consistently and everywhere. (**Zhou et al., 2023**).

Today, a new relationship has emerged between Vendor Managed Inventory (VMI) and lateral transshipment, which is being used in conjunction with artificial intelligence to manage inventory in a supply chain.

Lateral transshipment involves moving inventory between different points of sale or warehouses at the same level to quickly meet local demand. This practice reduces stockouts and optimizes the use of existing inventory without waiting for replenishment from the distribution center. Vendor Managed Inventory (VMI) is a system in which the supplier directly manages inventory at the customer's location, monitoring levels and automatically replenishing necessary products. The common goal of both lateral transshipment and VMI is to maintain a balance between product availability and reduced inventory costs. Artificial intelligence (AI) plays a crucial role by analyzing large amounts of data from sales, inventory, and demand forecasts. It automatically determines the optimal time and location for lateral transshipment, thus preventing stockouts. In a VMI system, AI can dynamically adjust inventory levels and replenishments based on demand fluctuations and market trends. It also predicts seasonal fluctuations, the effects of promotions, and customer behavior to improve planning. AI can automate transfer and replenishment decisions, reducing human error and accelerating operations. It improves real-time inventory visibility and traceability for suppliers and managers. Thanks to AI, lateral transshipment becomes more efficient, as excess inventory can be redistributed before a stockout occurs. It also helps reduce storage and transportation costs while increasing product availability for customers. The combination of VMI, lateral transshipment, and AI creates a smarter, more responsive, and sustainable supply chain. In short, AI acts as a catalyst, making VMI and lateral transshipment more accurate, faster, and more efficient in meeting market needs. Finally, this integration fosters better operational performance and a reduced environmental footprint by optimizing resource use at every stage of the chain. (**Timajchi et al., 2019**).

Secondly, it aims to automate replenishment, as algorithms can decide when to replenish, in what quantity, and with what frequency, without human intervention. AI can also take into account logistical constraints (delivery times, warehouse capacity, etc.) (**Silbermayr et al., 2017**).

Finally, it can detect anomalies, as AI can detect anomalies in consumption data: unexpected spikes, sudden drops in demand, data entry errors. This allows for rapid response and inventory adjustments. And thanks to enhanced decision-making thanks to intelligent recommendation systems, logistics and sales managers can make more informed decisions (e.g., stock more of a trendy product, reduce orders for a declining product) (**Timajchi et al., 2018**).

Thus, mathematical modeling aims to formalize supply chain decisions (warehouse locations, production, distribution, transportation, inventory) using variables, constraints, and one or more objective functions.

For example, a supply chain network model under uncertainty ("random demand") can be formulated as a stochastic or robust programming problem: product allocation, location decisions, flows between nodes, etc.

Therefore, typical variables generally include: quantities to produce/ship, inventory levels, line/transport capacity, lead times, total cost, and fill rate. Typical constraints include: production capacity, transportation capacity, demand fulfillment, inventory policy (e.g., stock availability, quantity), lead times, and logistical constraints (e.g., transshipment, multi-echelon delivery).

For example, in "Mathematical Modelling and Optimisation of Supply Chain Networks Under Uncertain Demand Scenarios" (**Huang et *al.*, 2022**) a robust stochastic programming/optimization model is proposed for the supply chain network, taking into account uncertain demand, facility site selection, and routing.

Another example, in the literature, is (**Ju et *al.*, 2023**) a nonlinear mixed-integer model (MINLP) for a maritime transshipment facility; it shows how transshipment location and flow can be formulated as an optimization problem.

However, in these mathematical models, real-time or near-real-time control of the chain variables (inventory, transport, transshipment, production) is always necessary to respond to disruptions, demand variability, stockouts, etc.

And, in its mathematical models, optimization approaches can be: deterministic optimization (if the data is known), stochastic optimization (if there is uncertainty), or simulation-optimization (a combination of simulation and optimization algorithms). For example, one project integrates mathematical modeling and simulation for production/distribution planning with lateral transshipment.

Control can also be implemented through inventory policies (e.g., s,S), and responsiveness rules (e.g., lateral transshipment, redeployment) to stabilize the supply chain in the face of uncertainties.

Lateral transshipment refers to the mechanism by which several nodes or distribution centers (at the same hierarchical level in the supply chain – e.g., two warehouses or two retailers) transfer inventory between them (or redeploy) to address shortages or imbalances in demand.

It improves demand coverage by leveraging flexibility between sites: if one site has a surplus and another a shortage, a transfer can improve the overall service level.

Lateral transshipment reduces the overall inventory required for a given service level by pooling stocks between sites. For example, the study by (**Jirasak Ji and Navee Chiadamrong (2022)** demonstrates that, even without full coordination, lateral transfer can reduce total costs in decentralized systems and improve resilience to demand fluctuations or localized stockouts. Artificial intelligence (AI) enables real-time analysis of inventory levels and demand trends to optimize these transfers. It can predict which warehouses or points of sale will have a surplus or deficit of products, facilitating targeted lateral transfers. In a Vendor Managed Inventory (VMI) context, AI automatically adjusts replenishments based on anticipated needs. Even without full human coordination, AI can recommend stock transfers to balance inventory and prevent stockouts. It reduces storage costs by minimizing excess inventory and optimizing available space. AI can also take into account external factors such as seasonality or promotions to adjust transfers. In decentralized systems, lateral transshipment makes the supply chain more flexible and resilient to local disruptions. AI can simulate different transfer scenarios to identify the most efficient strategy. It can also prioritize transfers based on urgency or the strategic value of the products. Thanks to these predictions, companies can reduce delivery times and improve customer satisfaction. Integrating AI into lateral transshipment and VMI contributes to better inventory visibility across the entire network. This allows for anticipating stockouts and reacting before they affect the supply chain. By combining lateral transshipment, VMI, and AI, decentralized systems become more robust and cost-effective. Finally, this approach promotes proactive and intelligent inventory management, reducing total costs while improving resilience to market uncertainties.

AI models analyze historical data, seasonality, and external trends to anticipate demand with greater accuracy. With improved forecasting, inventory levels can be optimized, and stockouts and overstocking reduced. For example, the research by (**Paul, et *al.*, (2025)**) focuses on demand, routing, and inventory management. AI is used to identify the best routes, anticipate congestion and delays, optimize fleets, and predict breakdowns to prevent downtime and delays. AI provides not only forecasts but also prescriptive analytics to influence the supply chain: it automatically optimizes decisions (inventory, transportation, transshipment) based on forecasts.
For example, combined with optimization/stochastic modeling, AI can refine model parameters, detect unmet needs, and suggest adjustments in real time. In the context of lateral transshipment, AI could anticipate shortages, detect overstocks and automate transshipment decisions between sites.

2. Case study : « Safran-Tunisia » :

2.1. Sample description

As part of its "Safran Tunisia Innovation Shaker" program, « Safran Tunisia » continues to work towards an innovative and technological future in the aeronautics industry in order to meet the requirements of the future. After successfully completing its first industrial innovation catalyst day in 2022, dedicated to the vision of tomorrow's building, it's back this year with another theme: "The Industrial Supply Chain". Thus, in the context of current and future global challenges, It, always bold and ambitious, aspires to stimulate innovation to establish an industrial supply chain that is resilient, sustainable and technological.
For « Safran Tunisia », resilience is achieved through robust planning, effective risk management and flexibility to deal with disruptions. Sustainability, for its part, is ensured by minimizing the carbon footprint, promoting ethical and responsible practices and optimizing the use of resources.
In the context of current and future global challenges, « Safran Tunisia » continues to push its ambitions to the top through a resilient, sustainable and technological supply chain
It is in the presence of many experts, academics and startups that Sfaran Tunisia organized, on November 21, 2023 at the Cité de la Culture, the second edition of its catalyst day for industrial innovation. Entitled "For a sustainable, resilient and technological Supply Chain", this major program aims to improve the industrial supply chain.
« Safran Tunisia », which continues to work for an innovative and technological future in the field of the aeronautics industry in order to meet the requirements of the future, has succeeded in bringing together the players in the ecosystem, inspiring thanks to feedback from experts and stimulating reflection around the supply chain theme. The aim here is not to replace the role of humans but to consolidate it through technology that remains at the service of humans. It is a kind of attempt to eliminate physically demanding operations, to facilitate the daily lives of workers throughout the supply chain, to maximize employee safety by eliminating any risk of accidents, etc.
During a dynamic and lively day, technical experts, students and researchers, startups and suppliers, support structures and manufacturers looked at the challenges of the industrial supply chain. A memorable day full of lessons where a host of questions were addressed around scientific research and entrepreneurship, not to mention the presentations of many startups.
During the event, « Safran Tunisia » and its partner Enactus Tunisia also presented the "Race Enactus by Safran". Dedicated to young Tunisian entrepreneurs, the "Race" supported them in the development and implementation of their innovative and technological projects with the main objectives : "Meeting the major challenges of the supply chain".
The main objective of the program is to foster harmony between humans and intelligent machines by exploring innovative technological solutions in fields such as robotics, artificial intelligence and industrial supply chain. Each edition focuses on specific themes, offering participants the opportunity to collaborate on concrete use cases, evaluate their solutions against real needs and benefit from tailor-made support to develop their innovations.

2.2. Application of Lateral-Transshipment and IA in « Safran-Tunisia »

Lateral-Transshipment (or lateral transshipment) in an industrial context such as that of Safran Tunisia, which operates in the aeronautics sector, can refer to a logistics process consisting of transferring materials, parts, or semi-finished products from one workstation to another equivalent (for example, between two parallel production lines or two storage areas on the same level), without passing through the main flow or central warehouse.

Transshipment can enable Safran Tunisia to optimize logistics flows between its sites, suppliers, and end customers (particularly in Europe), in a highly demanding aeronautics supply chain context.

First, in the case of a "local transshipment hub," for example, lateral transshipment aims to centralize the flow of aeronautical parts from various Tunisian or Maghreb suppliers to the hub, then ship them in batches to France or other Safran sites. This is achieved by identifying a site (or extension of an existing site) that can serve as a platform. It also involves setting up a dock for receiving, consolidation, and rapid reconditioning. It also involves using local road transport, followed by transshipment via sea freight or Ro-Ro, or via cross-dock in Europe.

Secondly, for the case of "Transshipment between Safran sites in Tunisia," the Transshipmnet aims to avoid longer direct transports or unnecessary detours by transshipping from site to site depending on the proximity or specificity of the component. This results from: - Mapping current internal flows (for example: parts produced in Soliman but used in Grombalia or Dhari), identifying the most optimal routes, and implementing "cross-dock" transfers or direct links rather than via France or external suppliers. Finally, for the "Optimized International Transshipment" case, the Transshipmnet aims to improve the connection between Tunisia and France (and other markets) for exports/imports, by using third-party hubs or transshipment platforms in Europe/France.

This will result in the use of logistics partners (such as CEVA) for road and maritime / Ro-Ro and cross-dock. Define fixed frequencies, consolidate shipments to maximize loads, and ensure traceability, customs compliance, and insurance.

Safran Tunisia is investing heavily in artificial intelligence to modernize the aerospace industry. It is developing predictive systems for aircraft engine maintenance. The goal is to reduce downtime and optimize aircraft availability. The company uses machine learning algorithms to analyze sensor data. These analyses make it possible to predict failures before they occur. Safran Tunisia is implementing computer vision solutions to inspect aeronautical parts. These solutions improve the accuracy and speed of quality control. AI is also being applied to production planning. Intelligent planning tools optimize manufacturing flows. The company uses digital twins to simulate industrial processes. These twins make it possible to test different scenarios without interrupting production. Safran Tunisia collaborates with AI startups. These collaborations accelerate innovation and the adoption of new technologies. AI is integrated into the supply chain to anticipate component needs. Predictive algorithms reduce delays and logistical costs. Safran Tunisia develops automated machine control systems. The goal is to increase operational efficiency and safety. The company trains its employees on artificial intelligence tools. This training promotes AI adoption across all teams. Safran Tunisia uses data analysis to optimize energy consumption. Reducing its carbon footprint is a strategic priority. AI improves the traceability of parts and materials. Each component can be tracked from production to installation.

Collaborative robots are integrated into production lines. These robots increase productivity and reduce human error. Safran Tunisia develops algorithms for inventory management. These algorithms reduce waste and improve parts availability. The company uses AI to strengthen industrial cybersecurity. The systems detect anomalies and intrusion attempts in real time. Artificial intelligence is applied to the design of new engines. Simulations accelerate the research and development process. Safran Tunisia leverages in-flight engine performance data. This data feeds predictive models to improve reliability. AI optimizes aircraft assembly lines. Workflows are automatically adjusted as needed. The company collaborates with universities to develop new applications. These partnerships foster innovation and knowledge transfer. Safran Tunisia is testing AI in predictive turbine maintenance. The trials demonstrate a significant reduction in operational costs. AI is used for analyzing the quality of composite materials. This analysis makes it possible to detect defects invisible to the naked eye. Safran Tunisia is implementing digital platforms to centralize data. Centralization facilitates AI-driven decision-making. The company is exploring augmented reality systems for parts assembly. These systems improve the accuracy and safety of operations. AI contributes to the logistical planning of spare parts. Delivery times are reduced thanks to more reliable forecasts. Safran Tunisia is developing condition-based maintenance models. These models adapt to the actual operating conditions of the engines. The company is optimizing the energy performance of its factories with AI. Algorithms identify areas where efficiency can be improved. Safran Tunisia is deploying automated turbine inspection systems. Inspections are faster and less prone to human error. AI is applied to flight data analysis to improve safety. Models identify critical trends and anomalies. The company uses optimization tools for its global supply chain. Decisions are based on accurate demand forecasts. Safran Tunisia is testing autonomous maintenance solutions for certain equipment. These solutions reduce reliance on manual interventions.

Artificial intelligence reduces production costs while increasing quality. AI is integrated into computer-aided design. Design models benefit from automatic optimizations. Safran Tunisia uses AI to detect microscopic defects. The systems are capable of identifying imperceptible anomalies. The company collaborates with cloud providers to store and analyze massive datasets. Data security and confidentiality remain top priorities. AI is applied to aerodynamic flow simulations. These simulations accelerate engine research and development. Safran Tunisia is testing the integration of AI in propeller and turbine maintenance. Performance gains are evaluated over the long term. The company develops tools to optimize production time. AI adjusts processes according to real-world constraints. Safran Tunisia encourages internal innovation through hackathons and AI competitions. Employees propose solutions to improve operations. AI is used to improve industrial waste management. Processes become more sustainable and less costly. The company is implementing intelligent dashboards for real-time monitoring.

Therefore, integrating lateral transshipment with artificial intelligence could prove relevant for Safran-Tunisia. This approach would optimize the flow of components within the production lines. AI could analyze the parts requirements for each workstation in real time. Predictive algorithms would anticipate the necessary movements to avoid delays. Automated lateral transshipment would reduce manual intervention, thus decreasing the risk of human error in component transport. Robots could move autonomously between stations, with AI coordinating these movements to maximize efficiency. Production flows would become smoother and more synchronized, and manufacturing lead times would be significantly reduced. Equipment maintenance could be planned more precisely, and unplanned downtime would be minimized. Inventory optimization would become easier thanks to real-time data, with parts available exactly where they are needed. Logistics costs would decrease through automation, allowing teams to focus on higher-value tasks. The risk of congestion in workshops would be limited. Production cycles would become faster and more consistent. AI would allow for the instant adaptation of flows to variations in demand. Systems could learn from historical patterns to improve performance. Operational safety would be enhanced. Accidents related to manual handling would be reduced. AI-driven lateral transshipment would facilitate parts traceability. Every movement could be recorded and analyzed. Performance indicators would be more accurate and reliable. Production adjustments could be made proactively. Processes would become more resilient to industrial disruptions. The integration of this technology would strengthen innovation within Safran-Tunisia. The company's competitiveness in the global market would be increased. Efficiency gains would translate into greater customer satisfaction. Operations planning would become more predictive and less reactive. AI could detect and correct flow anomalies in real time. Handling processes would be more sustainable and energy-efficient. Coordination between different production units would be improved. Delivery times for critical components would be shortened. Performance monitoring would become more transparent for management. Intelligent automation of lateral transshipment would offer strategic advantages. Systems could be adapted to different plant configurations. Gradual integration would allow for impact assessment before widespread implementation. Collected data would enrich optimization models. Teams would be trained to fully leverage AI tools. The company could virtually test different logistics scenarios. Feedback would fuel continuous improvement. AI would provide recommendations for reorganizing flows when needed. Anticipating constraints would be more effective. Resilience to breakdowns or staff absences would be strengthened. Finally, integrating lateral transshipment with AI would represent a major lever for the modernization and industrial performance of Safran-Tunisia.

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2.3. Mathematical model

2.3.1. Classical Cost Minimization Model with Lateral Transshipment and IA

We consider a supply network of N warehouses (or distribution centers).
Each warehouse can exchange inventory laterally with others to balance shortages and surpluses.
The objective is to minimize total system costs, including procurement, holding, shortage, and transshipment costs.

- **Parameters and Decision Variables**

The different parameters and Decision Variables of the model are presented in Table 1, By limiting the number of retailers to two.

Table 1 : Decision Variables of model with Transshipment-Lateral and IA

Symbol	Meaning
i,j∈{1,…,N}	Warehouses (or nodes)
D_i	Demand at warehouse ***i***
S_i	Initial stock at warehouse ***i***
Q_i	Quantity ordered from supplier to warehouse ***i***
T_{ij}	Quantity transshipped from warehouse ***i*** to warehouse ***j***
C_i^p	Unit procurement cost at warehouse ***i***
C_i^h	Unit holding cost at warehouse ***i***
C_i^s	Unit shortage (penalty) cost at warehouse ***i***
C_{ij}^t	Unit lateral transshipment cost between warehouses ***i*** and ***j***

- **Objective Function**

$$\min Z=\sum_{i=1}^{N}\left(C_i^p Q_i+C_i^h I_i^+ +C_i^s I_i^-\right)+\sum_{i=1}^{N}\sum_{j=1}^{N} C_{ij}^t T_{ij}$$

with $I_1 = PS_{1T} - D_{1T} - X_{12} + X_{21}$, $\forall$ R=kT et k=2, 3, 4, …, 10.

$I_2 = PS_{2T} - D_{2T} - X_{21} + X_{12}$, $\forall$ R=kT et k=2, 3, 4, …, 10.

and $i = 1$ and $j = 2$

- The constraints of the product transshipment strategy between these two sites,

(1) if $D_{1T}<PS_{1T}$ So $X_{21} = X_{12} = 0$; $\forall$ R=kT et k=2, 3, 4, …, 10.
(2) if $D_{2T}<PS_{2T}$ So $X_{21} = X_{12} = 0$;
(3) if $D_{1T} \geq PS_{1T}$ So $X_{21} = X_{12} = 0$;
(4) if $D_{2T} \geq PS_{2T}$ So $X_{21} = X_{12} = 0$;
(5) if $D_{1T}<PS_{1T}$ et $D_{2T}> PS_{2T}$ So $X_{21}= \min\{PS_{1T} - D_{1T}, D_{2T}-PS_{2T}\}$;
(6) if $D_{2T}<PS_{2T}$ et $D_{1T}> PS_{1T}$ So $X_{12} = \min\{PS_{2T} - D_{2T}, D_{1T} - PS_{1T}\}$.

For the Without-Transshipment (***No-Pooling***) case, the modeling by the ARENA 16.0 software can be presented by the figure 2.

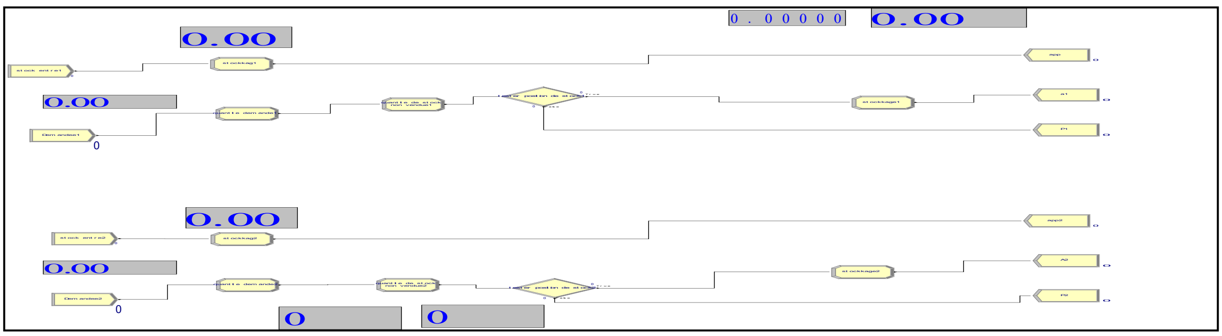

Figure 2. The simulation model Supply Chain: No-Pooling

Assumptions
To properly model this stock system using the Arena software, it is necessary to list the assumptions and the mode of operation retained in this work:
- The storage capacity of the central warehouse is infinite;
- Retailer *i* applies the storage policy (R, S_i);
- Partial satisfaction of an order is not allowed,
- Any unsatisfied order will be lost;
- Only one order (emergency according to the central depot) is allowed per supply cycle (at the end of period R); with $R = kT$
- There is no definite order of priority. All customer orders are managed according to the same FCFS (First Coming First Served) priority rule;
- The distribution center has sufficient storage capacity, so as not to introduce availability constraints (Unlimited storage policy).

For the first transshipment policy called “Complete-Pooling” the modeling by the ARENA 16.0 software can be presented in figure 3.

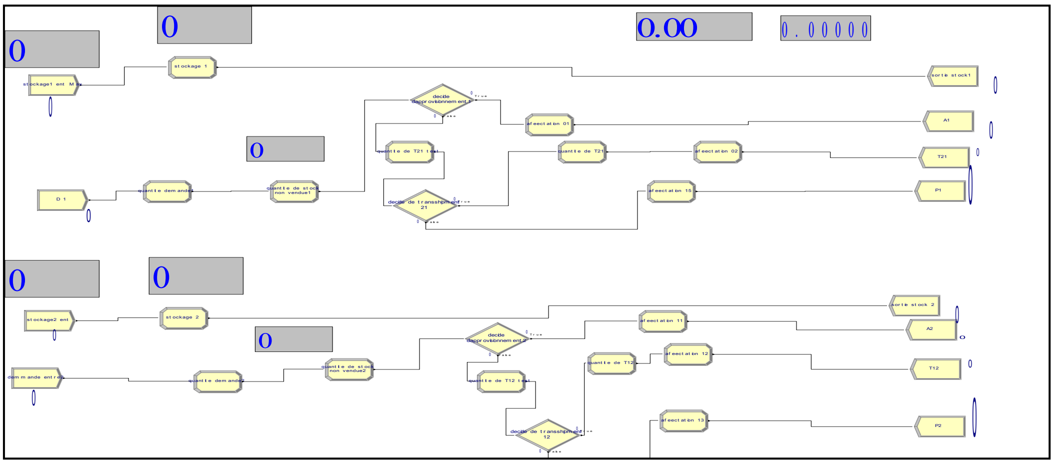

Figure 3. The simulation model Supply Chain: Complete-Pooling

Assumptions
We consider the following assumptions:
- Retailer 1 confronts a random demand independent of demands from retailer 2;
- The transshipment time is zero;
- In the case where a retailer 1 faces a stock shortage, whereas, the retailer 2 has a surplus of inventory, a transshipment of the necessary quantity (X_{21}) will take place from 2 to 1 to avoid or minimize the shortage: this is the correct transshipment (also called reactive transshipment). Otherwise depot 1 may require an emergency order of size Q1 at the distribution center;
- In the event of "Complete-Pooling", the retailer who is in the overstock position agrees to transfer all of his available stock if necessary.

Let's assume that Safran Tunisia has 2 sites at the same level. These two sites apply Transshipment -Tatéral, which is a logistics strategy in which stocks are transferred between sites located at the same hierarchical level of a distribution or production network to meet demand, avoid stockouts and optimize costs (see, table 2).

Table2. Real-world example for two retailers applying Lateral Trachipment by integrating AI in Safran-Tunisia

Site	Initial safety stock (units)	Forecast demand (units/month)	Stockout cost/unit (€)	Storage cost/unit/month (€)	Transshipment cost/unit (€)
A	500	1000	50	2	5
B	500	800	50	2	5

Therefore, demand can vary by ±20% per month (randomly) and sites can transfer stock between themselves at €5/unit instead of going through costly external orders (€50/unit).

Case 1: Without Lateral -Transshipment
Each site must cover its own stockouts solely with its safety stock. Let's assume that, on average, site B experiences a stockout of 200 units per month.
So, the stockout cost =200×50=10000€
Total storage cost= (500+500)×2=2000€
Total cost excluding transshipment= 2000+10000=12000€/mois

Case 2: With Lateral -Transshipment
By applying the Lateral Transshipment between its two retailers of the same echelon, we find the following result:Safety stock is reduced through pooling:
Site A: 300 units
Site B: 300 units
Total safety stock = 600 units instead of 1000 units
When a stockout occurs at B (200 units), A can transfer:
Transfer cost= 200×5=1000€
Breakdown cost = 0 (all needs covered)
Total storage cost= (300+300)×2=1 200€
Total cost with transshipment= 1200+1000=2200€/mois

Lateral transshipment (or the transfer of stock between retail outlets) minimizes the total cost in a two-retailer system by balancing inventory and preventing stockouts or overstocking in each store. Rather than simply ordering separately, a retailer with excess stock can transfer products to another retailer that is running low, thus reducing the need for new orders, excessive storage costs, and lost sales.
It primarily aims to coordinate stock balancing, as the two retailers coordinate their inventory levels. They share information on demand and current stock levels to anticipate imbalances. It also facilitates surplus transfer, because if one retailer has excess stock and the other is about to run out, the first can transfer products to the second. Furthermore, its objective is to reduce costs, as this action avoids the costs associated with urgent product transport from the central supplier, as well as the costs of holding excess inventory and lost revenue. Overall optimization: The goal is to minimize the total cost of the entire system (ordering, storage, transportation, and stockout costs) rather than simply optimizing the costs of each retailer in isolation.
In short, lateral shifting allows for a lower average inventory level across the entire system, while maintaining a high level of customer service, leading to a reduction in overall costs.

2.3.2. Position of "Safran-Tunisia" in the competitive international market

Safran Tunisia is a major player in the global aerospace supply chain, primarily specializing in the production of onboard systems, aircraft interior components (seats, galleys, compartments), and mechatronic equipment. The Tunisian sites are an integral part of Safran's global network, supplying critical parts to customers such as Airbus, Boeing, and other major international clients. Safran Tunisia produces more than 25,000 different references, with a high production rate (one part delivered approximately every 2 seconds), which demonstrates its significant industrial and logistical capacity.
Compared to other players in the sector worldwide, the following advantages are summarized in Table 1.

Table 1: The strengths of the company "Safran-Tunisia" in a competitive international market

Strength	Description	Advantage in the competition
Skilled workforce and competitive costs	Tunisian engineers and technicians are considered to be of a high level, coupled with production costs (salaries,	Allows us to offer components at relatively low costs, while maintaining the quality

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	infrastructure) which are generally lower than in many Western countries.	demanded by global aerospace customers.
Local integration and product diversification	Various products (interiors, on-board systems, seats, galleys, compartments, electronics, actuation etc.).	Allows Safran Tunisia to not be dependent on a single type of component, to respond to different ranges, which increases its resilience and attractiveness.
R&D capacity and local innovation	Development activities, filing of local patents, innovation programs (e.g. "Innovation Shaker") involving startups, etc.	This allows us to move up the value chain, not only in production but also in design and technological differentiation.
Strategic position & industrial attractiveness	Tunisia benefits from a developed aeronautics industry, numerous graduates, a training ecosystem, and government support for aeronautics.	This attracts investment; Safran can benefit from a favorable environment for growth, and a good cost/quality ratio.
Quality & compliance with international standards	As a supplier for Airbus, Boeing, etc., Safran Tunisia must meet very demanding standards.	This ensures credibility, allows access to global markets and exports without major compliance barriers.

According to the table , « Safran-Tunisia » occupies a Tier 1 or 1.5 supplier niche for integrated components, interiors, embedded systems, seats, etc. It is not (at least not yet) a producer of complete aerostructures or engines (overall, these activities remain predominantly located in France, the United States, the United Kingdom, etc.).
Through local innovation and the integration of Transshipment-Latéral, a partnership with IA, Safran-Tunisia is improving its positioning not only as a simple production workshop but also as a stakeholder in design chains, thereby increasing its added value.
This results from advantages such as:
- ***Increased local integration rate***: producing more components in Tunisia, reducing imports of intermediate parts, which reduces costs, lead times, dependency, and creates local value.
- ***Continued innovation/R&D***: in electrification, lightweight materials, sustainability, carbon footprint reduction, etc., to differentiate ourselves from competitors who simply produce standard parts.
- ***Strengthening the local supply chain:*** developing certified Tunisian suppliers for subcontracted components, which allows for better control over lead times, costs, and quality.
- ***Leveraging geographic/cost advantages*** to attract more assembly contracts and medium- to high-complexity subassemblies.
- ***Positioning ourselves*** in associated services (maintenance, recertification, modification, retrofitting), which often offer higher margins than pure production.

So, compared to suppliers in Southeast Asia or Eastern Europe: Safran Tunisia must compete on quality, lead times, and compliance, while maintaining reasonable costs. Some Asian competitors may be less expensive, but may be less similar in terms of lead times or quality standards. Also, compared to production centers in France or Western Europe: Tunisia offers lower labor costs, but transportation or certification costs can be higher depending on the type of component. Therefore, its positioning is often better in labor-intensive parts or subassemblies where labor is a significant factor, and less so in the manufacturing of highly technological parts with very high added value (excluding R&D, specialty materials), where R&D/advanced production centers remain in historical regions. Finally, compared to other African or Mediterranean countries: Safran Tunisia

already seems to be one of the leaders, thanks to its attractiveness, competence, relative stability, public support, etc. It is one of the success stories in this area for the aeronautics industry.
Safran Tunisia can achieve several competitive advantages in the international market, thanks to:
- ***Qualified labor at competitive costs***: Tunisia offers a good compromise between technical quality and lower labor costs than Western Europe or North America.
- ***Mature industrial ecosystem***: Presence of a network of certified local suppliers and infrastructure adapted to the aeronautics industry.
- ***Local innovation capacity: Safran Tunisia develops R&D activities, which allows it to*** upgrade its technological range and integrate more value into its products.

3. Conclusion

Today, the combined integration of AI, vendor-managed inventory (VMI), and lateral transfer is essential to Safran-Tunisia's competitiveness. AI enables real-time analysis of production flows, anticipating component needs to prevent stockouts. VMI ensures a constant and optimized supply from the supplier, with inventory levels automatically adjusted according to actual demand. Lateral transfer facilitates the rapid movement of parts between production stations, reducing manufacturing lead times and waiting times. Optimized flows improve overall plant efficiency. Human errors in handling are minimized through automation, significantly reducing logistics costs. AI analyzes historical data to predict peak activity periods, allowing the supplier to react quickly to demand fluctuations. Lateral transfer ensures the smooth flow of critical components, making processes more resilient to unforeseen events and strengthening coordination between different production units. The company can better meet customer deadlines and improve customer satisfaction. Strategic decisions are based on reliable and accurate data. Integrating these three levers creates a sustainable competitive advantage. Industrial performance is optimized at every stage. Safran-Tunisia thus consolidates its position in the global market thanks to this innovative synergy.

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