# Enhancing FedEx Supply Chain Management System Through Partial Automation and Smart Contracts

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## Introduction

In the complex logistics industry, FedEx constantly faces the challenge of optimizing its supply chain processes to increase operational efficiency and meet customer expectations. Supply Chain Management (SCM) systems have been critical in enhancing traditional supply chain activities by enabling larger visibility and control over the different activities including production and delivery (Fernando, 2024). These activities can be further enhanced with Industry 4.0 technologies, such as automation and digitalization, which can increase efficiency in processes involving repetitive tasks. FedEx can take advantage of these technologies to streamline operations, reduce redundancies, and enhance overall performance by integrating various components such as procurement, transportation, warehousing, and distribution.

Implementing new technologies into working systems must be carefully evaluated considering potential benefits, investments, and strategic goals. A systematic yet holistic approach is necessary to ensure that any changes and technologies implemented can be developed successfully to achieve the expected results. Systems engineering can be used to ensure that all components are designed and validated to work together to achieve the desired objectives harmoniously. The following project aims to improve efficiencies in FedEx packaging sorting and handling systems, using automation and advanced algorithms, while also implementing smart contracts to expedite agreement execution, completion of payments, and reduction of documentation handling. The proposed system is developed following systems engineering principles and is structured following the different stages from concept to operation and support.

# Concept Development Phase

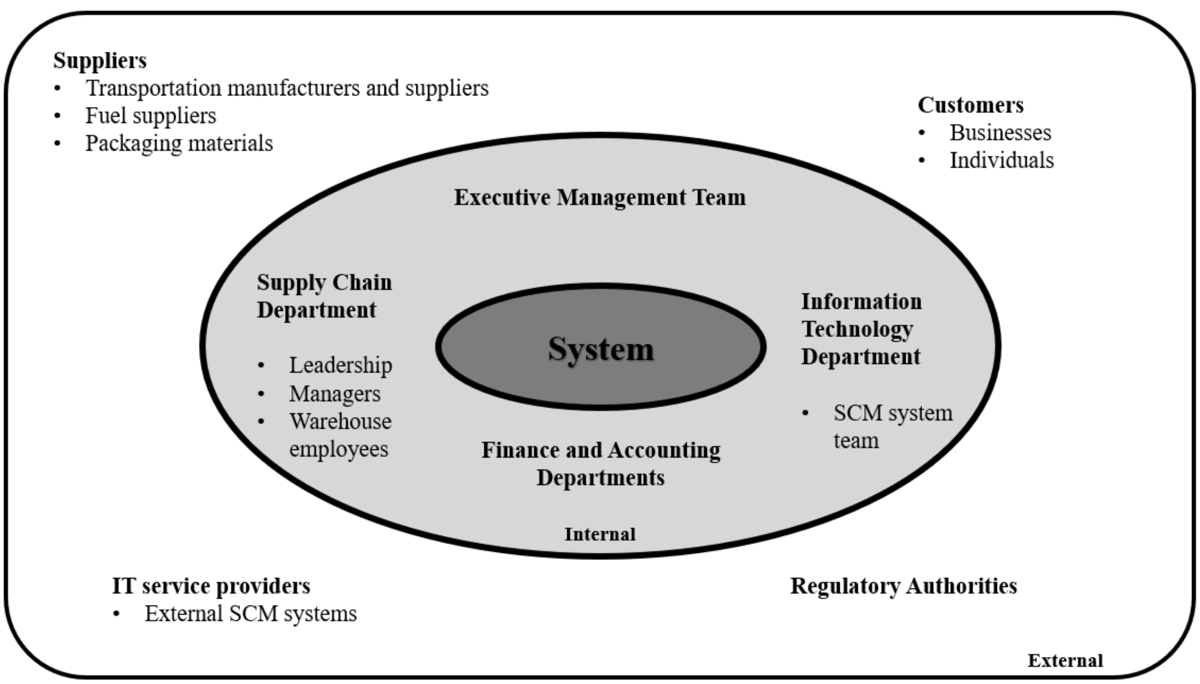
## System Needs Analysis

### *Stakeholder Identification*

Stakeholder identification is the first step to understanding and developing the requirements for the system. Stakeholders can be any individual, business, or organization that can influence or be affected directly or indirectly by the system. These can be internal or external to the business or organization (CIPS, n.d.). These were identified according to their potential impact on the system, with special attention to the supply chain and warehouse processes (Hopstack, n.d.). **Figure 1** shows the different identified stakeholders.

**Figure 1**

*Identification of Internal and External Stakeholders.*



**Internal Stakeholders**

***Executive Management Team.*** They are focused on providing strategic objectives and making decisions to guide the company at aiming to increase revenue, efficiencies, reducing costs, and pursuing competitive advantages. They are a critical stakeholder in supporting the development and execution of the system given the potential impact on business operations.

***Supply Chain Leadership and Management Teams.*** They are a critical stakeholder in the relationship management and handling of customers, suppliers, and supply chain workers. Their main interests are to drive performance improvements in the daily operations for logistics, inventory, and fulfillment of orders (Hopstack, n.d.).

***Finance and Accounting Departments.*** These departments focus on managing the overall finances of the company including planning and analysis for achieving goals. They are key players in the management of payments for suppliers and the processing of orders.

***Warehouse Employees.*** They run all the different operations and processes in the warehouses for the fulfillment of orders. These include processing orders, handling and classification of packages, managing inventory, and control of quality, among others. Their feedback is key because any changes will directly affect how they interact with the system and perform their activities (Hopstack, n.d.).

***Information Technology Department.*** Their main focus is to develop, implement, and maintain the systems that enable business operations. They must ensure that the system is compatible with other systems in use and that all information is securely protected. Their inputs must be considered to ensure the system can be easily integrated and does not represent a safety concern or is vulnerable.

**External Stakeholders**

***Suppliers.*** They enable the company to perform through the supply of the necessary resources for business operations. Examples are transportation manufacturers and suppliers, fuel suppliers, packaging materials suppliers, and IT service providers, among others. Suppliers must be considered because they are likely to be affected by changes in the system that may affect the execution of contracts and payments.

***Regulatory Authorities.*** Their main objectives are to ensure that the system and overall processes comply with the latest standards and regulations. Their input and constant revision are necessary to ensure the system is developed and validated appropriately. Any irregularity can lead to the system being modified or re-designed leading to delays and other issues.

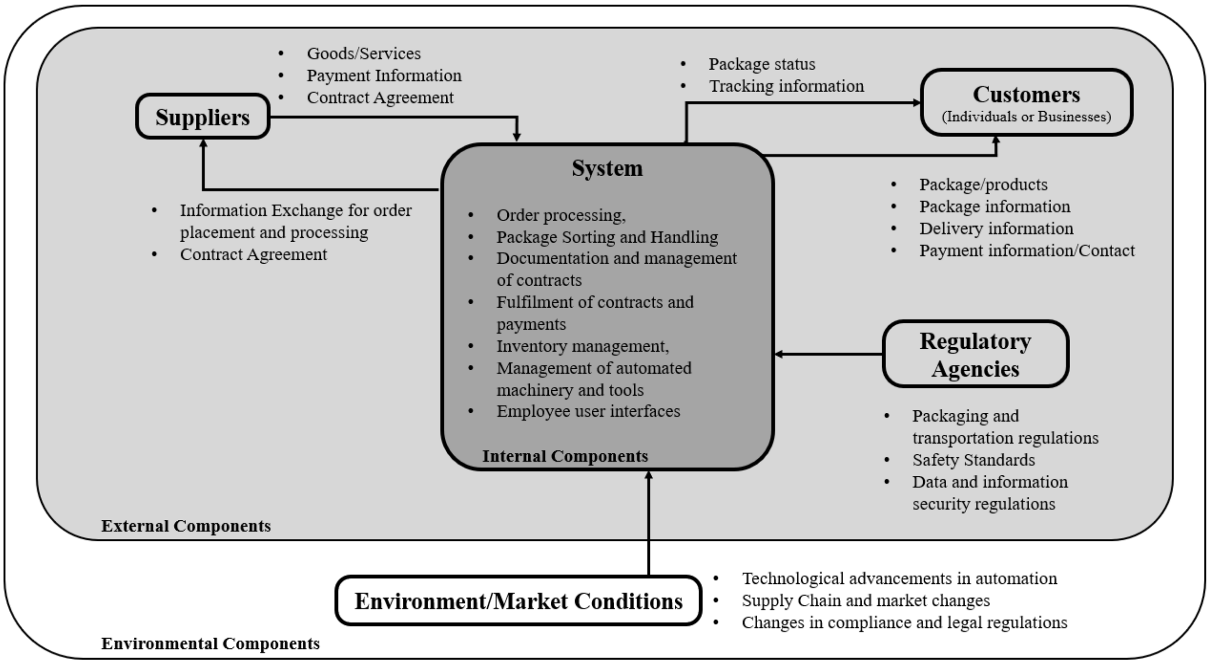
***Customers.*** They include businesses that rely on FedEx for their supply chain services and individuals that need to send and receive personal packages. Their main interest is to have a reliable service that delivers the goods on time and safely. They are critical stakeholders because they are the company's source of income.

***System Boundaries***

The system boundaries are identified to ensure the system is developed within the established requirements and prevent project creep. The boundaries for the developing system cover the internal components, interactions with external components, and the system environment (Kossiakoff et al., 2020). **Figure 2** illustrates the relationship between these components and the system boundaries.

**Figure 2**

*Context Diagram Illustrating Interactions of Internal, External, and Environmental Components*




There are a variety of activities and interactions within and across the system components and boundaries. The internal components of the system perform activities such as processing of orders, data analysis, and management of inventory, documentation, and equipment. The external components interact with the system through exchange of information for processing of orders, payments, and tracking of packages, among others. It is worth nothing that the system and its components are also affected by environmental factors such as changes and development of new technologies, changes in regulations, and even issues in the supply chain market.

### ***Needs and Requirements Analysis***

A clear understanding of the needs of the different stakeholders is critical for the success of the developing system. Observation and research are used to understand the stakeholders' needs based on their priorities and roles in the supply chain operation process. This data is collected, reviewed, and analyzed to narrow down and prioritize the needs to be addressed by the system. **Table 1** summarizes the interests and needs of each identified group of stakeholders.

**Table 1**

*Identification of Stakeholder Needs.*

| Stakeholder | Category | Interests | Influence | Impact |
|---|---|---|---|---|
| Executive management team | Internal | Improve efficiency, reduce operational costs, ensure system scalability, and drive innovation. | High | Medium |
| Supply chain leadership and management | Internal | Speed up the package handling and sorting, reduce order processing time, acquire real-time analytics on automation, high system reliability, and seamless integration with the current processes. | High | High |
| Finance and Accounting departments | Internal | Automatic document management and payments, real-time information and tracking of payments, integration with current financial systems, and automatic detection of errors for troubleshooting. | Medium | High |
| Warehouse employees | Internal | Easy to use, understand, and troubleshoot, and seamless integration to complement and speed up activities. | Medium | Medium |
| Information technology department | Internal | Compatibility with current structure and systems for supply chain, and robust data safety and security system. | High | Medium |
| Suppliers | External | Easy, fast, and reliable way of processing orders including physical and digital services, documentation management, and payments. | Medium | Medium |

| | | | | |
|---|---|---|---|---|
| Regulatory authorities | External | Compliance with the latest standards for safety, transportation, handling of materials, data, and information protection. | Medium | High |
| Customers | External | Safe and reliable means for shipping, tracking, and receiving packages and goods. | Medium | Medium |

Based on the different inputs from the stakeholders, the system must be developed to fulfill the following requirements:

- Increase efficiency in handling and sorting of packages and fulfillment of contacts,
- Drive cost-effectiveness in overall processes for cost savings,
- Maintain performance and reliability of the system including its hardware and software components,
- Protect data and information from the different processes and transactions executed internally and externally,
- Ensure compatibility and integration with existing operating systems,
- Minimize complexity of tasks and system operations for customers, suppliers, and employees,
- Comply with safety regulations applicable for personnel, information, and handling and transportation of goods.

**Requirements Analysis**

Separating functional and non-functional requirements will ensure a complete project scope for FedEx's state-of-the-art package handling and automation system. Functional requirements put attention on identifiable system features that affect the direct functional operations of robotics and advanced algorithms. Non-functional requirements are responsible for guaranteeing general system features like security, accuracy, and efficiency, without which the success of the system as a whole would not be possible.

### *Non-Functional Requirements*

**Improve Efficiency.** One of the primary requirements is to improve efficiency and increase the speed of package sorting and handling processes. The goal is to cut the amount of time spent sorting and managing materials by at least 20%. To achieve this, the steps include streamlining workflows, reducing bottlenecks, and implementing advanced automation technologies.

**Accuracy and Reliability.** Another requirement is to sort packages more accurately to reduce errors and guarantee reliable delivery. The intended sorting accuracy is at least 99.5%. To achieve this, precise sensors, real-time data analytics, and continuous monitoring will be used.

**Integration.** A smooth integration with FedEx's existing IT systems and infrastructure. To achieve this, compatible software and hardware interfaces and thorough testing will be done with the current systems. It will identify integration problems and will allow swift troubleshooting.

**Cost-Effectiveness.** Maintain effectiveness by making modifications that do not incur additional expenses. Automation of tasks and enhanced productivity can even reduce operational expenses by 15%. This can be accomplished through phased implementation and strategic technology investment.

**Security.** More importantly, the data and transactions should be secure, especially when dealing with smart contracts (Santosh et al., 2024). This means robust encryption, scheduled security audits, and adherence to industry-accepted standards for safeguarding against cyber threats. Employees will be trained on security best practices; to minimize human-error and increase overall system security.

### *Functional Requirements*

**Robotics Integration.** To handle shipments, use automated guided vehicles (AGVs) and robotic arms (Jagdev & King, 2023). Together, these robots will sort, move, and collaboratively handle packages, decreasing the amount of manual labor required and increasing throughput. The software maintenance and updates will extend the life of the robotic systems and continue to be effective.

**Smart Contracts.** Create and implement Smart Contracts in SCM to automate agreements and reduce manual operations. These contracts will be designed to save processing time and increase efficiency by automatically executing transactions when specific conditions are met. Detailed logging and monitoring of Smart Contracts will create transparency and traceability.

**Advanced Algorithms.** Develop and implement machine learning (ML) algorithms to sort packages in real-time and optimize delivery routes. Large datasets will be analyzed by these algorithms, which will then use machine learning techniques to continuously improve their accuracy as they forecast the most effective sorting and routing patterns. The algorithms will have to be periodically evaluated and retrained so they remain in sync with changing patterns and continue to give a high performance.

## Evaluation and Selection

Many system alternatives were considered for improvements to FedEx's packaging handling and automation system. The proposed criteria for evaluation were cost, time, performance, and security. Ultimately, the best hybrid system found was one that combines partial automation with Smart Contracts, providing a balance between transactional speed and operational efficiency for both the core and the edge business cases.

***Evaluation of System Alternatives***

To accomplish the project goals, multiple solutions were considered. **Table 2** compares the three system alternatives for implementing Industry 4.0 technology to enhance package handling and automation for FedEx in terms of costs, operational benefits, and efficiency improvements. Operational performance is referred to as efficiency. Costs include both one-time and ongoing costs. Time shows how long an implementation will take. More security is achieved by reducing human involvement, which protects against mistakes and unwanted access.

**Complete Automation with Cutting-Edge Robots.** Built on top of advanced robots, the solution automates the sorting and handling process. While this has major long-term efficiency benefits, the initial cost can be high. This option can dramatically bring down manual labor as well as human errors for stable high throughput. However, the initial cost requires solid financial backing and careful cost-benefit evaluation.

**Manual Sorting with Incremental Automation.** The best part about this solution is that it leaves some human touch in the process and gradually integrates automated solutions. Even though the cost is lower to start with, the improvements in efficiency rates are slower. This option allows the system to ease into automation and reduce operational disruption. Slow efficiency gains, however, could push back ultimate efficiency gains.

**Hybrid Solution Utilizing Smart Contracts.** This solution utilizes smart contracts for SCM in combination with semi-automation. The initial cost of this solution is moderate, and the efficiency improvements are reasonable. Powered by smart contracts, it improves the automation of transactional processes and decreases the need for manual monitoring. The blend of reasonable upfront costs and mild efficiency boosts is the best option that allows for updates but does not break the bank.

**Table 2**

*Evaluation of System Alternatives*

| Criteria | Complete Automation with Cutting-Edge Robots | Manual Sorting with Incremental Automation | Hybrid Solution Utilizing Smart Contracts |
|---|---|---|---|
| Efficiency | High | Moderate | High |
| Cost | High | Lower | Moderate |
| Time | Fast | Slow | Moderate |
| Security | High | Moderate | High |

*Note. Three system alternatives for improving FedEx's package handling and automation with Industry 4.0 technology are compared in* ***Table 2****.*

### *Evaluation Criteria and Measurements*

The assessment was carried out by going along with the integrated criteria and metrics, which was, in fact, the next setup used to evaluate the possible solutions and measure the success of the project. The metric targeted 99.5% or better sort accuracy, and the performance for sort accuracy and throughput were performance criteria. To guarantee cost-effectiveness, a breakdown was compared between the initial investment and ongoing operational costs against the current expenses. This includes the scaling or provisioning cost and also the long-term operational costs.

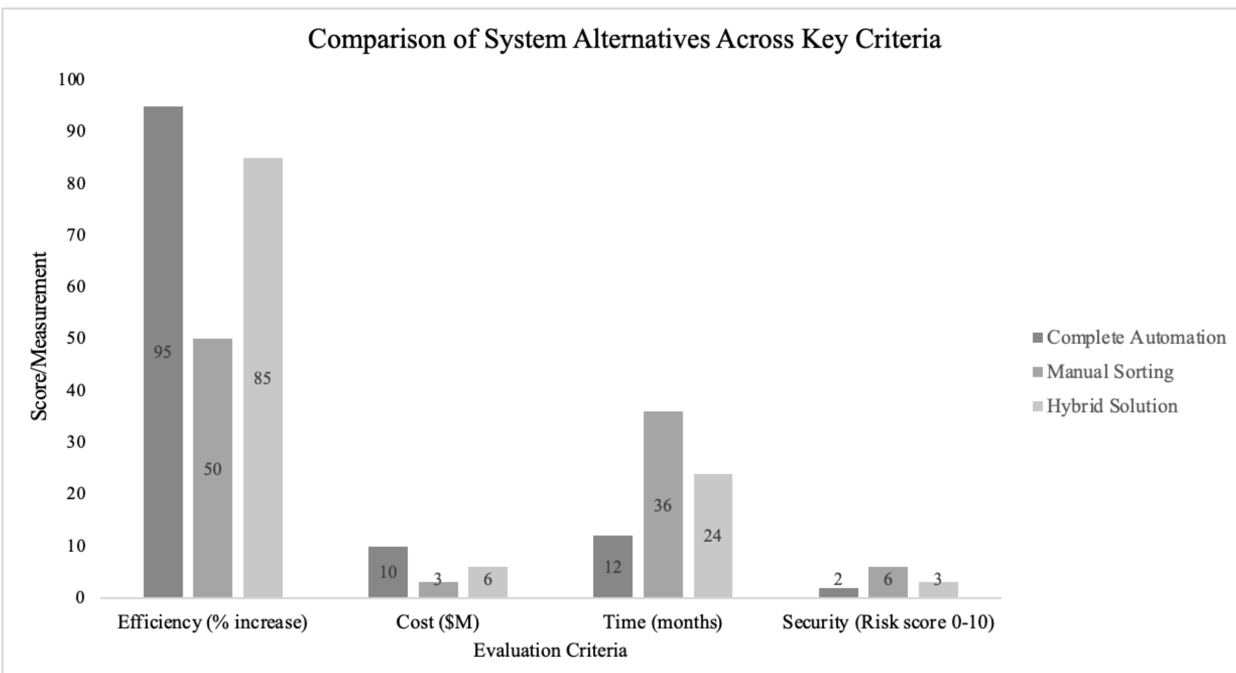
The main measurement focus was on the percentage improvement in sorting and handling time from current processes, and the evaluation focused on the time required for implementation and the decrease in sorting and handling time (Online, 2023). It is important to ensure data security and transaction integrity when utilizing Smart Contracts. The measurement focused on how long it took for Smart Contracts to carry out transactions, with the goal of doing so in a matter of seconds.

***Preferred final solution***

The hybrid system with Smart Contracts came out to be the best option after evaluating all of the solutions. This system ensures operational efficiency and transactional speed without having excessive expenses by providing a well-balanced mix of automation and cutting-edge SCM approaches. ***Figure 3*** shows the comparison of system alternatives across key criteria such as efficiency, cost, time, and security.

**Figure 3**

*Evaluation Criteria and Measurements*



## System Architecture

To achieve a supply chain through innovation through FedEx, the following below was implemented:

### *Internet of Things (IoT)*

**Real-time Tracking.** Having IoT on packages and containers provides real-time data on location and temperature. This therefore allows the control of the supply chain to prevent any loss.

**Inventory Management.** IoT, such as a smart bin, will allow an automatic update on the inventory level, therefore reducing the manual error. This approach helps with accuracy in stock management.

### *Machine Learning and Artificial Intelligence*

**Forecasting.** The AI algorithm analyzes market trends and historical data to predict demand in the future. This process optimizes inventory levels and reduces waste.

**Optimization of Route.** Using machine learning, this can process the pattern of traffic, and the conditions of the weather to help find the most efficient route for deliveries.

### *Blockchain Technology*

**Secure Transaction.** Creates a secure record of transactions to enhance security. This process helps reduce fraud risk and improve data integrity.

### *Robotics and Automation*

**Automated Warehouse.** The robots will perform tasks like picking and sorting in the warehouse, thereby improving efficiency.

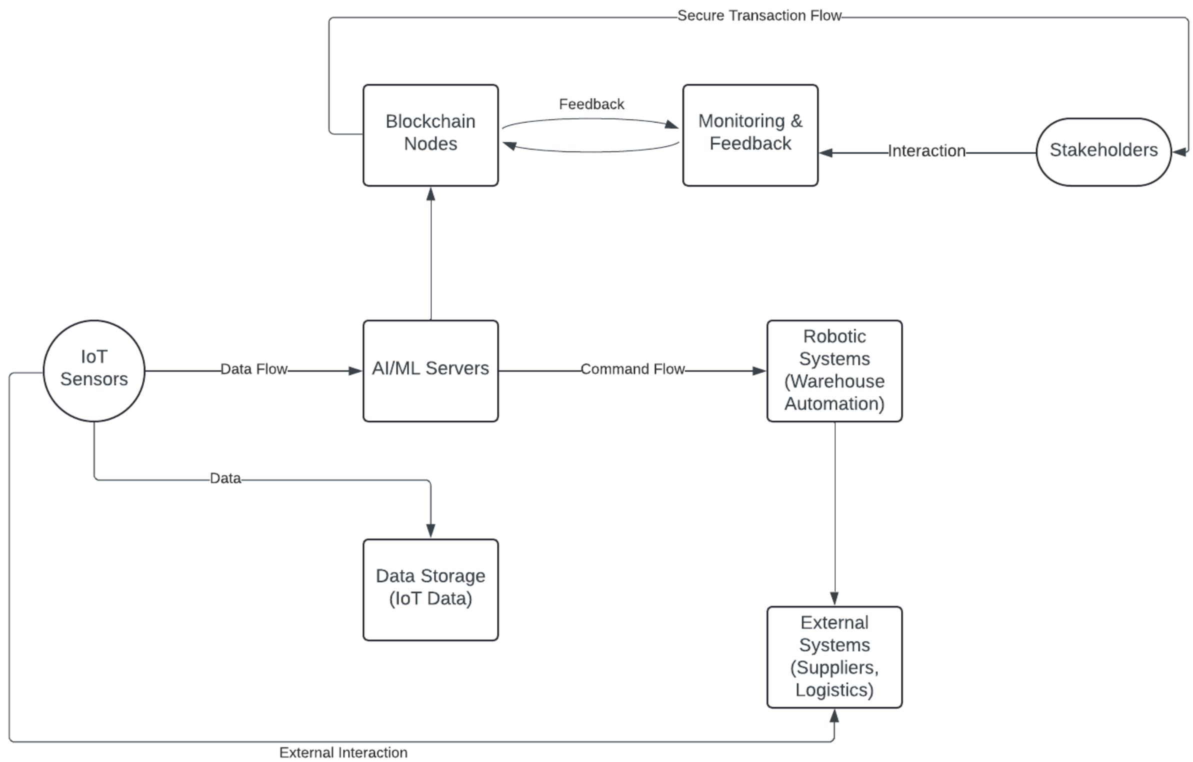
**Automated Delivery Vehicle.** Using a drone allows for last-minute delivery. This is used when hard areas cannot be reached.

***Operational System Architecture***

***Figure 4*** shows the operational structure of FedEx's upgraded package handling system with Industry 4.0. IoT sensors send data to AI/ML servers for processing, after which robotic systems receive commands for automation. Blockchain nodes communicate with stakeholders and monitor safe transactions. Continuous improvement is ensured by feedback loops and monitoring, and IoT sensors link with external systems to enable smooth operations.

**Figure 4**

*Operational System Architecture*



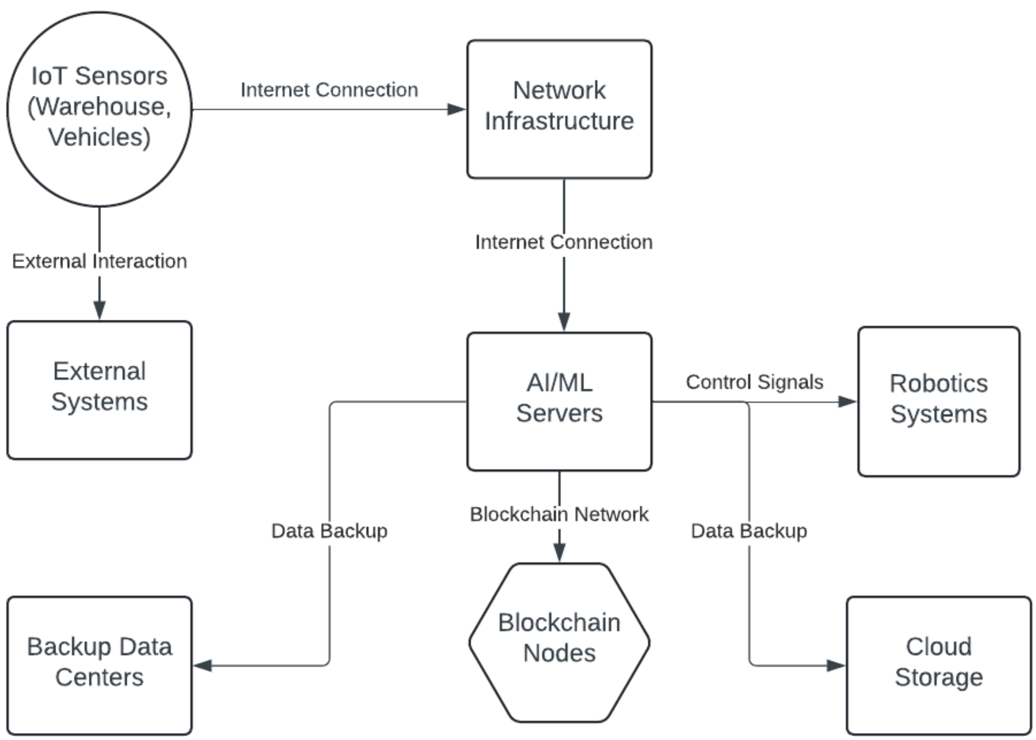

*Note. The interactions of FedEx's upgraded package handling system using Industry 4.0 technology are shown in **Figure 4**.*

***Physical System Architecture***

***Figure 5*** shows the network architecture and hardware configuration of FedEx's upgraded system. IoT sensors gather data, which is then sent over the internet to servers for AI and ML via network infrastructure. Robotic systems receive control signals from servers after data processing. Secure transactions are handled by blockchain nodes, and data redundancy is ensured by cloud storage and backup data centers. IoT sensors communicate with external systems to keep things running smoothly.

**Figure 5**

*Physical System Architecture*




*Note. The network architecture and hardware configuration of FedEx's upgraded system are shown in **Figure 5**.*

## Decision Analysis and Support

### *Simulation with a strategic plan*

The goal is to ensure that the integration of Industry 4.0 meets the required requirements as needed. Identifying the inefficiencies allows the optimization of the process towards an enhanced performance in operation, assessing the potential risks will allow a strategy developed to ensure the system's validity, and providing insight into data shows a strategic decision.

### *Types of Simulation*

**Discrete Event Simulation (DES).** The models involved are a sequence of discrete events. For example, consider the departure and arrival of a delivery vehicle. The tools we could use for this would be FlexSim, and this process will allow an evaluation of the flow in the warehouse to optimize scheduling and find any bottlenecks during the delivery phase.

**Agent-Based Simulation (ABS).** This simulation model acts as an interaction with the agents, such as the delivery trucks and robots, to better assess the effect on the system. The tool needed will be NetLogo, and this process analyzes the long-term impact of a decision or strategy, such as the supply chain network.

### *Simulation Strategy*

**Validation Incrementally.** Validating the components in the system one piece at a time before integration in the system can ensure each part is functional, which makes it easier to isolate and address issues later.

**Sensitivity Analysis.** Assessing the changes in the variable input that affect the variable output in the system is done by identifying these variables that are important and have an impact on the performance of the system.

### *Tools for Simulation*

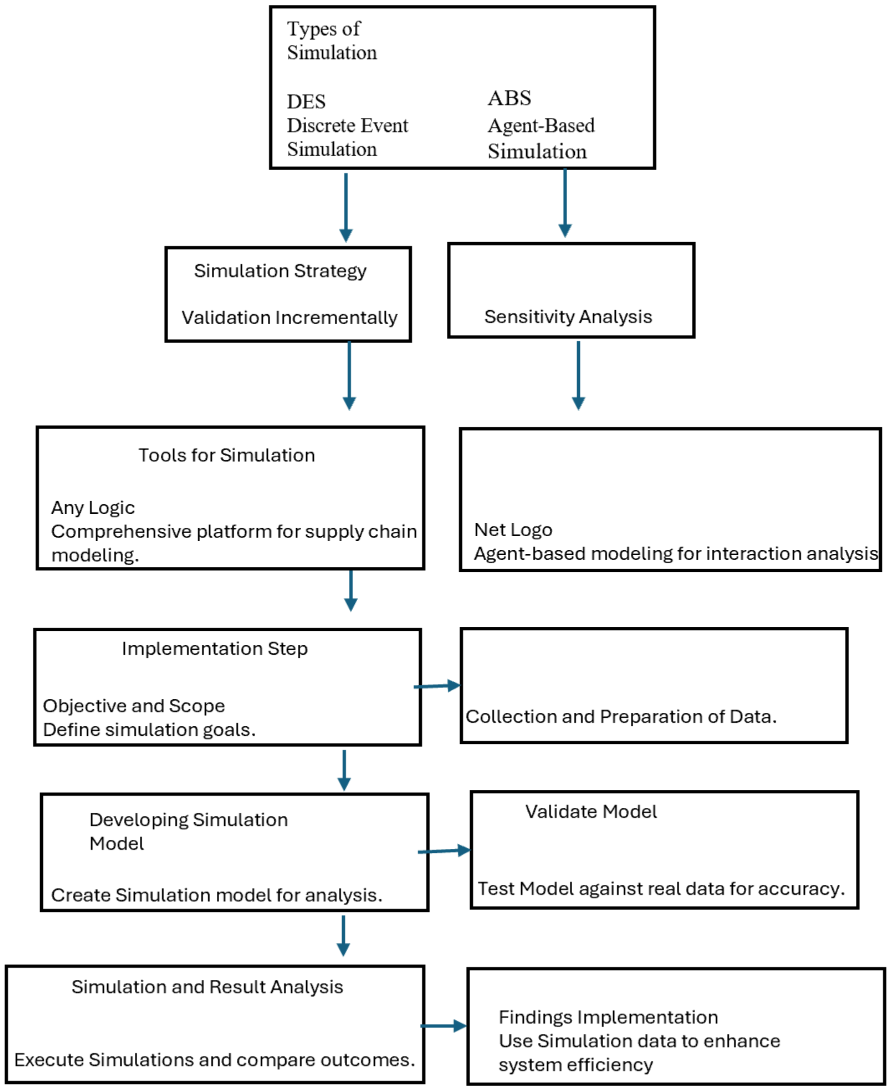
- **AnyLogic:** A comprehensive platform for complex modeling in the supply chain system.
- **NetLogo:** Used for agent-based modeling, used to stimulate the interaction between agents.
- **FlexSim:** Helps in the visualization and optimization of logistics in the manufacturing process.

### *Implementation Step*

- **Objective and Scope:** Outline the goal of the simulation to ensure alignment with the strategic objective,get  accurate data on the system components that are collected which builds a solid foundation for a reliable model, create a simulation model using the tools to allow a complete analysis of the system dynamics, have a test model against the real data will allow accuracy which in turn builds a confident simulation result, execute various simulations, and outcomes then compare against the expected result. This simulation analysis identifies areas that need improvement towards validating the performance of the system,and using the data from simulation to get an informed theory on the system design to help enhance the system efficiency.

**Figure 6**

*Flow Diagram for Simulation*




## Risk Management

Risk management in supply chains for FedEx involves identifying, assessing, and mitigating potential risks that can affect the reliability and overall efficiency of its logistics and delivery services. Effective risk management is necessary to sustain uninterrupted service and maintain market reputation. By applying system engineering principles to risk management, FedEx can enhance its ability to anticipate, mitigate, and respond to supply chain risks, ensuring continuity and reliability in its operations. Although most of the risks are recurrent and a mitigation strategy is established to handle such risks, unique risks categorized as critical are to be identified and a strategy to reduce such risks is necessary for long-term sustainability, described as follows.

1. **Operational Risks:** Risks relating to the day-to-day functions of the supply chain are categorized as operational risks. Delays due to transportation failures, equipment failures like vehicle breakdowns or sorting machine issues, and labor shortages can cause backlogs across the supply chain.
2. **Supplier Risks:** For fuel, vehicles, and technology, FedEx relies on various suppliers, creating a scope for supplier risks. Inconsistent quality of supplies can affect FedEx's operations and customer service.
3. **IT System Risks:** In today's digital world, cybersecurity is a critical factor in the successful operation of the supply chain system. Loss of customer data can result in financial loss and reputational damage. The IT system should adhere to data protection regulations to avoid possible fines and legal issues.
4. **Economic and Market Risks:** Economic risks like recession or economic instability can directly affect the supply chain by reducing demand and overall profitability. Even fluctuations in fuel prices can affect operational costs and pricing strategies. Competitive pressure is another factor that can disrupt cost efficiency.
5. **Strategic Risks:** Misaligned business strategies and adapting to market shifts result in long-term strategic risks. Implementing new technologies across the supply chain helps maintain a competitive edge. Ineffective acquisitions or integrations can lead to supply

chain disruptions and financial losses.

**Table 3**

*Risk Rating*

| Risk Category | Interests | Mitigation Strategies | Risk Rating (1-5) |
|---|---|---|---|
| Operational Risks | Risks relating to the day-to-day functions of the supply chain. Examples include transportation failures, equipment failures, and labor shortages. | Regular maintenance schedules, alternative transportation arrangements, staff training, and backup plans for labor shortages. | 4 |
| Supplier Risks | Risks from reliance on suppliers for fuel, vehicles, and technology. Inconsistent quality of supplies can affect operations and customer service. | Diversifying suppliers, setting quality standards, conducting regular audits, and establishing long-term contracts with reliable suppliers. | 3 |
| IT System Risks | Cybersecurity risks and compliance with data protection regulations. Loss of customer data can result in financial loss and reputational damage. | Implementing robust cybersecurity measures, regular system updates, data encryption, and compliance with data protection regulations. | 5 |
| Economic and Market Risks | Economic risks like recession or instability reduce demand and profitability. Fuel price fluctuations and competitive pressure can affect costs and strategies. | Financial hedging strategies, cost control measures, market analysis, and adaptive pricing strategies. | 4 |

| | | | |
|---|---|---|---|
| Strategic Risks | Misaligned business strategies and market shifts. Implementing new technologies and making ineffective acquisitions or integrations can disrupt operations. | Continuous market analysis, strategic planning, investment in R&D, and careful evaluation of mergers and acquisitions. | 4 |

**Risk Mitigation Strategies**

Establishing reliable risk management strategies is critical for the successful operation of the supply chain. Below are some of the common areas where FedEx can implement risk management strategies to improve resilience against supply chain issues.

1. **Supplier Diversification:** Avoiding dependency on a single supplier for logistics and raw materials and establishing relationships with multiple suppliers can help maintain the seamless functioning of the supply chain.
2. **Inventory Buffer and Safety Stock:** To handle unexpected supply chain disruptions, it is a good strategy to maintain additional inventory and critical material stock to ensure continuity. The shortcomings of the COVID-19 pandemic are a good example of such situations.
3. **Risk Assessment and Audits:** Conducting regular risk assessments and audits to evaluate financial health, regulatory compliance, and operational efficiency can help identify potential risks at an early stage and allow FedEx to mitigate these risks proactively.
4. **Technology and Automation:** Implementing advanced technologies like artificial intelligence, IoT, and blockchains for inventory management and supply chain management to enhance accuracy and reduce human errors is a good risk mitigation strategy.

5. **Training and Development:** Providing training on risk management and new technologies to its employees ensures FedEx is well-prepared to handle any supply chain disruptions.

**Table 4**

*Risk Category*

| Risk Category | Risk Description | Impact | Likelihood | Mitigation Strategies | Monitoring Methods |
|---|---|---|---|---|---|
| Vendor Management | Third-party service failures or breaches | Medium | Medium | Due diligence, regular performance reviews, and contractual security requirements | Vendor performance reviews and regular audits |
| Scalability | Inability to scale systems to meet increasing demand | Medium | Medium | Scalable architecture, cloud solutions, and regular capacity planning | Capacity monitoring, scalability testing |
| Data Integrity | Data corruption or loss | High | Low | Data validation protocols, regular backups, and integrity checks | Regular data audits and automated integrity checks |
| Technology Changes | Rapid changes in technology are leading to obsolescence | Medium | Medium | Continuous investment in R&D, adoption of scalable and flexible technologies | Technology roadmap reviews and market analysis |
| Integration Issues | Problems with integrating different data systems | Medium | Medium | Robust integration testing, use of standardized APIs, and middleware solutions | Integration testing and system performance monitoring |

# Engineering Development Phase

## Cost and Profitability Analysis

### *Cost Analysis*

We conducted a cost analysis, considering the initial costs, ongoing ROI, and long-term gains of integrating Industry 4.0 technology into the FedEx package handling and automation system which is shown in ***Table 5***. This analysis incorporates the cost of procuring and using blockchain technology, IoT sensors, robotics, and AI/ML systems. This will evaluate the expense costs to determine if they are feasible and also to put in the necessary funds that would enable proper execution.

**Table 5**

*Cost Analysis*

| Cost Component | Initial Cost ($) | Ongoing Cost ($/year) |
|---|---|---|
| Robotics | 2,000,000 | 100,000 |
| AI/ML Systems | 1,500,000 | 200,000 |
| IoT Sensors | 500,000 | 50,000 |
| Blockchain Implementation | 300,000 | 30,000 |
| Maintenance | 200,000 | 150,000 |

*Note:* ***Table 5*** *shows the cost component and expected initial and ongoing costs for the implementation of Industry 4.0 technologies into the FedEx automation system.*

### *Profitability Analysis*

Profitability analysis is the task of estimating the financial profits for the proposed system which is shown in ***Table 6***. This consists of calculating the return period and the stopping point. The projected profitability over time of this system is shown in ***Figure 7***, which combines the increases in efficiency, reduced labor costs, and improved accuracy. This analysis demonstrates the potential of a technology investment to generate substantial financial value for FedEx.

**Table 6**

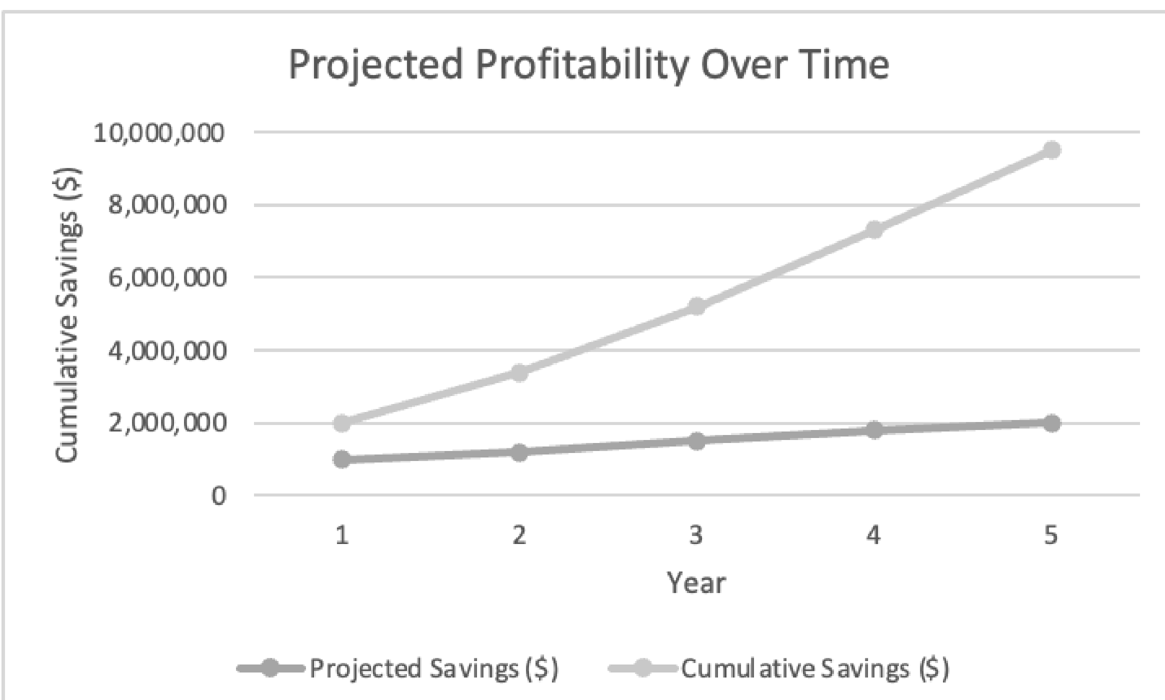
*Profitability Analysis*

| Year | Projected Savings ($) | Cumulative Savings ($) | ROI (%) |
|---|---|---|---|
| 1 | 1,000,000 | 1,000,000 | 25% |
| 2 | 1,200,000 | 2,200,000 | 45% |
| 3 | 1,500,000 | 3,700,000 | 70% |
| 4 | 1,800,000 | 5,500,000 | 95% |
| 5 | 2,000,000 | 7,500,000 | 120% |

*Note: **Table 6** represents the projected savings, cumulative savings, and ROI over a five-year period.*

**Figure 7**

*Projected Profitability Over Time*



## System Design

The aim is to create a fully defined design comprising functional analysis, component design, and design validation during the engineering development phase. This is the phase when it corroborates that systems are built that serve the specific requirements and the operation objectives of FedEx. Component design also attaches functionality to devices and software components, but functional analysis decomposes the system into its fundamental building blocks and describes what needs to be done. In design validation, the exact scope of different testing and simulation procedures that are undertaken to make sure that the system is working properly under all circumstances is considered.

### *Functional Analysis and Design*

Analyzing the system into smaller parts and identifying the capabilities needed for each part is known as functional analysis (Kossiakoff et al., 2020). The main features of FedEx's supply chain management system include data processing, automated sorting, and smart contracts. To guarantee smooth operation, the design will specify how these features integrate and interact with one another within the system. To get the expected operational efficiency, this involves defining the data flow between components, creating communication protocols, and making sure that every system component functions in sync.

**Data processing.** To control sorting robots, complex algorithms will process data from sensors and cameras. By examining patterns and adjusting to differences in package flow and characteristics, these algorithms will make use of machine learning to continuously increase sorting accuracy and speed (Szozda, 2017).

**Automated Sorting.** Packages will be sorted by robots according to factors including size, weight, and destination (Robotics, n.d.). The sorting robots will minimize manual handling and error-prone processes by effectively identifying and sorting packages using a mix of sensors and actuators.

**Smart Contracts.** Transactions and documentation procedures will be automated and streamlined using blockchain technology. This incorporates utilizing smart contracts to guarantee the safe, open, and prompt execution of contracts between different supply chain stakeholders.

***Component Design***

Specific components, such as data processing units, robotic sorters, and blockchain nodes, match each functional requirement. Together, these components will be engineered to guarantee that every functional requirement is met. The way these components are integrated will be carefully designed to provide easy maintenance, upgrades, and scalability, guaranteeing that the system can keep up with evolving technology and future demands.

**Data Processing Units.** Data processing units are high-end computers and servers that process data in real-time using machine learning techniques. To ensure maximum efficiency and precision, these units will gather data from several sensors, analyze it, and provide the robotic sorters with instructions.

**Robotic Sorters.** Robotic sorters are capable of handling packages with sensors and actuators (Robotics, n.d.). The purpose of these robots is to pick up packages, move them through the sorting facility, and then, depending on where they are going, drop them in specific bins or conveyor belts.

**Blockchain Nodes.** Blockchain nodes are computers that manage and carry out smart contracts to facilitate safe and effective transactions. These nodes will be a component of a distributed database system, which will guarantee transparent and immutable recording of all transactions and minimize the need for human verification and documentation (Szozda, 2017).

### *Design Validation*

Design validation verifies that the system operates as intended and meets all requirements (Kossiakoff et al., 2020). This includes Prototyping, User Input, and Modeling and Simulation. Validation guarantees that FedEx's operational requirements are met and that the system is dependable. Any problems can be resolved early in the development phase, leading to a reliable and effective SCM system, by extensively testing every component and the system as a whole.

**Prototyping.** Building and testing working models of blockchain systems and robotic sorters is known as prototyping. To make sure these prototypes can manage the anticipated number of packages and transactions and meet performance standards, they will go through a thorough testing process.

**User Input.** To improve the design, FedEx employees and other stakeholders will be surveyed. To ensure that the final system is user-friendly and satisfies operational needs, this feedback will be essential in detecting practical concerns that might not be evident during the simulation and prototype.

**Modeling and Simulation.** Simulating data processing and robot sorting using software tools is included in this validation phase. Before real prototypes are constructed, these simulations will assist in identifying any bottlenecks, inefficiencies, and places for improvement.

## Systems Integration

### *Subsystems*

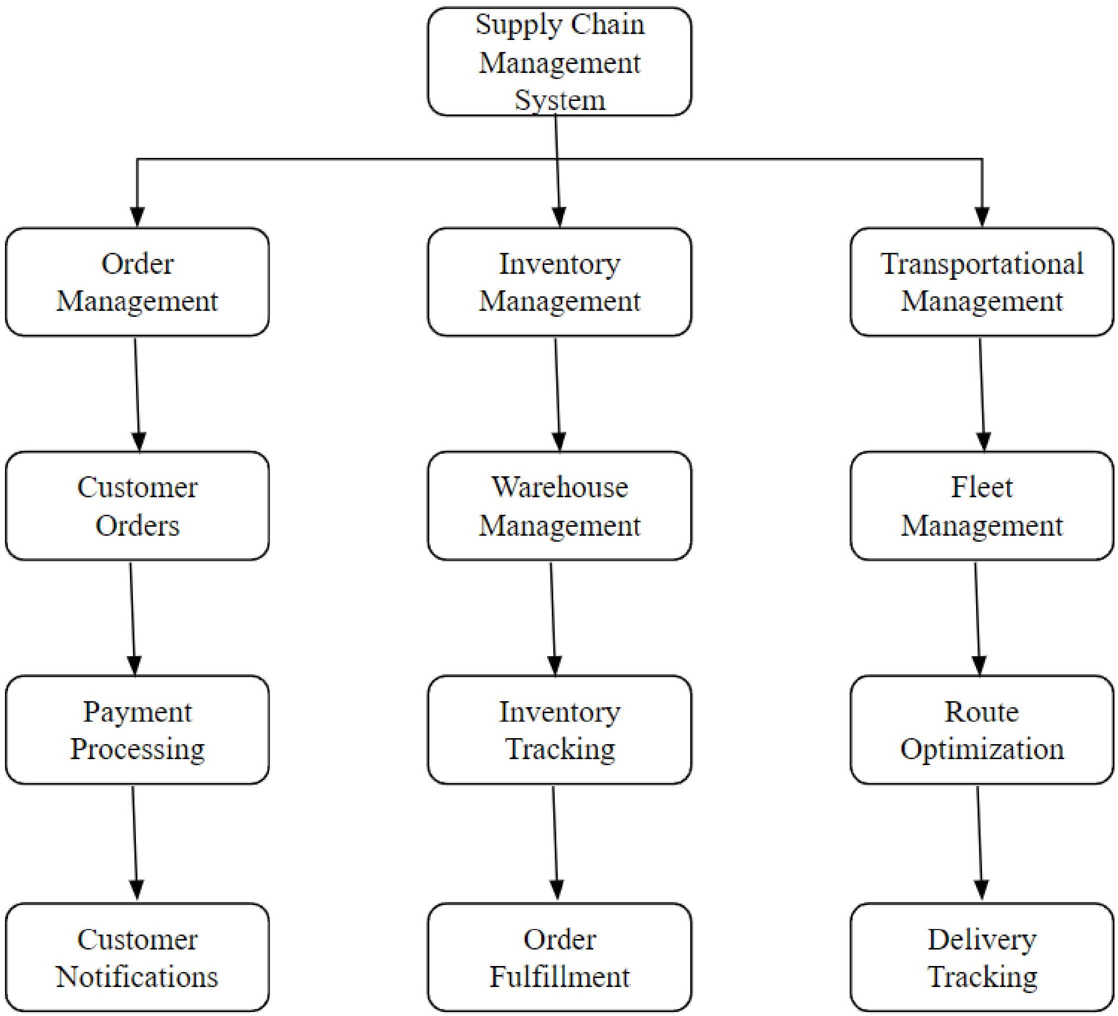
Depending on their role in the overall system, subsystems across FedEx are characterized by several key roles described as follows:

- **Supply Chain Management:** Logistics and supply chain management involve management of storage facilities, inventory control, and material handling, aiding in the efficient execution of goods transport by air, ground, and sea while simultaneously managing facilities for sorting, packaging, and distribution of shipments. Optimizing software algorithms to determine the most efficient route for delivery enhances overall profitability.

- **Information Technology:** FedEx incorporates a reliable IT system supporting features like real-time package tracking using barcodes and GPS, customer relationship management (CRM) to handle service requests and feedback, big data analytics for performance analysis, and demand forecasting, along with protecting systems and data from cyber threats.
- **Financial and Billing Systems:** FedEx incorporates secure payment processing for handling various payment methods through an automated billing and invoicing system for efficient financial transaction management. For financial reporting, FedEx also uses different tools for financial analysis, reporting, and compliance with regulatory standards.
- **Research and Development:** FedEx constantly develops new services and solutions to meet evolving customer needs to improve operational efficiency and reduce overall costs. Incorporating new technologies like drones, autonomous vehicles, and blockchain helps FedEx gain a competitive advantage.

**Figure 8**

*Flow Block Diagram of Systems Integration*




***Interface***

FedEx uses RESTful Application Programmable Interfaces (APIs) to integrate different software applications internally for scalable, stateless communication and to handle a wide variety of data formats. For more secure and standardized communication, like financial transactions and sensitive data exchanges, SOAP APIs are used. Platforms like RabbitMQ or Apache Kafka are used to handle asynchronous messaging and ensure reliable data transmission between subsystems. ETL (Extract, Transform, Load) tools are used for data integration processes where data is extracted from various sources, transformed into a suitable format, and loaded into a target system or data warehouse.

Standard protocols like HTTP or HTTPS are implemented for web communication, ensuring secure and reliable data transfer. Lightweight messaging protocols like MQTT (Message Queuing Telemetry Transport) are used for connections with remote locations where network bandwidth is limited. SFTP (Secure File Transfer Protocol) and FTPS (File Transfer Protocol Secure) are incorporated for secure file transfers between systems, ensuring data integrity and security. Specifically tailored protocols are used for communication between IoT devices and central systems, enabling real-time monitoring and control of logistics operations.

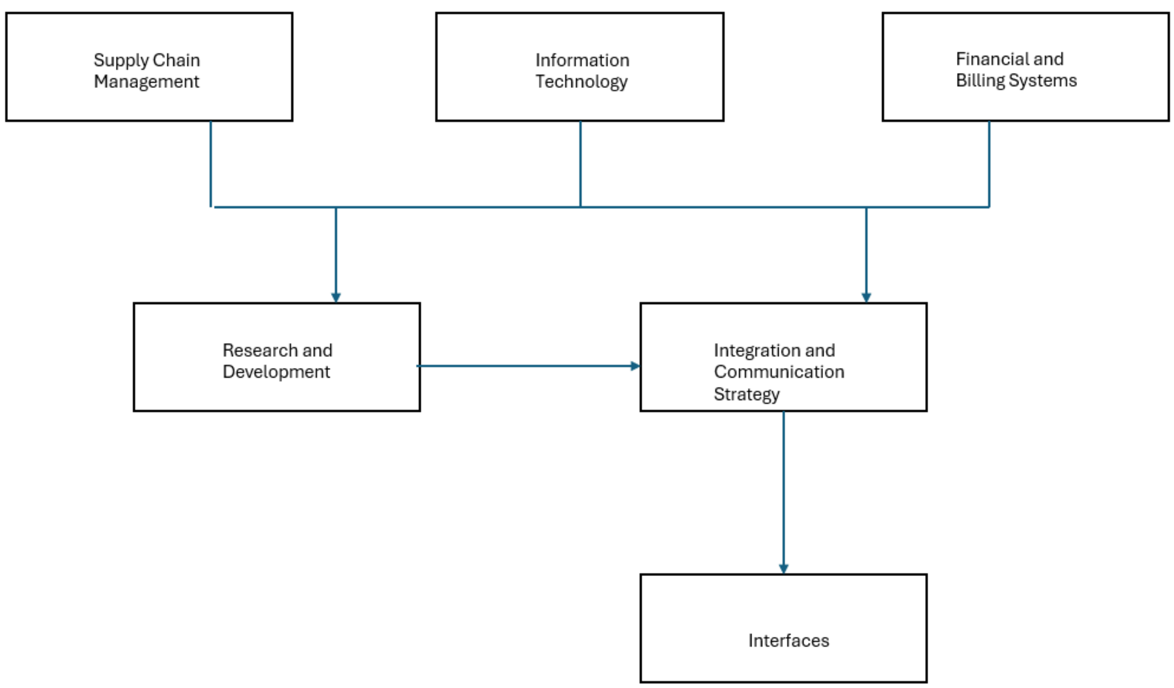
***Integration and Communication Strategy***

Subsystems integration in FedEx systems engineering is essential for ensuring seamless and efficient operations across the company's extensive logistics and delivery network. This integration involves harmonizing various subsystems to work together cohesively, allowing for real-time data exchange, coordinated workflows, and optimized performance. Middleware solutions like Enterprise Service Bus (ESB) and message brokers facilitate communication between these subsystems by managing message routing, transformation, and protocol conversion. Additionally, APIs and web services enable interoperability between applications, ensuring that data flows smoothly across the system. For instance, real-time tracking information from transportation management can be integrated with customer service platforms, providing up-to-date delivery status to customers.

Effective subsystem integration leads to enhanced operational efficiency and a superior customer experience. By consolidating data from different subsystems through tools like ETL and data pipelines, FedEx can leverage big data analytics for predictive maintenance, demand forecasting, and performance optimization. Real-time communication protocols such as WebSockets and MQTT ensure timely updates and responsiveness, essential for dynamic route optimization and shipment tracking. Security and compliance are maintained through protocols like OAuth and TLS/SSL encryption, protecting sensitive data during transmission. Overall, integrated subsystems enable FedEx to streamline processes, reduce redundancies, and provide reliable, real-time information to both internal stakeholders and customers, ultimately driving better service and operational excellence.

**Figure 9**

*Flow Block Diagram of Systems Integration*




## Test and Evaluation

The system requires the integration of hardware and software components to enable the automation of packaging sorting and smart contract processes. Hardware components used for the packaging and sorting include a variety of sensors (such as scanners and cameras) to identify and distinguish the different packages and a series of automated guided vehicles (AGVs) and robotic arms to move and allocate packages. Different software is to be created or integrated to receive and process the signals from the sensors and send the actions. Moreover, a specific software system is to be developed for creating, processing, and tracking smart contracts using blockchain.

A robust and strategic testing plan is developed to ensure adequate performance of all the different hardware and software components, their interactions and processes, and the overall performance of the system. Tests are to be conducted continuously at the development stage for proper system design and at the execution stage for overall evaluation and improvements. The following section reviews the testing plan and evaluation methods.

### ***Purpose of Testing and Evaluation***

The following points describe the main objectives of the test and evaluation process and are considered in the development of testing and validation plans.

- Ensure that the system can automatically pick and sort packages accurately.
- Ensure that the system automatically executes all the necessary steps of the smart contract blockchain.
- Ensure compatibility with the other SCM systems and platforms used by the business and its suppliers.
- Ensure the system is reliable and incorporates a robust data and information security system.

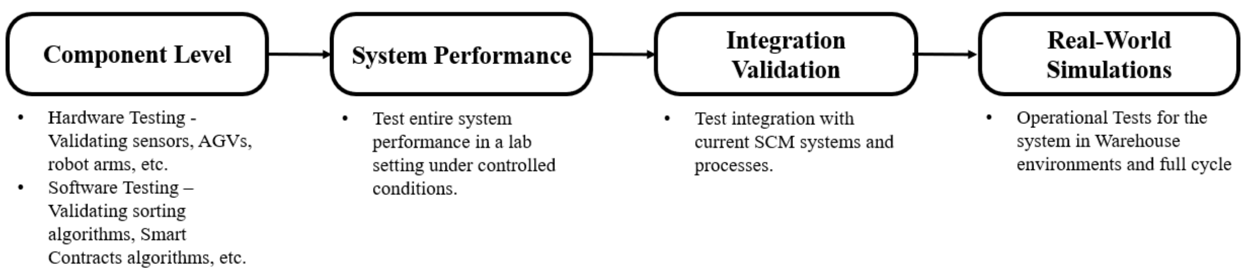
### ***Test Strategy***

The system is to be continuously tested and validated across the design and execution stages to refine and improve the different components and processes. Strategically, testing and validation are performed first at a component level and continuously escalate toward the entire system validation, as shown in **Figure 10**. Therefore, the system strategy includes:

- Validate the performance of each hardware and software component individually,
- Test the performance of the system as a whole and review it under controlled circumstances, such as a lab,
- Validate integration with the existing SCM system, and
- Simulate scenarios to verify usage in warehouses under real-world conditions.

**Figure 10**

*Flow Diagram for Test Strategy and Validation of the System.*




### *Test Plans and Types of Testing*

Test plans developed include detailed testing objectives, procedures, tools to be used, dates, metrics to match, and acceptance criteria. Note that a test report will be generated at the end of each test with specific dates, conclusions, and recommendations for next steps.

#### *Component Performance Test and Validation*

#### *Hardware Components*

- Tests to evaluate the specifications and functionality of sensors and cameras are within specified use parameters, with special attention to sensor accuracy and image quality for image processing.
- Functionality and operation tests for the AGVs and robotic arms capabilities.

Focus on capabilities for pick-and-place and moving packages to different coveys or containers.

- Performance testing for autonomous AGVs and robotic arms. Focus on validating the operational speeds, loading capabilities for maximum weight, item dimensions, and reliability before maintenance is needed *(FasterCapital, n.d.)*.

***Software Components***

- Tests to evaluate the image recognition and sorting algorithms to be used in the system. Focus on packaging recognition, processing, and signal output *(Metana Editorial, 2024)*.
- Unit Tests for the individual components of the Smart Contracts for accuracy. Focus on improving accuracy and detecting what went wrong when a test fails. Use Solidity Coverage to run tests (Sakharchuk, 2023).
- Static Analysis to review the Smart Contracts source code to detect vulnerabilities and compliance with common practices. Use Slither to run tests (Sakharchuk, 2023).

***System Performance Test and Validation***

- Tests to evaluate the integration of picking and sorting software with the sensors, cameras, AGVs, and robotic arms. Focus on validating the correct execution of both components in the system.
- Dynamic Analysis tests review the behavior of the smart contracts code under execution to detect vulnerabilities and violations. Use Echidna to run fuzz tests (Sakharchuk, 2023).
- Validation of the system interaction of the smart contracts with the picking and

sorting inputs and outputs.

***Integration Tests***

- Tests to review and ensure the system and its components run smoothly with the remaining parts of the SCM used by the Supply Chain team and suppliers.

***Operational tests***

- Test the entire system in a warehouse environment, simulating the packages arriving and being sorted and the different smart contact processes. Focus on validation under real-life conditions.

***Evaluation Methods***

**Inspection**. All hardware components (sensors, cameras, AGVs, and robotic arms), tools, and system set-up must be inspected to ensure they match expected requirements and specifications.

**Testing and Demonstrations.** Conduct a variety of experiential tests to simulate real-life scenarios, including edge cases, and monitor the overall system behavior. This is based on its inputs and outputs.

**Data Collection and Analysis.** Use different software and simulations to evaluate and verify components and system performance. System performance based on:

- Accuracy of the packaging sorting process,
- Number of packages sorted over a specific time,
- Reliability of the system and components run time,
- Error detection in packages or smart contracts, and
- Vulnerabilities and bugs in the smart contracts processes.

## Post-Development Phase

### Production

With the advent of Industry 4.0 technology, companies such as FedEx are leveraging advanced automation, analytics of data, and IoT solutions to enhance the handling of packages and systems automation. This plan includes an implementation and prototype plan that is important for the deployment of complex systems and has to focus on how to incorporate these concepts into a real-life scenario.

#### *Implementation Plan*

To implement a plan towards integrating Industry 4.0 technology into FedEx package handling and automation systems, there is a systematic approach to allow smooth integration and optimal performance.

1. **Needs Analysis**

   ***Objective***

   Getting to understand what the current challenges are and the requirements in the package handling process of FedEx.

   ***Activity***

   - **Interview:** Having an engagement with the stakeholders, which can include the management of FedEx and the staff warehouse, to gather information about the current issue and requirements, then examining the current workflow to provide an identifier that classifies bottlenecks and inefficiencies, and finally analyzing performance data that is current to establish the baseline to identify areas and improve on them (Nayernia, Bahemia, & Papagiannidis, 2021)

2. **Concept Exploration**

   ***Objective***

   Getting to explore and identify the potential Industry 4.0 solutions that are needed, such as IoT sensors, an automated guided vehicle, and an algorithm for machine learning towards having a predictive nurture.

   ***Activity***

   - **Research in the market:** Having to investigate the needed technology in the market that will help address the identified issue. Conducting various feasibility studies then leads to an evaluation of practicality to provide a potential impact of various solutions and conducting brainstorming with the experts to explore an innovative idea (Ali et al., 2023).

3. **Definition of Concept**

   ***Objective***

   Defining the work of the architecture and design of the chosen solution.

   ***Activity***

   - **Design in the system Architecture:** creating a high level of architecture to show the outlines, and how they will interact with the components. Using a simulation model helps in creating a validation of the design to help with the outcome of predicting performance.

4. **Advanced Deployment**

   ***Objective***

   Developing and testing the components of the solution.

   ***Activity***

- **Hardware Development:** Developing and assembling the components of the hardware, such as IoT sensors and Automated Guided Vehicles (AGVs), coding the software that helps with the processing of data, and machine learning, and implementing a conduct towards integration test will allow the components to function and be seamlessly integrated (Cupek et al., 2020).

5. **Pilot Deploying**

   ***Objective***

   Incorporating the solution into the environment towards validating performance.

   ***Activity***

   - **Selection of site:** Choosing a FedEx facility for the pilot deployment, Installment and configuration at the selected site, and reviewing the performance of the system to collect data that is used in evaluation and effectiveness.

***Prototype Plan***

Developing a prototype is important because this ensures the system's operation and performance before incorporating a full-scale implementation. The steps below will show the integration of Industry 4.0 technology into FedEx.

1. **Plan and Design.** Outlining the scope of the prototype objective and requirements.

   ***Activity***

   - **Scope Definition:** Defining the scope by showcasing the industry 4.0 technology that will be tested, like IoT sensors, Automated Guided Vehicles, and machine learning algorithms. The objective is to improve package handling and efficiency, minimize errors, and provide enhanced system reliability. Having a detailed understanding of the existing challenges and requirements for the future, gathering data from different stakeholders like the IT team, and having the requirements that cover the performance metric with needs of integration for the expectation of the user experience (SamSaber, November 9).

2. **Development.** Building an initial form of the prototype.

   ***Activity***

   - **Assembly of hardware:** Developing and assembling the important hardware, such as IoT, Automated Guided Vehicles, and RFID tags for package identification, ensuring the hardware is compatible with and making a seamless integration with the existing system. Developing the software for processing data, control of automation, and implementing an algorithm towards real-time analytics and optimization of workflows that include package handling and integrating the hardware and software tools will create a cohesive approach and ensure that the data obtained from the IoT sensors and Automated Guided Vehicles are correctly processed.

3. **Validation and Testing.** By correctly ensuring that the prototype has met the required requirements to perform effectively.

   ***Activity***

   - **Testing Unit:** Testing each individual software and hardware tool to make sure they are functioning properly and verifying that IoT accurately tracks the status of packages to operate as intended (Soori et al., 2023). Conducting various integration tests help in ensuring the components are working together properly and validating the data flow between IoT, Automated Guided Vehicles, and the central control system. By having an engagement with the end users, such as the staff in the warehouse, in testing the prototype of validation for performance and collecting feedback from the experience of the user to identify any issues. By collecting the data from metrics of performance such as speed of handling, and accuracy, then analyze the data to ensure the prototype meets the proposed requirement.

4. ***Improvement with Iteration.*** Getting a refinement of the prototype that is gotten from the feedback testing.

   *Activity*

   - **Identification of Issue:** Getting to identify the issue for improvement obtained from the test result from the feedback of the user, and putting first the issues that are based on the impact on system performance and the experience of the users.
   - **Implementation for Improvement:** By incorporating the important improvement to address the issue and validating the prototype to work optimally.
   - **Retesting:** Having to conduct a retest to ensure that the improvements have been addressed.

***Real World Implementation***

To implement this in the real world, different key steps are important to ensure a lucrative deployment.

1. **Engagement with Stakeholders.** Ensuring that there is alignment and support from the important stakeholders.

   *Activity*

   - **Communication:** Creating regular communication with the stakeholders to allow the information to be shared and give them updates on the progress and any milestones reached. Workshop conduct and sessions of training will allow for the familiarization with the new system with the stakeholders, and ensure the users gain an understanding of the functionality, and procedure of the operation in the new system.

2. **Preparation of Infrastructure.** Gathering the necessary infrastructure that will be needed for the new system.

   ***Activity***

   - **Upgrades in Network:** Upgrading the infrastructure network then allows for the support of high-speed data for transmission that is required for the connectivity of IoT ensuring that the network is robust in terms of reliability and handling of any real-time traffic data. Getting to install the important hardware tools, such as IoT sensors and station charging, to ensure that there is a proper installation in the configuration to allow the facilitation of an ideal operation.

3. **Support and Training.** By making sure that the staff members are trained to use the new system and also have access to support.

   ***Activity***

   - **Training:** Providing training to the staff on the new system operation and ensuring the staff are comfortable with the new technology towards making an understanding of how to address any troubleshooting issues. Creating a framework to address any issues during the transition period and having access to a technical support team to create a feedback loop to address problems that emerge (Bleich, 2019, April 17).

4. **Security and Data Management.** Incorporating practices of robust data management

towards handling the huge data that is generated by the new system.

***Activity***

- **Solutions of Data Storage:** Incorporating storage devices will manage the data that is gotten from the IoT device, and ensure that the solutions in storage can handle the volume of data that keeps on increasing. Creating a protocol will allow the privacy of sensitive information and incorporate encryption to protect the integrity of data.

## Operation and Support

The operation and support become major parts of the project when the post-development phase starts. Comprehensive documentation and monitoring strategies are essential to keep the system in good condition and address any issues that arise (Kossiakoff et al., 2020). Documentation includes spare parts lists, maintenance schedules, and troubleshooting handbooks to ensure efficient functioning. Monitoring plans include methods for proactive maintenance and real-time performance tracking to ensure system reliability and anticipate future problems.

### *Installation and Test Plan*

The installation plan involves configuring the hardware and software components at FedEx facilities (Porter & Heppelmann, 2020). The test plan in detail explains the processes of ensuring the functioning of the system in different scenarios and the satisfaction of all operational constraints (Kossiakoff et al., 2020). This will contain pressure testing of sensor data, load testing at peak load, and performing transactions between blockchains in a secure and proper manner.

Key steps consist of Site Preparation, Hardware Setup, and Software Integration. Site Preparation includes arranging the physical space, setting up network and electrical installations, and ensuring all security measures are met. This also includes training employees in the safety of new equipment. Hardware Setup means putting together the data processing devices and robotic sorters for the layout plan. (Porter & Heppelmann, 2020). Equipment must be placed in a secure, temperate environment. Software Integration includes the installation of required applications, configuration of blockchain nodes necessary to execute smart contracts, deployment of machine learning algorithms, and network configuration. Initial Testing includes operational tests that help to confirm system behavior in real environments, software integration tests to guarantee proper communication and hardware diagnostic tests.

***Maintenance Documentation***

The system needs maintenance documentation to document how it works. With proper documentation, FedEx employees may keep the system up as well as possible and reduce downtime. Also, it keeps records for maintenance monitoring, making sure all the tasks are completed on time and their issues are noted down for future reference.

Routine maintenance schedules are the kinds of daily, weekly, and monthly tasks to keep the system running, such as cleaning sensors, performing software updates, and verifying that all systems are working properly. Troubleshooting Guides complete with examples utilizing flowcharts and visual aids, guide users through how to troubleshoot anything from a data processing concern and network problem to misbehaving robotics. Spare Parts is a list of specific parts with part numbers, vendors, and a potential life span for a replacement part. Keeping essential spares on hand ensures quick replacements and minimal downtime.

Including real-world examples or case studies to this documentation to explain how and why this component matters would make it even more comprehensive. For example, citing the maintenance procedures used by Amazon in their fulfillment centers might show the benefit of detailed documentation and preventative reliability testing programs to keep downtime at a minimum while maximizing operational efficiency. Similarly, the maintenance method implemented in some DHL automatic sorting plants can be a powerful model for effective work with qualitative maintenance documentation. Studying UPS can also show best practices for running incredibly complex logistics.

### *Monitoring Plan*

A robust monitoring strategy is required for ongoing support and operation. This enables us to ensure the system functions correctly and that any issues are dealt with swiftly. By adopting real-time monitoring combined with scheduled maintenance and regular audits, FedEx can reduce unscheduled downtime, maintain high operational quality, and ensure continuous system upgrades.

Real-time Monitoring  monitors system performance via sensors and software. The dashboards present real-time information on Key Performance Indicators (KPIs) like throughput, error rates, and equipment status. Predictive maintenance is the concept of applying machine learning to historical data patterns to predict and avoid breakdowns that allows a proactive approach to problem-solving. It decreases costs and increases the lifetime of devices and equipment. Regular Audits involve verifying that proper procedures are followed, maintenance records are maintained, and system components are examined.

## Conclusion

The use of automation and digitalization for FedEx packaging sorting and handling and automating the execution of contracts can certainly improve supply chain operations efficiency. The proposed system has been developed following the systems engineering approach across the different stages of concept development, engineering development, and post-development. The needs analysis revealed each stakeholder's different needs and requirements, which focused on increasing efficiency in the process, reliability, safety, and compliance. Different system alternatives were evaluated and compared based on efficiency, cost, time, and security criteria, leading to the selection of a hybrid system that combines partial automation and the use of smart contracts. This approach was used to further develop the proposed system and create the appropriate system architecture, simulations, testing methods, and integration. Moreover, a risk management plan was developed to review the possible challenges and issues that the system may face. Overall, the proposed system illustrates the feasibility and execution of the use of automation for package handling and sorting and the implementation of Smart Contracts to enhance FedEx supply chain processes.

Enhancing supply chain management at FedEx through systems engineering offers a holistic approach to streamline operations and boost efficiency. Systems engineering integrates various components of the supply chain, such as transportation, warehousing, and inventory management, into a cohesive and optimized system. By applying principles of systems engineering, FedEx can design and implement solutions that address the interdependencies and complexities inherent in its supply chain. This integration ensures that all elements work synergistically, reducing redundancies, improving coordination, and ultimately leading to faster and more reliable deliveries.

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**Contribution Table**

| **Team Member** | **Assignment Section** |
|---|---|
| Twisha Patel | Compilation of information from previous assignments and overall formatting<br>Updated Requirements Analysis (Non-functional requirements, Functional Requirements), Evaluation and Selection, System Design, Operation and Support, Cost and Profitability Analysis based on feedback<br>Updated Table for Evaluation of System Alternatives (Table 2)<br>Updated Figure for Evaluation Criteria and Measurements (Figure 3)<br>Updated Figure for Operational System Architecture (Figure 4)<br>Updated Figure for Physical System Architecture (Figure 5)<br>Updated Cost Analysis (Table 5)<br>UpdatedProfitability Analysis (Table 6)<br>Updated Projected Profitability Over Time (Figure 7) |
| Washington Silva | Updated Title Page<br>Updated Table of Contents<br>Updated Introduction to enhance flow and mechanics<br>Updated Needs Analysis section<br>Updated Stakeholder sections and System Boundaries to improve overall structure and organization<br>Corrected and updated titles for Figure for Stakeholder Identification (Figure 1) and System Context Diagram (Figure 2)<br>Updated Identification of Stakeholder Needs (Table 1)<br>Updated Test and Evaluation |
| Chukwuebuka<br><br>Ozueigbo | Updated references<br>Updated citations<br>Reworded sentence on the system architecture<br>Reworded sentence on the decision analysis and support<br>Reworded sentence on production |
| Siva Teja Vejandla | Updated Introduction<br>Systems Integration<br>Risk Management<br>Review of Risk Management relating to systems engineering<br>Updated Subsystems Category<br>Updated Risk Category (Table 4)<br>Updated Flow Block Diagram of Systems Integration (Figure 8)<br>Updated Conclusion |