Bridging Industries with AI: Innovative Approach to Sustainable Waste Management

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**Abstract - This study investigates using artificial intelligence (AI) to mitigate food waste within supply chains through a simulation model that predicts waste generation and assesses reduction strategies. Using real-world and simulated data, the model offers insights into effective interventions for waste minimisation. Rigorous testing ensures model accuracy, while the analysis identifies critical strategies for stakeholders. The research highlights AI's potential in enhancing supply chain sustainability, providing a foundation for future exploration in sustainable practices and technology-driven waste reduction.**

**Keywords - *artificial intelligence, food waste, supply chain management, simulation model, sustainability, waste reduction strategies***

1. Introduction:

Addressing the issue of food waste within global supply chains is critical for achieving sustainability and efficiency, particularly as the global population is projected to reach 10 billion by 2050 (Sadigov, 2022). With approximately one-third of all food lost or wasted contributing to significant economic, environmental and social challenges, food waste management is an urgent priority (Ishangulyyev et al., 2019). This project uses Artificial intelligence (AI) models with simulated data to predict waste generation; it assesses the efficiency of current waste strategies and explores the feasibility of converting food waste into valuable resources for cross-industry waste pathways. This allows for the simulation of a wide range of scenarios, reflecting the complexities of food supply chains from production to consumption and aims to enhance both the theoretical understanding and practical management of food waste. In alignment with the European Union's commitment to halve food waste at the retail and consumer levels by 2030, this research contributes to the discourse on sustainable waste management and circular economy practices (EU, 2018). Through this, the project illustrates novel approaches to food waste management, paving the way for informed policy-making and adopting a circular economy.

1. Problem statement:

The issue of food waste within the food industry's supply chain poses significant challenges to resource efficiency (Jagtap et al., 2021). Despite the potential for by-products to enhance a circular economy, frequent disposal worsens the environment (Jamaludin et al., 2022). This is intensified by the slow integration of technologies like AI, which could mitigate waste management. This study is driven by the need to improve supply chain efficiencies and enhance the integration of food waste into other sectors. The application of AI to facilitate cross-industry reuse presents an opportunity.

By using AI and simulated data, the project seeks to address environmental impacts and enhance resource efficiency. The goal is to uncover the factors influencing food waste management and devise actionable strategies that fill a gap in research and operational practices.

1. Objectives:

* Develop a simulation model to represent food supply chain dynamics and identify major food waste points, validated by assessments of its accuracy and alignment with known waste patterns.
* Use a model to evaluate food waste reduction strategies, identifying those that lower waste, improve efficiency, and reduce emissions. The effectiveness of these strategies will be measured by quantifiable benchmarks.
* Explore three pathways for repurposing food waste across industries, assessed for economic and environmental benefits through simulated data analysis.
* Generate clear, actionable recommendations for reducing food waste based on simulation insights, focusing on feasibility, potential barriers and solutions for implementation.

1. User Requirements:

This research is designed to fit the needs of diverse stakeholders within the food waste management space.

Policymakers require evidence-based insights to inform the creation of impactful legislation and guidelines aimed at minimising food waste. These strategies must highlight tangible environmental, economic, and social advantages.

Businesses within the food supply chain need practical, cost-effective methods to decrease waste and enhance operational sustainability, potentially identifying new revenue streams through repurposing food waste (Kharola et al., 2022).

Environmental Agencies look for detailed environmental impact data on food waste and the effectiveness of mitigation strategies to shape policy development and inform public awareness campaigns (Cattaneo et al., 2021).

This project aims to deliver insights needed for informed decision-making and practices aligned with sustainability and efficiency goals for each stakeholder.

1. Data Collection Methods:

A multi-tiered approach will be adopted for data collection and analysis:

Data on food production, waste at different supply chain stages, and environmental impacts of food waste will be collected from government databases, industry reports, and academic research. Collaboration with businesses, governments and NGOs will be crucial for accessing up-to-date and comprehensive datasets. A simulation model will be developed based on real-world data to test various food waste reduction strategies under different conditions. Taking into account consumer behaviour adoption rates and other confounding factors, they will be manipulated to evaluate impacts. Statistical methods will be applied to evaluate the impacts based on environmental, economic and operational conditions. Ethical guidelines will be followed for handling sensitive data, including anonymisation and obtaining necessary permissions. All data collection and analysis methods will adhere to relevant legal and ethical standards, ensuring the research's integrity and transparency.

1. Methodology:

The study uses a quantitative research design, using simulated and real-world data to understand and predict food waste dynamics in supply chains.

Data collection is split into two types:

Real-world Data: Sourced from government databases, scientific literature, and public reports. This data focuses on supply chain operations, waste volumes, and environmental impacts of food waste.

Simulated Data: This is generated by the AI model to predict food waste hotspots and assess the impact of various reduction strategies. It allows for the exploration of scenarios that might not be readily observable in the real world.

The research involves developing an event simulation model that mirrors the complexities of food supply chains. The model will be programmed to simulate conditions, allowing for an in-depth analysis of potential interventions.

The study interprets data using data analysis methods, enabling the prediction of intervention impacts. A quality assurance process ensures accuracy and reliability. The model's assumptions and outcomes are compared against existing research and theoretical frameworks to ensure they align with known supply chain and waste management principles.

The research is gathered in a detailed report that summarises objectives, an overview of the methodology, results, a discussion and conclusion, and the study's contributions to reducing food waste in supply chains. The report also includes recommendations for stakeholders and suggestions for future research.

The methodology is structured to align with the project's timeline, ensuring a systematic approach from the initial data collection phase to the final reporting, which spans from April 1, 2024, to July 8, 2024.

1. System interaction specification:

The simulation model represents a supply chain system, allowing data input through a graphical user interface (GUI) and file uploads (CSV, Excel, JSON). AI algorithms simulate waste scenarios, generating outputs as visualisations and reports to summarise waste management strategies. The GUI enables stakeholders to adjust simulation variables, providing real-time feedback and tools for evaluation. The system integrates with APIs for real-time data, enabling export to statistical tools for further analysis. The system supports the development of supply chain sustainability.

1. Technical specifications:

The primary development language is Python 3.8, which supports AI and machine learning. FastAPI is the web framework due to its performance in building RESTful APIs (Kornienko et al., 2021). PyTorch is the machine learning library of choice for its dynamic use. PyCharm was chosen for its debugging and testing features. Code changes and collaboration are managed using GitHub. Jupyter Notebook facilitates data exploration, prototyping, and visual analysis. It is suitable for interactive development phases; NumPy supports advanced numerical computations, enhancing data analysis capabilities. PostgreSQL is used for data manipulation. An Intel i7 processor is used to support the demands of data processing. The operating system is Windows 10 for its compatibility with the development tools and frameworks. To ensure secure data transmission, TLS 1.3 and AES-256 encryption are used. Compliance with GDPR and relevant data protection standards is maintained to protect user data. The system architecture is designed to be scalable without compromising performance. Scheduled software updates and a support system through email are planned to ensure the system's reliability and address any technical issues promptly.

1. Workplan:

The Gantt chart provides a visual representation of the project's schedule, ensuring that the project adheres to its timelines.

Phase 1: Literature Review and Model Design (March 20, 2024 – April 1, 2024)

The initial phase focuses on reviewing the literature to assess current methodologies and identify research gaps in food waste within supply chains. It will also involve drafting the preliminary design of the simulation model.

Phase 2: Data Collection and Model Development (April 1, 2024 - April 27, 2024)

This phase focuses on the systematic collection of data and the foundational development of the simulation model. This includes collection of datasets, followed by data preprocessing tailored to align with the proposed AI model's framework. Subsequent activities will encompass the integration of these datasets into the initial build of the simulation model, ultimately leading to a working prototype.

Phase 3: Model Testing and Refinement (April 28, 2024 - June 6, 2024)

During this phase, the model undergoes testing to evaluate predictive capabilities and intervention feasibility. Refinement follows, aimed at enhancing model accuracy and reliability.

Phase 4 Interface and Integration (June 7, 2024 - June 23, 2024)

The interface design will prioritise user experience, focusing on clarity and functionality. The design process will involve the creation of wireframes and interactive elements that reflect the model's complexity in a user-friendly format. Upon design finalisation, the implementation phase will render these designs into a fully operational interface ready for interaction with the simulation model.

Phase 5: Quality Assurance (June 24, 2024 - July 7, 2024)

This phase is dedicated to testing the simulation model and the user interface, ensuring both accuracy in the simulation outputs and a seamless user experience. It will involve identifying defects, verifying bug fixes, and validating the interface with end-users. This iterative process is critical for enhancing the reliability and usability of the simulation tool.

Phase 6: Formulation of Recommendations and Final Reporting (July 8, 2024 - September 8, 2024)

The final phase includes integrating the research findings into actionable recommendations. Drawing upon insights gained from the quality assurance phase, recommendations will be tailored to address the challenges of food waste in supply chains. The final report will record the project's methodology, findings and proposed recommendations, offering a comprehensive account of the investigation and its implications for future research and practice.

A close-up of a gantt chart

Description automatically generated

Figure 1: Gantt Chart of Project Schedule for the development of the project

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