Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

ΔΡΑΣΗ ΕΘΝΙΚΗΣ ΕΜΒΕΛΕΙΑΣ

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ΕΡΓΟ: Ολοκληρωμένη Πλατφόρμα Blockchain και ‘’Εξυπνη’ Εφαρμογή Κινητής Συσκευής στη Μάχη Ενάντια στη Σπατάλη Τροφίμων προς Όφελος των Επισιτιστικά Ανασφαλών Πολιτών

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Development of a Blockchain-based Technology Solution for Tackling Food Waste and Supporting Food Insecure People

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Abstract

Food waste constitutes a major global issue, entailing immensely significant environmental and socio-economic repercussions. The increase in the atmospheric concentrations of greenhouse gases, land degradation and irrigation water scarcity turn out to be the most ecologically destructive ones. Furthermore, the substantial detriment in the form of economic loss owing to food cultivation, storage, processing, transportation, distribution and disposal, while millions of people, both in developing and developed countries, are affected by food insecurity, indicates the social and economic ramifications of the problem. The alleviation of this situation can be achieved through focusing on food waste throughout the food supply chain, which, as far as developed countries, are concerned, occurs during the final consumption stage. The presented research introduces a technology solution, allowing food-service establishments to utilize the surplus food, which would otherwise be disposed of, by providing it to food insecure people. The research concentrates on the intersection of two rapidly growing scientific areas, that of food waste management and that of Blockchain technology, which will be used to ensure continuous communication between food-service establishments and food insecure people, using an online ledger, where the quantity and type of food made available by each contracting party will be shared with a view to optimizing the allocation of excess food. The aim of the project is to develop a mobile platform, composed of three subsystems: a) A data collection subsystem, gathering data streams such as photos and nutrition information, pertinent to the available portions of food, for visualization purposes, b) A reward subsystem, through which food donations are monetized, by providing tokens, as a reward, to the contracting parties, thereby creating a co-operative incentive and c) An application subsystem, enabling the visualization of the information gathered and offer value-added services to both food-service establishments and food insecure users of the application. The integrated system is used to ensure continuous communication between both parties, so as to optimize the allocation of excess food and thus, minimize food waste. In the long term, the abovementioned project aspires to promote an analytical and sustainable plan to reduce food waste in food-service establishments, while providing food aid to people in need. Moreover, it plans on scaling the implementation of its results up into such a way that it also permits consumers to provide edible food, which they do not need and would otherwise dispose of, to food insecure people.

Keywords: Food waste, Blockchain, Mobile platform, Tokens, Food insecurity

Acknowledgments: The present work is co-funded by the European Union and Greek national funds through the Operational Program "Competitiveness, Entrepreneurship and Innovation" (EPAnEK), under the cal "RESEARCH-CREATE-INNOVATE" (project code: T2EDK-05051 and Acronym: BLOCKFOODWASTE).

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UTILIZING BLOCKCHAIN TECHNOLOGY TO TACKLE FOOD WASTE IN SMART CITIES

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ABSTRACT

Food waste is a major global issue and responsible for significant environmental and socio-economic repercussions, while millions of people worldwide, are affected by food insecurity. Food insecurity occurs even in large cities with high economic growth, where at the same time there is a large number of catering businesses and restaurants, which due to wrong forecasting and their effort to meet the predicted demand, prepare more fresh meals than necessary. As a result, quality food ends up in the garbage, in a daily basis. The research presented in this paper introduces a solution, based on Blockchain technology, that allows food-service establishments to offer the extra meals they have already prepared and would otherwise be disposed of, to food insecure people. The project's research focuses on the one hand on mitigating the food waste phenomenon in urban areas with high number of businesses providing fresh meals and on the other hand, on providing free, safe and nutritious meals to food insecure people. The integrated system ensures continuous communication between both parties and optimizes the allocation of food surplus and thus, minimizes food waste. The aim of the project is to develop a unique marketplace for food surplus, through a mobile platform and application, that can be utilized in the concept of smart cities, in order to mitigate the food waste phenomenon and actually contribute to the well-being of insecure members of our society, with the discretion and anonymity that is offered by the Blockchain characteristics.

KEYWORDS

Food Waste, Food Insecurity, Blockchain, Decentralized Applications, Tokens

1. INTRODUCTION

Food waste is a major global problem with multidimensional consequences. According to the Food and Agriculture Organization of the United Nations (FAO), one third of the global production, or else approximately 1.3 billion tons of edible food are lost or wasted every year (Ishangulyyev et al., 2019), creating a series of serious environmental and socio-economic impacts (Martin-Rios et al., 2018). Apart from the immediate consequences of the wasted resources, the problem acquires a moral component, due to the fact that 828 million people worldwide faced hunger in 2021 (FAO, 2022). Food waste occur mostly in developed countries (Buzby & Hyman, 2012), as the geographic profile of the phenomenon is heavily influenced by the level of income and the urbanization (Chalak et al., 2016). The above profile matches the description of smart cities, a term that represents a plethora of cities around the world with high levels of economic growth, trying to transform and upscale their services to their citizens, through the utilization of new technologies. In this context, such cities are capable of finding solutions to address the food waste problem, even through the use of technologies that they are not yet familiar with, such as Blockchain.

The alleviation of the food waste phenomenon in cities can be achieved through focusing on food waste taking place at the final stage of the food supply chain, the consumption stage. In particular, in food service establishments of a developed country, half a pound of food waste is created per meal served (Bloom, 2012), which indicates that for every 4 meals consumed, almost a kilogram of food is wasted. The waste is generated from food scraps either from customers, after completing their meal, or from the kitchen, due to ineffective demand forecasting. In the first case, awareness has to be raised against food waste among consumers that paid for it and they can easily avoid it, by packaging, freezing and consuming it, at some other time. However, the solution to the problem in the latter case is not simple, as demand cannot always be predicted with absolute precision. It is therefore imperative to create an integrated, clearly defined system through which food providing establishments, such as restaurants, cafes, pubs, etc., can find new ways to deal with food that is not consumed, such as the solution presented in this paper that offers them the capability to donate the generated surplus to food insecure people.

2. PROPOSED SOLUTION

Blockchain is a distributed ledger shared among the members of a network and is continually updated with the recording of all transactions transmitted by the network's nodes (Christidis & Devetsikiotis, 2016). The first Blockchain network (Bitcoin) was presented by Nakamoto (2008), but its operation is based on the combination of many pre-existing technologies and concepts, namely Peer-to-Peer networks, hash functions, public key cryptography, digital signatures and consensus mechanisms. This decentralized technology offers the opportunity to create self-executing contracts between parties (smart contracts) and create tokens (tokenization), which can function as the digital representation of real-world assets on the Blockchain network. The project presented in this paper takes advantage of the tokenization capabilities and develops a decentralized application (dApp), with a back-end based on an existing public Blockchain network.

The project's research focuses on the intersection of two rapidly growing areas of scientific interest i.e., Food Waste management and Blockchain technology, in order to simultaneously mitigate the food waste problem and provide safe and nutritious meals to food insecure citizens and their families. The decentralized ledger provided by the Blockchain technology is utilized to ensure the anonymous two-way communication between food establishments (suppliers) and citizens (food seekers), in order to optimize the allocation of the prepared meals surplus. In a high level, the solution in this paper can be described as a standard digital marketplace offering supply and covering demand. The sole product exchanging between the users are the meals prepared from food establishments that would be otherwise disposed of, in the end of the day. So, the suppliers connect to the project's database to upload data about the meals they would like to donate and the users pick up the food of their preference, anonymously, with the necessary discretion. The completed transactions are transmitted and verified transparently by the Blockchain network, and every transaction triggers the project's smart contract, that donates tokens to both parties rewarding them for their active participation in the effort to tackle the food waste problem. The food seekers can use the new tokens to purchase food again and the suppliers can donate their tokens to food insecure citizens or spend them in other businesses that also participate in the project's ecosystem against food waste, by offering discounts at their products and services, in exchange for the project's token.

The integrated system is composed of the three following subsystems:

- A data collection subsystem, gathering data streams such as photos and nutrition information, pertinent to the available portions of food, for visualization purposes, in the application's interface. The food establishments, upon their registration are connected to the project's network and upload this data about the meals to the subsystem, where they are processed using appropriate data analysis tools. This data, combined with data from external sources with an emphasis on geospatial computing, are analyzed for real-time decision-making and visualizing information.
- A blockchain subsystem, through which food donations are monetized, by providing tokens, as a reward, to the contracting parties, thereby creating a co-operative incentive. Every decision that saves a portion of food, by providing it to a user of the application, will be recorded in the blockchain network and will be translated into tokens.
- An application subsystem, enabling the visualization of the information gathered and offering value-added services to both food establishments and food insecure users of the application. The project's application is a dApp, which means that the front-end is designed like any other common app, but the back-end is running on a blockchain network, not a central server.

Any user of the application, either a citizen looking for meals, or a supplier offering the daily surplus, is able to proceed with the registration instantly through the mobile application. With the registration, a new anonymous account is created in the project's public Blockchain network, which means that the user is a new node of the network, with the same capabilities like any other node of the blockchain. If the user has already an account in the same public Blockchain, it is possible to use it as well, without a registration. With the blockchain account activated and registered in the mobile application, the user has to define the user profile, either as a food seeker or as a supplier, during the logging in process. The new food seeker accounts will receive tokens with their registration, in order to use them for their first meal. In the case of the suppliers, they have to provide basic information about their establishment (Name, Cuisine, Address, Work hours, E-mail, Telephone number etc.). Indicative screenshots are presented in Figure 1.

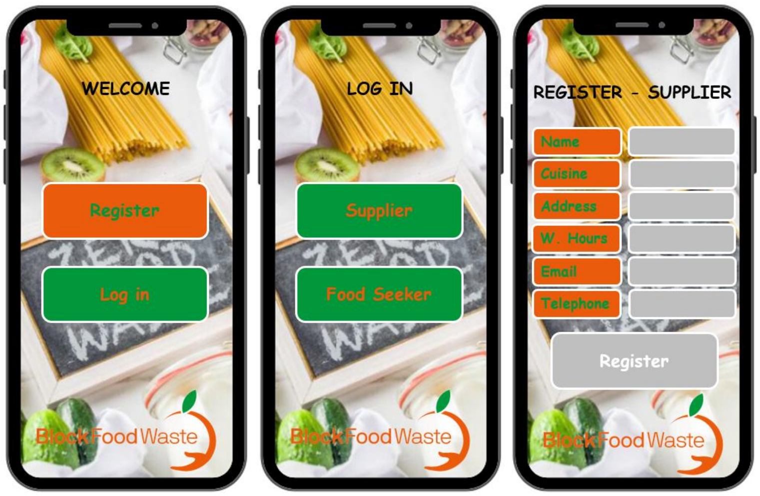

Figure 1. Application's interface (register and log in)

As a result, depending on the user profile, the application's interface is customized accordingly. For the food seekers, upon opening the application and activating geolocation using GPS, a map is loaded and displayed, highlighting the location of the user's closer suppliers, who offer at least one free meal available, in real-time. Through the mobile application the food seekers are easily informed about all the available choices from of all suppliers (with photos, food ingredients etc.) and then, they are able to select one of the available meals, taking into account both the distance to the establishment and the nutritional needs. The interface offers a booking option for the meals, as well as the option to navigate to the restaurant's location, in order to calculate the exact distance and expected time of arrival at the destination, based on the current traffic volume, using maps and routing services. The user selects the type of meal he/she wishes to consume, by making a reservation for it, with a validity period limited to one hour. In case the meal is not picked up after this time, it will be available again through the app, automatically. With the reservation, the user is provided with a QR code, which is required to be scanned by a food establishment's employee, in order for the transaction to be completed and verified in the Blockchain. Every QR is generated uniquely by the application and is related to one specific transaction. The QR code is the main oracle for the proper operation of the project's smart contract. Indicative screenshots for food seekers' interface are presented in Figure 2.

Figure 2. Application's interface (food seeker)

In the use case of suppliers, two options are presented in the application's interface: a) the uploading of new donations and b) the mechanism for the declaration of the completed pick up. The first option concerns fresh meals, which the supplier thinks should be distributed freely to consumers through the application, due to a poor forecast of daily demand. By selecting the listing of food for free distribution in the application interface, two columns are displayed, one for the type of food and one for the quantity of meals per type. Correspondingly, the meals become available and visible to application's users. When a food seeker arrives for the pickup, the supplier's employee uses the application's mechanism (scanner) to scan the QR code provided by the citizen and instantly the transaction is finalized and transmitted to the Blockchain network and is removed from the list of available products. Indicative screenshots of the application for the suppliers' interface are presented in Figure 3.

Figure 3. Application's interface (supplier)

The benefits of the integrated solution are not limited to just those involved in the marketplace through the dApp. Municipalities, NGOs, and other charitable organizations, which until now, have been exclusively responsible for providing food to people in need, through soup kitchens and donations in a centralized way, will be significantly relieved. Also, in addition to the decentralized operation of the application, the solution proposes also a decentralized last mile management, which is extremely important for the success of the project as a whole. Most of the restaurants have just a very small number of portions to offer every day and it would be too expensive logistics-wise to be transferred in centralized location to be distributed. With the project's solution restaurants can participate with even one meal, since the last mile is handled by the citizen that choses to reserve it.

The authors are currently in the phase of developing the final version of all the subsystems of the project and designing the specifications and scenario details for the project's large-scale pilot program. At the same time, the authors are already working to release another version of the dApp in order to create a complete ecosystem around the project's token targeting all citizens, by providing cheaper prices for those interested in paying less for food and helping to tackle food waste, at the same time. The project partners aspire to add businesses selling packaged food products close to their expiration date, which are also an important form of food waste.

3. CONCLUSION

The effort to reduce food waste is imperative, and the aim of the solution presented in this paper is a step towards that direction. Blockchain plays a cardinal role in the integrated system, due to the anonymity that provides to food insecure citizens and its tokenization capabilities. With the project's token, an ecosystem around food waste is created and also incentives are offered to food establishments, in order to participate in the program. The project, therefore, aims to contribute decisively to the fight against the phenomenon of food waste and to provide relief to a significant part of the food insecure population of the cities, with a simple mobile application.

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REFERENCES

Bloom, J. (2012). For Restaurants, Food Waste Is Seen As Low Priority. Retrieved from: https://www.npr.org/sections/thesalt/2012/11/27/165907972/for-restaurants-food-waste-is-seen-as-low-priority (Accessed: 10 April 2023)

Buzby, J. C., & Hyman, J. (2012). Total and per capita value of food loss in the United States. Food policy, 37(5), 561-570.

Chalak, A., Abou-Daher, C., Chaaban, J., & Abiad, M. G. (2016). The global economic and regulatory determinants of household food waste generation: A cross-country analysis. Waste management, 48, 418-422.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. Ieee Access, 4, 2292-2303.

FAO. (2022). Food and Agricultural Organization of the United Nations. Hunger and food insecurity. Retrieved from: https://www.fao.org/hunger/en/ (Accessed: March 30, 2023).

Ishangulyyev, R., Kim, S., & Lee, S. H. (2019). Understanding food loss and waste—why are we losing and wasting food?. Foods, 8(8), 297.

Martin-Rios, C., Demen-Meier, C., Gössling, S., & Cornuz, C. (2018). Food waste management innovations in the foodservice industry. Waste management, 79, 196-206.

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. Decentralized business review, 21260.

A BLOCKCHAIN-BASED APPLICATION FOR FOOD WASTE REDUCTION

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ABSTRACT

Food waste is a major global concern and engenders profound ramifications of environmental and socio-economic dimensions, while on the other hand, food insecurity affects a significant part of the global population. The co-existence of food waste and food insecurity in urban environments is a paradox of modern cities. The research project presented in this paper introduces a solution using blockchain technology to address both of these issues, simultaneously. The project aims to develop a decentralized mobile application (dApp), which facilitates the reduction of food waste and provides safe and nutritious meals to food-insecure individuals. The tokenization capability provided by the blockchain technology, through the utilization of smart contracts, is used to incentivize food waste reduction and track surplus availability. Citizens use the project's token as currency to purchase food portions, while the participating food service establishments from the retail sector, receive the tokens in exchange for the saved surplus. In this paper the architectural design and all the components of the decentralized application are outlined and described and a holistic view of their interconnection into an IT architecture is provided. This description is followed by an initial discussion of the tokenization process of the proposed ecosystem and its main characteristics that are going to guide the development of the project's tokenomics, by taking into account token's supply, distribution, utility and market demand to estimate the token's value.

KEYWORDS

Blockchain, Smart Contracts, Tokens, Tokenization, System Architecture, Food Waste

1. INTRODUCTION

Food waste is an increasingly critical issue worldwide, impacting environment and society in a multi-dimensional way. It contributes to greenhouse gas emissions and depletes water and land resources (Munesue & Masui, 2019). If food waste was a country, it would be the third largest emitting country in the world, after China and USA (UNEP, 2021). Economically, it causes $936 billion per year in economic damages (FAO, 2014) and socially, it exacerbates inequalities, especially in metropolitan areas where it occurs along food insecurity. Food waste takes place in every link of the food supply chain (Parfitt et al., 2010) from primary producers and processing to retail stores and final consumers. Especially in hospitality and food service sector, according to studies, nearly one third of all food is wasted and almost half of the waste, can be avoided (Papargyropoulou et al., 2019). The level of the food supply chain that includes among others, the restaurants and eateries in the cities, i.e., the retail sector, plays significant role in arising food waste. Initiatives to mitigate the phenomenon include improved supply chain management, innovative packaging and storage solutions, redistribution of surplus food to those in need, and educational campaigns that aim to shift consumer attitudes and behaviors (Attiq et al., 2021; Strotmann et al., 2017; Wikström et al., 2019). The efforts of the project presented in this paper target those in need, that suffer from food insecurity, as the recipients of the food surplus generated by the retail sector, in order to try to effectively tackle the repercussions emerging from food waste, with the utilization of the blockchain technology and its derivatives, i.e., smart contracts and tokens.

2. SYSTEM ARCHITECTURE

The core objective of the project presented in this paper, namely BLOCKFOODWASTE, is to develop a mobile application based on blockchain, for reducing food waste from the food service establishments of the retail sector, such as restaurants, eateries, bakeries etc. The users of the application are divided in two categories: a) the Food Service Establishments (FSEs) that offer their food surplus (supply) and the citizens that suffer from food insecurity or are willing to help the mitigation of food waste problem (demand). The IT architecture is critical in the development of any information system no matter of its size, development approach, structural type and domain of application and the same applies to this project's case. The technical components that are used to build the project's decentralized application (dApp) help to ensure that it is secure, scalable and interoperable with other dApps and systems. The research team decided to treat the development efforts of the discrete components separated, in order to rationalize software development processes and gain time. This decision separated the first two large building blocks of the architecture i.e., BFW blockchain from the Application system. The software development follows an agile approach, because agile methods are suited to develop systems whose requirements are not completely understood since the beginning, or tend to change, as it is this case. The choice for the public blockchain network that will be utilized in the Proof-of-Concept phase of this project is the Ethereum blockchain, but due to its high gas fees, it may not be the blockchain of the project's final product. Based on the above, an initial take of the high-level system architecture is depicted in **Figure 1**. For figure clarity purposes, interconnections between nodes in the blockchain component have not drafted, yet they are implied. All the nodes are connected to each other, and they continuously exchange the newest information on the blockchain with each other. This ensures all nodes are updated.

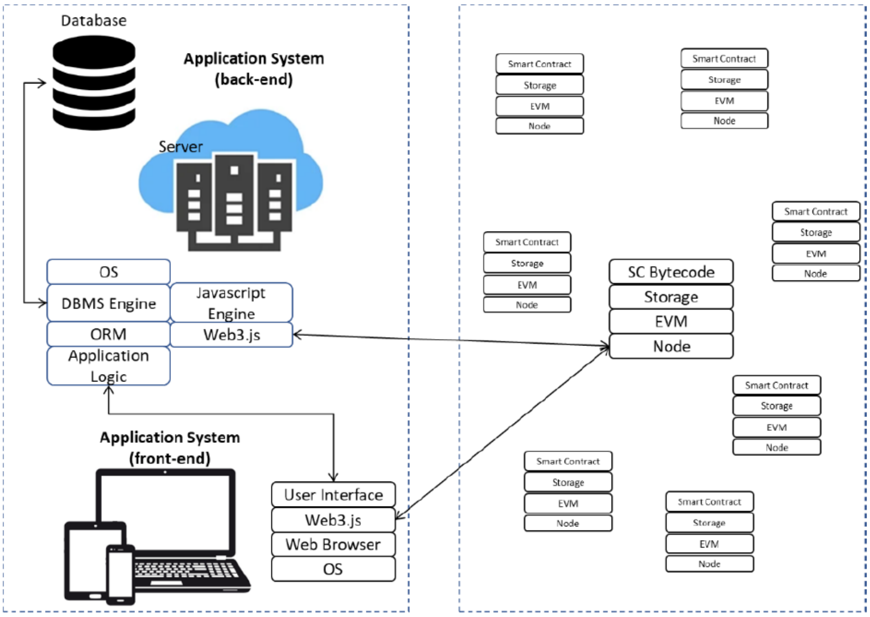

Figure 1. High Level IT Architecture of the BFW Distributed Application

The Application system is composed of a software system running on mobile devices and/or on servers, exchanging information with users and external devices. Its User Interface (UI) runs on a Web browser and in a mobile app interface. The server component stores data that cannot be stored in the blockchain and performs business computations. As shown in **Figure 1**, interaction between Ethereum nodes and the system application (mostly managing the creation and dispatches of transactions) will be carried out using Web3.js through HTTP, IPC, or WebSocket. Object-relational mapping (ORM) is a programming technique in which a metadata descriptor is used to connect object code to a relational database. Object code will be written in object-oriented programming (OOP) languages such as Java or C#. Finally, in the blockchain component, EVM (Ethereum Virtual Machine) is the runtime environment that executes Ethereum smart contracts. Ethereum contracts are written in Ethereum's proprietary Turing-complete scripting language, called Solidity, which will be used to develop the project's smart contracts and their embedded business logic.

Further drilling down in the dApp architecture, at this point, outlining the interaction of the two discrete blocks of **Figure 1** is in order. In **Figure 2**, a simplified version of the interaction between the two components is presented, along with available software tools for creating the smart contracts (VScode and Remix IDEs), cloud service providers such as Microsoft Azure and Amazon Web Services and finally Ethereum wallets, such as MetaMask and Exodus.

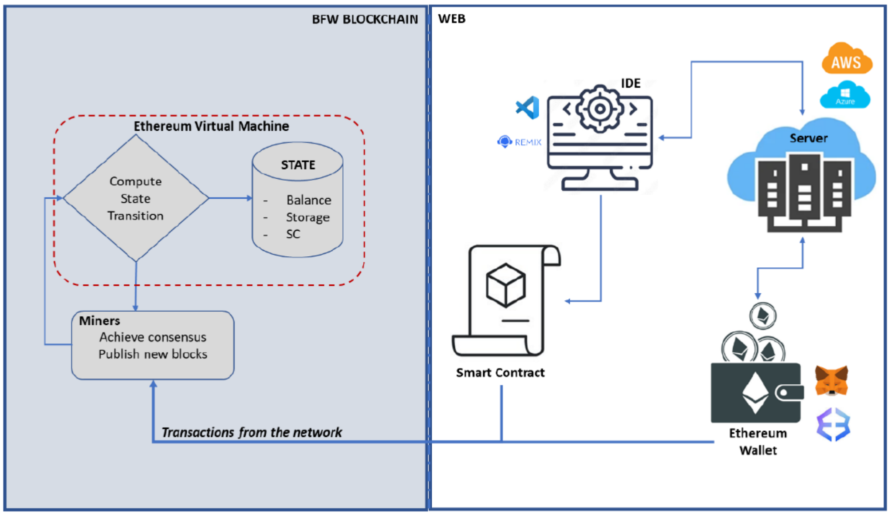

Figure 2. Component Interaction

Having determined the upper-level architecture of the project's dApp and in order to provide more details of the proposed approach, an outline of the iterative software development process is provided. The high-level expectations (requirements) for each discrete component, are the following:

Mobile App: The mobile app should have a user-friendly interface for citizens to browse and place an order for surplus food from participating FSEs. It should have integration with blockchain to securely record transactions and track food waste reduction and use GPS or other location-based services to show available surplus food nearby the interested citizens.

Web Platform: The web platform should provide an interface for food service establishments to manage their surplus food inventory and track food waste reduction. It should have integration with blockchain to securely record transactions and track food waste reduction. Additionally, it should have an analytics dashboard to monitor food waste reduction and track the performance of participating FSEs and a reporting system to generate reports, such as on food waste reduction goals.

Blockchain: The blockchain should be used to securely record transactions and track food waste reduction. It should provide transparency and immutability in recording the transactions and food waste reduction and allow for the creation of smart contracts to automate the process of surplus food distribution and food waste tracking.

Database: The database should store the information about participating food service establishments, surplus food inventory, citizen orders, and food waste reduction tracking. It should be scalable to accommodate the growing number of transactions and data as the food waste reduction platform grows and should be securely managed to protect sensitive information.

The information above, constitutes the generic requirements of the BFW project so it can efficiently reduce food waste while providing a free, secure and transparent solution for both citizens and FSEs. Additionally, the research will decide later in the project for the inclusion of an advertising system, as a result of a full-blown cost and sustainability analysis. The advertising system should be integrated into the mobile app and web platform to provide funding for the food waste reduction initiative and should display relevant and non-intrusive advertisements to customers, which can provide the necessary funding to support the free food waste reduction platform.

Finally, data architecture is also an important aspect in the development of a dApp because it defines how data is stored, organized, and managed within the dApp. A well-designed data architecture helps ensure data integrity, security, scalability, and accessibility, all of which are critical for the success of a dApp. Additionally, a clear and consistent data architecture makes it easier for developers to build and maintain the dApp, and for users to interact with the dApp and its data. Ultimately, a strong data architecture is essential for the long-term viability and success of a dApp. In the case of this project, the proposed data architecture for the BFW dApp has the following dimensions:

Data Storage: The blockchain would be used to securely store data such as food types, food inventory levels, expiration dates, and any transactions related to food waste reduction. This data would be immutable and transparent, ensuring that all stakeholders can have trust in the information stored.

Data Access: The data stored on the blockchain and processed by the backend system would be accessible to all users and FSEs for free, in line with the goal of reducing food waste and making a positive impact on the environment. Access to the data would be controlled through secure authentication and authorization mechanisms to ensure that only authorized users can access the data.

Data Processing: A backend system would process the data stored on the blockchain and generate reports and insights for both citizens and FSEs.

Data Visualization: The mobile app and web platform would provide interactive visualizations of the data to help eating citizens and FSEs understand the impact of their actions on food waste reduction. These visualizations would include graphs, charts, and maps that provide insights into the sources and causes of food waste and highlight the successes of food waste reduction efforts.

Data API: A REST API would be provided to allow mobile app and web platform users to access the data stored on the blockchain and processed by the backend system. This API would enable users to see real-time information about food waste reduction efforts in their area and take action to support these efforts.

3. TOKENIZATION

The first step in the tokenization process is to identify the asset that will be represented by the digital token that is going to be created. In the context of the BFW project, tokenization is used to track and incentivize the reduction of food waste with the cooperation of participating citizens and FSEs. As such, the asset that is represented by the digital token is the surplus food available to the ecosystem everyday by the FSEs. The project’s token, which is named BFW, will be created using a smart contract that outlines the terms and conditions of the token, such as its value, ownership, and transferability and will be added in a blockchain. As it was mentioned, for the proof-of-concept phase of the project, the smart contract will be added in Ethereum blockchain that supports token creation and management. So, the project’s smart contract will be used to manage the allocation, transfer, and redemption of the BFW tokens. A detailed description of the smart contract building process in Ethereum follows:

− The smart contract will be deployed on the Ethereum blockchain, making it available to all participants in the above-mentioned network. The smart contract will define the rules and conditions for the allocation, transfer, and redemption of tokens.

− Tokens will be issued through the smart contract, and the contract will determine the number of tokens that will be issued and the conditions under which they can be issued to FSEs and citizens, based on their food waste reduction efforts.

− The contract will be monitored by all parties on the Ethereum blockchain, providing transparency and accountability for the tokenization process. For example, citizens and FSEs will be able to view the terms of the contract and the status of token transfers and trades on the blockchain ledger.

− The smart contract will manage the allocation of tokens to eating establishments and users based on predefined conditions.

− The smart contract will validate and execute token transfers and will ensure that tokens are transferred only in accordance with predefined conditions.

− The smart contract will define the conditions under which tokens can be redeemed and the rewards that will be provided.

− The contract could be updated as needed by the BFW consortium, allowing for flexibility and adaptation to changes in the food waste reduction efforts. Contract updates will be validated by the Ethereum network and recorded on the blockchain ledger.

− The code for the smart contract in Ethereum will be designed to be secure and transparent, and to enforce the terms of the agreement for reducing food waste. The contract will be publicly available on the Ethereum blockchain for review and auditing. The code will be free for everyone to use, allowing for widespread adoption and participation in reducing food waste.

The novel ecosystem is built around the BFW token, so the token's smart contract will automatically issue the tokens to participating FSEs and citizens based on their food waste reduction efforts. Tokens will be used as a currency to purchase surplus food or other products from participating business entities. This incentivizes users to participate in food waste reduction and aligns their interests with the goals of the platform. For example, for every kilogram (or portion) of food saved from going to waste, the participating establishment would receive a certain number of BFWs. FSEs can redeem their tokens in exchange for free access or discounts on platform services (e.g. ads), access to analytics and resources and other incentives, or even donate the tokens back to food insecure citizens, directly or through other organizations. This aligns the interests of eating establishments with the goals of the platform, as they will have an interest in reducing food waste to earn more tokens. The same applies to citizens who place an order from their mobile App, to receive meals from participating FSEs.

The BFW tokens will be managed using a blockchain wallet, integrated into the mobile app to provide customers and restaurants with a secure and convenient way to manage their tokens and track food waste reduction. Traditionally, the equivalent of one token would depend on the value assigned to the token by market demand and supply. In that sense, the exact value of one (1) BFW token can only be determined through market dynamics, i.e., the use of the token within the food waste blockchain ecosystem, and the overall success of the food waste reduction efforts. In the beginning, a potential approach could be to set the initial value of one BFW token based on the cost of preventing a certain amount of food waste, for example, 1 BFW token could represent the cost of preventing 1 kilogram of food waste. This value could then fluctuate over time based on market demand and supply. Ultimately, the value of one BFW token would be determined by a combination of factors, including the success of the food waste reduction efforts, the adoption of the food waste blockchain application, and the demand for the token within the ecosystem. The project's initial take on the subject has produced three alternatives, which can also can be used in combination, as follows:

− Mass of food not wasted (kg): Assign a fixed value to each kilogram of food waste prevented, for example, 1 BFW token per kilogram of food waste prevented. This approach would directly reflect the environmental impact of the food waste reduction efforts and incentivize users to reduce as much food waste as possible.

− Food portions: Assign a fixed value to each portion of food waste prevented, for example, 1 BFW token per portion of food waste prevented. This approach would be more accessible for consumers and could be more easily translated into everyday actions.

− Food market value: Assign a fixed value to each dollar of food waste prevented, for example, 1 BFW token per dollar of food waste prevented. This approach would reflect the economic impact of the food waste reduction efforts and incentivize users to reduce food waste in a cost-effective manner.

The blockchain can enforce rules and conditions for token transfer, such as minimum food waste reduction goals, to ensure that the tokens are used effectively to incentivize food waste reduction. The tokenization process within the ecosystem has to be designed meticulously, as the main objective is to keep the platform sustainable, so it's important to carefully consider all revenue sources and how they align with the project's mission against food waste. In the future, project partners will consider all available options in terms of initiating alternative revenue streams, in order to remain sustainable such as: Advertising, Sponsored content, E-commerce, Data licensing etc. The initial token supply and exchange rate depends on several factors such as the purpose of the token, the target audience, market demand, and competition. The purpose of the token will dictate the total supply and the exchange rate. In the project's case, the token will be used as a medium of exchange and as such, its supply should be large enough to meet the demand. The market demand for the token will also play a role in determining the initial supply and exchange rate. The token's exchange rate should be in line with the market demand. Since, BFW will operate in a closed market, the need for the token exchange rate to be in line with similar tokens in the market is absent.

The next step in the project for the research team, is to decide the overall tokenomics of the system and then use financial modeling and market analysis tools to estimate the potential value of the BFW token. The tokenomics will be decided considering the following parameters:

− Token supply: The total number of tokens that will be created and set in circulation.

− Token distribution: The allocation of tokens to various stakeholders, including project partners (in essence the founders and early investors) and community members.

− Token utility: The function of the token within the food waste blockchain application, such as serving as a medium of exchange, reward, or governance mechanism.

− Token economics: The underlying economic model, such as inflationary or deflationary, and how it affects token supply and demand.

− Network effects: The potential for the value of the token to increase as more people use the food waste blockchain application.

− Market demand: The potential demand for the token from various groups, such as food waste reduction organizations, consumers and later investors. Competition as expressed by the presence of other food waste blockchain solutions and how they compare in terms of tokenomics will be evaluated but not considered as decisive factor at this stage of business model development.

4. CONCLUSION

Food waste is a challenge that calls for collaborations, in order to create a more equitable, efficient and sustainable food system. By understanding the multifaceted nature of food waste, technology can be utilized to significantly reduce waste, alleviate hunger and conserve resources. The high level of the BLOCKFOOWASTE project's technology landscape and baseline data, provided in this paper, aligns with the above-mentioned goals, by minimizing food waste, and contributing to the well-being of food insecure individuals in urban areas. The project's system and data architecture aspire to provide a secure, transparent, and scalable solution for reducing food waste from restaurants and other eating establishments. It can enable the members of the community to work together towards a common goal, leveraging the strengths of blockchain, to make a positive impact on the environment. By using tokenization, the project's application can incentivize participating FSEs and citizens to reduce food waste, track their progress, and reward them for their efforts. Blockchain technology offers an anonymous and automated manner to accomplish the food donations from the FSEs, using smart contracts. The use of smart contracts provides a secure way to manage the tokenization processes (token issuance, allocation, transfer, trading, and redemption), allowing for widespread adoption and participation in reducing food waste.

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REFERENCES

Attiq, S., Chau, K. Y., Bashir, S., Habib, M. D., Azam, R. I., & Wong, W. K. (2021). Sustainability of household food waste reduction: A fresh insight on youth's emotional and cognitive behaviors. International Journal of Environmental Research and Public Health, 18(13), 7013.

Munesue, Y., & Masui, T. (2019). The impacts of Japanese food losses and food waste on global natural resources and greenhouse gas emissions. Journal of Industrial Ecology, 23(5), 1196-1210.

Papargyropoulou, E., Steinberger, J. K., Wright, N., Lozano, R., Padfield, R., & Ujang, Z. (2019). Patterns and causes of food waste in the hospitality and food service sector: Food waste prevention insights from Malaysia. Sustainability, 11(21), 6016.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. Philosophical transactions of the royal society B: biological sciences, 365(1554), 3065-3081.

Strotmann, C., Friedrich, S., Kreyenschmidt, J., Teitscheid, P., & Ritter, G. (2017). Comparing food provided and wasted before and after implementing measures against food waste in three healthcare food service facilities. Sustainability, 9(8), 1409.

UNEP (2021). UNEP food waste index report 2021. Nairobi. Retrieved from: https://www.unep.org/resources/report/unep-food-waste-index-report-2021

Wikström, F., Williams, H., Trischler, J., & Rowe, Z. (2019). The importance of packaging functions for food waste of different products in households. Sustainability, 11(9), 2641.FAO. (2014). Food wastage footprint. Full-cost accounting. Final Report. Retrieved from: https://www.fao.org/3/i3991e/i3991e.pdf

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rethink food resources, losses, and waste 2023

Development of a Blockchain Ecosystem Based on the Tokenization of Food Waste

Stavros Ponis, George Plakas, Eleni Aretoulaki, Dimitra Tzanetou and Antonios Kitsantas

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Abstract

The coexistence of food waste and food insecurity is a paradox of modern times, especially in the urban environment. In this context, the core objective of the project presented in this paper is to develop a decentralized application (dApp) running on mobile devices, for reducing food waste by providing safe and nutritious meals, mainly to food insecure citizens. There are two basic user profiles of the BLOCKFOODWASTE system, the Food Service Establishments (FSEs) and the citizens. FSEs are the suppliers of the system's core product i.e., food surplus, and the citizens are the consumers that purchase these meals using the project's tokens. Tokenization is the process of converting assets into digital tokens on a blockchain and in the context of the presented project is used to track and incentivize the reduction of food waste. The asset represented by the digital token is the food surplus available to the ecosystem by the FSEs. Each citizen, upon registration, is granted an initial number of tokens to spend and acquiring more tokens is possible by collecting meals from the suppliers. The project's token is created using a smart contract that outlines the terms and conditions of the token, such as its value, ownership, and transferability. The smart contract automatically executes the terms of an agreement between both parties and is used to manage the allocation, transfer, and redemption of tokens issued to FSEs and citizens, based on their food waste reduction participation. The contract will be monitored by all parties on a public blockchain, providing a secure and transparent way to manage the process, allowing for widespread adoption and participation in reducing food waste. Every participating establishment receives a certain number of tokens in exchange for every portion of food saved from going to waste. FSEs can redeem their tokens for access to data analytics and other incentives from the community, or donate the tokens to food insecure citizens. On the other hand, citizens use the tokens as a currency to purchase food surplus or other products from participating business entities. This incentivizes users to participate in food waste reduction and aligns their interests with the goals of the project. The tokens are managed using a blockchain wallet, integrated into the mobile app to provide customers and restaurants with a secure and convenient way to manage their tokens and track food waste reduction. The blockchain can also enforce rules and conditions for token transfer, such as minimum food waste reduction goals, to ensure that the tokens are used effectively. The logic of the proposed blockchain ecosystem, considers parameters such as, supply, distribution, utility and economics of the token, along with network effects and market demand. Based on these parameters and with the utilization of financial modeling and market analysis tools, the authors will estimate the potential value of the token and the overall tokenomics of the BLOCKFOODWASTE application.

Keywords: Food waste, Food insecurity Blockchain, Tokenization, Smart contracts

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rethink food resources, losses, and waste 2023

A Review of Food Waste Within the Food Service and Hospitality Sector: Mapping the Causes, Effects and Technological Opportunities for a Sustainable Future

Eleni Aretoulaki, Stavros T. Ponis, George Plakas, Dimitra Tzanetou and Antonis Kitsantas

National Technical University of Athens, Greece

Abstract

Food production is a resource intensive process accompanied by a wide range of environmental impacts. To add insult to injury, almost one third of the food produced for human consumption is wasted on a worldwide scale, amounting to a total of 1.3 billion tonnes per year, rendering all of the resources utilized for producing, processing, transporting and packaging that food also wasted. Not only does this waste further deteriorate environmental impacts, but it also raises social and humanitarian concerns by increasing food insecurity. In 2019, the food service and hospitality sector was found responsible for nearly 26% of the total food waste and despite its wasteful character being politically acknowledged, this topic still remains quite understudied in the academic field. In this paper, a review is carried out to shed light on this aspect of food waste. Through the mapping of the causes, effects and technological opportunities emerging from academic papers published from 2002 to 2022, this paper aims to contribute to the understanding of the true magnitude of the issue by policy makers, practitioners, academics and consumers, and the identification of significant research gaps. After reporting descriptive statistics, a content analysis of the papers evaluated ensued, revealing several valuable insights. The review divulged that a number of programmes have been developed around the world to mitigate food waste in such operations through the provision of proactive strategies, consumer awareness, redistribution of excess food as well as recycling and composting. These programs are designed to create a "chain reaction" to encourage the industry to minimize food waste and subsequent environmental impacts, while increasing revenue and customer satisfaction. However, although the interest in the adoption of food waste management practices by food service and hospitality businesses has grown exceptionally, there is still no standardised methodology on how to assess the volume and characterise the content of food waste resulting from the operation of the food service and hospitality sector. Several state-of-the art technologies have started to be applied for such purposes, including artificial intelligence, machine learning, Internet of Things (IoT) and smart sensors as well as blockchain. However, even though there is evidence of successful mitigation, as evidenced by efforts made by food service and hospitality businesses on a global scale, there is no comprehensive list of good operational practices that could be universally adopted and used in a single management framework.

Keywords: food waste, food service and hospitality sector, food security, blockchain, Internet of Things

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RETASTE Conference Abstracts
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When is it Really Dead? Ethnographic Reflections on Animals as Food and (Food) Waste

Nafsika Papacharalampous

Researcher, NTUA

Abstract

In this paper I present some ethnographic observations on the cultural processes by which an ingredient can be food or waste. More specifically, I wonder how the senses, values and cultural perceptions of edibility transmute food into waste and waste into food. I ask: how do people perceive food waste? What renders foods inedible? Is it just the expiration dates or is it a more complex process? What is the role of the senses, values and culture in the shaping of behaviours and attitudes around food waste, especially when it comes to animal foods? How are food waste practices and attitudes shaped? But also, how do they become tropes for the negotiation of grander ideas around planetary sustainability? My regional focus is Athens, Greece. Methodologically, I will be conducting digital ethnography, following conversations related to food waste on social media platforms such as Facebook and Instagram, as well as specialised food waste forums. I will also be conducting ethnographic research (participant observation) in selected Athenian middle-class households, engaging with the dynamics, behaviours and motivations around food waste. Theoretically, I approach food waste as an assemblage of organic, social and symbolic elements which result in interesting multi-species entanglements with significant impact on human lives, and reflect on how waste and humans cultivate one another in the wake of climate change and biodiversity loss. These enquiries and reflections seek to illuminate several cultural aspects around food waste attitudes which may be useful in generating future-oriented solutions when it comes to managing food waste.
*This research has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T2EDK-05051).

Keywords: food waste, multispecies ethnography, anthropology, sustainability

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Article

An Innovative Layout Design and Storage Assignment Method for Manual Order Picking with Respect to Ergonomic Criteria

Vasiliki Kapou, Stavros T. Ponis *, George Plakas and Eleni Aretoulaki

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Abstract: *Background*: This paper aims to improve the overall performance of manual warehouse Order Picking (OP) processes by proposing an innovative method for designing a picking area layout, and introducing a storage assignment strategy with respect to ergonomics and workers' physical fatigue. *Methods*: The proposed method categorizes the available picking slots based on size and ABC analysis. It takes into consideration a set of ergonomic constraints pertinent to the rack heights and travel distance restrictions for each slot type, leading to the assignment of a location to each slot type based on its individual characteristics. In doing so, the proposed method introduces an innovative 'flame-shape' aisle layout. Finally, the products are assigned to their optimal locations, targeting OP time minimization, balanced workload allocation, and ergonomics optimization through a ranking system measuring the 'difficulty' of retrieving the products based on their weight, popularity, and slot location. *Results*: The proposed method led to a productivity rise of 14.9% along with a significant decrease of the 'difficulty' index, by 31%. *Conclusions*: The results prove that a prominent performance improvement can be achieved when both travel distance and manual workload minimization are targeted for determining the picking area layout and storage design.

Keywords: intralogistics; order picking; warehouse; process optimization; ergonomics; slotting

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1. Introduction

In today's shifting competitive landscape, supply chain networks need to continuously change to accommodate ever-increasing customer expectations. Due to the evolution of e-commerce especially, customer requirements are becoming increasingly complex, demanding enhanced responsiveness, speedy deliveries, and highly customized and variable product assortments, all of which have brought new challenges and requirements for warehouse order fulfillment processes [1].

Order Picking (OP) is widely considered a core warehouse process and its efficiency is considered an important Key Performance Indicator of warehouse management [2], as it can affect delivery times and, hence, influence customer satisfaction. Although OP is an eligible process for automation, according to the works presented in [3], small and medium companies prefer to avoid high investments and maintain their agility by utilizing traditional and conventional methods. Therefore, the majority of warehouses, amounting to 80%, still rely on manual OP activities [4,5] while only 5% of them are fully automated [6]. Given the fact that OP is the most expensive process in contemporary warehouses, accounting for 50% of the total operating costs [7,8], organizations strive for efficiency and cost reduction through decreasing OP time [9]. This need has driven scientific literature to concentrate on travel time minimization, namely the time spent walking between storage locations, which takes up 50% of the total picking time, while overlooking secondary activities, such as setup, search, and pick [8,10].

Apart from efficiency aspects, OP is undoubtedly one of the most labor-intensive, repetitive, and monotonous processes in the warehouse [11]. Considering body posture during travel, setup, and search, pickers maintain either an upright walking or standing position. However, to extract an item from a rack, they might have to bend over, stretch, or twist their body while manually transferring, holding, pulling, or opening large and heavy storage units [12]. These repetitive body postures overload specific muscles due to the force exerted, especially on the back, shoulders, and knees, resulting in daily physical fatigue [13,14], severe chronic injuries, and MusculoSkeletal Disorders (MSDs) [15]. MSDs are the most reported causes for absence from work, being responsible for more than half of all work-related illnesses in the European Union [16].The financial damage caused by MSDs in pickers is equivalent to the costs associated with reduced productivity, work injury compensations, and high employee turnover rate, with the latter dictating the need for new joiners requiring intensive training all over again.

Consequently, in order to ensure increased efficiency and productivity levels, organizations need to shift their focus on the Human Factor (HF) and workers' well-being. In doing so, it is imperative that factors pertinent to physical fatigue, work safety, discomfort, and common errors be incorporated into the OP decision-making processes [17]. Although this should be a highly prioritized issue, the extant research on that scientific field is still limited. Many prominent studies have shed light on this literature gap, starting from the works presented in [18], which analyzed the interaction between operators and the system, concluding that the research community resorts to unrealistic assumptions (e.g., deterministic time of completion, homogeneity among workers, disregard for rest allowance needs, and physical fatigue etc.) to simplify operating process modeling, thus entirely failing to properly consider the HF impact on operations efficiency and vice versa. Additionally, the authors in [19] elucidated the lack of connection between operating performance and the HF, while in [10] the existence of said gap was also confirmed a few years later, adding that OP research merely focuses on quantitative methodologies, without being able to mathematically integrate work ergonomic factors. Following that, recent studies concluded again that despite the emphasis paid on Industry 4.0 technologies, the HF, in terms of safety and health, has been superficially approached in the literature [20,21]. Moreover, modern supply demands require multi-objective approaches, considering not only travel time reduction, but also equal distribution of workload to avoid picker blocking [22,23], the optimization of staffing levels, error prevention, and successful integration of the HF. Lastly, the authors in [24] noticed that the hits for the keywords "Industry 4.0" and "Internet of Things" account for 29,521, compared to 254 hits for "Ergonomics" and "Human Factor", revealing that scholars still pay much less attention to the human aspect in such operations.

Motivated by the aforementioned considerable literature gap in the area, this paper proposes an innovative method for integrating storage ergonomic criteria into layout and storage location assignment design models, with the aim of mitigating physical fatigue in manual OP activities. According to the authors' knowledge, such an attempt to include and appropriately consider the HF in OP optimization has not yet been introduced in the academic literature. The proposed method is validated through a case study conducted in a high-tech retail industry. The remainder of this paper progresses as detailed below. In Section 2, a short literature review on OP methods, storage policies, and relevant research on HF in OP is provided. In Section 3, the problem description is presented, i.e., the operating weaknesses in the OP processes of the case study company. Section 4 demonstrates the proposed method and algorithm, while in Section 5 computational results are demonstrated and discussed. Finally, the paper concludes with Section 6, where the study's findings and limitations are summarized and future research suggestions are made.

2. Literature Review

For the purposes of this study, it is highly important that OP methods be thoroughly analyzed, with an emphasis on manual OP. Additionally, the advantages and disadvantages of various Storage Policies (SP) are extensively examined. Lastly, as far as the ergonomics and HF in OP activities are concerned, relevant studies are discussed and literature gaps in this specific scientific field are highlighted.

2.1. OP Methods

Picker-to-Parts is the most common method for OP, according to which the picker, after receiving a transfer order, walks to the corresponding slot location and retrieves the demanded unit quantity, either manually or by using complementary means [25]. Two categories of picker-to-parts are identified: the low-level and high-level OP [26]. In the former case, the worker collects the goods from racks near their body height or from a bin shelving storage, while in the latter, which is also referred to as "man-aboard", lifting order-pick tracks or cranes are used for product retrieval. In this method, picking can be achieved in various ways. First, there is the *Pick-to-Box* method, also referred to as *Discrete Picking*, where the storage area is divided into picking zones occupying specific staff positions [27]. Order retrieval is achieved via either a progressive or synchronized zone picking system. In *Progressive Zone* picking, also called *Pick-and-Pass*, an order container strictly designated for an individual order progressively passes from each zone, where the pickers place the demanded products until all required items are collected [28]. On the contrary, during *Synchronized Zone* method, operators from different zones simultaneously retrieve and place the products into the same order container [4]. This way, less total picking time is required, under the condition of equally distributed workload among the zones [29].

Contrary to discrete picking, *Pick-and-Sort* is a method used for grouped customer orders, i.e., batch picking/picking by article; in other words, having pickers collect bigger quantities of a product in one trip which are designated for more than one order [30]. Additionally, this method can be combined with the *Picking Wave* method, when orders with common destination or shipping time are grouped together so as to accelerate the picking process [31]. Upon retrieval completion, all goods are sorted accordingly to meet customer requests, a time-consuming procedure that is prone to miscounts and errors. Additionally, in *Sort-while-Pick*, a method relatively similar to *Pick-and-Sort*, after performing batch picking of one SKU, the picker instantly sorts the items into individual containers before moving to the next one [4]. A sub-category of this method is *Put-to-Light*, in which the picker moves bin after bin, each consisting of multiple items of a particular SKU (SKU bin) along a lane of sequentially arranged orders [32]. A light signal, located above each container designated for an individual customer order (order bin), turns on and informs the picker where and how many items of each SKU he/she should place in it. Put-to-Light can be particularly efficient provided that the grouped orders have common characteristics and product requirements.

Relevant to the latter method, the *Parts-to-Picker* strategy includes mechanized and automated retrieval means, such as AS/RS, aisle-bound cranes, mini loads, and carousels, which bring the items in front of the worker [33,34]. Although this method has started to attract research interest [4] since it results in substantial expenditure drop, limited need for human interaction, and therefore fewer mistakes, it is also associated with various operational limitations. For instance, bottlenecks due to mechanisms' fixed order retrieving capacity can be responsible for delays, high lead times, and decreased workforce utilization rates [30].

2.2. Storage Policies

A storage policy is defined as a set of rules and parameters according to which the products are stored inside a warehouse until picked to fulfill a customer order [4]. There are two main and commonly separated stock areas inside a distribution centre. The first one, called the "pick stock", is the area from which pickers pick items to fulfill an order, and is restricted by dimensional limitations to ensure fast product collection, while the other, called the "bulk stock", is responsible for replenishing the "pick stock" [4]. The storage policies detailed below mostly refer to product allocation in the "pick stock".

First, according to the *Random Storage Policy*, every incoming SKU is assigned to any currently available picking slot [35]. This method provides high levels of space utilization [36], while due to randomized product allocation, an equal workload distribution is commonly observed, thus eliminating worker congestion issues [22]. However, high differentiation of goods prevents pickers from familiarizing themselves with picking locations, thus impacting retrieval speed and efficiency. The exact opposite of the random is the *Dedicated Storage Policy*, in which every product maintains a fixed position based on its characteristics [4]. Although this method allows pickers to develop cognitive ergonomics and be instantly aware of the exact location of goods [37], space utilization drops since a slot remains unavailable to other products, even when the associated SKU is out of stock. To add insult to injury, this method cannot be efficiently applied to seasonal products, which need to change positions often.

A policy highly associated with product popularity is the *Full-Turnover Storage Policy*, in which products are assigned to storage locations based on their turnover, i.e., the fast-moving SKUs are assigned near the depot in order to minimize picker travel distance [36]. A predecessor strategy of that method is the *Cube-per-Order (COI) Storage Policy*, in which items are assigned based on the ratio of an item's storage space requirement (cube) to its popularity (number of storage/retrieval requests for the item) [38]. Also, the Full-Turnover demonstrates similar characteristics to the *Volume-Based Storage Policy*, in which SKUs are assigned to locations near the pick-up/drop-off point based on their picking volume [39]. The *Class-Based Storage Policy* is a combination of previously detailed methods and the most commonly employed one [40], according to which products are divided into classes, i.e., A, B, C, etc., based on their popularity. Although each class covers a dedicated storage area, product allocation inside each class is random [41]. This way, this storage policy combines benefits from both the dedicated and random storage policies. The number of classes is quite important. According to the works presented in [42], by assuming an infinite number of items, the number of classes does not impact the demanded storage capacity. However, for a finite number of items, the choice of the number of classes is critical, since the bigger the number of classes, the smaller the number of items per class and, therefore, more storage space is required to store all items, which then increases the average travel time for storing/retrieving items [40]. According to [4], frequently preferred classification layouts are the *"Across-aisle"* or the *"Within-aisle" Storage Policies* (Figure 1), in which high-moving products are assigned to locations near the depot and hence, the travel distance required is minimized.

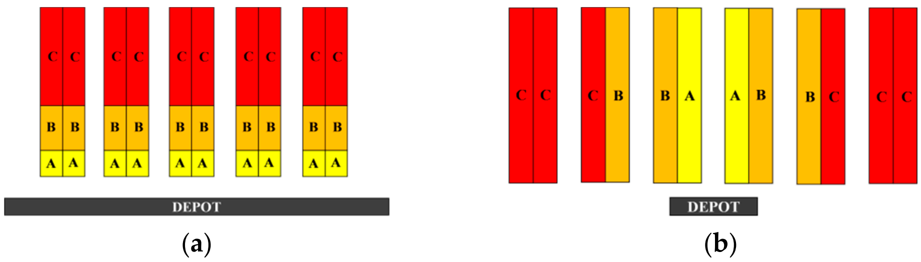

Figure 1. (**a**) Across-aisle Storage Policy; (**b**) Within-aisle Storage Policy.

Last, according to the *Correlated Storage Policy*, alternatively called family grouping, the more items with demand dependence that are assigned to nearby storage locations, ideally in the same aisle or zone, the quicker the picking process will be [43–45]. The authors in [22] considered the correlated policy as the optimal storage method, when combined with traffic control and equal workload distribution.

2.3. Human Factor in OP

Besides accelerated technology advancement, humans still comprise a core factor in logistics operations due to their ability to remain agile and adaptable in a dynamic environment [3]. Other than that, mental capacity and analytical thinking allow humans to handle and solve complex problems, which is their main competitive advantage over machines. Although the human contribution to OP efficiency is an important field of research, only a few prior studies have examined that connection, as discussed below.

The authors in [46] created a stochastic model to optimize product layout in a manual OP warehouse, aiming at picking time minimization, while the authors in [47] developed a storage policy based on a logical, from pickers' perspective, OP sequence, with the aim of reducing OP duration and errors. The research presented in [48] investigated the impact of handling storage units from pallets on the spine. The authors concluded that the most severe impact is observed during the manual lifting of boxes from the ground level. In [49], the authors conducted a pioneering analysis utilizing the concept of "Golden Zone" picking, as introduced in the works of [50,51] in order to improve OP performance. The authors of the latter study found a statistical difference in the pick times of SKUs in the golden zone, i.e., the area between a picker's waist and shoulders, compared to SKUs not in the golden zone. Although the authors in [49] concluded that placing fast moving products in the golden zone can significantly reduce time and effort, they did not take into account potential congestion of warehouse operators in the aisles and assumed fixed space capacity for all SKUs regardless of their daily demands in units.

In 2011, the authors in [52] analyzed and highlighted the importance of the understudied field of human safety in storage operations, while the authors in [53] explored employees' mental capacity, focusing on the ability of human learning in OP systems. In [54], a model for designing ergonomic OP operations was developed, taking into consideration pickers' individual characteristics and physical stress. The numerical validation of the model concluded that 0.85 m is the optimal height for storing popular products. Following that, two notable literature reviews were conducted on human and ergonomic aspects in OP processes to evaluate how these factors could improve operators' performance and well-being [10,55].

Additionally, the authors in [56] generated a bi-objective optimization model based on Pareto frontiers, which produced a set of trade-offs between picking time and energy expenditure based on the energy expenditure model presented in [57]. The authors suggested that future research should focus on warehouse and aisle layout design, with the aim of reducing manual effort in OP. Based on the aforementioned study, economic and ergonomic analyses were performed in [12], considering three technical design options for racks, i.e., full-pallets, half-pallets, and half-pallets equipped with a pull-out system. The authors concluded that succeeding research should assess different rack layouts, accommodating products stored in boxes, or conduct case studies using already developed models. Furthermore, the authors in [58], by utilizing the OWAS (Ovako Working Posture Analyzing System) index and the energy expenditure concept, concluded that the least ergonomic height for OP is the ground floor level, while heights at 1.4 m and 0.85 m from the floor were deemed as the most ergonomic ones. Also, the setup, travel, and search phases, which are performed in standing or upright walking positions, require relatively low energy consumption, while pick postures including twisting, stretching, and bending substantially affect body fatigue. Similar to [58], the authors in [59] used the OWAS method to propose a solution to the storage assignment problem. The authors developed a multi-objective model based on binary integer linear programing, taking into consideration OP time, energy expenditure, and health risks. The research presented in [17] also pointed out which devices should be used in industrial contexts to monitor fatigue level in OP, with to the aim of enhancing picker performance. Later on, the same authors proposed an integration model for product assignment based on both workload and cost, using both full and half pallet configurations [60]. In [61], a layout and assignment optimization was performed in a U-shaped picking area whose shelves are built from pallet cages, aiming to minimize walking distance and body strain during OP, using the model proposed in [57]. In [62], a Monte Carlo simulation model was presented, estimating the average rate of energy expenditure (Kcal/min) and fatigue allowance for female order pickers in manual OP systems with high demand rates. Finally, analyses on fatigue accumulation and rest allowance were also performed in [63,64].

3. Problem Description

The picking area of the facility studied in this paper fulfills both physical and online orders. It consists of 40 identical aisles equally divided into two mezzanine floors, where material flow is achieved via a conveyor belt. On both floors, the layout overview is designed as follows. The depot aisle and conveyor belt cross vertically each aisle from its front side. On the opposite side, the aisles lead to a back aisle as depicted in Figure 2, where bins replenish the picking slots before they become empty. It can be assumed that all aisles maintain equal distance from the depot.

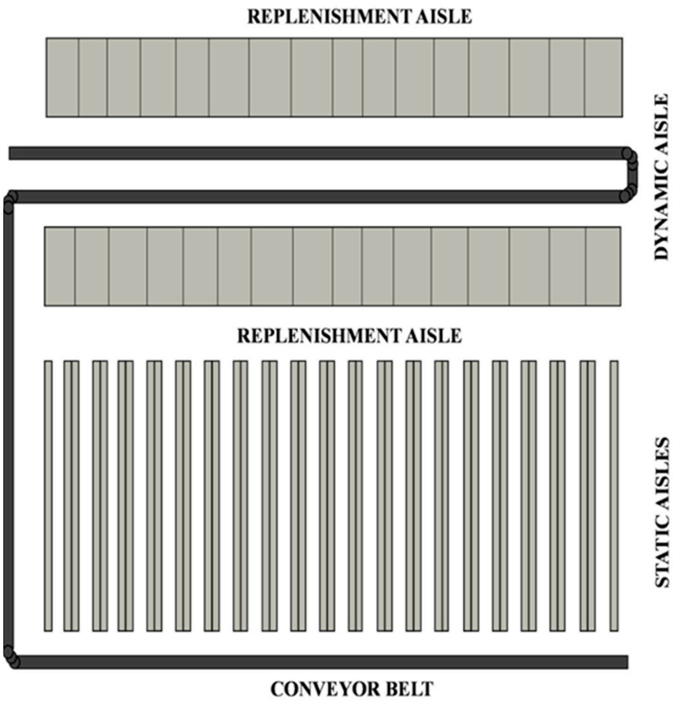

Figure 2. Mezzanine Floor Overview.

Each double-sided aisle is approximately 8 m long and consists of two similar sides of static slots divided into five bays, each estimated at 1.6 m, with five racks, each with a depth of 0.5 m. The static racks have a height of 0.39 m; thus, the total bay height is roughly 2.4 m (Figure 3).

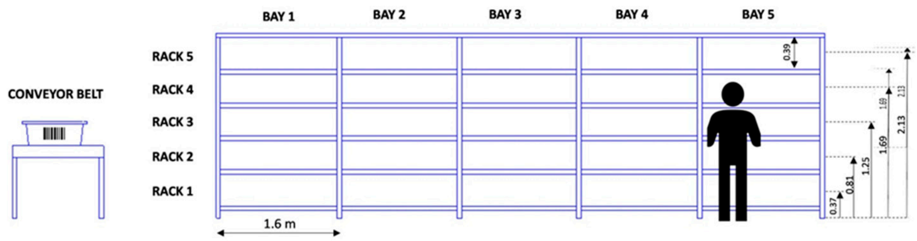

Figure 3. Aisle's Left Side.

The storage area provides an additional storage type called dynamic slots. These slots consist of inclined rollers, as illustrated in Figure 4, and their depth is 2.5 m, i.e., five times the depth of a static rack. When replenishing from the backside of the bay, storage units slide to the front, from where they are retrieved during picking. The case here is that the conveyor belt progresses across the dynamic slots. Thus, a sequential number of bays are assigned to each picker, who moves in a narrow space between the conveyor belt and the dynamic storage slots to pick the required items. As a result, the required travel distance is limited to the bare minimum, since pickers already stand in front of the picking locations. Although dynamic slots will not be further analyzed in the specific study, the products stored there have been considered in the overall analysis for developing the proposed method, so they extensively affect the produced results.

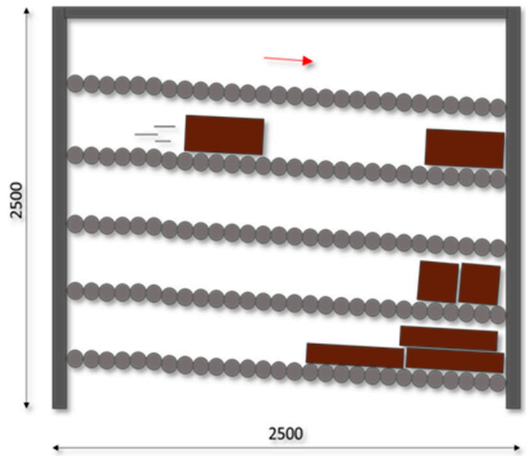

Figure 4. Dynamic Slotting.

The OP method chosen is *Progressive Zone Picking*, as the storage area under discussion is divided into eight zones. Each zone requires roughly the same number of pickers, which fluctuates throughout the day depending on the workload. In each zone, both discrete and batch picking take place. Radio Frequency (RF) picking is implemented for identifying products and receiving order information, since it ensures greater efficiency and lower error possibility than the paper based method. When an order container arrives at the pick zone, the first picker available scans its barcode to identify which SKUs and quantities are needed to be retrieved. In case the container is strictly designated for an individual order, discrete picking is applied. However, if there is a multitude of similar orders consisting of few items, they are grouped together, so that pickers can retrieve bigger quantities from each SKU in one travel. Following that stage, upon returning to the depot area, pickers transfer the SKUs into smaller boxes; each with a unique barcode for each order placed inside the order container.

As far as product assignment into picking locations is concerned, the *Random Storage Policy* has been chosen. Three picking slot sizes are provided; small-, medium- and large-sized slots, with the latter having twice the volume of the second, and four times the volume of the former. Upon a new arrival, the product is assigned to the smallest slot size into which its storage unit can fit. However, the location of the selected slot, i.e., floor, aisle, bay, rack, is random. Every SKU maintains the same slot, for as long as it is in stock or an upcoming arrival is scheduled. Otherwise, namely in the case an SKU becomes obsolete, a different SKU takes its place and is assigned to this particular slot.

Although this operational strategy seemed to have been working satisfactorily in previous years, the ever-growing, fast-paced business environment has led to hampered performance and productivity issues which need to be addressed. First, the storage location assignment strategy applied led to inadequate inventory in the picking slots. Consequently, replenishment needs skyrocketed during periods of high demand, and the system's resources were unable to fulfill them on time. Second, the oversight of not conducting turnover and popularity analyses led to constant congestion of pickers in specific aisles, while others remained almost unvisited during the day. Hence, the unequal distribution of transfer orders among aisles was conducive to a significant increase in average picking time. Third, it was observed that the *Random Storage Policy* severely impacted pickers' physical health, since highly popular SKUs were assigned to locations far away from the depot at inefficient heights, requiring long travel distance and forcing pickers to resort to unnecessarily intense body motions. Thus, over the course of time, workforce performance substantially dropped.

Taking into account the aforementioned operational weaknesses, the current study aims to boost productivity rates, by reducing picking time and relieving workers' physical fatigue. To do so, it aims to redesign the aisles' layouts by proposing an upgraded slotting policy in accordance with product characteristics and enhanced warehouse ergonomics.

4. Proposed Method

The proposed method discussed further on was developed using MATLAB software and Microsoft Excel. For the purposes of this study, a sample of 5842 SKUs was examined. After defining the new types of slots needed, a layout redesign and storage assignment method was proposed and implemented in the case study facility, with the aim of enhancing OP performance by mitigating workers' physical fatigue through an innovative OP difficulty ranking system.

4.1. Selection of Slot Sizes

In the initial layout, products were assigned to slots based on their unit dimensions, so that the required picking storage space was minimized. However, this strategy overloaded the system with frequent replenishment demands. Therefore, the company decided to determine the slot size selection based on the demanded unit quantities of each SKU, with the aim of achieving sufficient inventory levels for seven days, with no replenishment needs in the meantime. Based on the average daily demand and number of items included in one unit, the number of boxes needed was estimated for each product. In this direction, an algorithm was developed, exploring the six degrees of freedom of a rigid body in a three-dimensional space. In such a manner, the optimal placement orientation or combination of orientations was defined for each SKU, targeting the storage of all the demanded units per product while minimizing the dead volume in the selected slot. Nevertheless, this algorithm is out of scope for the current study, and will be presented in authors' future work.

Although all slots have the same depth and height because of the fixed rack structure, their length varies according to their size. Assuming S is the length of the medium-sized slot, S2 would be the length of the small-sized slot, equal to half the length of S, and 2S the length of the large-sized slot, equal to double the length of S.

4.2. Classification of SKUs Using ABC Analysis

In order to decrease picking time and effort, it is imperative that a popularity analysis be conducted based on products' turnover rates, which is defined as the daily number of times a picker needs to travel to a specific location and retrieve a demanded quantity of an SKU. By applying Pareto's principle, products were classified into three categories. SKUs with more than five transfer orders per day were classified as "A" products, i.e., the most fast-moving ones. SKUs with less than five but more than one transfer order fell into class "B", while the rest into class "C". Every SKU is characterized by two factors; its popularity class and the minimum slot size in which it can fit. Thus, by having three turnover classes and three slot sizes, nine different combinations emerge; in other words, nine different slot types. The new slot types are notated as XY, with the first symbol designating the class, i.e., A, B, or C, and the second the slot size, i.e., S2, S, or 2S.

4.3. Number of Slot Types per Aisle

The main goal of the proposed method is to design an "ideal aisle" which meets the system's needs and can be reproduced across the picking area, assuming equal travel distance from the depot to the starting point of each aisle. First, it is important to specify the exact number of slots which can fit in a rack, i.e., the space between two consecutive columns separating bays from one another.

- Nine small-sized slots (S2)
- Four medium-sized (S) plus one small-sized slot (S2)
- Two large-sized (2S) plus one medium-sized (S) or two small-sized slots (S2)

As it can be easily inferred, there can be diverse combinations, given that every length type is a multiple of the others. The steps for estimating the number of slots per aisle are detailed below.

1. Calculation of the number of products classified in each category of the nine slots developed above, according to their characteristics and corresponding percentages.
2. Assuming that each aisle can accommodate 100 products in total, the percentages found in Step 1 are converted in S length according to Equation (1).

$$\text{Length of XY Slots per 100 Products} = (\text{Percentage of products demanding XY slots}) * \frac{L_{XY}}{L_S} \quad (1)$$

3. The total length per aisle of XY slots needed for 100 products is calculated in S length.
4. Since each rack can accommodate four S-sized slots and one S2-sized slot, the total rack length equals to 4.5 S. Therefore, for an aisle consisting of 50 racks, the total slot length equals to 225 S.
5. Knowing the length of each slot type per aisle in S level, the total rack length required for 100 products, and the total rack length per aisle, the number of each slot type per aisle is calculated according to Equation (2).

$$\text{Number of XY Slots per Aisle} = \text{round}\left(\left(\frac{(\text{Length of XY Slots for 100 Products}) * (\text{Total Rack Length per Aisle})}{\text{Required Rack Length per Aisle for 100 Products}}\right) * \frac{L_S}{L_{XY}}\right) \quad (2)$$

After applying the above described methodology, the total length of the estimated number of slots resulting from the ROUND function was adjusted accordingly, so as to approach as much as possible the maximum rack length per aisle, i.e., 225 S.

4.4. Ergonomic Constraints

As previously mentioned, the conveyor crosses all aisles from their front side. According to literature, the classification of slots preferred in such a layout structure is the "across-aisle", based on which a vertical separation of classes can be observed, such as the one shown in Figure 5, with "A" products occupying the bays closest to the depot, followed by "B" and "C" ones at the back.

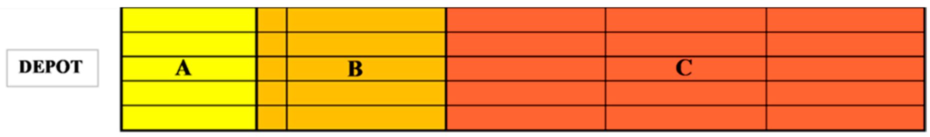

Figure 5. Across-aisle storage policy of the left side of an aisle implementing ABC Classification.

Although the aforementioned classification has considerable merit, the approach taken in this paper differs in that it introduces several ergonomic criteria, which refer not only to the travel distance but also the ergonomics of the height at which each slot is located. Considering that walking is the least intense physical activity in a warehouse, this study proposes that "A" products, which would be expected to be placed in slots close to the conveyor, should occupy positions in distant bays with one essential limitation: rack ergonomics.

According to the concept of "Golden zone" picking, in our case the most ergonomic rack is the 3rd one, as its middle point is approximately 1.2 m from the ground, which is higher than a picker's waist but lower than his/her shoulders (Figure 3), taking into consideration that the average picker height is around 1.73 m. The 2nd and the 4th rack are almost equally ergonomic, placed in second and third rank respectively, since their height levels are not far away from the golden zone yet they require more intense movements compared to the 3rd rack. The 4th rack, at 1.69 m, forces pickers to resort to constant arm raising, thus leading to shoulder straining and pain, while the 2nd one requires slight bending for reaching items at 0.8 m. The 1st rack, placed at the ground level, is a quite inefficient picking height since it compels workers to bend over or kneel repeatedly, thus hurting their back, waist, and knees in the long run. The 5th rack, situated at a height of 2.13 m, is indisputably the least ergonomic one since it requires the use of a step stool enabling pickers to reach for the products and endangers them of getting hit by a falling object, which can cause severe blunt force trauma and leave them out of work for a long period of time, or render them incapable of returning to work. This is why placing bulky and heavy products on high racks should be prohibited.

It goes without saying that decreasing human workload will yield substantial results in terms of performance improvement. In the short-term basis, workers will be more efficient and faster in their day-to-day OP tasks, while in the foreseeable future physical pain will substantially diminish. Thus, by investing in ergonomics and ameliorating working conditions inside their distribution centers, companies will manage to extend the productive lifespan of workers. Based on the above, Tables 1–3 present the bay and rack constraints based on each slot class and size.

Table 1. Bay Constraints based on Class.

CLASS	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5
A	√	√	-	-	-
B	√	√	√	√	-
C	√	√	√	√	√

Table 2. Rack Constraints based on Class.

CLASS	A	B	C
Rack 5	-	-	√
Rack 4	-	√	√
Rack 3	√	√	√
Rack 2	√	√	√
Rack 1	-	√	√

Table 3. Rack Constraints based on Slot Size.

SLOT	S2	S	2S
Rack 5	√	√	-
Rack 4	√	√	-
Rack 3	√	√	√
Rack 2	√	√	√
Rack 1	√	√	√

It is worth underlining that the bays' identification numbers, i.e., 1 to 5, represent the sequence of bays at each side of an aisle, starting from Bay 1 at the front side next to the depot, culminating in Bay 5 at the back. So, the bigger the identification number of the bay is, the longer the travel distance. It is worth mentioning that A-class slots may be located at more distant bays as long as they are placed in ergonomic racks. On the contrary, "C" slots can be situated at bays right next to the depot on condition that they are placed at the least ergonomic heights. Also, with regard to size, 2S slots, i.e., the large sized ones, are not allowed to be placed in racks above the 3rd one, as they are more likely to accommodate heavy and bulky products.

4.5. Layout Algorithm

An aisle is visualized as a four-dimensional matrix, notated as

$$SL(r,x,y,s)$$

- The first dimension of the matrix (r) can take the values 1 or 2, and represents the left or right side of an aisle, as perceived by a picker looking at the aisle from the conveyor side.

- The second dimension (*x*) represents the bay number and increases as the picker progresses along the aisle. Since each side of the aisle has a total of five bays, *x* takes values from 1 (closest to the depot) to 5 (farthest from the depot).
- The third dimension (*y*) represents the rack number in each bay and can take values from 1 (lowest rack) to 5 (highest rack).
- The fourth dimension (*s*) represents the ascending number of slots on each rack, starting from the point closest to the depot. Each rack can accommodate from three (two 2S and one S2) to nine (S2) slots.

The required number of slots per aisle will be equally divided between its two sides. However, because the number of some slot types per aisle is not even, the storage assignment on the two sides will be different. Table 4 summarizes the location constraints for each slot type for variables x and y in the SL matrix, i.e., bay and rack, based on the above-analyzed ergonomic factors.

Table 4. Constraints of X and Y Values.

Slot Type	**Bay**		**Rack**	
	X_{min}	X_{max}	Y_{min}	Y_{max}
A2S	1	2	2	3
AS	1	2	2	3
AS2	1	2	2	3
B2S	1	3	1	3
BS	1	3	1	4
BS2	1	3	1	4
C2S	1	5	1	3
CS	1	5	1	5
CS2	1	5	1	5

The algorithm receives as input the needed number of each slot type per aisle and the ergonomic constraints specified above. The process begins with placing the slots on the left (r = 1) and then on the right side (r = 2) of the aisle.

The order in which slots will be placed is in accordance with Table 4 and, thus, class "A" will be first, "B" second, and "C" third, since assignment starts from Bay 1. As far as the slot sizes within each class are concerned, large slots, i.e., 2S slots, will be placed first followed by S, and finally S2 slots. Large sized slots have a height restriction and, thus, must be placed before the smaller ones. Also, small sized slots can be placed in the space left by large- and medium- sized slots.

For each type considered, in order to achieve as much uniformity as possible between the two sides of the aisle, the condition to be checked for an even number of slots is

$$N_{XY\_stored} < \frac{N_{XY_{tot}}}{2} = N_{XY\_max} \tag{3}$$

while, for an odd number of slots, the condition to be checked is

$$N_{XY\_stored} < \frac{N_{XY_{tot}}}{2} + 1 = N_{XY\_max} \tag{4}$$

where

$$N_{XY\_stored} = \text{number of XY slots per side}$$

$$N_{XY_{tot}} = \text{total number of XY slots per aisle}$$

Conditions (3) and (4) specify that for even numbers, half slots will be stored on the right and half on the left side. For odd numbers, half slots plus one will be stored on the left side for as many types as they can fit. As for the rest, one additional slot will be placed on the right side. The final number of slots per aisle side is presented in Table 5.

Table 5. Number of slots per aisle side.

Slot Type	Left Side	Right Side	Total Slots per Aisle
A2S	4	4	8
AS	3	3	6
AS2	2	2	4
B2S	10	10	20
BS	16	15	31
BS2	8	7	15
C2S	12	13	25
CS	26	26	52
CS2	21	20	41

For each slot type, following the order above, the algorithm starts by filling all empty slots starting from the bay closest to the depot, i.e., x_{min} with respect to the bay and rack limitations. Then, it moves on to the next bay until it reaches the farthest bay allowed, i.e., x_{max}, or until all slots of the specific type, for the particular side of the aisle are placed.

As far as the racks are concerned, the placement does not necessarily start from the lowest to the highest rack. As for the large sized slots, which need to be located in low level racks, the process will be initiated from the lowest (y_{min}) to the highest rack (y_{max}). On the contrary, medium- and small-sized slots are progressively assigned from the highest to the lowest rack with regard to their respective ergonomic constraints. For this reason, variables x_{pr} and y_{pr} are used, indicating the bay and rack from which the placement will start.

Starting from the left side of the aisle (r = 1) for the first slot type, the starting point (x_{pr}, y_{pr}) is assessed. The algorithm examines if there is available length (L_{xy_remain}) for the slot under consideration (L_{SLOT}) to be placed in. If there is not, the rack examined is increased or decreased by one, according to the slot type and the same condition is checked again.

$$L_{xy\_remain} > L_{SLOT} \tag{5}$$

In case the available length of a particular rack is sufficient, the slot is assigned there. The length of the slot at hand is then subtracted from the available length of the rack. Note that the initial available length for all racks is 1.6 m.

$$L_{xy\_remain} = L_{xy\_remain} - L_{SLOT} \tag{6}$$

The number of XY slots stored (N_{XY_stored}) is increased by one.

$$N_{XY\_stored} = N_{XY\_stored} + 1 \tag{7}$$

Finally, the total number of slots available on the specific rack is increased by one. This step is very important for slot naming which will be conducted after the placement. The number above is fed in a matrix as

$$D(r, x, y) = D(r, x, y) + 1 \tag{8}$$

which represents variable *s* in the matrix *SL*(*r*,*x*,*y*,*s*).

Consequently, conditions (3) or (4) are checked again for the left side of the aisle. In case the logical condition is true, the process is repeated. However, if the available length of the initial rack is not adequate, the algorithm proceeds to examine the next rack in order. If no rack of the bay under examination fulfills this condition, the next bay in sequence is assessed, starting again from the initial rack. The loop is completed either when all the slots of a particular type, for the left side, have been placed in a rack, i.e., conditions (3) or (4) have turned false, or when there is no more space left for the specific slot type, so until condition (5) turns false for all racks. In such case, the same steps are followed again for the next slot type in order. Once all nine slot types have been examined, the algorithm continues with the right side of the aisle (r = 2), initializing the available rack length and repeating the whole process for the remaining slots. This way, an "ideal aisle" is created, which can be reproduced across the picking area.

The same layout design policy was also applied for dynamic slots, where the only ergonomic factor examined is the rack height since walking is negligible in this case, as stated in Section 3. However, that configuration is out of scope for this study and is only mentioned to support the final findings that incorporate products stored in that area.

Next, new names have to be assigned to the altered slot layout. To that end, an 8-number code is used, notated as

$$AA\ BB\ CC\ DD$$

The first two numbers represent the number of the aisle, while the second two define the number of the bay. Note that the value ***BB*** can take values between 1 and 10, since there are 10 bays per aisle and the sequence is diagonal, with Bay 1 being the first bay on the left side of the aisle, Bay 2 the first bay on the right side, Bay 3 the second bay on the left side and so on. ***CC*** represents the number of the rack, starting from the ground floor, and can receive values between 1 and 5. Finally, ***DD*** is a counter of the consecutive slots in each rack, starting from the point closest to the depot. The layout algorithm is demonstrated in the flowchart presented in Figure 6.

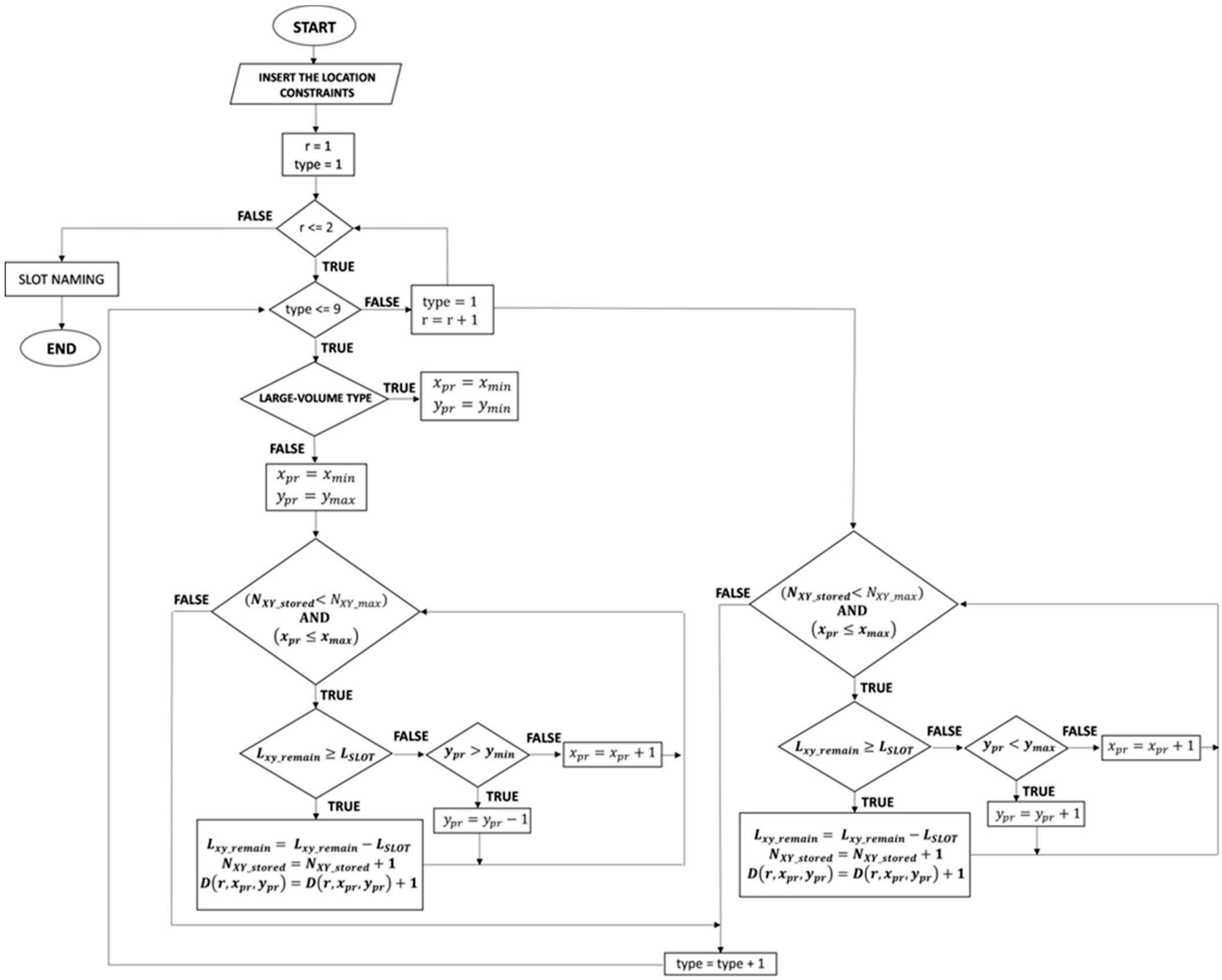

Figure 6. Flowchart of the Layout Algorithm.

4.6. Optimal Storage Location Assignment

Following the layout redesign, products have to be assigned to their optimal locations in order to minimize OP time, improve resource allocation, and mitigate the intensity of physical workload. However, several factors require further examination, as explained below:

- The slot type, which is defined by product popularity class and the size required to accommodate them.
- The weight of storage units, which is an extremely important factor, since products with unit weight above 10 kg should not be assigned to racks higher than the 3rd one.
- Equal allocation of workload and transfer orders among aisles, with to the aim of preventing picker collision.
- The initial storage aisle of each product is the first to be examined, so that the time and movements needed for transferring the products to their new locations are limited to the bare minimum.

Knowing the daily turnover value of 5842 SKUs, the total daily orders can be easily calculated and divided equally among the 40 aisles, considering a maximum margin of error of 1.26%, found after trials. The maximum transfer orders per aisle are therefore defined according to the following equation:

$$\text{Max Transfer Orders per Aisle } (\mathrm{T_{max}}) = \frac{\sum_1^{5842} \text{Turnover Product i}}{40}(1 + 0.0126) \quad (9)$$

Applying a random order of the given SKUs, the slot type required for the first product in line, its initial aisle, and its daily turnover are provided as inputs in the algorithm. Subsequently, the availability of the demanded slot type is examined for the initial aisle, followed by checking whether the total transfer orders of the aisle, including the turnover of the product to be assigned there, exceed the maximum limit or not. After examining these conditions, all slots are sequentially examined, starting from the first slot of Rack 1 in Bay 1, until an empty slot of the demanded type is found whereupon the product is assigned and the available number of its slot type in this specific aisle is reduced by one and registered as “full” in the system. This way, double entries are prevented and only empty slots are checked.

However, if the transfer orders of an aisle exceed the maximum limit (Equation (9)) or there is no empty slot of the demanded type, then the next or previous closest aisle of the same mezzanine floor is examined. This process continues until the product is successfully assigned to a location. After completing the loop, the next SKU in line is examined.

4.7. OP Difficulty Ranking System

Considering that ergonomics is hard to quantify, the authors suggest that in order to compare the initial and improved layout with respect to this metric, the difficulty of OP should be measured. In this vein, an innovative OP difficulty ranking system was proposed, according to which, the difficulty of handling each product is rated based on its daily transfer orders, rack, bay and weight (Table 6), as follows.

$$\text{Difficulty Rate}_\mathrm{i} = (\mathrm{TO_i}) * [(\mathrm{D_{Bi}}) + (\mathrm{D_{Bi}}) * (\mathrm{W_{Ui}}) * (\mathrm{AU_i}) + (\mathrm{D_{Ri}}) + (\mathrm{D_{Ri}}) * (\mathrm{W_{bi}})] \quad (10)$$

$$\mathrm{AU_i} = \frac{\mathrm{d_i}}{\mathrm{TO_i}} \quad (11)$$

According to Equation (10), there are several factors impacting the difficulty in product handling. First, a “Bay Difficulty Rate” ranking system is defined (Table 7, since the location of bays in a picking area determines how difficult it will be for a picker to walk to a slot and back to the depot, while carrying the average number of units of product *i* retrieved per transfer order. Likewise, a “Rack Difficulty Rate” ranking system is defined (Table 8), taking into consideration the effort required to retrieve a product from a particular rack based on its storage box weight. Box handling might include replenishing, shifting, opening of cartons, moving to reach, and count products etc. Daily transfer orders of the product under examination are also included in this equation. This is essential, because the more repetitive a task is, the more difficult it becomes. Thus, the bigger the turnover, the more times a picker has to handle a particular SKU and as a consequence, the greater his/her physical fatigue will be.

Table 6. Description of Symbols used in Equations (10)–(12).

Symbol	Description
TO_i	daily transfer orders for product i
D_{Bi}	bay difficulty rate for product i
D_{Ri}	rack difficulty rate for product i
W_{bi}	storage box weight for product i
W_{Ui}	weight of one unit of product i
AU_i	average number of product i units carried per transfer order
d_i	daily demand of product i in number of units

Table 7. Bay Difficulty Rate Ranking System.

Bay	1	2	3	4	5
Difficulty Rate (D_B)	0.5	1	1.5	2	2.5

Table 8. Rack Difficulty Rate Ranking System.

Rack	Difficulty Rate (D_R)
5	5
4	3
3	1
2	2
1	4

As depicted, the racks have been rated according to the ergonomic constraints presented in Section 4.4, starting from a minimum value of 1 for the 3rd rack to a maximum of 5 for the 5th one. As far as the bay difficulty rating values go, it was decided by the authors for them to be exactly half of the respective rack difficulty rating values, since according to the existing literature on this topic [58], walking is the least intense activity a picker is required to perform. Hence, the closer the bay is to the deposition point, the lower the difficulty rate, starting from 0.5 for the 1st bay and reaching up to 2.5 for the 5th one.

For the SKUs stored in dynamic slots, a different formula was developed based on the same variables and rating system as Equation (10). Again, for the reasons mentioned above, only the ergonomics pertinent to racks are considered. Thus, Equation (10) is transformed into

$$\text{Difficulty Rate}_i = (TO_i) * [(D_{Ri}) + (D_{Ri}) * (W_{bi})] \tag{12}$$

Considering Equations (10) and (12), the “Total Difficulty Rate” is defined as

$$\text{Total Difficulty Rate} = \sum_1^{5842} \text{Difficulty Rate}_i \tag{13}$$

5. Results

Following the analysis presented in Section 4.2, the first metric to be examined is the categorization of products into the three classes based on their daily transfer orders. Therefore, class “A” accounts for 16% of the total SKUs and 55% of the total daily transfers. Correspondingly, the percentages referring to class “B” amount to 31% and 33%, while class “C” percentages are complementary, as depicted in Figures 7 and 8.

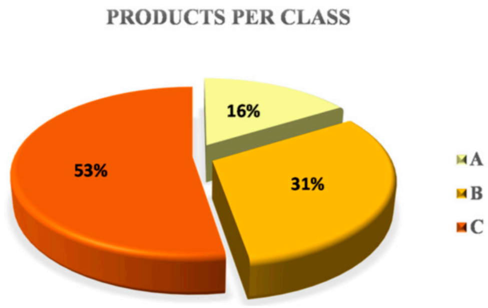

Figure 7. Products per Popularity Class.

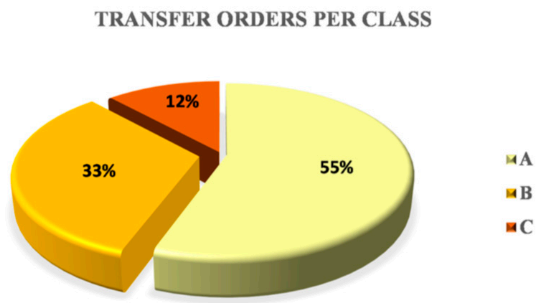

Figure 8. Transfer Orders per Popularity Class.

Considering the constraints presented in Section 4.4 and the layout algorithm for developing an "ideal aisle" described in Section 4.5, the resulting storage layout is demonstrated below.

As can be clearly noticed, the produced layout, which can be rightfully described as a *flame-shape*, has each class encircled by the next one. Figure 9 represents the left side of the "ideal aisle", as perceived by a picker standing between the two sides of racks. In this case, the conveyor is located at his/her left side. Respectively, Figure 10 illustrates the right side of the "ideal aisle". With respect to the ergonomics constraints, A-class slots are located only in the 2nd and 3rd rack, occupying space up to the 2nd bay. It is worth mentioning that even though "A" slots in Bay 2 are not located right next to the depot, their rack level is significantly more ergonomic than the 1st or 4th rack of Bay 1, where they would be placed instead, according to the traditional strategy (Figure 5). "B" slots are assigned around "A" slots starting from Bay 1, where they occupy moderately ergonomic racks, and progressing up to Bay 3, where they are spread across all allowed racks. "C" slots can be found in any bay or rack, even next to the conveyor belt, at the least ergonomic height, i.e., the 5th rack. This way, the common perception which suggests that fast-moving products should always be placed near the depot and slow-moving ones at the back of the aisle, can be brought down, as it only considers travel distance while overlooking the importance of retrieving effort and physical fatigue. Finally, it is important to highlight that under no circumstances can large volume slots (2S) exceed the 3rd rack, as they can potentially contain heavy and bulky products.

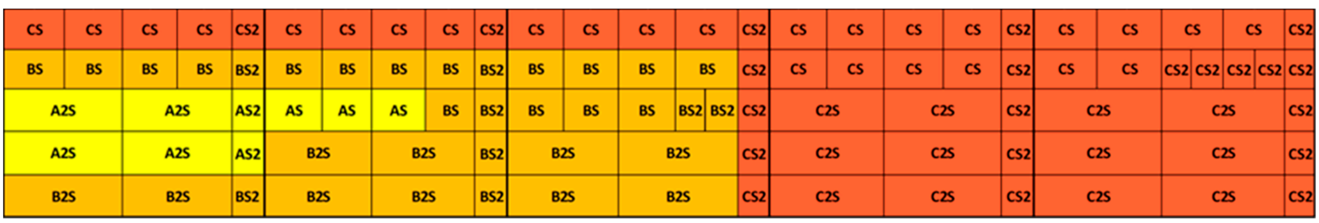

Figure 9. Left side of the "ideal aisle".

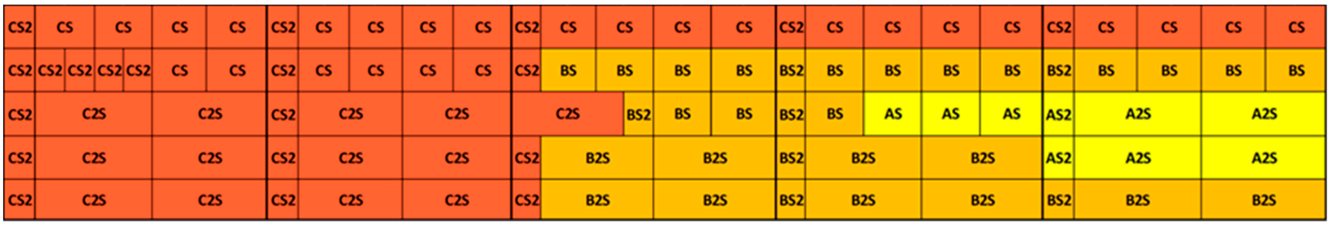

Figure 10. Right side of the "ideal aisle".

This placement not only decreases picking effort, from an ergonomic point of view, but it also reduces total picking time since pickers can perform repetitive tasks faster and more efficiently throughout their daily work shift. Following the implementation of the proposed storage layout, the company's WMS reported a notable productivity growth by 14.9%. In particular, the transfer orders performed by a picker in one hour increased from 94 to 108.

Considering the distribution of transfer orders among the aisles, the initial system presented major discrepancies, with total daily orders fluctuating between 70 and 350 (Figures 11 and 12). These conditions created considerable operational problems in several aisles, where picker congestion obstructed material flow, leading to surges in picking time and effort. By applying the optimal storage location assignment strategy presented in Section 4.6, products were allocated not only based on their slot type but also the maximum number of orders allowed per aisle, hence, resulting in equally distributed workload (Figures 13 and 14). It is worth noting that the increase in total orders, which can be observed in the improved system, is completely justified, since the products transferred from dynamic to static slots are also taken into consideration as a consequence of the slotting redesign.

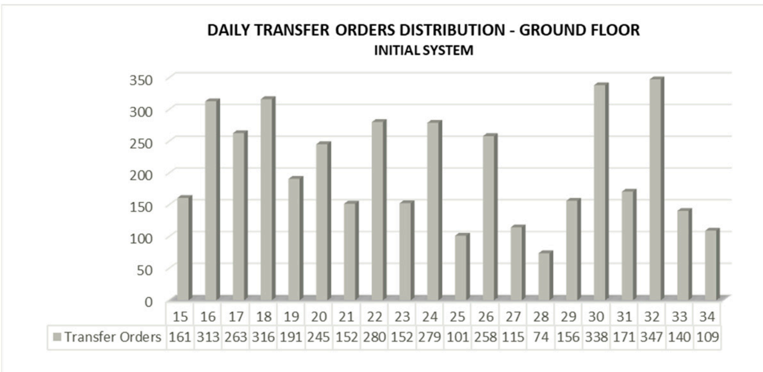

Figure 11. Daily Transfer Orders Distribution—Ground Floor (Initial System).

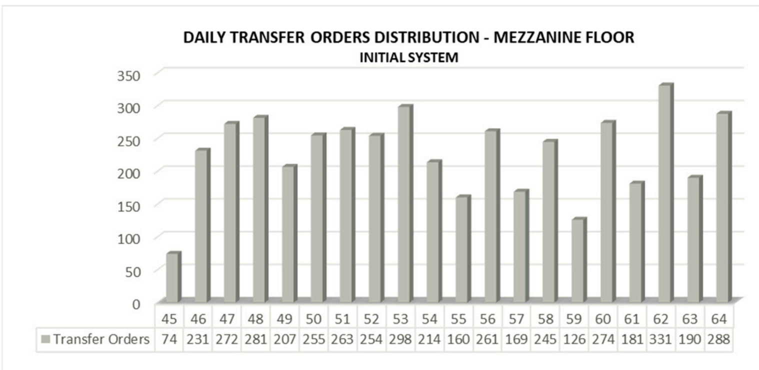

Figure 12. Daily Transfer Orders Distribution—Mezzanine Floor (Initial System).

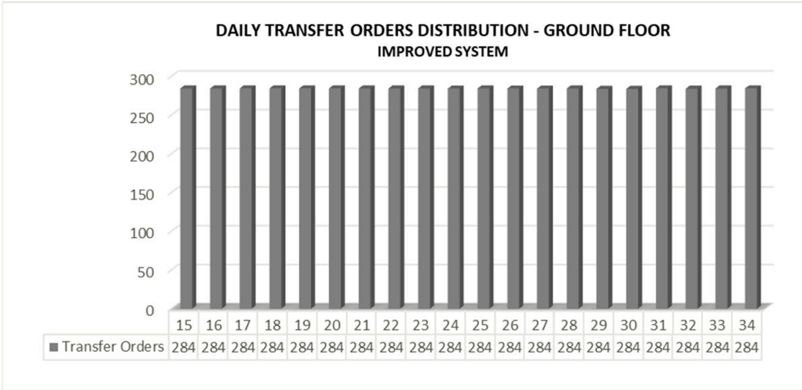

Figure 13. Daily Transfer Orders Distribution—Ground Floor (Improved System).

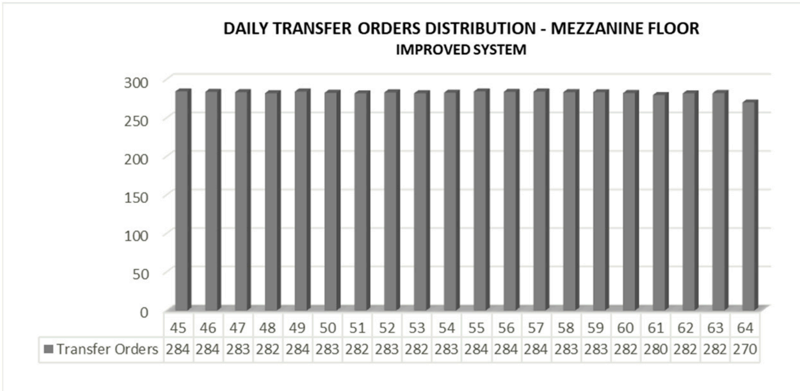

Figure 14. Daily Transfer Orders Distribution—Mezzanine Floor (Improved System).

Additionally, taking into consideration the aisle where each SKU was initially located, the needed transfers of products to new aisles were limited down to the bare minimum, as the primary aisle was the first to be examined for slot availability. Only 18% of products were assigned to new aisles, while only 1% had to change floors. Lastly, 8% of all processed SKUs were transferred from dynamic to static slots, 5% from static to dynamic ones and, hence, 87% of the products maintained their initial storage area.

Finally, as far as the ergonomics improvement goes, after comparing the "Difficulty Rate" of OP for the initial and improved system, it was observed that it plunged by 31% (Table 9).

Table 9. Ergonomics Improvement.

Storage System	Difficulty Rate
Initial	994,121.69
Improved	682,525.12
Change Percentage	**−31%**

6. Conclusions

OP is a labor intensive activity which is still conducted manually in the vast majority of contemporary warehouses. Research has been focusing on decreasing OP time by minimizing travel distance in order to reduce OP expenses, which comprise a substantial part of a warehouse's overall operating costs. Although the need of integrating human factors into design models has been challenging scholars for many years, only a few academic studies focus on enhancing OP performance by alleviating workers' physical fatigue. To that end, this paper aims to address the aforementioned research gap by introducing a layout design and storage assignment model for OP with respect to ergonomic criteria. The proposed method was implemented in the distribution center of a major retail corporation which offers more than 50,000 different SKUs in total. Approximately 6000 SKUs were examined in the current study, which were divided into nine storage types based on their popularity class, i.e., A, B, and C, by applying Pareto's principal. The volume of each slot was determined based on the retailer's decision to maintain adequate inventory levels for seven days, with no replenishment needs in the meantime. After categorizing products into classes, the layout design was developed to meet the system's needs in terms of slot types, followed by products' optimal assignment into slots based on their individual characteristics, i.e., daily transfer orders, demand, weight, and initial aisle while targeting equal workload distribution among aisles to avoid picker collision. Finally, by utilizing the proposed OP difficulty ranking system, the initial and improved storage layouts were compared. Based on the above, this case study introduces a new layout type, the *flame-shape*, according to which fast-moving products should be placed not only closer to the depot, compared to slow-moving ones, but also in efficient height levels that will not force pickers into strenuous and repetitive body movements. Vice versa, this new layout dictates that less popular goods are eligible for being assigned to slots right next to the depot, under the condition of being placed in less ergonomic racks. Following the proposed method's implementation, a productivity rise to 14.9% was observed and equal distribution of transfer orders into aisles was achieved, with a maximum variation of 1.26%, as well as a decrease in difficulty levels by 31%.

It is beyond the shadow of a doubt that this study, in spite of its merits, has its fair share of limitations. First, the proposed method is customized based on the layout configuration, OP methods, capacity, and requirements of the particular distribution center. Thus, future research may extend its application in different storage configurations, covering broader product characteristics and dimensional restrictions. In this direction, the proposed algorithm could be adjusted accordingly to be able to take as input variables the aforementioned factors, which were constants in the current case, and, therefore, be used by any distribution center. Second, the difficulty ranking system, and, more precisely, the generated difficulty rates were defined empirically, through observation and interviews with pickers as well as academic sources. On those grounds, future studies could incorporate alternative methods for measuring physical effort, such as electromyography techniques monitoring muscular stress, the energy expenditure model proposed in [57], and devices recording heart rate or oxygen consumption. Last but not least, the correlation between SKUs could be considered in future works, for instance, by placing products that appear often in same orders near one another with the aim of maximizing OP efficiency.

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References

1. Ponis, S.T.; Plakas, G.; Agalianos, K.; Aretoulaki, E.; Gayialis, S.P.; Andrianopoulos, A. Augmented Reality and Gamification to Increase Productivity and Job Satisfaction in the Warehouse of the Future. *Procedia Manuf.* **2020**, *51*, 1621–1628. [CrossRef]
2. Heizer, J.H.; Munson, C.; Render, B. *Principles of Operations Management Sustainability and Supply Chain Management*; Pearson: London, UK, 2017.
3. Richards, G. *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*; Kogan Page Publishers: London, UK, 2017.

4. de Koster, R.; Le-Duc, T.; Roodbergen, K.J. Design and Control of Warehouse Order Picking: A Literature Review. *Eur. J. Oper. Res.* **2007**, *182*, 481–501. [CrossRef]
5. Napolitano, M. 2012 Warehouse/DC Operations Survey: Mixed Signals. *Logist. Manag.* **2002**, *51*, 54–63.
6. Kudelska, I.; Pawłowski, G. Influence of Assortment Allocation Management in the Warehouse on the Human Workload. *Cent. Eur. J. Oper. Res.* **2020**, *28*, 779–795. [CrossRef]
7. Frazelle, E. *World-Class Warehousing and Material Handling*, 1st ed.; McGraw-Hill Education: New York, NY, USA, 2001.
8. Tompkins, J.A.; White, J.A.; Bozer, Y.A.; Tanchoco, J.M.A. *Facilities Planning*; John Wiley & Sons: Hoboken, NJ, USA, 2010.
9. Battini, D.; Calzavara, M.; Persona, A.; Sgarbossa, F. A Comparative Analysis of Different Paperless Picking Systems. *Ind. Manag. Data Syst.* **2015**, *115*, 483–503. [CrossRef]
10. Grosse, E.H.; Glock, C.H.; Jaber, M.Y.; Neumann, W.P. Incorporating Human Factors in Order Picking Planning Models: Framework and Research Opportunities. *Int. J. Prod. Res.* **2015**, *53*, 695–717. [CrossRef]
11. Bright, A.G.; Ponis, S.T. Introducing Gamification in the AR-Enhanced Order Picking Process: A Proposed Approach. *Logistics* **2021**, *5*, 14. [CrossRef]
12. Calzavara, M.; Glock, C.H.; Grosse, E.H.; Persona, A.; Sgarbossa, F. Analysis of Economic and Ergonomic Performance Measures of Different Rack Layouts in an Order Picking Warehouse. *Comput. Ind. Eng.* **2017**, *111*, 527–536. [CrossRef]
13. Gawron, V.J.; French, J.; Funke, D. An Overview of Fatigue. In *Stress, Workload, and Fatigue*; CRC Press: Boca Raton, FL, USA, 2000.
14. Rose, L.M.; Neumann, W.P.; Hägg, G.M.; Kenttä, G. Fatigue and Recovery during and after Static Loading. *Ergonomics* **2014**, *57*, 1696–1710. [CrossRef]
15. Neumann, W.P.; Village, J. Ergonomics Action Research II: A Framework for Integrating HF into Work System Design. *Ergonomics* **2012**, *55*, 1140–1156. [CrossRef]
16. Schneider, E.; Copsey, S.; Irastorza, X. *OSH [Occupational Safety and Health] in Figures: Work-Related Musculoskeletal Disorders in the EU-Facts and Figures*; Office for Official Publications of the European Communities: Luxembourg, 2010.
17. Calzavara, M.; Persona, A.; Sgarbossa, F.; Visentin, V. A Device to Monitor Fatigue Level in Order-Picking. *Ind. Manag. Data Syst.* **2018**, *118*, 714–727. [CrossRef]
18. Boudreau, J.; Hopp, W.; McClain, J.O.; Thomas, L.J. On the Interface Between Operations and Human Resources Management. *Manuf. Serv. Oper. Manag.* **2003**, *5*, 179–202. [CrossRef]
19. Patrick Neumann, W.; Dul, J. Human Factors: Spanning the Gap between OM and HRM. *Int. J. Oper. Prod. Manag.* **2010**, *30*, 923–950. [CrossRef]
20. Grosse, E.H.; Glock, C.H.; Neumann, W.P. Human Factors in Order Picking: A Content Analysis of the Literature. *Int. J. Prod. Res.* **2017**, *55*, 1260–1276. [CrossRef]
21. Kadir, B.A.; Broberg, O.; da Conceição, C.S. Current Research and Future Perspectives on Human Factors and Ergonomics in Industry 4.0. *Comput. Ind. Eng.* **2019**, *137*, 106004. [CrossRef]
22. Lee, I.G.; Chung, S.H.; Yoon, S.W. Two-Stage Storage Assignment to Minimize Travel Time and Congestion for Warehouse Order Picking Operations. *Comput. Ind. Eng.* **2020**, *139*, 106129. [CrossRef]
23. Pan, J.C.-H.; Wu, M.-H. Throughput Analysis for Order Picking System with Multiple Pickers and Aisle Congestion Considerations. *Comput. Oper. Res.* **2012**, *39*, 1661–1672. [CrossRef]
24. Neumann, W.P.; Winkelhaus, S.; Grosse, E.H.; Glock, C.H. Industry 4.0 and the Human Factor—A Systems Framework and Analysis Methodology for Successful Development. *Int. J. Prod. Econ.* **2021**, *233*, 107992. [CrossRef]
25. de Koster, R. *How to Assess a Warehouse Operation in a Single Tour*; Erasmus University: Rotterdam, The Netherlands, 2004.
26. Caron, F.; Marchet, G.; Perego, A. Optimal Layout in Low-Level Picker-to-Part Systems. *Int. J. Prod. Res.* **2000**, *38*, 101–117. [CrossRef]
27. Ii, C.G.P. An Evaluation of Order Picking Policies for Mail Order Companies. *Prod. Oper. Manag.* **2000**, *9*, 319–335. [CrossRef]
28. Le-Duc, T.; de Koster, M.B.M. Determining Number of Zones in a Pick-and-Pack Orderpicking System. Rochester, NY. 2005. Available online: https://papers.ssrn.com/abstract=800205 (accessed on 26 October 2022).
29. Goetschalckx, M.; Ashayeri, J. Classification and design of order picking. *Logist. World* **1989**, *2*, 99–106. [CrossRef]
30. Dallari, F.; Marchet, G.; Melacini, M. Design of Order Picking System. *Int. J. Adv. Manuf. Technol.* **2009**, *42*, 1–12. [CrossRef]
31. Marchet, G.; Melacini, M.; Perotti, S. Investigating Order Picking System Adoption: A Case-Study-Based Approach. *Int. J. Logist. Res. Appl.* **2015**, *18*, 82–98. [CrossRef]
32. Boysen, N.; Füßler, D.; Stephan, K. See the Light: Optimization of Put-to-Light Order Picking Systems. *Nav. Res. Logist. NRL* **2020**, *67*, 3–20. [CrossRef]
33. Manzini, R.; Gamberi, M.; Regattieri, A. Design and Control of an AS/RS. *Int. J. Adv. Manuf. Technol.* **2006**, *28*, 766–774. [CrossRef]
34. Lolli, F.; Lodi, F.; Giberti, C.; Coruzzolo, A.M.; Marinello, S. Order Picking Systems: A Queue Model for Dimensioning the Storage Capacity, the Crew of Pickers, and the AGV Fleet. *Math. Probl. Eng.* **2022**, *2022*, e6318659. [CrossRef]
35. Petersen, C.G. An Evaluation of Order Picking Routeing Policies. *Int. J. Oper. Prod. Manag.* **1997**, *17*, 1098–1111. [CrossRef]
36. Wang, W.; Han, P.; Peng, P.; Zhang, T.; Liu, Q.; Yuan, S.-N.; Huang, L.-Y.; Yu, H.-L.; Qiao, K.; Wang, K.-S. Friction Stir Processing of Magnesium Alloys: A Review. *Acta Metall. Sin.* **2020**, *33*, 43–57. [CrossRef]
37. Adil, G.K.; Muppani, V.R.; Bandyopadhyay, A. A Review of Methodologies for Class-Based Storage Location Assignment in a Warehouse. *Int. J. Adv. Oper. Manag.* **2010**, *2*, 274. [CrossRef]

38. Malmborg, C.J.; Bhaskaran, K. A Revised Proof of Optimality for the Cube-per-Order Index Rule for Stored Item Location. *Appl. Math. Model.* **1990**, *14*, 87–95. [CrossRef]
39. Petersen, C.G.; Aase, G.R. Improving Order Picking Efficiency with the Use of Cross Aisles and Storage Policies. *Open J. Bus. Manag.* **2017**, *5*, 95. [CrossRef]
40. Yu, Y.; de Koster, R.B.M.; Guo, X. Class-Based Storage with a Finite Number of Items: Using More Classes Is Not Always Better. *Prod. Oper. Manag.* **2015**, *24*, 1235–1247. [CrossRef]
41. Graves, S.C.; Hausman, W.H.; Schwarz, L.B. Storage-Retrieval Interleaving in Automatic Warehousing Systems. *Manag. Sci.* **1977**, *23*, 935–945. [CrossRef]
42. Hausman, W.H.; Schwarz, L.B.; Graves, S.C. Optimal Storage Assignment in Automatic Warehousing Systems. *Manag. Sci.* **1976**, *22*, 629–638. [CrossRef]
43. Bindi, F.; Manzini, R.; Pareschi, A.; Regattieri, A. Similarity-Based Storage Allocation Rules in an Order Picking System: An Application to the Food Service Industry. *Int. J. Logist. Res. Appl.* **2009**, *12*, 233–247. [CrossRef]
44. Zhang, Y. Correlated Storage Assignment Strategy to Reduce Travel Distance in Order Picking∗∗Zhang Thanks the Financial Support of the China Scholarship Council (CSC). *IFAC Pap.* **2016**, *49*, 30–35. [CrossRef]
45. Frazele, E.A.; Sharp, G.P. Correlated Assignment Strategy Can Improve Any Order-Picking Operation. *Ind. Eng.* **1989**, *21*, 33–37.
46. Jarvis, J.M.; Mcdowell, E.D. Optimal Product Layout in an Order Picking Warehouse. *IIE Trans.* **1991**, *23*, 93–102. [CrossRef]
47. Brynzér, H.; Johansson, M.I. Storage Location Assignment: Using the Product Structure to Reduce Order Picking Times. *Int. J. Prod. Econ.* **1996**, *46–47*, 595–603. [CrossRef]
48. Marras, W.S.; Granata, K.P.; Davis, K.G.; Allread, W.G.; Jorgensen, M.J. Effects of Box Features on Spine Loading during Warehouse Order Selecting. *Ergonomics* **1999**, *42*, 980–996. [CrossRef]
49. Petersen, C.G.; Siu, C.; Heiser, D.R. Improving Order Picking Performance Utilizing Slotting and Golden Zone Storage. *Int. J. Oper. Prod. Manag.* **2005**, *25*, 997–1012. [CrossRef]
50. Saccomano, A. How to Pick Picking Technologies. *Traffic World* **1996**, *13*, 39–40.
51. Jones, E.C.; Battieste, T. Golden Retrieval: Raising Warehouse Productivity with Ergonomically Responsible Inventory Policies. *Ind. Eng.* **2004**, *36*, 37–42.
52. de Koster, R.B.M.; Stam, D.; Balk, B.M. Accidents Happen: The Influence of Safety-Specific Transformational Leadership, Safety Consciousness, and Hazard Reducing Systems on Warehouse Accidents. *J. Oper. Manag.* **2011**, *29*, 753–765. [CrossRef]
53. Grosse, E.H.; Glock, C.H. An Experimental Investigation of Learning Effects in Order Picking Systems. *J. Manuf. Technol. Manag.* **2013**, *24*, 850–872. [CrossRef]
54. Weisner, K.; Deuse, J. Assessment Methodology to Design an Ergonomic and Sustainable Order Picking System Using Motion Capturing Systems. *Procedia CIRP* **2014**, *17*, 422–427. [CrossRef]
55. Loos, M.J.; Merino, E.; Rodriguez, C.M.T. Mapping the State of the Art of Ergonomics within Logistics. *Scientometrics* **2016**, *109*, 85–101. [CrossRef]
56. Battini, D.; Glock, C.H.; Grosse, E.H.; Persona, A.; Sgarbossa, F. Human Energy Expenditure in Order Picking Storage Assignment: A Bi-Objective Method. *Comput. Ind. Eng.* **2016**, *94*, 147–157. [CrossRef]
57. GARG, A.; CHAFFIN, D.B.; HERRIN, G.D. Prediction of Metabolic Rates for Manual Materials Handling Jobs. *Am. Ind. Hyg. Assoc. J.* **1978**, *39*, 661–674. [CrossRef]
58. Calzavara, M.; Sgarbossa, F.; Grosse, E.; Glock, C. Analytical Models for a Joint Posture and Fatigue Analysis in Order Picking. In Proceedings of the International Conference on Industrial Engineering and Systems Management, Saarbrücken, Germany, 11–13 October 2017.
59. Gajšek, B.; Šinko, S.; Kramberger, T.; Butlewski, M.; Özceylan, E.; Đukić, G. Towards Productive and Ergonomic Order Picking: Multi-Objective Modeling Approach. *Appl. Sci.* **2021**, *11*, 4179. [CrossRef]
60. Calzavara, M.; Persona, A.; Sgarbossa, F.; Visentin, V. A Model for Rest Allowance Estimation to Improve Tasks Assignment to Operators. *Int. J. Prod. Res.* **2019**, *57*, 948–962. [CrossRef]
61. Diefenbach, H.; Glock, C.H. Ergonomic and Economic Optimization of Layout and Item Assignment of a U-Shaped Order Picking Zone. *Comput. Ind. Eng.* **2019**, *138*, 106094. [CrossRef]
62. Al-Araidah, O.; Okudan-Kremer, G.; Gunay, E.E.; Chu, C.-Y. A Monte Carlo Simulation to Estimate Fatigue Allowance for Female Order Pickers in High Traffic Manual Picking Systems. *Int. J. Prod. Res.* **2021**, *59*, 4711–4722. [CrossRef]
63. Daria, B.; Martina, C.; Alessandro, P.; Fabio, S. Linking Human Availability and Ergonomics Parameters in Order-Picking Systems. *IFAC Pap.* **2015**, *48*, 345–350. [CrossRef]
64. Visentin, V. Human Factors in Industrial Contexts: Fatigue and Recovery Modelling for Manual Material Handling Activities, Universita' Degli Studi di Padova Department of Management and Engineering. 2018. Available online: https://www.research.unipd.it/handle/11577/3425388 (accessed on 26 October 2022).

Development of a Blockchain Solution for Food Waste Management

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Keywords (3-6): Food Waste, Blockchain, Smart Contracts, Tokenization, Decentralized Applications, Smart Cities

ABSTRACT

Food waste is a problem with serious and multidimensional implications (Manika et al., 2022). Environmentally, it contributes to greenhouse gas emissions and depletion of water and land resources (Sun et al., 2018) and economically, it represents a significant loss of resources and money for both enterprises and society as a whole, as it causes almost $1 trillion per year in economic damages (FAO, 2014). Socially, food waste coexists with of hunger and food insecurity, hence exacerbating disparities. Actions against hunger (SDG 2) and the impacts of food waste (SDG 12.3), are both parts of the Sustainable Development Goals, implemented by United Nations. Especially in metropolitan areas, Food Service Establishments (FSEs) contribute significantly to the problem's development, due to a variety of reasons. Overproduction, insufficient inventory management, poor portioning, plate waste, inefficient food preparation procedures, and customer behaviour (Canali et al., 2016; Özbük & Coşkun, 2020) are some examples of these. Viable strategies are needed to reduce the problem's incidence and, in this context, business owners and consumers should cooperate to adopt effective waste reduction programs, which are able to overcome the complexities and ramifications of food waste. To address food waste in urban FSEs, a holistic approach including all stakeholders is required, and the use of effective technology solutions can play a crucial role towards this direction, especially in the context of smart cities. Local governments and municipalities can also be critical in assisting waste reduction efforts, through legislation and regulations (Treutwein & Langen, 2021), by rewarding business owners and citizens with sustainable habits. In this paper, a project is presented that aspires alleviate food waste in FSEs, by offering free or discounted meals to consumers, especially to food insecure citizens.

The research project presented in this paper, namely BLOCKFOODWASTE, lies in the intersection of two scientific areas e.g., food waste management and blockchain technology. The project's final product is a decentralized application (dApp) that operates as a marketplace providing to its users supply of and demand for food surplus from FSEs. The back-end of the application, as implied by its type, runs on a blockchain network. The Ethereum blockchain was chosen by the project partners, due to its public nature and the capabilities it provides to programmers for the development of smart contracts, which play a critical role for the project's scope. FSEs (supply) and consumers (demand) consist the two main user profiles of the application, but the integrated system provides open access to all stakeholders that can benefit from the project's implementation, i.e., municipalities, local governments, NGOs etc. The main function of the solution, is the supply of food meals, that otherwise would be disposed of, by the FSEs in real time and the reservation and pick up of these meals by the consumers. As a result, food waste transforms in safe and nutritious meals for possibly food insecure citizens, with the complete anonymity provided by the blockchain technology.

The keystone of the proposed ecosystem is the project's token (BFW), which is used as a mean of exchange for the purchase of meals by the consumers, directly through the application. A blockchain wallet is incorporated in the dApp, to provide users with a secure and convenient way to manage their tokens. For the creation of BFWs, solidity language is utilized, in order to develop the project's smart contract that controls token supply and distribution. Food surplus offered by FSEs, acts as the underlying asset that is transformed in BFWs, in this tokenization process. Given that the project's smart contract is a node of a public blockchain, the solution is secure and transparent to anyone and it supports widespread adoption and engagement. The project's token tracks food waste reduction and encourages participation and behavioural change, as it is offered as incentive. Initially, each citizen is given a number of tokens to spend

upon registration and afterwards, the smart contract releases more tokens to both parties (supply and demand) for every successfully completed pick up of food surplus. Citizens utilize the tokens as currency to buy meals or other things from participating business units. This encourages users to participate in food waste reduction efforts in a regular basis. On the other hand, every participating establishment receives tokens as a reward for every portion of food saved from waste, in addition to the tokens that are transferred to it directly, by the consumer. FSEs can use their tokens to gain access to valuable data analytics and advertisement by the platform, transfer the tokens directly to food insecure citizens or gain benefits from the application's stakeholders. Municipalities or waste management companies, are able to offer discounts to the business owners through the application in exchange for their collected tokens, in a way to further motivate FSEs in food waste reduction efforts. Blockchain sets its rules and conditions for token transfer, to guarantee that tokens are utilized effectively and their use is aligned with the project's goal. The authors are currently in the phase of assessing the potential value of the token and the overall tokenomics of the BLOCKFOODWASTE application, by assessing market demand along with basic token characteristics such as, supply, distribution, utility and economics.

Food waste mitigation efforts are essential and possible, especially in metropolitan areas that are characterized as "smart cities". FSEs may considerably reduce food waste, promote sustainability, and contribute to a more resilient and equitable food system by implementing comprehensive initiatives that incorporate all stakeholders, like the blockchain-based approach suggested in this research paper. Due to the solution's ability to guarantee the anonymity of the consumers and its tokenization capabilities, the dApp offers significant advantages to its users, in an effort to promote a sustainable behavioural change towards food waste reduction. So, the above-mentioned blockchain characteristics play a crucial part in the integrated system and the project's ecosystem, which is built around the BFW token, can transform into an integrated solution to tackle food waste on every step of the food supply chain.

Acknowledgements

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References:

Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., ... & Vittuari, M. (2016). Food waste drivers in Europe, from identification to possible interventions. Sustainability, 9(1), 37.

FAO. (2014). Food wastage footprint. Full-cost accounting. Final Report.

Manika, D., Iacovidou, E., Canhoto, A., Pei, E., & Mach, K. (2022). Capabilities, opportunities and motivations that drive food waste disposal practices: A case study of young adults in England. Journal of Cleaner Production, 370, 133449.

Özbük, R. M. Y., & Coşkun, A. (2020). Factors affecting food waste at the downstream entities of the supply chain: A critical review. Journal of Cleaner Production, 244, 118628.

Sun, S. K., Lu, Y. J., Gao, H., Jiang, T. T., Du, X. Y., Shen, T. X., ... & Wang, Y. B. (2018). Impacts of food wastage on water resources and environment in China. Journal of Cleaner Production, 185, 732-739.

Treutwein, R., & Langen, N. (2021). Setting the agenda for food waste prevention–A perspective on local government policymaking. Journal of Cleaner Production, 286, 125337.

Θέμα: Abstract notification acceptance, IEES23 Conference Chania
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Building a Sustainable Future: A proposed technology solution for demand response management based on blockchain in smart grid

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ABSTRACT

Smart grid technology is gathering significant attention, as the world transitions to cleaner and more sustainable energy systems in order to gradually tackle climate change. The critical requirement for rapid decarbonization has led to a reduction in the usage of fossil fuels and the integration of zero-carbon renewable energy sources, electric vehicles and heat pumps. As a result, the complexity of electricity grids has increased, rendering the balance between electricity supply and demand vital. Demand response is an effective solution to this challenge, allowing Electricity Distribution Network Operators (EDNOs) to manage electricity demand during peak hours and incentivizing consumers to reduce electricity demand. This paper proposes a blockchain-enabled demand response technology solution that leverages smart contracts to automate communication between EDNOs and consumers with smart electricity meters. The approach based on Blockchain technology ensures security, reliability and transparency of transactions and the two-way flow of information between stakeholders. The proposed system allows EDNOs to set dynamic pricing signals that motivate consumers to time-shift their energy demand, contributing to the stability of the electricity grid. Furthermore, the solution provides tools to monitor and optimally manage the electricity consumption of Households and SMEs (Small and Medium-sized Enterprises) through a user-friendly and gamified cloud-based platform, utilizing demand response algorithms.

KEYWORDS

Blockchain, Demand Response Management, Demand Response, Smart Contract, Smart Grid

1. INTRODUCTION

The effects of climate change are increasingly visible. Heatwaves, drought wildfire, flooding and hurricanes have gotten more severe and more frequent (Trenberth, 2018). In addition, the impacts of climate change have now been tracked in every ecosystem on Earth (Scheffers et al., 2016). To tackle climate change, global greenhouse gas (GHG) emissions must be reduced in the coming decades. (Trenberth, 2018). In 2022 it was observed that global CO2 emissions from energy combustion and industrial processes a rose to new all-time high of 36.8 gigatons (Gt), with 40% of emissions coming from electricity and heat generation and 21% from transport (IEA, 2023). Therefore, the global transition to zero-carbon renewable energy sources (RESs) for electricity generation and the increase in the use of heat pumps and electric vehicles (EVs) are essential for the protection of biodiversity over the year. According to Peirelinck (2022), the integration of renewables will lead to volatility in electricity supply and the electrification of heating and transport will dramatically increase electricity demand, both of which can lead to problems of instability in grid operation.

In this context, smart grid technologies offer a way to evolve towards a cleaner electricity grid that is more energy efficient and sustainable, and to meet the challenges of integrating a growing number of RESs and increasing demand. (Kim et al., 2019). Based on Clastres (2011) the Smart Grid (SG) can be defined as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies''. SG provides two-way communication between suppliers and consumers, advanced metering infrastructure, smart meters, load balancing and unauthorize usage detection, as well as detecting and recovering from faults (Saleem et al., 2019). Smart metering and bi-directional communication enable a much more dynamic, reactive pricing mechanism that takes into account the variability of renewables in real time, opening up new opportunities for Demand Response (Saffre and Gedge, 2010).

Demand Response (DR), is an integral part of the SG and encourages consumers to make more efficient choices about electricity demand (Siano, 2014). DR programs aim to balance supply and demand by changing when electricity load is used by giving reward/punishment incentives to consumers (Hao et al., 2016). More specifically, if there is an increase in demand that cannot be supplied, there will be incentives to reduce electricity consumption, and if there is surplus green energy production from RES, there will be incentives to consume at that time. Vardakas et al. (2014) and Vázquez-Canteli and Nagy (2019) suggest the use of intelligent DR algorithms based on reinforcement learning to improve efficiency in DR project. According to Junaidi et al. (2023) a DR program faces a number of challenges, such as transparency of data measurement, reliability of the central database and violation of user privacy. The use of blockchain technology can address these issues by providing a transparent and secure ledger of program data, thereby increasing trust and encouraging consumer acceptance and participation. Blockchain is a distributed ledger that consists of a chain of data packets (blocks), where a block contains multiple transaction information (Nofer et al., 2017). Further, smart contracts, which are self-executing contracts using blockchain technology, can be used to achieve reliable transactions and agreements between different parties in the smart grid (Merrad et. al, 2022). The potential for tokenization is another benefit of using the blockchain. This makes it possible to convert the value of participants' actions in a DR program into marketable units of account, called tokens.

In this paper, the authors propose an integrated technological solution by presenting a DR program that leverages cutting-edge technologies such as smart metering, intelligent DR algorithms, Blockchain and Smart Contract in one cloud-based platform. The main stakeholders of the proposed solution are Electricity Distribution Network Operators (EDNOs), providing them with a valuable tool that will contribute to grid stability and load balancing, and Households and SMEs, enabling them to consume electricity in a more environmentally friendly and at the same time cost effective way. The proposed technology aims to promote the active participation of low-voltage electricity consumers in a smart grid that is resilient, secure, and produces affordable and green electricity. It also serves to highlight the benefits of green energy and the application of demand response management. The massive participation of consumers is crucial for the successful implementation of the proposed solution, therefore the platform will be user-friendly and will use gamification techniques. Gamification, which is "the use of game design elements in non-game contexts to improve user experience and user engagement, loyalty and fun" (Richter et al., 2015), has been shown to contribute to the achievement of the above objective.

For the implementation of the proposed solution to have a significant impact and value, the right conditions are required, i.e. consumers with smart meters and a market with a choice of dynamic pricing. Dynamic pricing is a method by which retail electricity prices change throughout the day by passing at least some of the volatility of wholesale prices to consumers. Its implementation would have high added value in microgrids that are either solely based on renewable energy or are located in isolated areas, such as small islands, where blackouts occur frequently.

2. THE PROPOSED SOLUTION

The proposed solution involves the development of an integrated demand response platform that runs on a cloud server and mobile devices, exchanging information between stakeholders and IoT devices. User interface (UI) runs in a mobile application and in a web browser. Citizens and SMEs, hereafter referred to as Users, will be able to efficiently monitor and control their electricity consumption through the platform. Users will need to give permission to use their smart meter data and provide information about their dynamic pricing program, if there is not a universal program for all consumers.

The proposed system will receive real-time data from Users and EDNO on the supply and demand of the grid, the consumption of each User and the price of electricity, in the case of a microgrid the price of electricity is not necessary. This data will be stored in a database where it will be analyzed by an intelligent DR algorithm. The algorithm will also have access to data from specific models that are accurate predictors of supply and demand on a daily basis. Under the analysis of the algorithm, dynamic signals will be sent to consumers to time-shift their electricity consumption. The data from the dynamic signals and the User's response to them will be stored on the blockchain, and smart contracts will be executed based on it. Blockchain and smart contracts will be used to automate the communication between Users and EDNO with absolute transparency and security. In addition, smart contracts will be used to regulate the distribution, transfer and redemption of tokens. The platform will reward Users with tokens based on how much they adjust their consumption and follow the DR concept. In this way, Users will have an additional incentive to participate more actively in the ecosystem. On the other hand, EDNO, local authorities and the government have a strong interest in adding value to the token (by offering discounts on bills, fees and taxes) as it contributes to the stability and sustainability of the grid. In addition, businesses could receive tokens for discounting their products or services. This will allow the contracting businesses to increase their social responsibility and advertise for free on the platform. Furthermore, the use of tokens based on Smart Contact technology provides the EDNO with an additional tool to offer tokens to Users for immediate consumption reduction. This tool can further reduce prices by keeping the marginal cost low and help prevent blackouts.

The user's interaction on the platform will be in a gamified environment. The User will be able to watch short educational videos, on the benefits of renewable energy and demand response, and will be asked to answer comprehension questions in a gamified format. There will also be consumption targets, the achievement of which will be rewarded with additional tokens for the User. In addition, the proposed platform will optionally enable the provision of a Smart Home Hub that will allow consumers to remotely control the use of their electrical appliances and consumption. Moreover, Users can access the platform through the smart home hub to optimally manage a portion of their electricity consumption within the limits they set. For example, the consumers will set the electric vehicle to charge and specify that within the next 12 hours he wants to charge his vehicle for 3 hours, and the platform's algorithm will decide when the consumption occurs. In Figure 1, a schematic of the proposed solution is presented.

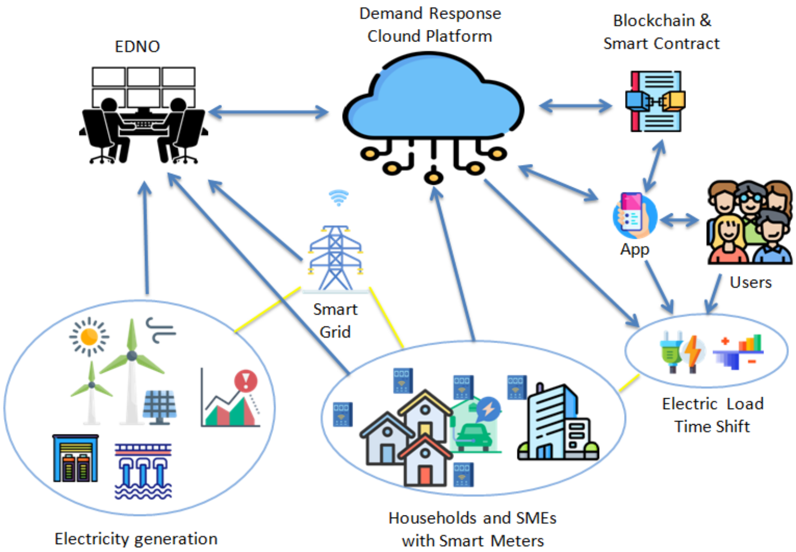

Figure 1. The proposed technology solution

The authors are currently reviewing the system's technological performance and key fundamentals, assessing its technical viability, and looking for potential ideas for upgrades. Their future goal is to create a small, but fully customized and pilot-tested Proof of Concept [POC] of a First of a Kind [FOAK] integrated product service and business model including:

- A cloud-based platform and user-friendly application.
- The intelligent DR algorithm, which analyses the data and sends dynamic signals to Users.
- A suitable mechanism for storing dynamic signals in the blockchain and transmitting them via smart contracts.
- A new calculator of the value of the User's response to dynamic signals, capable of determining, in real time, the impact of the response to grid stability and its environmental footprint.
- An advanced system for securely storing and tokenizing User responses, using blockchain and smart contract.
- An integrated system for remote control and management of electricity consumption.
- A gamified system can increase User participation and promote the environmental benefits of green energy and demand response.

3. PURPOSE OF THE PROPOSAL SOLUTION

In this section, a hypothetical and simplified example will be described in order to have a better understanding of how the proposed system will work and its benefits. During a sunny day where it is predicted that there will be an excess of energy produced by the PV systems during the noon hours, that the renewable energy production will not be sufficient to meet the demand during the afternoon hours, while during the other hours of the day there will be a balance between supply and demand, with hydropower acting as a balancer. Depending on whether there is a shortage or surplus of electricity, the price of electricity will fluctuate dynamically. Users will be able to be informed through the application about the price of electricity per hour according to three categories of consumption divided by different colors: green hours (surplus energy), yellow hours (balance) and red hours (shortage energy). The goal of the platform is to influence demand and shift consumption from red hours to green hours as much as possible. Therefore, during red and green hours, the algorithm will send users a dynamic signal through the app to increase or decrease their consumption. Users will have an obvious financial incentive to adjust their consumption, as the price of electricity will be lower during green hours, and they will also be rewarded with tokens. They will therefore have additional environmental, social and indirect economic benefits that are not so obvious. As, during the red hours, when RES production does not cover demand, there are three options: first, a blackout with severe social consequences; second, the use of fossil fuels with environmental consequences; and third, the use of electricity from storage, such as batteries and pumped storage. In a society that does not use fossil fuels, the third option is the only acceptable option because it allows for flexibility in consumption. However, for every additional MWh that must be stored, there is an increase in costs due to losses and depreciation on the huge investments required for these projects, and an environmental footprint due to the construction of the projects.

4. CONCLUSION

The proposed solution aims to change the way electricity is consumed by promoting the concept of Demand Response and aims to be an end-to-end solution to address the challenges of volatile renewable energy production and demand growth. This will ensure the resilience, sustainability and efficiency of the Smart Grid and enable faster decarbonization, which will make a significant contribution to the fight against climate change. The proposed solution exploits Blockchain and Smart Contract technology in Demand Response Management to increase the transparency and reliability of transactions and to ensure the security of the data in the bidirectional flow of information between consumers and EDNO. In addition, the gamified environment enhances the user experience and the token-based reward logic increases the level of active participation. The proposed solution accelerates the transition to a sustainable future without the use of fossil fuels for electricity generation, and empowers households and SMEs to advocate for balancing supply and demand, with significant social, environmental and economic impact.

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REFERENCES

Clastres, C., 2011. Smart grids: Another step towards competition, energy security and climate change objectives. Energy policy, 39(9), pp.5399-5408.

Hao, H., Corbin, C. D., Kalsi, K., & Pratt, R. G. (2016). Transactive control of commercial buildings for demand response. IEEE Transactions on Power Systems, 32(1), 774-783.

IEA (2023), CO2 Emissions in 2022, IEA, Paris https://www.iea.org/reports/co2-emissions-in-2022, License: CC BY 4.0

Junaidi, N., Abdullah, M. P., Alharbi, B., & Shaaban, M. (2023). Blockchain-based management of demand response in electric energy grids: A systematic review. Energy Reports, 9, 5075-5100.

Kim, S. C., Ray, P., & Reddy, S. S. (2019). Features of smart grid technologies: an overview. ECTI Transactions on Electrical Engineering, Electronics, and Communications, 17(2), 169-180.

Merrad, Y., Habaebi, M. H., Toha, S. F., Islam, M. R., Gunawan, T. S., & Mesri, M. (2022). Fully Decentralized, Cost-Effective Energy Demand Response Management System with a Smart Contracts-Based Optimal Power Flow Solution for Smart Grids. Energies, 15(12), 4461.

Nofer, M., Gomber, P., Hinz, O., &Schiereck, D. (2017). Blockchain. Business & Information Systems Engineering, 59, 183-187.

Peirelinck, T., Kazmi, H., Mbuwir, B. V., Hermans, C., Spiessens, F., Suykens, J., &Deconinck, G. (2022). Transfer learning in demand response: A review of algorithms for data-efficient modelling and control. Energy and AI, 7, 100126.

Richter, G., Raban, D. R., &Rafaeli, S. (2015). Studying gamification: The effect of rewards and incentives on motivation. Gamification in education and business, 21-46.

Saffre, F., &Gedge, R. (2010). Demand-side management for the smart grid. In 2010 IEEE/IFIP Network Operations and Management Symposium Workshops (pp. 300-303). IEEE.

Saleem, Y., Crespi, N., Rehmani, M. H., & Copeland, R. (2019). Internet of things-aided smart grid: technologies, architectures, applications, prototypes, and future research directions. IEEE Access, 7, 62962-63003.

Siano, P. (2014). Demand response and smart grids—A survey. Renewable and sustainable energy reviews, 30, 461-478.

Vardakas, J. S., Zorba, N., &Verikoukis, C. V. (2014). A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. IEEE Communications Surveys & Tutorials, 17(1), 152-178.

Vázquez-Canteli, J. R., & Nagy, Z. (2019). Reinforcement learning for demand response: A review of algorithms and modeling techniques. Applied energy, 235, 1072-1089.

Paper Title: Blockchain-Enabled Green Supply Chain Management: Innovating Agricultural Plastic Waste Recovery and Reverse Logistics

Authors:
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Abstract:
In the scientific field of green supply chain management and reverse logistics, addressing the escalating issue of plastic pollution stands as a critical challenge, particularly within the agricultural sector. The integration of sustainable practices and innovative technologies in managing agricultural plastic waste is par-amount to advancing environmental stewardship and operational efficiency. In that direction, the research presented in this paper delves into the development of a novel approach that harmonizes with the principles of reverse logistics and green supply chain management, aiming to mitigate the environmental footprint of agricultural plastics. Central to this study is the exploration of an advanced system for the management of agriplastic waste, leveraging Blockchain technology to foster a transparent, efficient, and sustainable supply chain. This system proposes a decentralized platform that enables seamless interaction be-tween stakeholders, including farmers and waste collectors, facilitating the effective tracking, collection, and recycling or energy recovery of agricultural plastics. By establishing a reliable network for the detailed reporting of agriplastic usage and disposal, the research underscores the potential of digital ledger technologies to enhance traceability and accountability in waste management processes. Furthermore, this research emphasizes the importance of reverse logistics in the lifecycle management of agricultural plastics, from their initial deployment to their final disposal or repurposing. Through the creation of a mobile application and the formulation of a comprehensive business model, the study aims to facilitate the recovery and recycling of materials and thus, to contribute to the reduction of environmental pollution, the promotion of sustainable agricultural practice and the broader objectives of environmental conservation and sustainability.

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Θέμα: Fwd: Acceptance Letter for 5th Olympus International Conference on Supply Chains
Από: Stavros Ponis <staponis@gmail.com>
Ημερομηνία: 25/2/2024, 1:08 μ.μ.
Προς: Giorgos Plakas <plakasg@gmail.com>

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Date: Κυρ 25 Φεβ 2024 στις 1:01 μ.μ.
Subject: Acceptance Letter for 5th Olympus International Conference on Supply Chains
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Dear Stavros Ponis

Congratulations! You paper entitled Blockchain-Enabled Green Supply Chain Management: Innovating Agricultural Plastic Waste Recovery and Reverse Logistics with ID:50 has been reviewed and selected for publication at the 5th Olympus International Conference on Supply Chains.

If you have submitted only the abstract, as for the next step you need to prepare and timely submit your full paper. The full paper will not go under extra review process. However, you need to make sure that you follow the camera ready guidlines exist in the conference website. In parallel you may proceed with the registration.

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