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Traceability Automation in Coffee Production: A Case Study on QR Code Integration to Optimize Manual Steps

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Abstract: Agriculture and coffee production are vital to Brazil's economy, generating jobs, driving regional development, and contributing significantly to the trade balance, making Brazil a leading coffee producer and exporter. In this context, this scientific article proposes automating coffee production traceability using QR codes to optimize processes and enhance quality, safety, and sustainability in the supply chain under the Industry 4.0 paradigm. We employ Business Process Model and Notation modeling to delineate coffee production stages, leveraging QR codes for data collection and registration during activities like harvesting, washing, drying, processing, storage, and farm certification validation. QR codes streamline operations, reduce errors, and enhance traceability, involving actors ranging from harvesters to quality personnel, inspectors, and clerks. The study scrutinizes coffee transfer from rural producers to warehouses, optimizing stock and delivery management. The main results obtained were the significant reduction in the number of employees, the reduction of activities and consequently the time, and finally, the assertiveness to complete the process.

Keywords: production engineering, traceability, automation, QR code, coffee productive chain, manufacturing paradigm, 4.0 industry

1. Introduction

Agriculture and the coffee industry play a crucial role in the Brazilian economy, contributing significantly to the country's gross domestic product [1]. Coffee production is an essential field within both Production and Agriculture Engineering, and it holds great significance, generating jobs, foreign exchange, and promoting development in various regions of Brazil [2, 3]. Furthermore, coffee farming is strategically significant for Brazil both economically and socially. Despite considerable amount of attention environmental issues received from the world leaders, it is often been a center of discussion and debate for decades [4]. Therefore, it is imperative to study science teacher's attitudes toward SWMR in terms of belief, concern, and practice.

Apart from being a major export product, coffee cultivation involves thousands of rural producers, cooperatives, and industries, fostering rural development and empowering local communities [5, 6]. Brazil's prominent position in the global coffee market is a result of its high-quality beans [7]. Additionally, Brazil has diverse producing regions and sustainable practices. The country is internationally recognized as a leading coffee supplier, earning consumer trust in terms of quality, origin, and environmental responsibility in production.

Traceability is an essential aspect of coffee production, particularly within the Industry 4.0 framework, automation, and artificial intelligence (AI), a novel manufacturing paradigm. It ensures safety and sustainability across the supply chain [1]. AI-driven automation, data analytics, and decision-making are at the core of the 4.0 Industry [8, 9]. Nevertheless, numerous manual processes within even sizable coffee farms persist, introducing time inefficiencies and potential errors [10]. Manual oversight remains prevalent in both public and private services [10]. This study introduces a comprehensive automated business process employing Business Process Model and Notation (BPMN) modeling [11–13]. It identifies each coffee production phase, from harvesting to storage, and seamlessly integrates them into the traceability system. QR codes act as the primary tool for data collection and registration at every juncture [14]. Moreover, farm certification is meticulously validated, reflecting in printed forms, which subsequently enhances the coffee's value.

In this study, we propose a streamlined process for coffee traceability, utilizing the existing data management system SSW to receive and store information via QR codes. Once forms are completed and signed by responsible personnel, the data are input into the traceability system. Subsequently, vouchers are generated for workers, and coffee sample income is recorded [15]. The process also includes completing the Coffee Guide Transfer Route (GTR) traceability form, collecting quality analysis samples, and requesting transport invoices.

Managing various stakeholders involved in coffee production and traceability, including harvesters, personnel at different stages, quality department staff, inspectors, coffee receivers, and clerks [1], is a complex task. QR code adoption as an automation tool enhances efficiency by eliminating manual form printing and reducing errors

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[15], resulting in improved traceability, enabling more precise monitoring of the coffee supply chain. Our study thoroughly analyzed the coffee transfer process, improving stock and delivery management by streamlining it.

To overcome these challenges, this scientific article proposes automating coffee production traceability using QR codes [15]. The main objective is to optimize manual steps, improve process efficiency, and enhance coffee traceability. Therefore, the aim of this scientific article is to propose a fully automated business process based on QR codes to optimize manual steps in the coffee production traceability process. The specific objectives are as follows: (i) to identify activities involved in coffee production, from harvesting to storage; (ii) to integrate QR code scanning at each stage to expedite data collection and registration; (iii) to propose a new process to automate form filling and worker voucher issuance, reducing errors and processing time; (iv) to enhance coffee traceability, allowing for more accurate and reliable monitoring of the supply chain; (v) to establish processes for correct coffee identification and data verification at different stages of the process, and (vi) to assess the benefits of the automated process, such as error reduction, increased efficiency, and improved traceability.

2. Theoretical Framework

This section provides the theoretical foundation for conducting this scientific article. Besides that, concepts related to agribusiness and coffee production, quality management, and traceability will be presented. Finally, we are going to present aspects related to business processes and information technologies in agribusiness companies.

2.1. Agribusiness and coffee production in Brazil

Coffee has been part of Brazil's history since the 19th century, during the Empire era. After the economic cycles of brazilwood, sugarcane, and gold, the coffee cycle, which lasted until the 20th century [16], represented the country's greatest source of wealth and the main export product[1]. Coffee arrived in Brazil in 1727, entering through Pará and being cultivated in the city of Belém [16]. In the following years, it was taken to Maranhão and Rio de Janeiro, where it was cultivated for domestic consumption. From there, it reached the lands of Serra do Mar and arrived at Vale do Paraíba around 1820, where it found the "terra roxa" (purple soil), rich soil for coffee plantations. From São Paulo, it spreads to Minas Gerais, Espírito Santo, and Paraná.

According to the National Supply Company (CONAB), Brazil is the world's largest producer and exporter of coffee, with an area devoted to coffee cultivation (both Arabica and Conilon) totaling 2.26 million hectares in 2023. Brazilian coffee production can reach 54.94 million sacks of processed beans. Coffee is the second most consumed beverage in the world, only surpassed by water. According to the International Coffee Organization[2], the world produced 170.83 million 60-kg sacks of coffee and consumed 164.9 million sacks between October 2021 and September 2022. Brazil is the second-largest coffee consumer globally, trailing only the United States[3].

As the world's top coffee producer, Brazil exported approximately 2.2 million tons (about 39.4 million sacks) of coffee in 2022 to 145 countries, with the United States and Germany as primary destinations, followed by Italy, Belgium, and Japan. This resulted in a total export value of 9.2 billion, fueled by high coffee prices both domestically and internationally [5, 6, 17]. Coffee cultivation is highly concentrated in family-owned properties, representing a significant source of income for families and employing a substantial workforce not only in production but throughout the entire industrial and commercial process [2, 5].

Coffee is a natural source of several essential vitamins [18], including small amounts of B vitamins (niacin and riboflavin) and potassium, contributing to the overall nutritional content of the beverage. Currently, coffee is a vital contributor to Brazil's economy, holding the position of the world's largest coffee producer and exporter. This dynamic industry fosters job creation, stimulates agricultural engineering across regions, and bolsters Brazilian exports [19]. The coffee production chain encompasses diverse sectors, including rural producers, input suppliers, roasting industries, and distribution, forming a complex network of interdependence and value addition. Furthermore, Brazilian coffee is globally esteemed for its quality, enhancing the nation's competitiveness and global market standing.

Figure 1 presents a series of representations related to coffee production and consumption, highlighting the importance of this crop for Brazil's economy. Sub-figure shows a coffee farm, highlighting the extent of the plantations and the magnitude of production. Sub-figure depicts a coffee plantation in detail, with plants aligned in rows. In Sub-figure, we have the representation of a coffee shop, emphasizing the consumption stage and the popularity of the beverage. Lastly, sub-figure illustrates a served cup of coffee, emphasizing the final purpose of the production process. This figure underscores the relevance of coffee as a significant economic sector in Brazil and highlights the production chain, from plantations to the consumption of the beverage.

Figure 1
Representations of coffee plantations from different perspectives and the importance of coffee for Brazil's economy

[1]Available on the Rehagro website, Tips for a post-harvest of quality coffee: https://rehagro.com.br/blog/dicas-para-uma-pos-colheita-do-cafe-de-qualidade/

[2]International Coffee Organization (ICO) Accessed on June 9, 2023. https://www.ico.org/pt/about_statistics_p.asp? section=Estat%EDstica

[3]Available on the Coffee Valore website, Traceability, quality, visibility for your coffee: https://coffeevalore.com.br/rastreabilidade-qualidade-e-visibilidade-para-o-seu-cafe/

2.2. Quality management and traceability

Traceability in an agribusiness company is the ability to track the entire journey of a product, from planting to sale to the end consumer, through process control. According to International Organization for Standardization – ISO 8402[4], traceability is defined as the ability to trace the history, use, application, and location of a product or commodity through process controls. In the case of coffee, traceability starts from planting and includes all processes related to plantation care, harvesting, processing, storage, reprocessing, and sale of the final product to the end consumer [1]. It is mainly associated with the logistics and supply chain control of the company, enabling knowledge of the product's origin, production process, and procedures it underwent before reaching the end consumer. Traceability is essential to ensure product quality, food safety, and production transparency, in addition to meeting regulatory and market requirements. According to Meuwissen et al. [20], identification and traceability systems play different roles in monitoring and controlling products and processes. Besides identifying the causes of problems and implementing improvement actions, traceability systems in agribusiness production chains also aim to (a) increase transparency among supply chain links; (b) reduce the risks of legal liability; (c) provide an efficient product recall system; and (d) assist in controlling epidemics, zoonoses, and phytosanitary issues. The different traceability purposes mentioned by Meuwissen et al. [20] highlight the multidisciplinary nature of the subject. In other words, adopting traceability systems can be motivated by the pursuit of efficiency in coordinating production chains, product and process differentiation, establishing rights and responsibilities of chain agents, ensuring better defense control, and, above all, complying with regulatory and commercial requirements, which can condition agents to adopt identification and traceability mechanisms, either out of obligation or voluntarily.

Beyond ensuring food safety, communicating various quality attributes to consumers is increasingly essential in agribusiness chains. This is vital for enhancing product value and accessing new markets. Requirements such as implementing identification and traceability systems, Hazard Analysis and Critical Control Points, Good Manufacturing Practices, mandatory in the US and the European Union, and Eurepgap (a voluntary protocol adopted by producers, developed by a consortium of European retail networks establishing good handling practices in fruit and vegetable production), necessitate enhanced coordination and operational control throughout agribusiness production chains [1]. According to Vinholis and Azevedo [21], a traceability system, whether computerized or not, allows tracking and tracing different types of information (related to process, product, personnel, and/or service) upstream and/or downstream of a chain link or an internal department of a company. Traceability allows establishing a product history, and the complexity of this history will depend on the objective to be achieved. This objective can be influenced by adopted strategies and the competitive environment in which the company operates.

3. Materials and Methods

In this section, the data collection methods, sources of information, and procedures adopted for analyzing and interpreting the obtained data will be presented. Additionally, the tool used, which was considered an important material for optimizing business processes, will be introduced.

3.1. Scientific methodology

In this section, the data collection instruments and information processing, as well as the research type addressed, will be discussed. Additionally, the study's limitations and strategies adopted to mitigate possible biases will be discussed. The methodology plays a fundamental role in ensuring the reliability and validity of the results, providing a solid framework for conducting the research.

This research falls into the category of descriptive, as it focuses on delineating an existing agribusiness company's process, highlighting its features and potential enhancements through BPMN modeling. The study combines field research, where no direct intervention occurs, and documentary research when proposing a system form in the company.

This research is applied, addressing a specific issue within a coffee agribusiness company's existing processes. It centers around BPMN for process optimization. The research results can be directly implemented within the company, particularly in creating an electronic Transfer Guide form, enhancing information accuracy and agility during coffee entry into the warehouse. This can lead to substantial process improvements, better information control, heightened traceability, enhanced inventory management, and greater efficiency in coffee movement.

3.2. Modeling tool

HEFLO[5] is a modeling and business process automation tool based on the BPMN notation, available online with a free version. With HEFLO, users can create BPMN diagrams in a visual and intuitive way, allowing them to draw, document, and improve their business processes efficiently. The HEFLO tool offers advanced resources for process modeling, including a wide range of BPMN elements, such as activities, events, gateways, sequence flows, pools, and lanes. Additionally, it allows the creation of customized forms, definition of business rules, and integration with other systems.

One of the main advantages of HEFLO is its user-friendly interface, making it easy to create and modify BPMN diagrams. Team collaboration is also facilitated, as multiple users can work simultaneously on the same project, enabling real-time visualization and editing. The tool selected herein also offers process automation features, allowing workflows to be executed automatically, with the possibility of integrating external systems, defining approval flows, and monitoring process performance. For these reasons, HEFLO was chosen as a powerful and flexible tool for BPMN modeling and automation.

4. Case Study

This case study was conducted with a group of coffee producers in the Alto Paranaíba and Triângulo Mineiro regions of Minas Gerais, Brazil, in the Biome of Cerrado. The group produces coffee for both domestic and international markets, with a focus on selling to various countries. So, as shown earlier, the study

[4]Quality Management and Quality Assurance - Terminology. https://www.normas.com.br/visualizar/abnt-nbr-nm/12/nbriso8402-gestao-da-qualidade-e-garantia-da-qualidade-terminologia

[5]The HEFLO tool can be accessed directly through the link: https://www.heflo.com/pt-br/

adopted a combination of field and documentary research approaches. It involved the analysis and proposed improvement of an existing business process in a specific company, using documents and information collected on-site. Additionally, the solution proposed herein involves implementing a new form in the company's existing system, which can also be considered a documentary research type.

4.1. Characteristics of the studied company

The study was conducted in a family group of coffee producers engaged in coffee processing. The coffee production started in the 70s, and all the company's properties are located in Cerrado Mineiro, a significant commercial center for coffee cultivation. This proximity ensures that all farms share the same region of land, contributing to the consistency and quality of the produced coffee. The production units are situated in altitudes ranging from 840 to 1140 m. This region is known for its unique territory, well-defined climatic seasons, uniform maturation, and abundant sunlight during the harvest. The Cerrado Mineiro, consisting of 55 municipalities, is recognized as a producer of distinguished coffees and was the first region in Brazil to receive Designation of Origin (DO) for coffee. Its specialty coffee production is valued both in the domestic and international markets. In Brazil, the coffee harvest takes place between May and September, using mechanized and careful methods to maximize the grain's quality and preserve the ecosystem [22].

The carefully selected coffee beans are stored in the facilities of General Storage Ltda. This warehouse is equipped with state-of-the-art technology and has the capacity to store $\approx 5 \times 10^5$ bags of coffee in a constructed area of $\approx 2 \times 10^4$ square meters. It also has two reprocessing lines that handle $\approx 4 \times 10^3$ sacks per day. The Classic Blends brand represents high-quality coffee lots from the Cerrado Mineiro, while the History Collection line stands out for its superior quality. The trading, import, and export company responsible for the green beans aims to add value to the internally produced coffees and meet the growing demand for high-quality, controlled-origin coffees in the international market. Considering the company's experience in coffee production, storage, and trading, it follows strict standards of excellence in quality [22].

Furthermore, the company's coffees are sold in Brazil and exported to 23 countries, including American's Continent, Asia, and Europe. Modern technology is employed, with state-of-the-art machinery, chip-based traceability, and automated processes. Security is ensured through camera monitoring and extensive insurance coverage. During the harvest season, the company offers flexible options for coffee reception, accepting jute sacks, bulk deliveries, and big bags. Sustainability is a central concern in coffee production. The company adopts good agricultural practices that promote sustainability, such as maintaining legal reserves of native vegetation, protecting springs and water body margins, and ensuring good working conditions on the farms. The company has legal reserves, permanent preservation areas, and an environmental preservation areas [22, 23].

Additionally, the company obtained Agricultural Certification to promote environmental conservation, worker well-being, and differentiate its products in the market. The Agricultural Certification Program aims to balance agricultural activity with socio-environmental conservation, ensuring compliance with social, environmental, and economic aspects on the properties and promoting sustainability. Another certification is Rainforest Alliance, which ensures strict standards for environmental conservation and worker rights. Besides coffee production, the group also cultivates cereals, wheat, beans, soybeans, and corn, although in smaller quantities [22, 23].

4.2. Business process of the studied company

The company adopts important strategies of vertical integration of production activities, and this kind of process allows rigorous control of quality and traceability throughout the coffee production. The company's farms have experimental fields where the best coffee varieties adapted to the Cerrado Mineiro are selected in partnership with research institutions. Technologies are employed in soil preparation to correct and improve the region's soil fertility, including the application of fertilizers from limestone, magnesite, and phosphate rocks, as well as the use of organic compounds produced internally on the farms [22, 23].

Another important thing is the cultural practices made by coffee company, that includes carefully planned made and also integrated pest and disease management. The company seeks to reduce the use of chemical pesticides by adopting ecologically sustainable methods for weed control and promoting the presence of predator insects, and as a result, the harvested product is organic. For this, even the water used in irrigation undergoes an important process of biochemical analysis. Irrigation is done intelligently to save water, ensure uniform flowering, and achieve a homogeneous harvest. The harvest is conducted when 90% of the beans are ripe and is mostly mechanized, followed by immediate processing in pulping units. The beans undergo drying processes, pre-drying in the sun, and mechanical drying to preserve their characteristics. The coffee is stored in wooden bins for a minimum of thirty days to achieve better drying homogeneity and rest [22, 23].

The company performs the coffee processing at its own production units, where the beans are carefully selected and stored in warehouses equipped with cutting-edge technology, ensuring the quality and safety of the produced coffee. The harvest is mostly mechanized, although some terrains with difficult access still require manual harvesting. Another alternative would be harvesting by autonomous robotics mechanisms [24, 25] and machine learning [26–28], however, the company studied here does not adopt this practice. The harvest is done by the group's harvesters, third-party harvesters, and manual harvesting. The harvest begins when a significant portion of the beans is mature to avoid wastage [22, 23].

The harvested coffee is taken to the drying patios, and the coffee that falls to the ground, known as "sweep," is collected and washed with water, stored in specific washers, and then taken to the patios for drying separately from the coffee that did not undergo the washing process. The coffee drying process is carried out in two ways: on cement patios and in mechanical dryers [22, 23].

4.2.1. Description of the coffee traceability process in the studied company

The coffee traceability process is a multi-stage process aimed at ensuring control and recording of information throughout the production cycle, which are divided into harvest, washing, drying patio, mechanical drying, storage, and processing, each of them identified by a specific form. The coding used for coffee traceability includes the type of coffee, the stage acronym, the crop identification, the origin farm code, and a numeric sequence.

The company, adopting this control, provides coffee traceability at any moment, ensuring product quality and safety.

For certified company's farms, the forms are identified as "certified coffee," reinforcing the importance of certification in the production chain, to achieve the coffee certifications. It is essential that all information is correctly filled in the forms and entered into the SSW data management system. The SSW system is used to record coffee traceability, where employees input relevant information about the coffee batch, considering the coffee origin and procedures adopted at each stage.

Additionally, it is necessary to print the forms for each stage and deliver them to responsible parties, such as farm supervisors, farm managers, production process inspectors, or coffee receivers, for them to fill in the requested data and monitor the processing. The completed and signed forms are returned to the bookkeeper, who records the traceability in the system. By ensuring complete traceability, including correct form filling and data management system usage, the inputting in the SSW system can begin. The data noted in the forms are transferred to the system, and the entries must follow a specific sequence. In company studied, it is essential to emphasize that, in cases of manual harvesting, vouchers are generated for workers' payment, which must be reviewed and delivered correctly.

Furthermore, traceability also involves recording sample incomes, sending coffee to other farms during processing, and transporting it to the warehouse. Forms such as the Coffee Transfer Guide and the Coffee Sample Sending Control must be filled out, as well as requesting the appropriate invoice. Finally, we can say that all these processes aim to ensure traceability, control, and quality of the coffee throughout its production and transportation, ensuring consumer confidence and compliance with established standards.

4.2.2. Actors in the coffee traceability process

This section presents the main actors involved in the coffee traceability business process, as described in this case study. Fourteen actors actively participate in the manual business processes, as identified through the conducted case study. In the business process optimization, some of these actors will no longer exist, as described in the Proposal section.

1) Manual or mechanical harvesters: Workers responsible for coffee harvesting, either manually, picking the beans directly from the plants, or mechanically, using specific harvesting equipment.
2) Washing control responsible: The person in charge of monitoring and controlling the coffee washing process after harvesting, ensuring quality and proper grain hygiene.
3) Natural drying control responsible: The individual responsible for overseeing and controlling the natural drying stage of coffee, where the beans are spread on patios to dry naturally, monitoring humidity and proper drying time.
4) Mechanical drying control responsible: The person in charge of supervising and controlling the mechanical drying process of coffee, which uses artificial dryers to accelerate the drying process, ensuring proper and efficient drying.
5) Warehouse coffee control responsible: The professional responsible for monitoring and controlling coffee storage in the warehouse, a place designated for depositing and preserving the dried beans, ensuring organization and lot quality.
6) Coffee processing control responsible: The individual in charge of monitoring and controlling the coffee processing stage, involving the removal of impurities and separation of different types of beans, ensuring quality and standardization of the processed coffee.
7) Quality department: The department responsible for conducting analyses and evaluations of coffee quality, in terms of taste, aroma, and appearance, ensuring compliance with established standards.
8) Central Fiscal Department: The department responsible for handling the company's or coffee production center's fiscal and tax matters, including issuing invoices, monitoring regulations, and complying with legal obligations.
9) Harvest inspector: The professional responsible for inspecting and monitoring the workers from harvest, ensuring compliance with established procedures and regulations, especially, the individual safety equipment of each worker
10) Coffee receiver: The person responsible for receiving the produced coffee, checking its quality and quantity, recording relevant information, and properly storing or forwarding it.
11) Farm supervisor/manager: The professional responsible for coordinating daily activities on the farm, ensuring compliance with processes and procedures related to coffee production. They supervise the harvest, processing, and other cultivation stages, ensuring operation quality and efficiency.
12) Production process inspector: A professional responsible for inspecting and monitoring all stages of the coffee production process, from harvesting to processing. They verify that practices comply with established norms and regulations, ensuring quality, traceability, and compliance with market standards.
13) Bookkeeper/clerk: The professional responsible for the activities of bookkeeping and registering information related to coffee, entering the data collected in the forms into the traceability system, ensuring organization and proper data storage.
14) Driver: Conducts coffee transportation and is informed by the Central Fiscal Department about transport details (farm name, destination, certifications, coffee type, quantity in kilograms, vehicle license plate).

4.2.3. Description of the business process

The first stage of this work consists of a detailed analysis and modeling of the Coffee Production, Traceability, and Shipment Process, which is divided into 15 fundamental activities (thorough analysis allows understanding each step of the process). Besides that, it is possible to identify interactions between them and ensure efficiency and quality in all phases of the coffee production chain.

The business process starts with coffee harvesting carried out by the designated responsible person, followed by the collection of a coffee sample. In the next stage, the responsible person manually fills out the COL (harvest form), while the washing control responsible fills out the CCL form. After a drying period of the sample for 5 to 7 days, the "manual drying control" responsible fills out the CSN form, and the "mechanical drying control" responsible fills out the CSM form. The weight of the sample income is calculated and informed through a document. In this case, in parallel, two processes can occur: the data are sent to the bookkeeper with the filled documentation, and the granary control form (CCT) is filled out by the granary controller along with the request for sending the coffee sample. The "benefit control form" (CBC) is filled out when necessary, and if there is a need for transportation, the invoice is requested, and the GTR (as mentioned above) form is filled out. The driver carries out the coffee transportation, following the instructions of the invoice and GTR number. The fiscal department is responsible for generating the invoice properly. After filling out the COL, CCL, CSN, CSM,

CCT, and CBC forms, the bookkeeper records the information in the SSW system. If the coffee is certified, the "certified coffee" field on the form must be filled; otherwise, it is left blank. The vouchers are printed by the bookkeeper, checked, and signed by one of the responsible individuals on the farm, such as the coffee receiver, farm supervisor, or production process inspector. The vouchers are manually delivered to the workers. The sample incomes, representing an alternative scenario, are entered into the system. If necessary, the coffee shipment is documented through the SSW system. The process is concluded when the main scenario is completed, and if there is an alternative scenario, the process is also concluded.

Therefore, the thorough analysis and modeling of the Coffee Production, Traceability, and Shipment Process, with its fundamental activities, provide a solid foundation for the automation and optimization of this process. By identifying interactions, establishing information flows, and adopting appropriate forms, it is possible to enhance efficiency, safety, quality, and sustainability throughout the coffee production chain, strengthening consumer confidence and boosting the coffee agribusiness in Brazil. Figure 2 is performed manually and automatically by the actors (responsible individuals) for each step of the process.

4.2.4. Gateways of the business process

In this study, the coffee traceability is entered into the SSW system, following a specific sequence of form entry: COL, CCL, CSN, CSM, CCT, and CBC. In the company studied, all data must be previously recorded in the control to be correctly entered. Vouchers must be printed when there are manual harvesters with production in sacks or by measurement. After harvesting, the samples must be dried for 5 to 7 days, and the weight of the income obtained is calculated by the responsible person for drying. The income calculation must be done within a specified time frame and immediately entered into the system. During the beneficiation, it may be necessary to send coffees to other farms.

1) The entry of coffee traceability is done in the SSW system. All data to be entered must be recorded in the control to be transferred to the system. The traceability entries must follow a sequence of entry: 1st COL, 2nd CCL, 3rd CSN, 4th CSM, 5th CCT, and 6th CBC.
2) In company studied, vouchers must be printed whenever there are manual harvesters with production in sacks or by measurement.
3) The period of sample drying lasts for 5 to 7 days from the day the coffee is harvested. After this period, the responsible person for sample drying will calculate the weight of the income obtained in the sample.
4) The income calculation must occur within 7 days after the day of coffee harvesting. The income entry into the system must happen immediately.
5) There may be a need for one farm to send coffees to other farms during the beneficiation stages.

In the business process at hand, there are three important gateways to consider. The first gateway involves verifying the correct identification of the coffee and the volume sent to another farm during beneficiation. This step aims to ensure that the information is accurate and consistent. The second gateway is related to observing the drying period of the samples, which must be 5 to 7 days after harvesting. This control is essential to ensure coffee quality. The third gateway pertains to the inspection of vouchers by the inspectors, where it is verified if the vouchers were filled out correctly and correspond to the production carried out by manual harvesters, ensuring transparency and accuracy of information.

- Verification of the correct identification of coffee (certified) and the volume sent to another farm.
- Observation of the drying period of coffee samples and calculation of sample moisture content.
- Inspection, signing, and delivery of vouchers by the Inspectors.

5. Proposed Optimization

To optimize this business process and make it more efficient, herein we propose that QR codes can be used to automate data collection. Instead of manually filling out forms, the responsible individuals for each step can scan the QR code corresponding to the control/form using a mobile device with a camera. After our research, by scanning the QR code, the SSW system can be accessed automatically, and the relevant information for that step will be filled in accurately and swiftly, improving the process quality. This step eliminates the need for manual data entry, reducing errors and streamlining the traceability process.

Additionally, the forms can be generated electronically in the SSW system, allowing for visualization and printing when necessary. The responsible individuals can receive the forms through a mobile application, avoiding physical delivery and the risk of losses or misplacements. After filling out the forms through the QR codes, the information will be automatically registered in the data management system, ensuring data integrity and accuracy in real time. This step, proposed herein, allows more efficient monitoring of the production process, facilitating the identification of potential issues and making well-informed decisions.

The detailed proposal presents the use of automation in some activities. In Figure 3, it is possible to perceive that many of the activities have the generation of a QR code, which facilitates coffee traceability. Moreover, the use of QR code facilitates data collection by the responsible individuals of each section in the collection and sending of data and information to the company's clerk. The clerk, in turn, has a lighter workload since the form data entry steps into the system have been automated through the generation and reading of QR codes by the responsible individuals for each section. We can say that, as a result, the process becomes faster. Additionally, two sections were eliminated, as the vouchers sent to manual harvesters were generated automatically. QR codes can be seamlessly integrated into the packaging process, serving a dual purpose. Firstly, they can facilitate data entry for farm employees. Secondly, each QR code generated and affixed to coffee bags offers a multifaceted insight into the product's origin and comprehensively delineates the key participants engaged throughout the entire coffee production process. QR codes offer a versatile solution when integrated into the packaging process:

1) Efficient Data Entry: QR codes are adept at expediting data entry for farm employees. For example, during the harvesting phase, workers can quickly scan QR codes on their picking baskets to record the type of coffee beans harvested, the quantity, and the date. This eliminates the need for manual form filling, reducing human error and expediting data collection.
2) Enhanced Traceability: Furthermore, when each QR code is generated and securely attached to the coffee bags, it becomes an invaluable tool for consumers. By scanning this code with their smartphones, customers can instantly access an array of information. For instance, they can discover not only the coffee's place of origin but also details about the specific farm,

Figure 2
Modeling using the HEFLO tool – Coffee traceability business process taking into account manual steps

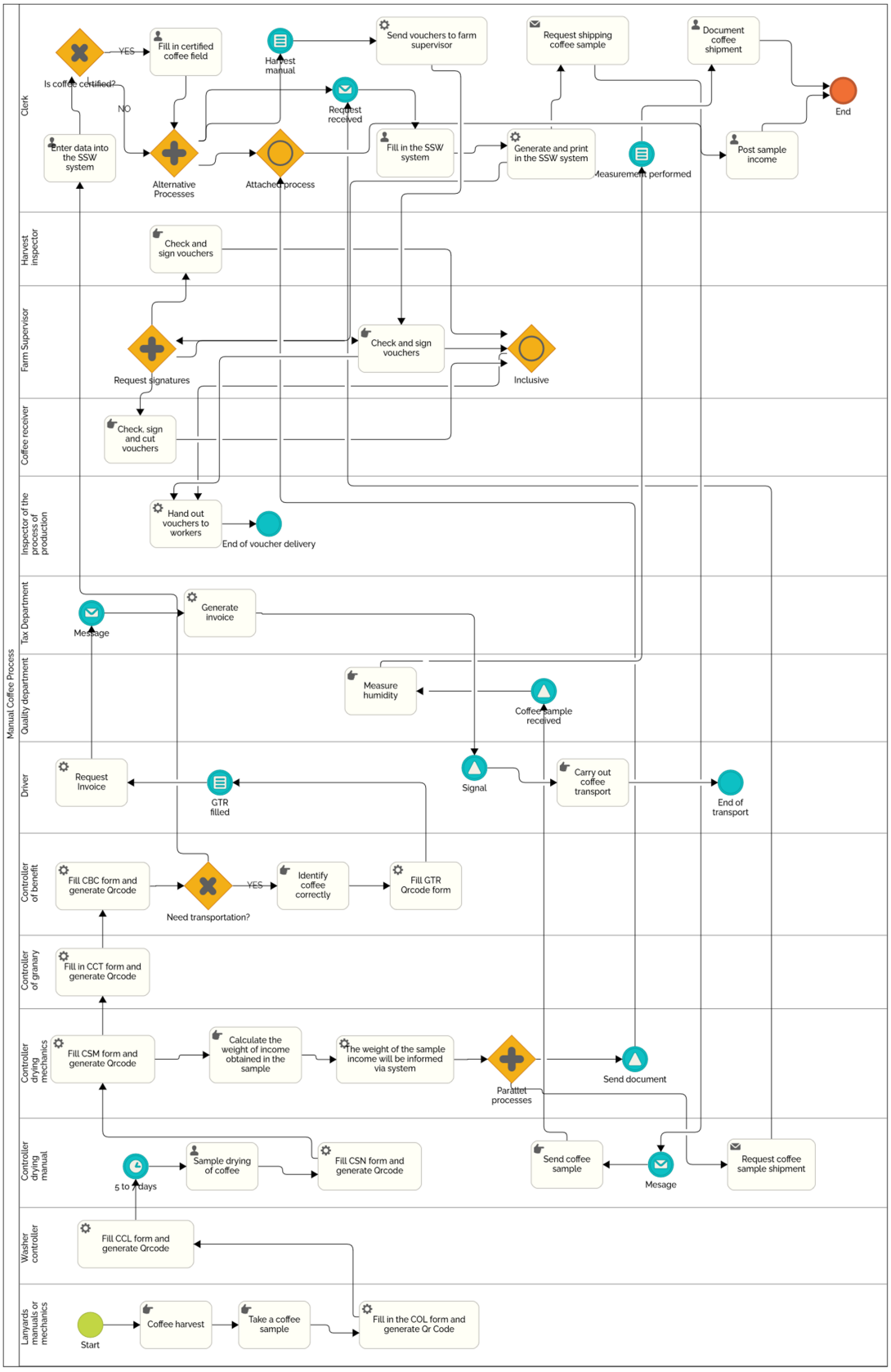
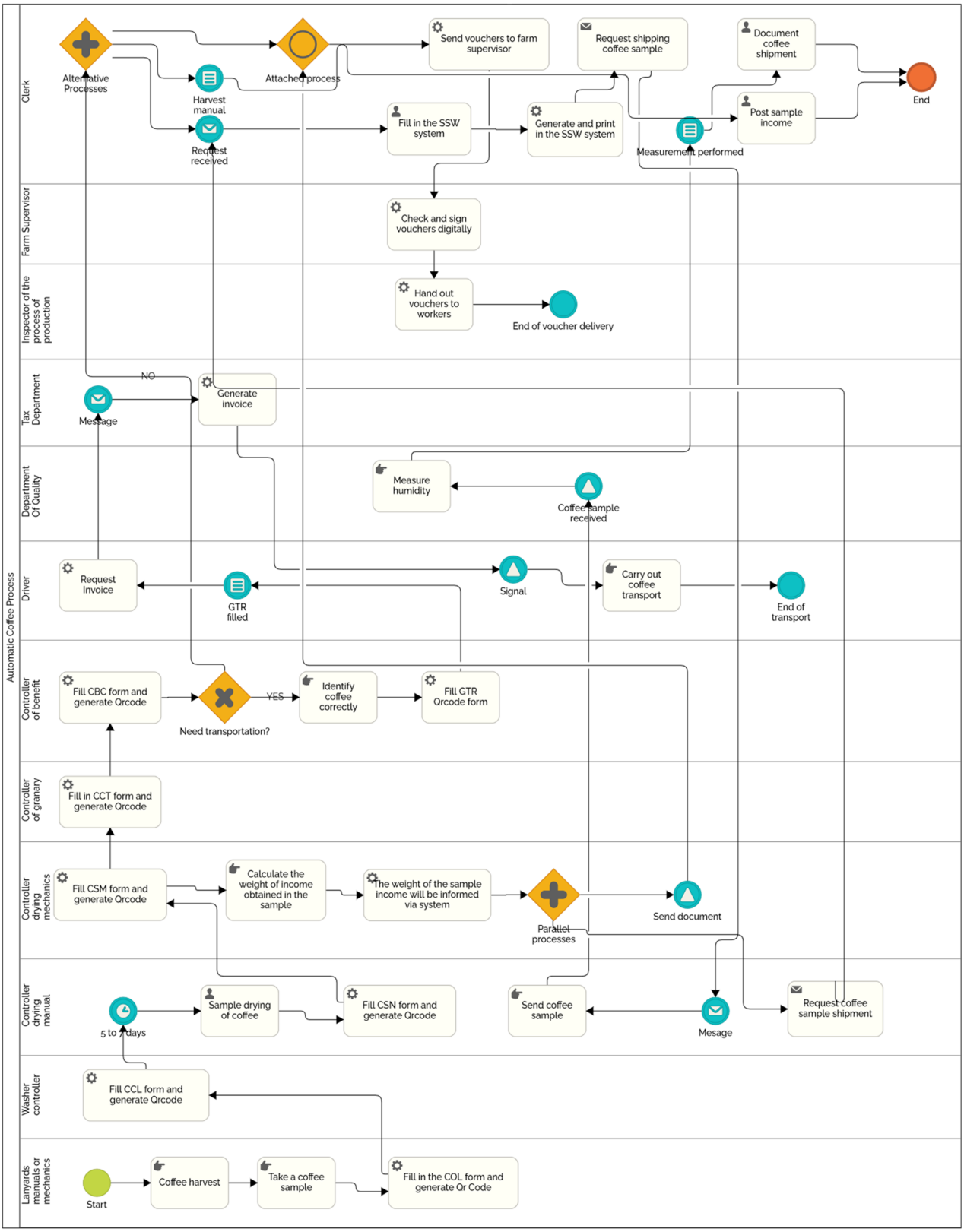


Figure 3

Modeling using the HEFLO tool – Coffee traceability business process taking into account automation and optimization of step



the harvesting methods employed, the individuals involved in each step (from growers to processors), and even quality certifications. This comprehensive traceability provides consumers with a deeper connection to the product and reassures them of its authenticity and quality.

In this context, the use of QR codes can provide greater security and transparency in coffee traceability. Each QR code will be unique and associated with a specific batch of coffee, allowing for the tracking of its origin, production stages, and certifications, when applicable. Finally, an important remark is that this strengthens consumer confidence and meets the growing demands for products with proven provenance.

6. Discussion of Results

The integration of QR codes into the traceability process presents a transformative shift in the coffee 4.0 industry, providing substantial benefits over the previous manufacturing approach [29]. In this context, the adoption of QR codes has resulted in a more efficient and agile traceability process, reducing the burden of manual data entry and paperwork [30]. By automating data capture through QR codes, responsible individuals can quickly and accurately input information into the system, leading to improved overall process efficiency. This streamlined approach not only saves time but also reduces the risk of errors and enhances the accuracy of the traceability data.

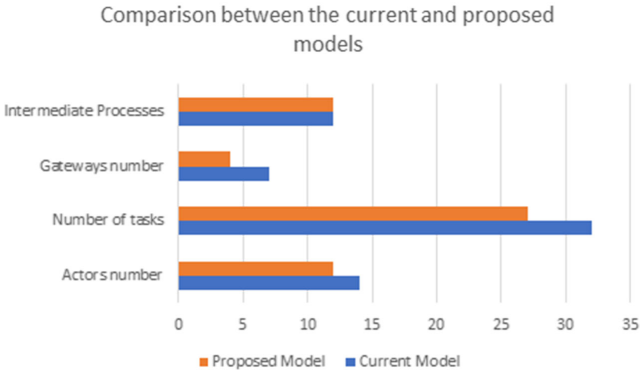
Furthermore, the introduction of QR codes has streamlined the traceability process by eliminating certain manual activities [30]. Automation in voucher distribution and reduced form filling tasks have resulted in a leaner and more optimized workflow. As a consequence, the traceability process becomes more precise, minimizing redundant steps, and increasing productivity [31]. The reduction in manual activities not only saves resources but also reduces the likelihood of human errors, enhancing the reliability and quality of the coffee production chain.

The integration of QR codes brings an added layer of security to the traceability process, which is essential for gaining consumer trust. Each unique QR code serves as an unalterable digital signature, ensuring the authenticity and accuracy of the data associated with a specific coffee batch [30]. This enhanced security reduces the risks of fraud and misinformation, instilling confidence in consumers regarding the origin and quality of the coffee they purchase. As consumer demands for transparency and product provenance grow, the implementation of QR codes strengthens the coffee industry's credibility and fosters brand loyalty [32].

Moreover, the automation provided by QR codes can potentially lead to a decrease in the required workforce. As manual activities are replaced with automation, the need for data entry clerks and other manual labor may diminish, resulting in cost savings for the coffee industry. This reduction in workforce requirements can be particularly beneficial for larger coffee production operations, improving cost-effectiveness without compromising traceability accuracy [30, 33].

To corroborate the results, the proposed model presents significant improvements compared to the current model in terms of efficiency and process optimization. These improvements are shown in Figure 4. In the current model, there are 14 actors involved, whereas in the proposed model, this number has been reduced to 12, streamlining the process and reducing complexities. Similarly, the number of tasks in the proposed model has been reduced from 32 to 27, eliminating redundant or unnecessary steps, resulting in a more streamlined and agile workflow. Additionally, the proposed model reduces the number of gateways from 7 to 4, simplifying decision-making points and ensuring a more straightforward flow of activities. Despite the reduction in certain elements, both models have 12 intermediate processes, indicating a consistent approach in maintaining crucial stages of the coffee production traceability. Overall, the proposed model showcases a more refined and optimized design, promoting increased efficiency, accuracy, and effectiveness in the coffee production traceability process.

Figure 4
Comparison between the current and proposed models



Finally, we observed herein that the adoption of QR codes and automation through the new BPM represents an advancement for the coffee industry. The incorporation of QR codes brings numerous advantages, such as: (a) increased efficiency; (b) reduced manual activities; (c) heightened security, and finally; (d) improved data accuracy. Embracing technological innovations in the traceability process enables the coffee industry to meet consumer demands for transparency, ultimately enhancing product quality and maintaining competitiveness in the market. As the coffee industry continues to evolve, further exploring automation and digitization possibilities presents promising opportunities for enhanced productivity, accuracy, and sustainability in coffee production and traceability.

7. Conclusions and Future Work

Coffee is an important economic driver for Brazil, contributing to growth, income generation, and sector development. In this work, BPMN played an essential role in optimizing business processes, specially providing a clear visual representation of existing processes. Another important thing that we noted is identification improvement opportunities, to increase sales and gain more credibility from customers. In this context, we demonstrated that our approach helps guide strategic decision-making, facilitates collaboration among teams, and contributes to increased efficiency and competitiveness of organizations. The adoption of QR codes in coffee traceability provides greater security and transparency as each code is unique and associated with a specific batch, and it is important in 4.0 industry. This strengthens consumer confidence, meeting the demand for products with proven provenance. This technology can enhance operational efficiency, decision-making, and user experience, bringing benefits to both organizations and customers.

The QR code technology also brings benefits such as reducing errors, expediting data entry, improving record accuracy, and enhancing transparency. The automation of data collection in the coffee production and traceability process optimizes the management of the coffee production chain, boosting efficiency and quality in this sector. Finally, it was possible to perceive herein that the detailed proposal of automation and the use of QR codes in the coffee traceability process offered an innovative and efficient solution, bringing significant improvements to the management of the production chain, ensuring product quality, and increasing agility in the traceability process, and it can be adopted by other companies for the production engineering of other plantation crops, such as cocoa, tea, fruits, and vegetables, aiming to ensure the provenance and quality of products. This usage application, as we proposed herein, would contribute to greater transparency and trust in various industries, helping consumers make informed decisions about the products they consume.

In future work, it is possible to explore optimization techniques and algorithms to further enhance the coffee traceability process. This would involve real-time data analysis, identifying bottlenecks and areas for improvement, and implementing strategies to maximize efficiency and reduce the time required to trace coffee from its origin to the end consumer. Another crucial aspect to consider is the security of the generated QR codes, in this case, ensuring authenticity and protection against counterfeiting and tampering becomes essential. Besides that, other study could focus on the development of advanced encryption and authentication techniques to strengthen consumer confidence and preserve the integrity of information associated with QR codes. Additionally, it is hoped that the proposed automation in this study can be extended to other agricultural, manufacturing, and food engineering production chains.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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