AN IMPLEMENTATION MODELING OF THE COFFEE AGROINDUSTRY SUPPLY CHAIN TRACEABILITY INFORMATION SYSTEM BASED ON BLOCKCHAIN TECHNOLOGY

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Bogor, Sept 2024

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SUMMARY

I GUSTI MADE TEDDY PRADANA. An Implementation Modeling of the Coffee Agroindustry Supply Chain Traceability Information System based on Blockchain Technology. Supervised by TAUFIK DJATNA, IRMAN HERMADI, INDAH YULIASIH.

The issue of food supply chain traceability is crucial for maintaining the integrity and safety of food products. In developing countries, coffee is a significant commodity traded internationally, holding strategic economic value. The economic potential of coffee has contributed to problems such as food fraud and adulteration. The development of traceability system models to address these issues is typically confined to the planning-analysis and design stages, resulting in conceptual models. The author's previous research proposed designing a blockchain-based traceability system for the Arabica coffee agroindustry in Kintamani, Bali. This model requires implementation modeling for adoption and practical application. Therefore, this study focuses on developing an implementation model for a blockchain-based traceability information system in the context of the Indonesian coffee agroindustry as a follow-up to previous research.

Developing a blockchain-based traceability system for the Kintamani Bali coffee agroindustry aims to create transparent and trusted (reliable) transaction records throughout the supply chain by the needs analysis gathered in the Requirements Engineering diagram. The initial system development involved six main actors: farmers, processors, distributors, roasters, coffee shops, and end consumers. In subsequent developments, the involved actors were simplified into three key actors: farmers (including processors), distributors (both local and exporters), and buyers, representing different layers of the business ecosystem. This revised design enables the system to be applied to a broader case study (Indonesian coffee) by focusing on green bean transactions not limited to local market channels. The blockchain-based traceability system model developed is designed using two popular frameworks—Ethereum and Hyperledger Fabric—to store primary data (on-chain), and IPFS to store additional data (off-chain), such as land certification documents or product photos with larger file sizes. A prototype user interface of the proposed traceability system has been presented as a timeline-based design, representing the physical architecture derived from the developed functional and logical architectural designs. The blockchain technology employed in the proposed traceability system is identified as one of the enablers for the Indonesian Coffee Digital Business Ecosystem (DBE), particularly within the digital layer. However, in addition to strengthening the flow of business layers and developing technology-based solutions at the digital layer, the Indonesian Coffee DBE requires the most fundamental support in the form of infrastructure. This layer demands a focus on capacity building, community empowerment, collaboration with the government and educational institutions, and active involvement of community leaders to create inclusive and sustainable solutions.

The readiness model for the implementation of a blockchain-based system was subsequently developed to evaluate the design of the developed system. Initially, this study proposes an integrated layered model for the readiness

assessment of blockchain-based systems. This model suggests a multi-layered approach covering technology, business, data, regulatory, and user interface layers. Two pilot tests were conducted in this integrated layer model, derived from the business layer elements: stakeholder engagement assessment and user readiness for change assessment. Stakeholder engagement assessment was conducted by confirming real-world interactions, visualizing using a BDD, and comparing them with the previously developed system design. In the Kintamani Bali coffee agroindustry case study, stakeholder interactions were successfully mapped based on their interests in achieving the system's objectives, which were confirmed to be consistent with the proposed system architecture design. Next, user readiness for change was analyzed using SEM-PLS, revealing that five exogenous variables—technological capability, top management support, security concerns, government policy, and perceived ease of use—explained 84.3% of the variance in blockchain adoption intention, with technological capability having the most significant impact ($t = 1.96$, $p < 0.05$). However, top management support exhibited a weak influence ($t = 0.044$), indicating the importance of technical factors over organizational ones. IPMA analysis confirmed that technological capability is the primary driver of adoption, while other variables, though performing well, were less significant in influencing adoption intention. These preliminary findings highlight the need to improve the business, regulatory, and user interface layers to maximize blockchain implementation in the Kintamani coffee agroindustry. Ultimately, the results of this pilot testing indicate that this five-layer model effectively evaluates the implementation readiness of blockchain-based systems more comprehensively and holistically.

A more robust implementation readiness assessment framework was subsequently proposed by integrating the TAM, TRI, TOE, and DOI theories, which have been widely used in the case of blockchain adoption in supply chains. The newly proposed framework for implementation readiness assessment consists of 14 variables and 64 elements organized within individual characteristics and innovation, as well as technology, organizational, and environmental contexts. Furthermore, the Kansei Engineering approach identified key elements needing improvement in system development. Employing the QTT1 approach and PCC value analysis, the ranking of elements across variables in different contexts and characteristics was obtained. In the technological context, perceived usefulness (PU2) and perceived ease of use (PEU5) were the most significant elements. In the organizational context, top management support (TOP3) and security concerns (SC4) ranked highest. Government policy (GP3) and vendor support (VS4) dominated the environmental context, while relative advantage (RA1) and technology compatibility (TC3) were key elements in innovation characteristics. Finally, optimism (OPT1), insecurity (INS3), and discomfort (DIS1) were the most influential individual characteristics. Based on this analysis, the author proposes a new approach for prioritizing improvements based on these high-ranking elements throughout the system development lifecycle to enhance implementation readiness. This approach is proposed as an Integrated Participatory Development (IPD) that details methods for iterating system improvements, incorporating user feedback, and emphasizing key areas such as improving users' quality of life, interaction quality, and ease of use to ensure successful real-world blockchain implementation.

The findings of this research provide several managerial implications and practical insights that stakeholders can refer to across four specific levels: operational, tactical, strategic, and support. Detailed SOP preparation and human resource capability enhancement are primarily needed at the operational level. At the tactical level, resource engagement and allocation for system development and continuous implementation assessment over a 2-10-year period are required. At the strategic level, organizations need to establish a long-term digital transformation vision (5-20 years) that integrates blockchain, IoT, and AI to strengthen competitive positioning. The support level emphasizes the importance of comprehensive training, the development of robust IT infrastructure, and ongoing technical support. These managerial implications require institutional support through policies that facilitate the adoption of blockchain technology. This holistic approach will ensure the successful and sustainable implementation of the system, with the ability to adapt to market and technological changes.

This study identifies several limitations, including infrastructure challenges in blockchain implementation in rural areas and the reliance on user input data that could potentially affect the proposed model or approach. Therefore, future research on the Indonesian Coffee DBE is advised not to rely solely on blockchain as the only solution but to explore integrating other technologies such as IoT, RFID, and ERP to improve production efficiency and supply chains. Additionally, it is crucial to develop a more inclusive approach that empowers smallholder farmers and SMEs in the digital business ecosystem. Future research is expected to focus on improving the adaptability of the layers in the proposed integrated assessment model and IPD approach, for example, by testing on broader case studies with diverse regulatory and market conditions. The author also recommends that future studies consider testing other technology adoption models, such as UTAUT and TTF, to refine or provide a comparison to the proposed implementation readiness assessment model.

Keywords: blockchain, coffee agroindustry, MBSE, supply chain, traceability

RINGKASAN

I GUSTI MADE TEDDY PRADANA. Pemodelan Implementasi Sistem Informasi Ketertelusuran Rantai Pasokan Agroindustri Kopi Berbasis Teknologi Blockchain. Dibimbing oleh TAUFIK DJATNA, IRMAN HERMADI, INDAH YULIASIH.

Masalah ketertelusuran rantai pasokan makanan sangat penting untuk menjaga integritas dan keamanan makanan. Di negara-negara berkembang, kopi merupakan komoditas penting yang diperdagangkan secara internasional dengan nilai ekonomi yang strategis. Potensi ekonomi kopi ini merupakan salah satu penyebab masalah terkait pemalsuan dan penipuan makanan. Pengembangan model sistem ketertelusuran untuk mengatasi masalah ini biasanya terbatas pada tahap perencanaan-analisis dan desain, yang menghasilkan model konseptual. Penelitian penulis sebelumnya telah mengusulkan desain sistem ketertelusuran berbasis blockchain untuk agroindustri kopi Arabika Kintamani Bali. Model ini membutuhkan pemodelan implementasi untuk adopsi dan aplikasi praktis. Oleh karena itu, penelitian ini berfokus pada pengembangan model implementasi untuk sistem informasi ketertelusuran berbasis blockchain dalam konteks agroindustri kopi Indonesia sebagai tindak lanjut dari penelitian sebelumnya.

Pengembangan sistem ketertelusuran berbasis blockchain pada agroindustri Kopi Kintamani Bali bertujuan untuk menciptakan catatan transaksi yang transparan dan terpercaya (dapat diandalkan) di seluruh rantai pasokan, sesuai dengan hasil analisis kebutuhan yang terhimpun pada diagram *Requirements Engineering*. Pengembangan awal sistem ini melibatkan enam pelaku utama yaitu petani, pengolah, distributor, pemanggang, kedai kopi, dan konsumen akhir. Pada pengembangan lanjutan, aktor yang terlibat disederhanakan pada tiga aktor kunci yaitu petani (termasuk pengolah), distributor (lokal dan eksportir) dan pembeli yang merepresentasikan lapisan ekosistem bisnis. Desain yang diperbaharui ini memungkinkan sistem dapat digunakan pada studi kasus yang lebih luas (kopi Indonesia) dengan berfokus pada transaksi *green bean* yang tidak terbatas pada saluran pasar lokal. Model sistem ketertelusuran berbasis teknologi blockchain yang dikembangkan, didesain menggunakan dua jaringan/kerangka kerja populer yaitu Ethereum dan Hyperledger Fabric untuk menyimpan data utama (on-chain), dan menggunakan IPFS untuk menyimpan data tambahan (off-chain)—seperti dokumen sertifikasi lahan atau foto produk yang memiliki ukuran lebih besar. Pada akhirnya, prototipe *user interface* dari sistem traceability yang diusulkan telah ditampilkan dalam bentuk desain berbasis linimasa waktu, merepresentasikan arsitektur fisik yang hasilkan dari desain arsitektur fungsional dan logis yang telah dikembangkan. Teknologi blockchain yang digunakan pada sistem ketertelusuran yang diusulkan merupakan salah satu teknologi *enabler* yang teridentifikasi untuk Ekosistem Bisnis Digital (DBE) kopi Indonesia, khususnya pada lapisan digital. Namun selain penguatan aliran lapisan bisnis dan pengembangan solusi berbasis teknologi pada lapisan digital, DBE kopi Indonesia memerlukan dukungan yang paling mendasar yaitu lapisan infrastruktur. Pada lapisan ini dibutuhkan fokus pada pengembangan kapasitas, pemberdayaan masyarakat lokal, kolaborasi dengan pemerintah dan lembaga pendidikan, dan keterlibatan aktif pemimpin masyarakat untuk menciptakan solusi yang inklusif dan berkelanjutan.

Model kesiapan implementasi untuk sistem berbasis blockchain selanjutnya dikembangkan dalam upaya mengevaluasi desain sistem yang telah dikembangkan. Pertama-tama penelitian ini mengusulkan model layer terintegrasi untuk penilaian kesiapan sistem berbasis blockchain. Model ini mengusulkan pendekatan multi-lapisan yang mencakup layer teknologi, bisnis, data, regulasi, dan antarmuka pengguna. Pada usulan model layer terintegrasi ini, dilakukan dua pengujian percontohan yang diambil dari elemen pada layer bisnis yaitu penilaian keterlibatan para pemangku kepentingan dan penilaian kesiapan pengguna untuk berubah. Penilaian keterlibatan para pemangku kepentingan dilakukan dengan mengkonfirmasi interaksi yang terjadi di dunia nyata yang divisualisasikan dengan BDD, selanjutnya dibandingkan dengan desain sistem yang telah dibuat sebelumnya. Pada studi kasus agroindustri Kopi Kintamani Bali, interaksi para pemangku kepentingan telah berhasil dipetakan berdasarkan kepentingannya untuk mencapai tujuan sistem, yang mana terkonfirmasi memiliki kesesuaian dengan desain arsitektur sistem yang telah diusulkan. Selanjutnya kesiapan pengguna untuk berubah dianalisis menggunakan SEM-PLS yang mana diperoleh hasil yang mengungkapkan bahwa lima variabel eksogen—kemampuan teknologi, dukungan manajemen puncak, kekhawatiran keamanan, kebijakan pemerintah, dan persepsi kemudahan penggunaan—berhasil menjelaskan 84,3% varians niat adopsi blockchain, dengan kemampuan teknologi memiliki pengaruh terbesar ($t = 1{,}96$, $p < 0{,}05$). Namun, dukungan manajemen puncak menunjukkan pengaruh lemah ($t = 0{,}044$), menandakan pentingnya faktor teknis di atas faktor organisasi. Analisis IPMA mengonfirmasi bahwa kemampuan teknologi adalah pendorong utama adopsi, sementara variabel lainnya, meski berperforma baik, kurang signifikan dalam memengaruhi niat adopsi. Temuan awalan ini menyoroti perlunya peningkatan pada lapisan bisnis, regulasi, dan antarmuka pengguna untuk memaksimalkan implementasi blockchain di agroindustri kopi Kintamani. Pada akhirnya, hasil percontohan pengujian ini menunjukkan bahwa model lima lapisan ini efektif dalam mengevaluasi kesiapan implementasi sistem berbasis blockchain secara lebih komprehensif dan holistik.

Kerangka kerja penilaian kesiapan implementasi yang lebih kokoh selanjutnya diusulkan dengan mengintegrasikan teori TAM, TRI, TOE dan DOI yang telah popular digunakan dalam kasus penerapan blockchain pada rantai pasokan. Kerangka kerja baru untuk penilaian kesiapan implementasi sistem yang diusulkan ini terdiri dari 14 variabel dan 64 elemen yang tersusun dalam karakteristik individu dan inovasi, serta konteks teknologi, organisasi dan lingkungan. Selanjutnya melalui pendekatan Kansei Engineering dilakukan pengidentifikasian elemen-elemen kunci yang perlu ditingkatkan dalam pengembangan sistem. Menggunakan pendekatan QTT1 dan analisis nilai PCC, diperoleh peringkat elemen-elemen tiap variabel dari berbagai konteks dan karakteristik. Dalam konteks teknologi, perceived usefulness (PU2) dan perceived ease of use (PEU5) merupakan elemen paling signifikan. Dalam konteks organisasi, dukungan manajemen puncak (TOP3) dan kekhawatiran keamanan (SC4) berada di peringkat teratas. Kebijakan pemerintah (GP3) dan dukungan vendor (VS4) mendominasi konteks lingkungan, sementara relative advantage (RA1) dan technology compatibility (TC3) menjadi elemen utama dalam karakteristik inovasi. Terakhir, optimisme (OPT1), ketidakamanan (INS3), dan ketidaknyamanan (DIS1) adalah karakteristik individu yang paling berpengaruh. Terakhir, berdasarkan analisis yang telah dilakukan, penulis mengusulkan suatu pendekatan baru untuk memprioritaskan perbaikan berdasarkan elemen-elemen yang memiliki peringkat tinggi ini di sepanjang siklus hidup pengembangan sistem, guna meningkatkan kesiapan implementasi sistem. Pendekatan ini diusulkan sebagai pengembangan partisipatif terintegrasi (IPD) yang merinci metode untuk mengulang perbaikan sistem, menggabungkan umpan balik pengguna, dan menekankan area kunci seperti peningkatan kualitas hidup pengguna, kualitas interaksi, serta kemudahan penggunaan agar implementasi blockchain dapat berhasil di dunia nyata.

Hasil yang telah ditunjukkan dalam penelitian ini memberikan beberapa implikasi managerial dan wawasan praktis yang dapat dijadikan acuan oleh para pemangku kepentingan pada empat tingkatan spesifik, yaitu operasional, taktis, strategis, dan pendukung. Pada tingkat operasional, utamanya dibutuhkan persiapan SOP yang terperinci dan peningkatan kemampuan sumber daya manusia. Pada tingkat taktis diperlukan pelibatan dan alokasi sumber daya untuk pengembangan sistem dan penilaian implementasi yang berkelanjutan selama periode 2-10 tahun. Pada tingkat strategis, organisasi perlu menetapkan visi transformasi digital jangka panjang (5-20 tahun) yang mengintegrasikan blockchain, IoT, dan AI untuk memperkuat posisi kompetitif. Tingkat dukungan menekankan pentingnya pelatihan yang komprehensif, pengembangan infrastruktur TI yang kuat, dan dukungan teknis yang berkelanjutan. Tentunya, implikasi managerial ini membutuhkan dukungan institusional melalui kebijakan yang memfasilitasi adopsi teknologi blockchain. Pendekatan yang holistik ini akan memastikan implementasi sistem yang sukses dan berkelanjutan, dengan kemampuan untuk beradaptasi dengan perubahan pasar dan teknologi.

Penelitian ini mengidentifikasi beberapa keterbatasan, antara lain tantangan infrastruktur dalam implementasi blockchain di daerah pedesaan serta ketergantungan pada data input pengguna yang berpotensi mempengaruhi model atau pendekatan yang diusulkan. Oleh karena itu, penelitian mendatang terkait DBE Kopi Indonesia disarankan untuk tidak hanya mengandalkan blockchain sebagai satu-satunya solusi, melainkan juga mengeksplorasi integrasi teknologi lain seperti IoT, RFID, dan ERP guna meningkatkan efisiensi produksi serta rantai pasok. Selain itu, sangat penting untuk mengembangkan pendekatan yang lebih inklusif yang dapat memberdayakan petani kecil dan UMKM dalam ekosistem bisnis digital kopi. Penelitian selanjutnya diharapkan dapat berfokus pada peningkatan adaptabilitas lapisan-lapisan dalam model penilaian terintegrasi dan pendekatan IPD yang diusulkan, misalnya melalui pengujian pada studi kasus yang lebih luas dengan regulasi dan kondisi pasar yang beragam. Penulis juga merekomendasikan agar penelitian di masa depan mempertimbangkan pengujian model adopsi teknologi lain, seperti UTAUT dan TTF, untuk menyempurnakan atau memberikan perbandingan terhadap model penilaian kesiapan implementasi yang telah diusulkan.

Keywords: agroindustri kopi, blockchain, ketertelusuran, MBSE, rantai pasok

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Dissertation
as partial fulfillment of the requirement
for the degree of Doctor in
the Agroindustrial Engineering Study Program

AGROINDUSTRIAL ENGINEERING STUDY PROGRAM
FACULTY OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
IPB UNIVERSITY
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Closed Doctoral Examination Date: August 8th, 2024 Passed Date:
Doctoral Defense Date: September 6th, 2024

PREFACE

Om Swastiastu. All praise is for God, Ida Sang Hyang Widhi Wasa, Ida Sang Hyang Parama Kawi, who gives the blessing, opportunity, health, and all the abundance of grace that has been given to the author so that the author can be born, grow, and study doctoral in Agroindustrial Engineering, Fateta, IPB University. The authors cannot finish this work without permission and the help of His grace. Peace can be poured upon Ida Batara Lelangit because it has guided me to become a better and more valuable human.

First, I would like to thank Prof. Dr. Ir. Eng Taufik Djatna, M.Si., Irman Hermadi S.Kom, M.S., Ph.D., and Dr. Ir. Indah Yuliasih, M.Si., for their support, patience, and guidance in supervising the author's completion of this dissertation. Second, I thank Prof. Dr. Ir. Yandra Arkeman, M.Eng., Prof. Ir. I Ketut Satriawan, MT., Prof.Dr.Ir. Hartrisari Hardjomidjojo, DEA, and Dr.rer.nat. Avinanta Tarigan, S.T., as examiners, who have provided significant input to improve this research. Lastly, I especially thank the Indonesian government, Kemdikbudristek, for the tuition fee, research grant through the PMDSU scholarship scheme, and Kemenpora for a grant to complete my final papers. I thank you for the golden opportunity that has been given. Furthermore, the author would like to express sincere love and gratitude for my parents, Ajik Suastana and Biyang Suteni, who always give love, affection, and full support. Moreover, I thank Nini and Bli Nano for being adorable grandmothers and brothers who keep the author's spirit. And all of my family at Jero Yeh Bakung and Jero Sudimara, I wish we always be prosperous and under God's protection.

I warmly thank Mr. Mangku Rupa—the head of MPIG Kintamani Coffee—and his family in Catur, who provided me with a place to stay during my field research. For all the information that I obtained for this research, I want to express my appreciation to experts from Kemenperin, BRIN, and Blocktogo and the representative of Distanpangan Bali, Dinas PKP Bangli, Disperindag Bali, Balai Karantina I Denpasar, Subak Abian/Farmers' Group, and MPIG Cooperative of Kintamani Coffee. Also, thank all the supply chain actors of Kintamani Coffee, who helped me as a respondent, and Pak Yoga, Mahen, Indra, Edi, Hendra, Andre, Satya, and Bintang, who helped me collect field data and surveys.

I thank the staff of my graduate study program, the TIP class of 2019 & 2020, and the Sensei Group for the memories. Special thanks to Bu Putu, Pak Arnata, Bu Tini, Mba Laili, Pak Irawan, Pak Ruhul, Bu Ryan, Kak Dewangga, Wahyu, Aries, Muslih, Mujib, Tika, Afaz, Hansen, and Adit for supporting of my study progress. As a place for self-actualization, I also thank Formatip, BSC, and KMHDI for the experience.

Hopefully, this dissertation will be valuable for stakeholders and the advancement of science.

Bogor, September 2024
I Gusti Made Teddy Pradana

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GLOSSARIES

B	Blockchain	A technology that enables secure, immutable recording of transactions on a distributed database.
D	Digital Business Ecosystem (DBE)	A network of interconnected businesses using digital platforms to collaborate and innovate.
	Digital Transformation	The integration of digital technology into all areas of a business fundamentally changes how businesses operate and deliver value to users. It involves using technology to improve the efficiency, effectiveness, and reach of business operations.
E	Ethereum	A blockchain platform that supports smart contracts and distributed applications.
G	Geographical Indication (GI)	A label that identifies products whose quality, reputation, or other characteristics are specifically linked to their geographic origin.
	Geographical Indication Protection Society (GIPS/ MPIG)	An organization in Indonesia that handles the registration of geographical indications.
H	Hyperledger	An open-source initiative to advance cross-industry blockchain technologies.
I	InterPlanetary File System (IPFS)	A decentralized file system aimed at making the web more open and efficient.
K	Kansei Engineering (KE)	An approach to product development that aligns product features with users' emotions and expectations.
P	Pearson Correlation Coefficient (PCC)	A statistic that measures the linear correlation between two variables.
	Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)	A methodological framework that promotes transparency and rigor in reporting systematic reviews and meta-analyses.
	Proof of Concept (PoC)	An initial small-scale implementation to demonstrate the feasibility or potential of a business idea or concept.
Q	Quantitative Theory Type1 (QTT1)	A method is used to test theories' strength and validity in a quantitative setting.
S	Smart Contract	A digital contract that automatically executes, controls, or documents legally relevant events.
T	Traceability System	A system that tracks and documents a product's journey through all production and distribution stages.