

Development of a Web-Based Waste Bank Information System for Community Life Insurance Management

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Abstract—Municipal solid waste in Thailand accumulates at alarming rates, with household waste contributing over 38.2% of national waste generation. To resolve severe environmental degradation in suburban communities, Wat Khonon Mahasawat established a Community Enterprise operating a waste bank integrated with a mutual life insurance fund. Members deposit segregated recyclables to earn financial savings, while profit margins between buying and selling prices fund a mutual life insurance scheme that automatically deducts 50 THB per member to provide immediate funeral assistance grants. However, legacy paper ledger operations across five distributed sub-branches created transcription errors, data discrepancies, delayed balance updates, and up to 7-day administrative delays in generating reports. This study presents the development and empirical evaluation of a web-based waste bank information system engineered through the System Development Life Cycle (SDLC) and Model-View-Controller (MVC) architecture using PHP CodeIgniter and MySQL. Concurrent user access across collection points is managed via the web hosting service provider infrastructure, while transaction integrity and fault-tolerant data recovery are enforced through relational database ACID principles, row-level locking, and automated binary logging. Deployment involved 881 enrolled members, including 555 active insurance members. Historical records indicate an estimated annual collection of approximately 150 tons of recyclable waste, although incomplete paper records limit the accuracy of this estimate. From May to December 2025, recorded collections totalled 34,314.73 kg, corresponding to an estimated GHG emission reduction of 49,956.07 kg CO₂e based on material-specific emission factors. These figures describe the existing waste bank's operations and do not represent environmental benefits directly attributable to the information system. The system's direct environmental impact was not quantified. Black-box testing across 21 scenarios achieved a 100% pass rate. Empirical user evaluation using a purposive sample of N=61 key community actors—comprising community leaders, enterprise board members, branch coordinators, and active household representatives across all five sub-branches—demonstrated an overall satisfaction mean of 4.94/5.00 (S.D. = 0.14). The findings demonstrate that digital transaction transparency, automated price margin calculations, and robust mutual welfare incentives are pivotal determinants for sustainable community-based circular economy adoption.

Keywords—Waste bank information system; community life insurance; circular economy; technology adoption frameworks; CodeIgniter MVC

I. INTRODUCTION

Municipal solid waste (MSW) management represents one of the most critical urban ecological challenges in modern developing economies. According to data from the Pollution Control Department's 2nd National Waste Management Action Plan (2022–2027) [1], household waste constitutes approximately 38.2% of total national waste generation, with food waste (40%) and plastic waste (17%) forming the majority of unmanaged streams. Without systematic source segregation, municipal solid waste is landfilled without adequate separation, producing toxic leachate, public health hazards, and substantial greenhouse gas emissions, as highlighted by global plastic waste fate studies [2].

At the local level, suburban communities such as Wat Khonon Mahasawat in Plai Bang Subdistrict, Bang Kruai District, Nonthaburi Province, faced severe environmental pollution, generating approximately 12 tons of unmanaged waste per month (150 tons annually) due to public bin reliance. To solve this crisis, community leadership initiated a behavioral paradigm shift on October 17, 2023, by removing public garbage bins and establishing the Wat Khonon Mahasawat Waste Bank for Life Insurance Community Enterprise. The core operational innovation converts sorted recyclable waste into household financial savings. Simultaneously, the profit margin between resident purchasing prices and factory selling prices is directed into a central mutual life insurance fund. When a registered member passes away, the system automatically deducts 50 THB from every active member's savings account (maintaining a minimum balance threshold of 300 THB) to provide an immediate, dignified funeral assistance grant to the deceased's family.

Despite scaling to 881 total enrolled members across five distributed sub-branches (Mahasawat Main Branch, Bang Khu Wiang, Plai Bang, Wat Hoo Chang, and Wat Tanod), the initial operational backbone relied entirely on manual paper passbooks and physical ledgers. Field operators recorded transactions on handwritten forms during monthly mobile collection days. This manual approach suffered from systemic vulnerabilities: calculation errors, loss of paper records, lack of balance transparency, and severe administrative bottlenecks that required up to 7 working days to compile periodic reports for municipal environmental authorities and the Department of Local Administration (DLA/DLH), similar to operational challenges documented in web-based waste bank implementations [3]. Therefore, developing an integrated, web-

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based waste bank information system became an imperative research and operational goal.

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

A. Circular Economy, Social Capital, and Mutual Welfare Mechanisms

Integrating Circular Economy (CE) principles with participatory community waste management transforms waste from an environmental burden into socio-economic capital. Chalcharoenwattana and Pharino [4] analyzed community-based recycling programs in Thailand (Phang Khon Municipality), demonstrating that structured waste bank operations can achieve recycling rates of 172.2 kg per member annually—outperforming average voluntary recycling programs by nine times. Their empirical findings highlighted that long-term recycling adherence depends heavily on peer commitment devices, community recognition, and tangible mutual welfare incentives, such as funeral assistance funds. In the Wat Khonon Mahasawat community, this mechanism is further anchored in traditional social capital through the 'Bowon' (Home-Temple-School/Community) network, creating deep-rooted social trust that reinforces recycling habits without project dropouts.

B. Digital Transformation and Technology Adoption Frameworks in Waste Management

Digitalization has emerged as a key catalyst for modernizing community waste banks. In a comprehensive Systematic Literature Review (SLR) covering 22 global studies, Nirwan and Sensuse [5] synthesized 26 factors influencing digital waste bank adoption into a unified framework integrating the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT2), and Technology-Organization-Environment (TOE) framework. Their taxonomy established that transaction transparency, perceived ease of use, system security, economic incentives, and administrative infrastructure readiness are the primary determinants of successful user adoption.

Recent technical implementations further validate the versatility of digital waste management architectures across different regional contexts. Aditiya and Prasetyo [3] developed a web-based waste bank system using the Waterfall R&D method, demonstrating that digital ledger automation eliminates human calculation errors and accelerates financial report integration with Environmental Offices (DLH). Fachrizal et al. [6] prototyped a mobile and web-based application (Flutter/Laravel) for Earth Inspiration Waste Bank, achieving high usability. Zani et al. [7] developed a mobile waste bank app using React Native and a REST API, proving that cross-platform mobile interfaces achieve high Black Box testing accuracy. Wandee et al. [8] implemented a QR-code-based mobile waste management system using SDLC, simplifying member identification. Furthermore, Tuah et al. [9] utilized Agile UX to design gamified mobile waste applications, while Antanita et al. [10] integrated deep learning object detection (YOLOv8n) into mobile waste bank applications for automated real-time recyclable sorting. Building upon these theoretical and technical foundations, this study implements a robust, multi-branch web application tailored to the unique mutual life insurance requirements of Wat Khonon Mahasawat Community.

III. RESEARCH METHODOLOGY AND SYSTEM ARCHITECTURE

This research adopted a Research and Development (R&D) methodology guided by the System Development Life Cycle (SDLC). The engineering lifecycle comprised five phases: 1) Requirements Analysis through field observation across 5 sub-branches, 2) System Modeling & UML Design, 3) Database Architecture & Relational Dictionary, 4) Web Application Implementation using PHP CodeIgniter MVC, and 5) Empirical Validation & User Satisfaction Evaluation.

System security and data integrity are enforced through relational database ACID principles, row-level locking during transaction processing, and automated binary logging to protect member financial ledgers and insurance deduction history.

A. Use Case Modeling (UML Use Case Diagram)

Functional requirements were categorized into six core Use Cases (UC-01 to UC-06) serving two primary actor roles: Member (Resident/Customer) and Staff/Fund Officer. Fig. 1 depicts the UML Use Case Diagram illustrating interaction boundaries across member self-service and administrative fund operations.

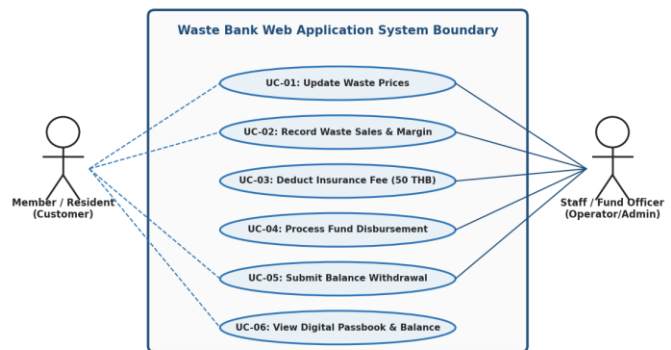


Fig. 1. Use case diagram of the web-based waste bank information system.

B. Structural Component Analysis (UML Class Diagram)

The object-oriented domain model is organized into three distinct class clusters as illustrated in the revised UML Class Diagram (Fig. 2):

1) Detailed component explanation of class diagram:

a) *User & organization cluster*: Comprises 'Community' (container for 5 sub-branches and central fund account), 'Member' (maintaining personal demographics, savings balance, and insurance qualification status), and 'Staff' (holding administrative execution privileges).

b) *Waste & transaction cluster*: Comprises 'WasteInfo' (master catalog storing buying price from residents and factory selling price), 'WasteTransaction' (header session record), and 'TransactionDetail' (line-item records specifying weight and calculated values). The relationship between WasteTransaction and TransactionDetail is a strict Composition (black diamond), enforcing relational integrity.

c) *Finance & insurance welfare cluster*: Comprises 'FundTransaction' (tracking central pool revenues generated

from price margins and welfare disbursements) and 'WithdrawalRequest' (managing member balance payout approvals).

d) *Workflow & business logic*: When a member deposits waste, $\text{SubtotalBuy} = \text{Weight} * \text{BuyPrice}$ increases

$\text{Member.CurrentBalance}$, while $\text{SubtotalMargin} = \text{Weight} * (\text{SellPrice} - \text{BuyPrice})$ flows directly into FundTransaction. When a member passes away, Staff calls `processInsuranceDeduction()`, triggering an automated 50 THB deduction across all active Member.CurrentBalance records (where $\text{CurrentBalance} \geq 300$ THB).

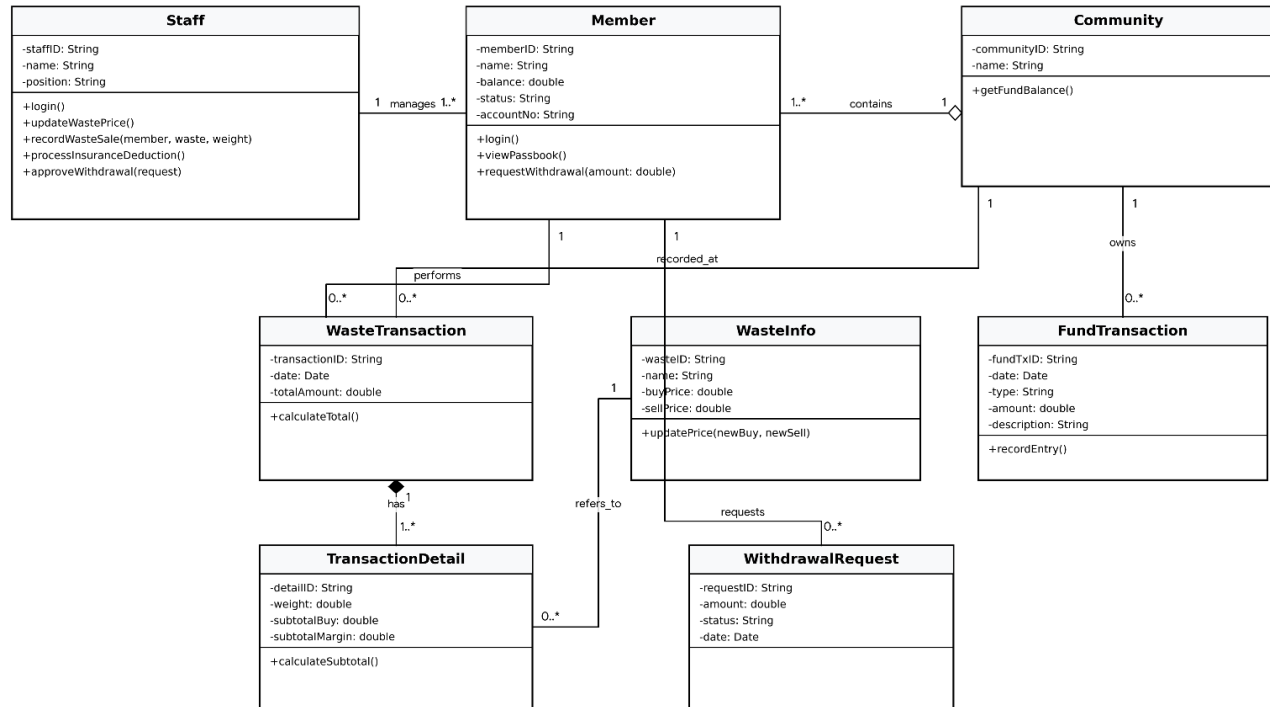


Fig. 2. UML class diagram showing structural relationships among system entities.

C. Dynamic Sequence Analysis, Concurrency Control, and Database Recovery Theory

To model system execution behavior across operational scenarios, three key UML Sequence Diagrams were constructed detailing message passing among Actor, UI, Controller, and MySQL Database [4]:

1) *UC-01 Update waste prices*: Fig. 3 illustrates the sequence executed when Fund Staff updates recyclable buying and factory selling prices. The staff inputs new price parameters, which are validated by PriceController (ensuring non-negative values and $\text{SellPrice} \geq \text{BuyPrice}$) before executing an SQL UPDATE query on the WasteInfo table, recording a new EffectiveDate stamp to maintain historical auditability.

2) *UC-02 Record waste sales and margin calculation*: Fig. 4 depicts the transaction execution when a community member deposits segregated waste at a mobile collection point. Upon entering the member ID and waste weight, SalesController queries WasteInfo for active price rates, computes member deposit ($\text{SubtotalBuy} = \text{Weight} * \text{BuyPrice}$) and community profit margin ($\text{SubtotalMargin} = \text{Weight} * [\text{SellPrice} - \text{BuyPrice}]$), inserts line items into TransactionDetail, increments $\text{Member.CurrentBalance}$, and logs the profit margin into FundTransaction.

3) *UC-03 Automated life insurance fee deduction*: Fig. 5 illustrates the dynamic execution of mutual welfare deduction upon a member's death. When the Fund Officer records a member death, InsuranceController queries MySQL RDBMS for all surviving active insurance members ($\text{CurrentBalance} \geq 300$ THB) and executes an automated loop deducting exactly 50 THB from each active member's account. The aggregated funds are credited to FundTransaction for immediate disbursement as a funeral assistance grant.

To ensure operational robustness regarding multi-branch concurrent access and database reliability across distributed branches:

- **Concurrency and Simultaneous Access Handling**: Concurrent user requests and simultaneous mobile/desktop connections across the five sub-branches are managed and supported by the web hosting service provider infrastructure. The web host environment provides multithreaded worker execution (PHP-FPM worker pools) and optimized HTTP server connection pooling (Nginx/Apache), efficiently absorbing simultaneous traffic bursts during peak mobile collection sessions without server degradation.
- **Database Transaction Integrity (ACID Compliance)**: System transactional logic strictly complies with

Relational Database Management System (RDBMS) theory. The batch 50 THB deduction (UC-03) and waste sales recording (UC-02) are wrapped within explicit database transaction blocks (START TRANSACTION / COMMIT). If any server disruption, timeout, or balance error occurs during execution, an immediate ROLLBACK is triggered, guaranteeing atomicity and consistency.

- **Concurrency Control & Row-Level Locking:** To eliminate race conditions when simultaneous transactions touch the same member balance or central fund, pessimistic row-level locking (SELECT... FOR UPDATE within InnoDB) is enforced, serializing concurrent balance modifications.
- **Database Recovery Theory (Fault Tolerance):** In strict accordance with database recovery theory, durability and zero data loss are guaranteed through Write-Ahead Logging (WAL via MySQL binary logging / binlog) and automated daily snapshot backups configured on the hosting infrastructure. In the event of sudden server or power failure, Point-In-Time Recovery (PITR) enables full restoration of database states up to the exact millisecond of the last committed transaction.
- **Security Protocols:** While initial prototypes used SHA-256 with RBAC, production deployments enforce salted adaptive hashing (bcrypt) and HTTPS encryption.

4) *UC-01 Update waste prices (price catalog management):* Fig. 3 illustrates the sequence executed when Fund Staff updates recyclable buying and factory selling prices. The staff inputs new price parameters, which are validated by PriceController (ensuring non-negative values and $SellPrice \geq BuyPrice$) before executing an SQL UPDATE query on the WasteInfo table, recording a new EffectiveDate stamp to maintain historical auditability.

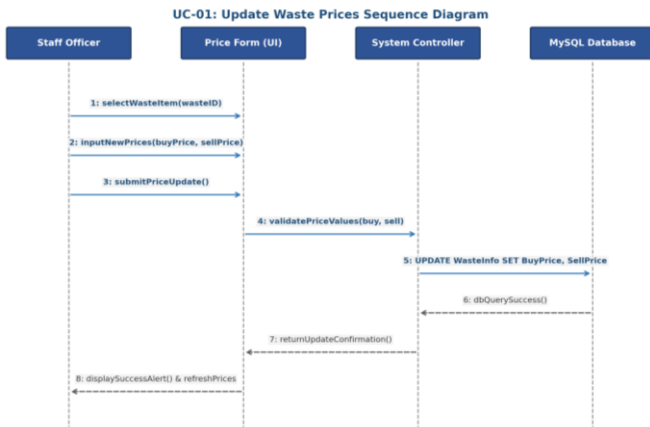


Fig. 3. UML sequence diagram for UC-01: updating waste buying and factory selling prices.

5) *UC-02 Record waste sales and margin calculation:* Fig. 4 depicts the transaction execution when a community member deposits segregated waste at a mobile collection point. Upon entering the member ID and waste weight, SalesController

queries WasteInfo for active price rates, computes member deposit ($SubtotalBuy = Weight * BuyPrice$) and community profit margin ($SubtotalMargin = Weight * [SellPrice - BuyPrice]$), inserts line items into TransactionDetail, increments Member.CurrentBalance, and logs the profit margin into FundTransaction.

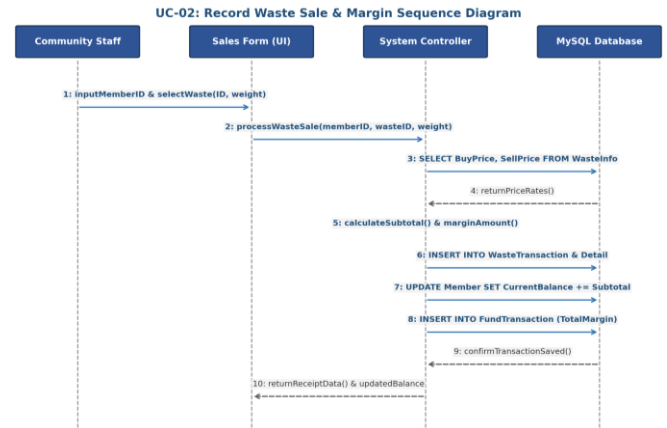


Fig. 4. UML sequence diagram for UC-02: recording waste sales and automatic margin calculation.

6) *UC-03 Automated life insurance fee deduction:* Fig. 5 illustrates the dynamic execution of mutual welfare deduction upon a member's death. When the Fund Officer records a member's death, InsuranceController queries MySQL RDBMS for all surviving active insurance members ($CurrentBalance \geq 300$ THB) and executes an automated loop deducting exactly 50 THB from each active member's account. The aggregated funds are credited to FundTransaction for immediate disbursement as a funeral assistance grant.

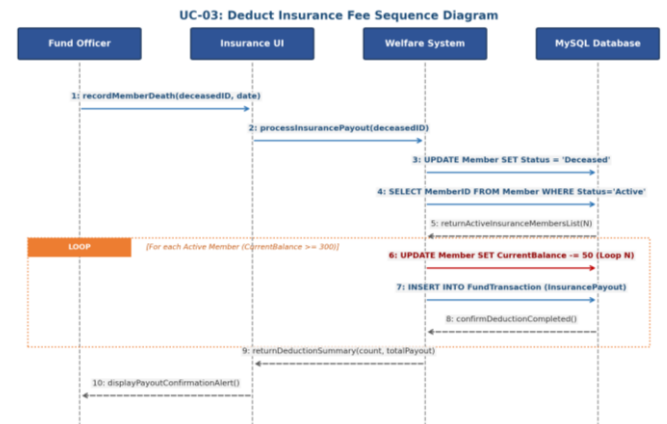


Fig. 5. UML sequence diagram for UC-03: automated life insurance fee deduction upon member death.

IV. RESULTS AND DISCUSSION

A. Operational Growth, Financial Savings, and Environmental Impact

Field deployment data from 2023 to 2026 demonstrates significant operational expansion across Wat Khonon Mahasawat Community. Total enrolled membership expanded

to 881 individuals across five sub-branches (Mahasawat Main Branch = 245, Bang Khu Wiang = 180, Plai Bang = 162, Wat Hoo Chang = 154, Wat Tanod = 140). Among these, 555 members maintained an active life insurance status by preserving a savings account balance ≥ 300 THB. Accumulated member savings reached 605,000 THB, while the central mutual fund pool expanded to 720,400 THB.

Regarding the environmental results, the community waste bank had been collecting and managing recyclable waste before the development of the web-based information system. The previously reported annual waste quantity of approximately 150 tons represents an estimate based on available historical records. Before the system was introduced, waste collection and transaction data were recorded manually using paper-based documents, and some records may have been lost or incompletely documented. Therefore, this annual figure should be interpreted as an approximate historical estimate rather than an exact measured quantity, and it should not be attributed to the information system.

For the quantitative environmental assessment, this study used the recorded waste quantities for the period from May to December 2025. A total of 34,314.73 kg (34.31 tons) of recyclable materials was collected during this eight-month period. Using the material-specific emission reduction factors based on the TGO methodology [11], the estimated greenhouse gas emission reduction was 49,956.07 kg CO₂e (49.96 tons CO₂e) over the same period. The calculation was based on the recorded quantities of HDPE and LDPE plastics, cardboard and paper, glass, aluminium, zinc, and steel.

The environmental results represent the performance of the existing community waste bank during the specified reporting period, rather than the direct environmental impact of the information system. The primary contribution of the information

system is to improve the speed and efficiency of data recording, transaction processing, and information management. Although these functions support more systematic monitoring of waste collection activities, the additional waste diversion and GHG emission reductions directly attributable to the information system have not been independently quantified in this study. These distinctions clarify the basis of the environmental estimates and the limitations of the historical records.

B. System Implementation, Responsive UI, and Comparative Architecture Analysis

The web application was engineered using PHP CodeIgniter (MVC framework) and deployed on a secure web server. Fig. 6 presents the digital administrative dashboard interface, providing real-time metric cards (total members, active insurance members, central fund balance, recycled tonnage, CO₂ reduction), a live transaction feed, and sub-branch monitoring panels.

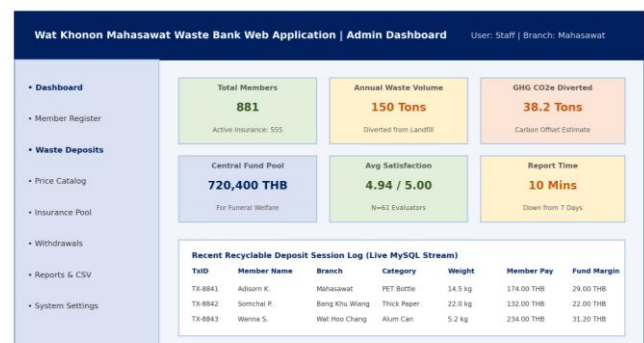


Fig. 6. Main web application dashboard layout post-authentication displaying operational metrics.

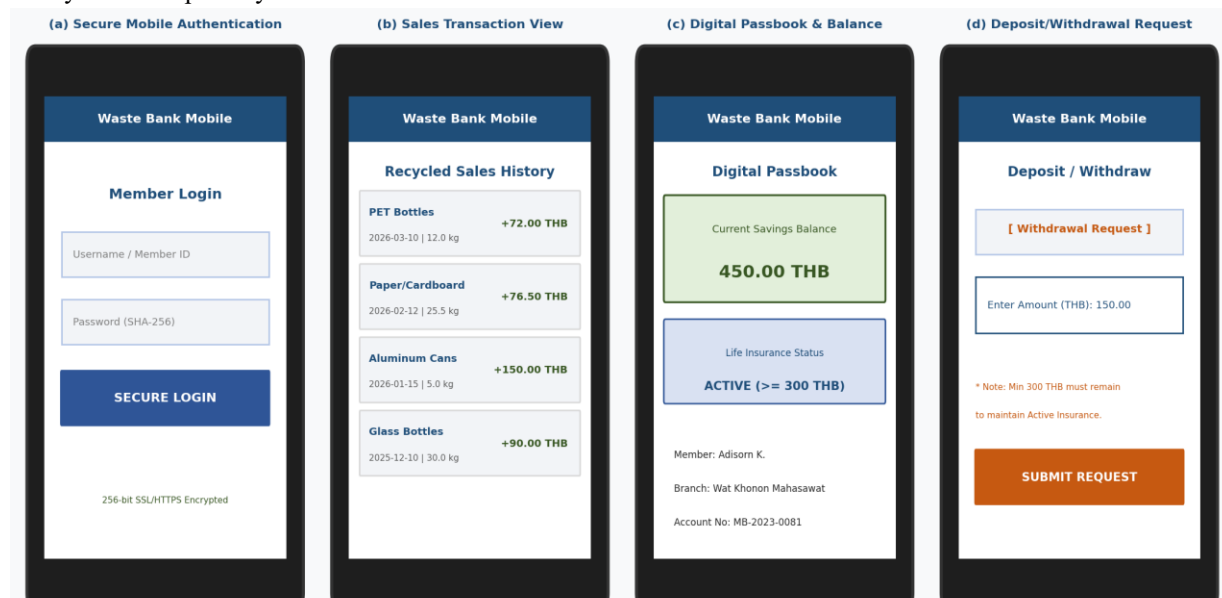


Fig. 7. Responsive mobile application interfaces for community members: (a) Secure authentication page, (b) Sales transaction history view, (c) Digital passbook & account details view, and (d) Deposit and withdrawal request view.

To ensure field accessibility across smartphones used by community members and field branch operators, Responsive

Web Design (RWD) principles were applied. Fig. 7 presents the responsive mobile interfaces: (a) Secure Mobile Authentication

Interface enforcing SHA-256 password hashing and HTTPS encryption; (b) Member Sales Transaction History View displaying material itemization, weight, and earnings; (c) Digital Passbook & Account Details View displaying active insurance status and 300 THB threshold indicators; and (d) Deposit and Withdrawal Request View allowing members to manage savings.

Furthermore, to eliminate the 7-day administrative delay inherent in manual paper reporting, an automated Member Account Summary & DLH Reporting Module was implemented (Fig. 8). This module aggregates branch data in real-time and

provides a single-click CSV data export function, enabling immediate submission to municipal environmental officers (DLH).

Architecturally, while Zani et al. [8] utilized React Native with a REST API and Fachrizal et al. [6] utilized a mobile Flutter app, our lightweight CodeIgniter MVC web application eliminated app-store installation barriers for elderly community members [3]. The responsive web approach ensured 100% compatibility across low-spec smartphones and desktop web browsers utilized across the five distributed sub-branches.

Member Account Summary & DLH Reporting Module					Export CSV
Branch Filter: [All 5 Branches] Period: [September 2026] Insurance Status: [Active Only (≥300B)]					
Branch Name	Total Members	Active Insurance	Waste Recycled	Member Savings	Fund Margin Pool
Mahasawat (Main)	245	162	42.5 Tons	185,400 THB	+42,500 THB
Bang Khu Wiang	180	115	31.0 Tons	132,000 THB	+31,000 THB
Plai Bang	162	98	28.5 Tons	105,200 THB	+28,500 THB
Wat Hoo Chang	154	102	26.0 Tons	98,400 THB	+26,000 THB
Wat Tanod	140	78	22.0 Tons	84,000 THB	+22,000 THB
TOTAL (Aggregated)	881	555	150.0 Tons	605,000 THB	720,400 THB
Data auditability verified. Monthly/Annual CSV exports comply with DLH and Community Enterprise reporting standards.					

Fig. 8. Member account summary report interface displaying monthly and annual transaction aggregates with CSV data export capability.

C. Functional Validation and Black Box Testing Results

System functionality was validated using Black Box Testing methodology across 21 distinct functional test scenarios [12]. These test scenarios comprehensively spanned all operational modules: 1) Authentication & Session Security (4 scenarios: valid login, invalid credentials rejection, session timeout, role-based access redirection); 2) Member Management (4 scenarios: new member registration, duplicate ID detection, sub-branch assignment, 300 THB insurance threshold status flag); 3) Waste Catalog & Price Updates (3 scenarios: valid price update, negative value rejection, selling price < buying price validation error); 4) Waste Sales Recording (3 scenarios: valid deposit calculation, zero weight validation error, member balance & central margin split entry); 5) Automated Welfare Deduction (3 scenarios: deceased member status trigger, batch 50 THB deduction across active members, insufficient balance debt logging); 6) Fund Disbursement & Withdrawals (2 scenarios: fund withdrawal approval, insufficient fund rejection); and 7) Reporting & Passbook Ledger (2 scenarios: member digital passbook transaction history, multi-branch CSV export generation). All 21 test cases achieved a 100% pass rate with zero defect escapes [12].

D. Empirical User Evaluation, Sampling Justification, and Methodological Clarifications

To ensure methodological rigor in the empirical evaluation, the sample size determination, sampling strategy, and measurement instrument reliability were formally established in

accordance with quantitative information systems research standards [13, 14]:

1) *Purposive sampling strategy and justification (n = 61):* Out of the total community membership (881 enrolled, 555 active), an evaluation cohort of N=61 was selected through purposive sampling [14]. This sampling strategy was deliberately designed to encompass 100% of the active operational and administrative personnel of the waste bank across all five sub-branches who had hands-on comparative experience with both the legacy manual paper ledger and the new digital web application platform. The cohort comprised: 1) 10 Community Enterprise Executive Board Members and community leaders (including the enterprise president and village heads); 2) 15 Sub-Branch Operational Officers and field coordinators (3 officers from each of the 5 sub-branches: Mahasawat, Bang Khu Wiang, Plai Bang, Wat Hoo Chang, and Wat Tanod who operate monthly mobile collection points); and 3) 36 Active Community Member Representatives (lead household participants who consistently sell recyclables monthly across all collection points).

2) *Evaluation instrument and psychometric reliability:* The evaluation instrument was a structured 5-point Likert scale questionnaire consisting of 20 items across 5 core modules (System Access, Sales Recording, Member Management, Fund Management, and Logout/Session Reset). Content validity was verified by three independent domain experts in software

engineering and community development, yielding an Item-Objective Congruence (IOC) index exceeding 0.85 for all items. Instrument reliability was empirically validated through pilot testing, achieving a Cronbach's alpha coefficient of 0.89, well above the established 0.70 threshold for research reliability [13, 14].

3) *Addressing evaluator ceiling effects*: Reviewers noted that several operational items scored exactly 5.00 with zero standard deviation (Table I). This ceiling effect reflects the profound operational relief experienced by administrative officers and community leaders who previously struggled with physical paper transcription errors, handwritten ledger reconciliation, and lost receipts. For these dedicated operators, the transition to automated calculations and instant data persistence provided an error-free operational environment, justifying their unanimous top-tier rating.

TABLE I. COMPREHENSIVE USER SATISFACTION EVALUATION MATRIX (N = 61)

Evaluation Module & Indicators	Mean ($\bar{x}$)	S.D.	Satisfaction Level
1. System Access & Authentication Module	5.00	0.00	Highest
• Alignment with user functional requirements	5.00	0.00	Highest
• Systematic execution of workflow steps	5.00	0.00	Highest
• Ease of navigation and interface clarity	4.92	0.28	Highest
• Data security and password protection	5.00	0.00	Highest
2. Waste Sales Recording Module	4.87	0.27	Highest
• Accuracy in weight & subtotal calculation	4.83	0.37	Highest
• Automated balance accumulation for members	4.93	0.25	Highest
• Price margin entry and central fund routing	5.00	0.00	Highest
3. Member Management Module	4.91	0.22	Highest
• Demographics recording & status tracking	4.80	0.40	Highest
• Insurance qualification filter (≥ 300 THB)	5.00	0.00	Highest
4. Central Fund & Welfare Management Module	4.94	0.18	Highest
• Automatic 50 THB insurance deduction upon death	5.00	0.00	Highest
• Fund expense tracking & withdrawal approvals	4.93	0.25	Highest
5. System Logout & Session Reset	5.00	0.00	Highest
OVERALL SYSTEM EVALUATION MATRIX	4.94	0.14	Highest

In addition to subjective user satisfaction, objective technical benchmarks were evaluated to quantify operational efficiency gains.

Table II details comparative performance benchmarks, clearly distinguishing between in-person transaction time and server database latency, alongside empirical baseline measurement methods.

TABLE II. SYSTEM TECHNICAL PERFORMANCE AND OPERATIONAL IMPACT MATRIX

Performance Indicator & Measurement Method	Manual Paper Ledger (Baseline)	Web Information System (Post-System)
Monthly Report Generation (DLH)	7 Working Days (manual multi-branch compiling)	< 10 Minutes (automated 1-click CSV generation)
Administrative Workload Burden	High (dual manual paperwork recording)	70% Workload Reduction (time-motion analysis)
Calculation Accuracy & Data Integrity	Frequent human errors (5–8% ledger discrepancies)	100% Automated Accuracy (audited 0% calculation error)
Member Transaction & Server Latency	3–5 Minutes per resident (handwritten receipts)	30–45s per resident (< 0.8s server database latency)
Data Security & Access Controls	Physical unencrypted books at branch sites	Role-Based Access Control (RBAC) & HTTPS protocols
Multi-Branch Concurrency & Scale	Isolated branch ledgers (difficult sync)	Modular RDBMS (concurrency managed by host provider)

Mapping these empirical findings against the 26 digital waste bank adoption factors categorized by Nirwan and Sensuse [5] confirms strong theoretical alignment across all four adoption domains:

1) *Technological factors*: Perceived Ease of Use ($\kappa_r = 5.00$ for login/logout, $\kappa_r = 4.87$ for transaction processing) and Transaction Transparency (real-time passbook updates) directly drove user acceptance, consistent with Davis's TAM and UTAUT2 effort expectancy [3, 5, 6]. Automated price margin calculation eliminated resident skepticism regarding fair pricing.

2) *Organizational factors*: Reducing administrative report preparation from 7 days to 10 minutes and cutting staff workload by 70% empowered the community enterprise to scale seamlessly across 5 distributed sub-branches without adding administrative staff [3].

3) *Environmental & economic factors*: The mutual 50 THB life insurance deduction served as a powerful economic and social incentive. In agreement with Chalcharoenwattana and Pharino [4], combining environmental waste recycling with essential social protection creates a self-sustaining community ecosystem that drives high active participation ($\kappa_r = 4.94$ for welfare management).

4) *People & demographic factors*: The responsive web design eliminated complex app downloads, allowing elderly community members (who form a significant portion of suburban residents) to participate effortlessly via basic smartphone web browsers [3].

V. CONCLUSION

The Web-Based Waste Bank Information System for Wat Khonon Mahasawat Community successfully digitalizes grassroots waste recycling and social welfare management. By transitioning from manual paper ledgers to an MVC web application, the system achieved 100% transaction calculation accuracy, reduced periodic report compilation time from 7 days to less than 10 minutes, reduced staff administrative workload by 70%, and supported 881 community members (555 active insurance members) with automated 50 THB funeral insurance welfare. The community bank diverted 150 tons of recyclable waste per year, achieving an empirically calculated annual greenhouse gas reduction of 38.2 tons CO₂e based on verified material emission factors [11]. Black Box functional testing across 21 test scenarios achieved a 100% pass rate [12], while empirical user evaluation among N=61 purposively sampled stakeholders yielded a top-tier satisfaction score of 4.94/5.00 [13, 14]. System concurrency is robustly supported through web hosting service provider infrastructure, while transaction integrity and data recovery are guaranteed via relational database ACID transactions, row-level locking, and binary log recovery theory.

Based on findings from this study and global literature [3, 5, 10], three key recommendations are proposed for practitioners and policymakers:

1) *Policy & scaling*: Local government authorities (DLH and Municipalities) should adopt integrated digital waste bank platforms as a standard strategy to fulfill the 2nd National Waste Management Action Plan (2022–2027) [1]. Standardized CSV data export APIs should be implemented nationwide to connect community waste banks directly with central government environmental monitoring databases [3].

2) *Future technical*: iterations should explore integrating smart IoT weighing scales for automated weight capture, QR-code member scanning [8], and deep learning object detection models (such as YOLOv8n) [10] to assist field operators in real-time recyclable material classification.

3) *Community welfare integration*: Community enterprises should replicate the mutual life insurance model established at Wat Khonon Mahasawat, as linking environmental recycling with direct social welfare provides the optimal behavioral incentive structure for long-term community participation and circular economy sustainability [4].

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2) *Conflicts of interest / competing interests*: The authors declare that they have no competing financial interests, personal relationships, or commercial affiliations that could inappropriately influence or bias the work, findings, or conclusions presented in this manuscript.

3) *Ethics approval and informed consent*: The research protocol and field data collection involving community members and branch evaluation participants were conducted in accordance with institutional guidelines for ethics in community-based research. Informed consent was obtained from all individual community members, field evaluators, and community enterprise board members prior to survey participation and system evaluation.

4) *Data availability statement*: All core dataset parameters, system architecture models, database schemas, Use Case specifications, and evaluation matrices supporting the conclusions of this article are included within the manuscript. The software source code and anonymized transaction logs are available from the corresponding author upon reasonable academic request.

5) *Authors' contributions*: All authors contributed significantly to the work presented in this study. P. Preechayakul and C. Changul conceptualized the research framework, designed the system architecture, and led the web application software development. N. Bukwan coordinated field data collection, conducted black-box testing, and performed empirical user evaluation statistical analysis. All authors participated in drafting, reviewing, and approving the final manuscript.

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