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Assessment of Smart Waste Management System Maturity Levels: A Case Study at PT.XYZ

Dimas Ahda Sabila[1], Yekti Wirani[2], Yudho Giri Sucahyo[3]
dimas.ahda@ui.ac.id[1], yektiwirani@cs.ui.ac.id[2], yudho@cs.ui.ac.id[3]
[1,2,3] Universitas Indonesia

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Abstract

Facing increasingly complex urban waste management challenges, this study evaluates the maturity level of Smart Waste Management implementation in Indonesia, with a case study of PT. XYZ. In Indonesia, the implementation of Smart Waste Management is still in its early stages, yet its urgency continues to grow due to increasingly complex urban waste problems. The study examines Smart Waste Management System maturity levels and identifies key implementation factors, utilizing both qualitative and quantitative approaches. Assessment results indicate an average maturity level of 3-Integrated out of 5-Smart, with variations across different processes. Key areas requiring enhancement include governance, social, technological, and economic dimensions. This evaluation provides valuable insights for improving operational efficiency, environmental impact, and community service delivery in waste management. The findings contribute to understanding SWMS implementation challenges and opportunities, offering strategic recommendations for advancing sustainable waste management practices in Indonesia.

A. Introduction

Indonesia is facing significant challenges in waste management, with national waste production exceeding 64 million tons annually in 2019. Data from the National Waste Management Information System (SIPSN) indicates that of the total waste generated, only around 60-65% is managed, while the remainder ends up in illegal landfills, is burned, or pollutes the environment [1]. The magnitude of Indonesia's waste management challenges is evidenced by its substantial annual waste production of 30-40 million tons, with projections indicating a 45% increase over the forthcoming twelve-year period, exacerbated by inequitable waste distribution and processing mechanisms across diverse regions.

The concept of sustainability has emerged as a critical global discourse and represents a key objective for nations worldwide [2]. Waste management is becoming increasingly critical as urban populations grow, with waste generation expected to double every decade, putting unprecedented pressure on collection and processing systems [3]. Furthermore, sustainability has evolved into a fundamental component of modern waste management practices. Sustainable waste management operates as a circular feedback ecosystem, encompassing operational processes, adaptive mechanisms, and waste diversity throughout the complete production-to-disposal lifecycle. This comprehensive approach integrates various elements to create a system that is efficient, equitable, and capable of evolving over time to meet society's needs while minimizing environmental impact [4]. The implementation of technology and digitalization serves as a catalyst for transformation towards a more sustainable circular economy [5]

Efficient waste collection systems contribute to sustainable development by promoting cleaner urban environments, enhancing public health outcomes, and supporting long-term environmental sustainability goals [6]. However, the implementation of sustainable and smart waste management systems in Indonesia faces substantial impediments across multiple domains: constrained financial resources, limited technical expertise, insufficient regulatory frameworks, inadequate institutional infrastructure, and complex sociocultural aspects [7] [8].

In the sustainability context, the assessment of SWM maturity levels has gained increasing relevance. The Sustainable Development Goals (SDGs) framework provides fundamental guidance regarding the significance of sustainable waste management in achieving sustainable development objectives, particularly concerning sustainable cities and communities (SDG 11) and responsible consumption and production patterns (SDG 12) [9] [10]

Maturity level evaluation facilitates the identification of SWM implementation's contribution toward achieving these SDG targets [11]. Furthermore, the Industry 4.0 era has necessitated digital transformation in waste management praprahactices. The integration of Internet of Things (IoT), artificial intelligence, and big data analytics in SWM presents revolutionary potential for transforming waste management methodologies [12]. Waste management incorporating circular economy principles facilitates material cycles that enhance product longevity and utility. This implementation of circular economy principles in waste management systems generates substantial long-term economic benefits while promoting environmental sustainability [13].

The accelerated pace of urbanization has generated a significant escalation in waste volume throughout Indonesia's urban centers, where conventional waste management methodologies have proven suboptimal. The Smart Waste Management System (SWMS) presents an innovative solution through the integration of Information and Communication Technology (ICT), enhancing efficiency and accuracy in waste management operations while promoting environmental sustainability and public health.

PT. XYZ, an organization dedicated to sustainable waste management practices, has implemented various Smart Waste Management (SWM) technologies, albeit encountering implementation maturity challenges. This study endeavors to evaluate the maturity level of these implementations, specifically focusing on the technological infrastructure supporting SWM [14]. The complexity of waste management challenges, coupled with the imperative for digital transformation in this sector, emphasizes the importance of evaluating SWM implementation maturity at the company [15]. This assessment aims to generate valuable insights for improving waste management practices and achieving sustainability goals.

PT. XYZ as a pioneer in technology-based waste management solutions in Indonesia. The organization has developed numerous innovations in waste management, including the implementation of comprehensive Waste Management Systems [16]. Based on documentation and observations from documentation and interview, the root problem analyzed using fishbone analysis with the main problem stated as "The implementation maturity of smart waste management systems demonstrates suboptimal performance and operational inefficiencies." Those problems will be categorized into four main domains: people, organization, processes, and technology [17]. They are explained in detail in **Table 1**.

Table 1. Problem Domain

Domain	*Problem*
People	• Human resource competency in terms of sufficient expertise to adopt new technologies • Inadequate adaptation capabilities and digital literacy levels across all staff members
Organization	• Technological transformation policies lack comprehensiveness and adequacy • Stakeholder coordination remains ineffective
Process	• Standard procedural operations demonstrate Inefficiencies with predominant manual processes • Incentives remain disproportionate to waste management costs
Technology	• System capacity and infrastructure are Insufficient for technological transformation • Technological implementation requires substantial investment costs

The implementation of smart waste management system is crucial for enhancing organizational performance in implementing modern and sustainable waste management. This study employs the Sustainable and Smart Waste Management Framework was selected as the evaluation methodology for maturity assessment in this study, as it provides a comprehensive standard aligned with modern and smart waste processing contexts [12]. This study addresses two primary questions: (1) What is the maturity level in the implementation of smart waste management systems at PT XYZ? and (2) What recommendations can be proposed to enhance the smart waste management system to achieve the desired maturity level for PT XYZ?

Organization seeking for excellent performance should evaluate their project management's maturity level through maturity model frameworks [18]. These models serve as diagnostic tools, helping organization evaluate their current waste management system and determine opportunities for enhancement. Through structured maturity assessments, organization can develop a better understanding of its strengths and weaknesses in its waste management system, ultimately guiding its path toward a SWMS.

The research also offers several benefits across multiple stakeholders. For society, it enhances waste management service quality with direct impacts on environmental aspects, while promoting active community participation through organized systems and fostering a healthier, more sustainable environment through improved technology implementation. This research contributes to academia by providing a comprehensive evaluation framework and real-world case studies for Smart Waste Management Systems, while creating opportunities for further research in technology-based waste optimization. The study enhances existing literature and bridges the gap between theoretical concepts and practical applications in waste management systems.

The industrial sector benefits from insights into best practices for implementing smart waste management systems, fostering innovation and technological development within the waste management sector. For policy makers, the study provides valuable understanding of system maturity levels that serve as references for regulatory development, supports the formulation of modern waste management standards and policies, and enables data-driven decision-making in infrastructure development. The benefits across these different stakeholders demonstrate the comprehensive impact and practical applications of this research in advancing sustainable waste management practices while contributing to both theoretical knowledge and practical implementation strategies.

This study aims to assess maturity levels and provide recommendations for SWMS design. The current and desired conditions at PT.XYZ were determined through document observation, interviews, and questionnaire distribution. This study is expected to serve as an evaluation tool for enhancing maturity levels at PT. XYZ

B. Research Method

The research methodology employs a mixed method approach, combining qualitative methods for problem identification and formulation with quantitative methods for maturity level assessment at PT. XYZ. Initial data gathering was

conducted through document observation and interviews with the head of IT division.

The research follows a systematic eight-stage process, as outlined in **Table 2**, beginning with Problem Identification using Fishbone Analysis and progressing through Literature Review and Methodology Identification to establish the research foundation. The study then advances to Research Instruments Preparation and Data Collection through questionnaires and interviews, followed by Maturity Level Measurement and Analysis using the Smart Waste Management System Model. Each stage's output serves as input for the subsequent stage, creating an interconnected research flow that concludes with improvement recommendations and final conclusions

Table 2. Research Flow

Research Stage	*Input*	*Method*	*Output*
Problem Identification	Interview, Organizational document, main task and function of the organization	Fishbone Analysis, interview, document studies	Research Question
Literature Review	Research Question	Study of literature	Relevant theory and research
Methodology Identification	Relevant theory and research	Study of literature	Research Material
Research Instruments Preparation	Research Material	Sustainability and Smart Waste Management System Model	Instrumentation stages data collection is in the form of a research examination form
Instrumentation Data Collection	Assessment Form	Questionnaires, document, and interview	Evaluation Maturity Level Results
Measurement of Maturity Level	Evaluation Maturity Level Results	Sustainability and Smart Waste Management System Model	Smart Waste Management Maturity Level
Maturity Level Analysis	Smart Waste Management Maturity Level	Sustainability and Smart Waste Management System Model	Improvement Recommendation
Preparation of Conclusions	Smart Waste Management Maturity Level	Sustainability and Smart Waste Management System Model	Conclusion and suggestion

This assessment aims to enhance insights of maturity level of smart waste management system. Expected results from this study are to provide insight and recommendations for organization.

The maturity level assessment on this study was conducted utilizing the Sustainability and Smart Waste Management Framework deployed in research titled 'Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia' [12], an evaluation and recommendations were provided regarding the maturity level of Smart Waste Management Systems in Indonesian waste

management companies. This research performed a comprehensive literature review of previous studies as a research reference. Generally, previous studies conducted evaluations of current maturity levels and subsequently provided improvement recommendations based on these assessments.

The scorecard for maturity level evaluation encompasses five key dimensions: Governance, Economy, Social, Environment, and Technology. In the Governance dimension, the focus is on information technology utilization, community engagement, funding accessibility, regulatory compliance, and stakeholder interaction channels. The Economic dimension evaluates factors such as cost affordability, productivity levels, resource efficiency, employment opportunities, infrastructure investments, and market development initiatives, including potential cost reductions through green campaigns.

The Social dimension assesses aspects related to safety and health standards, workforce capabilities, stakeholder coordination, community development, and educational initiatives for waste reduction and resource efficiency. Environmental considerations include waste collection and processing metrics, value chain management, carbon emissions, resource consumption, and environmental protection measures, particularly regarding hazardous waste and contamination risks.

The Technology dimension examines the implementation of waste transformation technologies, digital and IoT applications, contamination control measures, transportation infrastructure, and energy efficiency technologies.

As shown in **Table 3**, this comprehensive scorecard framework provides a structured approach to evaluating the maturity level of smart waste management systems across multiple critical aspects of operations and sustainability.

Table 3. Score card of maturity level

Dimension	***Sub dimension/feature***
Governance	• Use of information and communication technology for collecting, sharing, and receiving waste data • Community participation through a system which collect community voices • Easy access to government funding, and transparency and accountable investments for waste management • Regulations, guidelines, and standard operational procedures to follow on waste management • Availability of interaction channel between community, government, and industry
Economy	• Affordable cost of waste management and service • High productivity of waste treatment process • Low cost resource consumption • Job opportunities • Affordable infrastructure and technology investment • Availability of purchasing, marketing, and promotion division • Potential reduction cost from green campaigns and initiatives

Social	• Level of safety and healthy life of people in the area of waste management • Skilled labour and knowledge of the employees in the area of waste management • Solid coordination between employee, industry and government • Improvement of community living capacity • Education to community, industry to reduce waste and to increase resource efficiency • Informal sectors participation through Government supervision
Environment	• Ultimate amount of wastes collected • Ultimate amount of wastes processed, recycled, composted etc. • Appropriate waste management value chain • Low carbon emission of waste management process • Efficient resource consumption and production • Environmental protection and hazardous reduction activities • Contamination hazard to ground water, air
Technology	• Use of appropriate technology to transform waste into valuable materials/energy in the cities • Wide application of digitalization, ICT and IoT from collection to treatment • Contamination hazard to ground water, air • Availability of transportation vehicles • Efficient energy consumption technology

The sustainability and smart waste management maturity framework encompasses five fundamental dimensions that evaluate system effectiveness and sustainability. This comprehensive framework assesses governance, which progresses from basic systems with minimal public engagement to advanced, cohesive management involving all stakeholders. The social dimension, comprising five distinct levels, evolves from basic legal compliance through organizational structure, technological integration, procedural management, and ultimately to human competency development. Economic maturity traverses three levels, beginning with limited economic benefits, advancing through measurable business growth, and culminating in high-performance systems generating significant value. The technological dimension similarly progresses through three stages: from common available technologies to varied management systems, and finally to specialized, unique technological solutions. The environmental dimension evaluates impact management, ranging from significant environmental effects through managed impact with preventive measures, to achieving minimal or zero environmental impact. These interconnected dimensions collectively provide a structured approach to assessing and developing sustainable waste management systems, enabling organizations to identify current positions and plan strategic improvements.

The measurement of Smart Waste Management System (SWMS) maturity level in this study utilizes a questionnaire based on the SWMS Framework. The assessment categorizes waste management maturity into five stages, considering governance, economic, social, environmental, and technological aspects [12]. The

maturity level classification is determined through a scoring system with relevant intervals, as shown in **Table 3**.

Table 3. Score card of maturity level

Dimension	*Traditional*	*Common*	*Integrated*	*Smart*	*Organised*
Governance	5-7	7-8	11-12	13-15	9-10
Economy	7-9	10-12	16-18	19-21	13-15
Social	6-10	11-14	20-24	25-30	15-19
Enviroment	7-9	10-12	16-18	19-21	13-15
Technology	5-7	8-9	12-13	14-15	10-11
Total	**30-42**	**43-57**	**73-85**	**86-102**	**58-72**

SWMS maturity framework is classified into five stages based on governance, economic, social, environmental, and technological aspects. The classification ranges from Traditional (30-42 points), Common (43-57 points), Organised (58-72 points), Integrated (73-85 points), to Smart (86-102 points).

Each level has distinct characteristics:

1. Traditional: Basic manual operations with minimal technology, limited facilities, and poor interdepartmental communication.
2. Common: Semi-automatic operations with basic regulation compliance and minimal skilled workforce.
3. Organised: Streamlined processes with established communication channels, moderate community participation, and standard compliance.
4. Integrated: Modern system with comprehensive integration, skilled workers, and high community engagement.
5. Smart: Globally connected system utilizing IoT and big data, featuring real-time monitoring, highly skilled workers, and automated technologies for maximum efficiency.

Based on the detailed maturity level descriptions and scorecard, Smart being the highest level requiring a total score of 86-102 points across five dimensions. To achieve Smart level maturity in Smart Waste Management Systems, organizations need to focus on developing and integrating several key components across all five dimensions:

1. Governance (13-15 points):
    - Implement self-regulation compliance and real-time information systems
    - Establish transparent decision-making and stakeholder management processes
    - Develop advanced documentation and reporting frameworks
2. Economic (19-21 points):
    - Deploy automated operational systems with cost-effective technologies
    - Establish sustainable funding and efficient resource allocation mechanisms
    - Create value-driven waste management processes
3. Social (25-30 points):

- Develop highly skilled workforce through comprehensive training
- Foster active community involvement and participation
- Implement advanced health, safety protocols, and awareness initiatives

4. Environmental (19-21 points):
    - Establish comprehensive waste reduction strategies
    - Implement monitoring systems and circular economy approaches
    - Maintain strong environmental awareness culture
5. Technological (14-15 points):
    - Deploy integrated IoT systems and big data analytics
    - Implement real-time monitoring and control systems
    - Develop advanced automation technologies

Organizations must achieve high scores across all dimensions simultaneously, as the Smart level represents a holistic and integrated approach to waste management rather than excellence in isolated areas.

C. Result and Discussion

The assessment process involved identifying factors from previous research, conducting interviews, and administering questionnaires to determine maturity scores across 30 factors or sub-dimensions. Based on the evaluation results as shown in **Table 4**, PT. XYZ's smart waste management system implementation is at the "Organised" maturity level with a total score of 62 out of the 58-72 range. Among the five dimensions evaluated, the social dimension achieved the highest score with 16 points, followed by the environmental dimension with 14 points, technology dimension with 11 points, economic dimension with 10 points, and governance dimension with the lowest score of 9 points, indicating significant room for improvement particularly in technology integration and governance aspects to achieve higher maturity levels. This comprehensive assessment identified notable gaps, particularly in technological integration and economic optimization, highlighting areas requiring significant development to reach the desired "Smart" maturity level.

Table 4. Assessment analysis based on maturity score

Dimension	Score	*Current Maturiy Level*
Governance	9	Organised (9-10)
Economy	10	Common (10-12)
Social	16	Organised (15-19)
Environment	14	Organised (13-15)
Technology	11	Organised (10-11)
Total	61	Organised (58-72)

After determining the current maturity level, a gap analysis was conducted to compare the present conditions with the desired state. Based on analysis through interviews and questionnaire responses, the desired maturity level for smart waste

management at PT. XYZ is targeted to be at the Smart level. **Table 5** illustrate the gap analysis results of PT. XYZ's smart waste management system maturity level, which currently remains below the Smart level.

Table 5. Maturity Level Assessment

Dimension	Score	*Current Maturiy Level*	*Target Maturity Level*
Governance	9	Organised (9-10)	Smart (13-15)
Economy	10	Common (10-12)	Smart (19-21)
Social	16	Organised (15-19)	Smart (25-30)
Environment	14	Organised (13-15)	Smart (19-21)
Technology	11	Organised (10-11)	Smart (14-15)
Total	61	Organised (58-72)	Smart (86-102)

To achieve the "Smart" maturity level with a target range of 86-102 points, there remains a significant gap from PT. XYZ's current position of 62 points, indicating a substantial need for strategic improvements across multiple dimensions. The largest gaps are identified in the technology and economic dimensions, requiring substantial investment and development of more comprehensive integrated systems to bridge this 24-point difference. These gaps indicate the need for a structured development strategy, particularly in automation, data integration, and IoT technology implementation, along with strengthening stakeholder communication systems to support transformation toward higher maturity levels.

The maturity level gap assessment presented in **Table 6** demonstrates that PT. XYZ currently operates at an "Organised" maturity level with a score of 61. To achieve the targeted "Smart" maturity level, which requires a score between 86-102 points, the organization needs to bridge a considerable gap of at least 25 points. This assessment clearly identifies the extent of improvement required to elevate the organization's waste management system from its current structured state to a more advanced, smart-enabled operation.

Table 6. Maturity Level Gap Assessment

Current Maturity Score	*Current Maturiy Level*	*Target Maturity Level*	*Target Maturity Level*
61	Organised	86-102	Smart

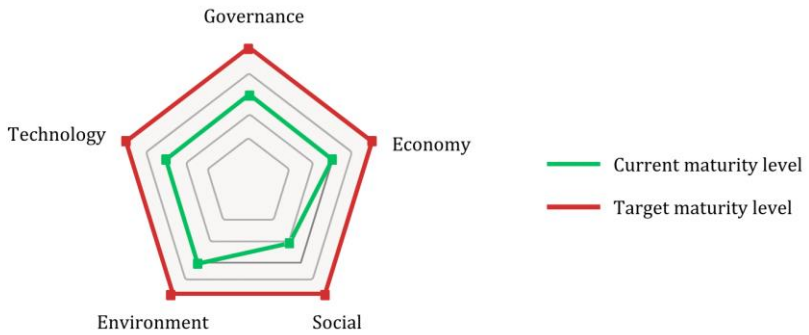

Figure 1. Maturity Level Gap Assessment

Following the gap analysis illustrated in **Table 6** and **Figure 1**, the assessment reveals specific areas requiring immediate attention and strategic intervention. In the technology dimension, the company needs to enhance its digital infrastructure, implement advanced IoT solutions, and develop more sophisticated data analytics capabilities. The economic dimension requires optimization of resource allocation, development of cost-effective solutions, and strategic investment planning to support technological advancement. Furthermore, while the social and environmental dimensions show relatively better performance, there is still room for improvement through enhanced stakeholder engagement, improved communication channels, and more robust environmental monitoring systems. This comprehensive gap analysis provides a clear roadmap for PT. XYZ to systematically advance its maturity level through targeted interventions and strategic investments across all dimensions.

Recommendations were developed to enhance maturity levels at PT. XYZ towards achieving Smart-level maturity, based on comprehensive analysis using the mapped maturity level scorecard. Achieving smart waste management is crucial as it effectively addresses growing waste management challenges through the integration of modern technologies, enhanced operational efficiency, and promotion of sustainable practices [19]. These recommendations, formulated through thorough analysis of current gaps and industry best practices, provide a structured approach to implementing smart waste management systems while ensuring sustainable development and operational excellence. The proposed improvements focus on strengthening technological infrastructure, optimizing operational processes, and fostering environmental sustainability, ultimately positioning PT. XYZ to meet future waste management demands effectively.

Table 7 outlines the detailed recommended improvements for enhancing the smart waste management system maturity level, encompassing strategic initiatives across technological, economic, social, environmental, and governance dimensions. The proposed recommendations focus on both short-term quick wins and long-term strategic improvements, ensuring a balanced approach to maturity enhancement. Each recommendation is prioritized based on its potential impact, resource requirements, and implementation complexity, providing PT. XYZ with a clear roadmap for systematic advancement.

Table 7. Recommendations for Maturity Level Improvement

Domain	*Recommendation*

Governance	Strengthen policy framework: • Develop comprehensive digital transformation roadmap • Create clear guidelines for technology adoption and implementation • Establish measurable KPIs for digital initiatives • Develop standardized operating procedures for digital processes Enhance stakeholder engagement: • Implement regular stakeholder meetings and feedback sessions • Create cross-functional teams for better coordination • Establish clear communication channels and reporting structures
Economy	Cost-benefit alignment: • Review and restructure waste management cost allocation • Implement performance-based incentive systems • Develop cost-sharing models with stakeholders
Social	Social responsibility: • Implement fair labor practices • Ensure health and safety standards • Create inclusive workplace policies • Support local social development initiatives Community responsibility: • Establish community feedback mechanisms • Develop public awareness programs • Create educational initiatives about waste management • Build partnerships with local communities
Environment	Sustainable practices implementation: • Create environmental impact monitoring systems • Establish waste reduction and recycling programs Environmental compliance: • Regular environmental audits • Update policies to meet environmental regulations
Technology	Implement a structured digital upskilling program: • Develop tailored training modules for different skill levels • Partner with technology vendors for specialized training • Create mentorship programs pairing tech-savvy employees with those needing support Establish continuous learning initiatives:

- Regular workshops and certification programs
- Cross-departmental knowledge sharing sessions
- Professional development paths focused on digital competencies

D. Conclusion

This research aims to assess the maturity level of SMWS implementation at PT. XYZ based on 5 maturity dimensions derived from previous research frameworks. The findings indicate that PT XYZ has not yet fully achieved the 'Smart' maturity level. Some recommended suggestions to enhance the project management maturity level include developing a comprehensive digital transformation roadmap, reviewing and restructuring waste management cost allocation, and establishing professional development paths focused on digital competencies.

The findings can serve as a guideline for organizations to implement a Smart Waste Management System, enabling them to better prepare and achieve an effective smart waste management system. For academic development, future research should expand the study's scope to include more waste management companies in Indonesia, as this study focused on a single company. Additionally, future studies should develop a more comprehensive evaluation framework with new dimensions and indicators relevant to technological advancements and industry needs.

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