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Development of a Scheduled Waste Inventory and Monitoring System (SWIMS) to Improve Operational Efficiency and Inventory Accuracy in the Homecare Manufacturing Sector, Petaling Jaya

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Abstract

The management of scheduled waste in Malaysia is a stringent legal requirement under the Environmental Quality Act 1974, yet many manufacturers still rely on manual, paper-based recording systems that are prone to transcription errors and compliance vulnerabilities. This study articulates the design and implementation of the Scheduled Waste Inventory and Monitoring System (SWIMS), an advanced digital tool developed within the Google Workspace ecosystem. By utilising mobile-optimised interfaces and automated scripts for mass balance evaluations, SWIMS aims to bridge the gap between physical inventory and digital records.

A thorough eight-week industrial pilot assessment revealed that the conventional manual recording method produced an average error rate of 6.37%, in contrast to SWIMS, which achieved a consistent error rate of 1.56%, reflecting a 75% reduction in recording discrepancies. In addition, the operational effectiveness experienced a notable rise, as the average duration for reconciliation per cycle fell from 25.21 minutes to 12.75 minutes, achieving a 49% increase in overall efficiency. Statistical validation through a Paired Sample T-Test confirmed that these enhancements were of substantial importance ($p < 0.001$). These findings demonstrate that cost-effective, low-code interventions can effectively transition waste management into the Industrial Revolution 4.0 paradigm, empowering EHS personnel to move from passive record-keeping to proactive risk management.

1. Introduction

The management of Scheduled Waste in Malaysia constitutes a stringent legal obligation as delineated by the Environmental Quality Act of 1974 [8]. Corporations are required to meticulously monitor hazardous waste from its inception until its ultimate disposal. R 4.0 is a paradigm shift affecting the entire industrial value chain. In the same vein, it marks the transition towards a smart and connected world enabled by the Internet of Things (IoT) and the Internet of Services (IoS) [2]. Considering that the manufacturing industry is the largest contributor of scheduled waste, the need for these laws to be adhered to is greater [9]. This study focuses on creating the Scheduled Waste Inventory and Monitoring System (SWIMS). It uses low-code tools, which are simple and customizable software like Google Forms, to move away from manual paperwork without spending a lot of money on new IT systems.

There is a clear need for this study because manual recording is slow and leads to many mistakes [1]. Most large corporate software lacks granular modularity. This is the ability to track small and specific details like individual waste drum dates and codes. As a result, staff must frequently enter the same data into multiple systems. This study is important because it offers a way to link the physical waste shed directly to digital records. This approach aids Environmental, Health, and Safety (EHS) teams in maximizing time resources and ensuring compliance with regulatory requirements.

The fundamental concern resides in the enduring inconsistencies between the actual waste present on the production floor and the data documented in the official Electronic Scheduled Waste Information System (eSWIS). Such transcription inaccuracies emerge when discrepancies manifest during the conversion of data from analog records to digital formats. These inaccuracies engender considerable compliance vulnerabilities. Should these discrepancies remain unaddressed, corporations may incur substantial fines or potentially face criminal prosecution in accordance with Regulation 9 of the Scheduled Waste Regulations of 2005. Poor tracking also creates safety risks. For example, without accurate records, a worker might accidentally store reactive chemicals too close together. This could lead to fires or leaks.

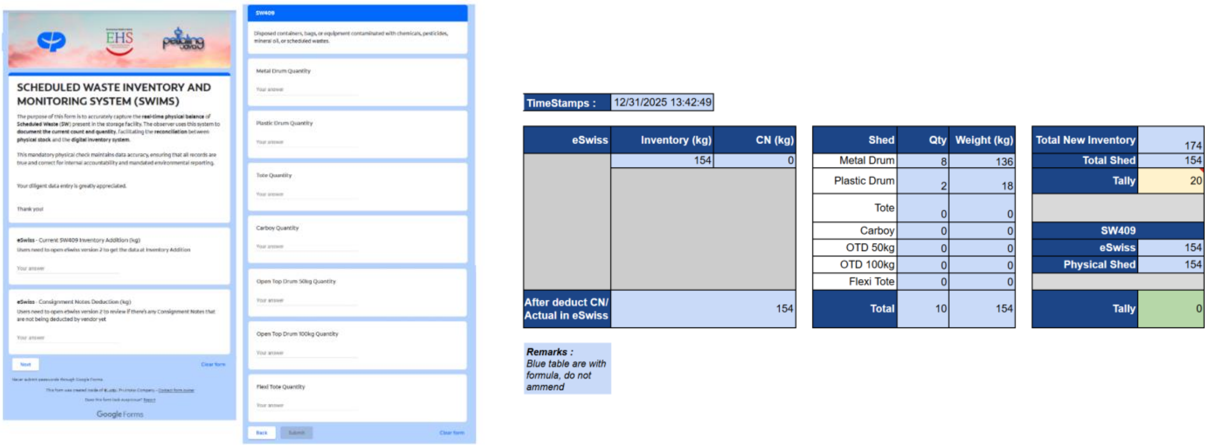
This research seeks to address these challenges by initially pinpointing the junctures at which the manual processes falter. Subsequently, the research will develop the SWIMS tool to automate the data entry processes and mass balance computations. Mass balance serves as a technique employed to verify that the quantity of waste entering storage corresponds accurately with the quantity exiting. The ultimate objective is to evaluate the extent to which this system mitigates error rates and reduces labor hours within a tangible industrial setting. In accomplishing this, the research facilitates manufacturers in the seamless integration of digital technologies. It ensures that waste management practices are not only environmentally sustainable but also fully compliant with governmental regulations. It ensures that waste management is both safe for the environment and fully compliant with government rules. Therefore, a management that is both responsive and responsible is required urgently [12]

2. Methodology

This section described the systematic approach used to develop and validate the SWIMS application. The project addressed regulatory risks and manual inefficiencies in scheduled waste management as required by the Environmental Quality Act 1974 (refer to Table 1 for weekly comparison data). The methodology employed a low-code implementation approach to move from paper-based records to a digital system. It utilized open-source technology from the Google Workspace environment to reduce financial and technical barriers.

2.1 Materials

The study utilized the Google Workspace as the primary development platform. Core concepts of IR 4.0 which physically tend to involve integration of hardware, are still directly relevant and necessary to environmental compliance topics in particular Cloud Computing and Advanced Analytics [6]. The choice of easily usable low-code tools, such as Google Forms can be used effectively for data collection and assessment in online contexts, presenting various advantages [7]. A Google Form served as the mobile-optimized user interface for data collection. Google Sheets acted as the centralized database for storing timestamped records. Advanced spreadsheet functions and scripts provided the logic for mass balance calculations (refer to Table 3 for technical logic details). Physical tools included mobile devices for on-site data entry at the waste storage shed. Industrial scales were used for verifying the weights of specific waste streams. Stopwatches were also employed to track the time spent on administrative tasks (Refer to Table 2 for statistical analysis of these tasks).



(a) (b)

Fig. 1 *Figure (a) Google Form Platform ; (b) Google Sheets Database*

2.2 Procedure

The system development followed a three-stage implementation process. First, the Google Form was designed to capture regulatory parameters like waste codes and container counts. Second, the Google Sheet was configured to receive all submissions automatically in a master log. Third, logic scripts were written to execute tally reconciliations and compliance checks. The research involved an eight-week parallel data collection period. Waste handlers performed two separate tasks for every batch of waste. They first wrote the details in the physical logbook and then entered the same data into the SWIMS mobile interface. Weekly physical audits were conducted to establish a benchmark for accuracy.

2.3 Characterization

The system was tested using a two-week pilot test with real data and synthetic edge cases. Performance was measured using two specific metrics: the Data Discrepancy Rate and Administrative Time. The Data Discrepancy Rate compared recorded counts against physical audit results. Administrative Time measured the minutes required to maintain and validate inventory records. A colour-coded alert system validated the compliance status. Green indicated compliance within a 0.5% tolerance, while red signalled a critical data integrity failure. The researcher also checked density constants to ensure consistency in weight conversions.

2.4 Data Analytic Strategy

The study used a quantitative before-and-after design to evaluate the system in an industrial setting. This involved comparing the performance of manual record-keeping against the new digital intervention. By using the same factory and staff, the researcher ensured that improvements were due to the system itself. The researcher compared the physical ground truth counts to both the manual logbook and the digital database. This comparison provided numerical evidence to prove whether the digital system was more efficient and accurate than the manual method. The data collection followed the requirements of Regulation 12 of the Scheduled Wastes Regulations 2005.

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3. Results & Discussion

3.1 Result

The study assessed data accuracy by measuring discrepancy rates to determine how often inventory records aligned with physical stock. The manual recording method produced an average error rate of 6.37% over the eight-week period. In contrast, the SWIMS application achieved a stabilized error rate of 1.56%. This represents a 75% reduction in recording errors by removing 'latent conditions' that lead to non-compliance. These systemic vulnerabilities are labeled as 'latent conditions' flaws concealed in the design of an enterprise that are dormant until they coincide with active performance failures to breach compliance [11]. Weekly performance trends showed that manual errors reached peaks of 8.45% and 7.64% during periods of high production, while SWIMS maintained significantly higher accuracy levels.

Table 1 *Comparison of Data Discrepancy Rates (8-Week Trend)*

Week	Manual Discrepancy	SWIMS Discrepancy	Gap	Observation
1	6.75%	1.60%	5.15%	Initial Implementation
2	7.44%	1.10%	6.34%	Rapid Familiarization
3	7.34%	0.60%	6.74%	Early Improvement
4	8.45%	7.12%	1.33%	High Production (Visual Obstruction)
5	6.92%	0.40%	6.52%	Stabilized Accuracy
6	6.38%	0.35%	6.03%	High Accuracy Achieved
7	0.00%	0.00%	0.00%	Low Production (Low Complexity)
8	7.64%	0.30%	7.34%	Fully Adapted
Average	6.37%	1.56%	4.81%	Significant Reduction

Operational efficiency was measured by the total time required for counting, calculating, and final recording. The manual process averaged 25.21 minutes per reconciliation cycle, whereas the SWIMS process averaged 12.75 minutes per cycle. The implementation of the digital system resulted in an average saving of 12.46 minutes per check and a 49% overall efficiency gain. Even in undemanding settings such as Week 7, SWIMS performed twice as fast as the manual baseline. These gains were primarily driven by the elimination of the "Office Trip" required for manual computing and filing.

A Paired Sample T-Test (a method to compare the manual and digital processes) was conducted on 40 daily observations (the total sample size, $n=40$) to verify the consistency of these findings. The analysis of discrepancy rates yielded a t-value of 18.51, and the analysis of man-hours yielded a t-value of 21.80 (the test statistics indicating the strength of the difference). Both variables showed highly significant p-values, $p < 0.001$ (the probability that results happened by chance is less than 0.1%), which decisively rejected the Null Hypothesis. This statistical evidence confirms that the improvements in accuracy and efficiency were a direct result of the SWIMS intervention rather than a random occurrence.

Table 2 *Paired T-Test Results*

Variable	Mean Difference	t-value	p-value ($\alpha=0.05$)	Result
Discrepancy Rate	4.81%	18.51	< 0.001	Significant
Man-Hours	12.46 min	21.80	< 0.001	Significant

3.2 Discussion

Findings suggest that manual inventory methodologies yield satisfactory results solely under conditions of minimal complexity, as evidenced in Week 7, where the incidence of errors was recorded at zero. Nevertheless, manual systems exhibit a distinct "failure mode" when confronted with peaks in industrial performance coupled with heightened cognitive demands, resulting in a notable increase in errors during Week 8. SWIMS operates as a "compliance cushion" that safeguards data integrity amid fluctuations in waste volume. This mechanism ensures that the chain of custody remains legally defensible, even in the face of augmented operational complexity.

The elevated data integrity afforded by SWIMS can be ascribed to the logic generated by the system, which effectively eradicates errors stemming from human calculation and transcription. This layer of logic, integrated within Google Sheets, functions as an expert system for compliance. It employs specific formulas such as IMPORTRANGE (Dynamically retrieves the latest official inventory record into the officer's mobile screen for accurate comparison) and QUERY (Instantly verifies the latest mobile form input against the existing master record to maintain the audit trail's integrity) to dynamically extract inventory records and validate form submissions in real-time. The resulting dashboard provides instant feedback, allowing the EHS officer to focus on data entry rather than manual tallies. Although the need to calculate storage days has an active effect, a manual calculation is a passive monitoring failure, as the system is not aware of storage days, nor is it able to activate an alert of the user [4].

Table 3 *Formula used for SWIMS*

Function	Purpose	Formula Example (Illustrative)
Real-Time Data Pull	IMPORTRANGE	=INDEX(IMPORTRANGE("URL", "Tab Name!I4:I"), COUNTA(IMPORTRANGE("URL", "Tab Name!I4:I")))
Latest Entry Verification	QUERY	=QUERY('Form Responses 1'!A:W, "SELECT B ORDER BY A DESC LIMIT 1", 0)

The traditional manual method was hindered by a two-step cycle that required personnel to record stock on paper and then return to the office the "Administrative Burden" to calculate mismatches and update logbooks. SWIMS transforms this into a single-step process completed entirely at the waste shed. While the system removes non-value-added activities like manual data duplication, the data from Week 4 shows that digital tools cannot overcome physical failures such as bad stacking or visual obstructions. This highlights that digital accuracy must be supported by stringent shop floor discipline and housekeeping measures.

3.3 Limitations of the Study

The enhanced data integrity offered by SWIMS can be attributed to the logic produced by the system, which proficiently eliminates errors associated with human calculation and transcription. It is suggested that manual data collection is fundamentally incompatible with contemporary quality standards, as the 'right-first-time' validation provided by real-time digital systems is not received [10]. Strong evidence for this claim is presented by findings indicating that the visual checking typically used to verify handwritten logbook entries is nearly 30 times less effective than automated or double-entry methods [3]. The pilot study was confined to a finite number of scheduled waste codes and conducted within a singular manufacturing facility, which may constrain the immediate applicability of the findings to other waste types or diverse industrial sectors. Moreover, given that the system is operational on a cloud-based platform, its functionality is contingent upon stable internet access within the waste storage environments. Additionally, while the system adeptly automates calculations, it remains dependent on the initial manual input of physical counts by waste handlers, thereby permitting a slight margin for potential input errors at the source.

3.4 Recommendations for Future Work

In order to capitalize on the successes of the SWIMS platform, several avenues for future enhancement and expansion are proposed. A pivotal recommendation involves the integration of IoT-enabled digital weight scales that directly interface with the cloud-based database; this would obviate the necessity for manual weight input and further mitigate human error. There exists significant potential for establishing a direct data conduit between the SWIMS platform and the Department of Environment's eSWIS platform to automate reporting at the conclusion of the waste life cycle. Finally, future endeavors should contemplate the implementation of an automated notification system via mobile messaging. This would enable plant managers to receive near real-time alerts when waste levels reach predetermined thresholds, thereby promoting a more proactive and efficient approach to environmental compliance.

4. Conclusion

This investigation adeptly illustrated that the adoption of the Scheduled Waste Inventory and Monitoring System (SWIMS) transitioned the management of industrial waste from traditional manual logbooks to a sophisticated, compliant electronic framework. Aligning waste management with the fourth industrial revolution involves a necessary evolution from manual oversight to automated, data-driven compliance [5]. By employing cost-effective low-code tools, the study accomplished a substantial reduction in data error rates in comparison to manual methodologies and significantly enhanced operational efficiency, reducing reconciliation tasks from several weeks to merely a few hours. In addition to technical performance indicators, the initiative redefined the roles of Environmental, Health, and Safety (EHS) personnel from passive record keepers to proactive risk managers, thereby demonstrating that digital interventions can effectively alleviate regulatory risks and resolve administrative challenges even within under-resourced industrial environments. Going forward, future research must emphasize the enhancement of system autonomy and integration to tackle current shortcomings, including the persistent reliance on manual physical counts and the requirement for stable internet connectivity. Significant areas for the development of research include the adoption of Internet of Things (IoT)-assisted digital scales to reduce human error in data entry methods, the establishment of a direct data pipeline to the national eSWIS platform for the automated facilitation of "cradle-to-grave" reporting, and the implementation of real-time automated alert systems to support a more proactive strategy regarding environmental compliance.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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This guide contains examples of common types of APA Style references. Section numbers indicate where to find the examples in the Publication Manual of the American Psychological Association (7th ed.).

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