Data-driven Lean 4.0 and VRP-Based Model to Improve OTIF in Food-Distribution SMES

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Abstract

Peru's food-distribution sector continues to face operational instability, low digitalisation and limited process standardisation, affecting logistics service reliability. This research addresses the low On-Time In-Full (OTIF) performance of a Peruvian food-distribution SME supplying non-perishable products to institutional and private clients. The initial diagnosis showed an OTIF of 65.4%, below the national average of 69% and the regional benchmark of 70–75%. The main causes were picking errors, documentation mistakes and inefficient route planning. To address these deficiencies, an integrated Lean 4.0 model was proposed, combining Standard Work to reduce picking variability, a Digital Poka-Yoke developed in AppSheet for barcode-based validation, and a Vehicle Routing Problem module implemented in Python with Google OR-Tools. The model was validated through a six-week pilot test and discrete-event simulation in Arena. Results showed that OTIF increased from 65.4% to 83.0%, picking cycle time decreased from 2374 to 890 seconds, documentation errors were reduced from 27% to 3%, and on-time delivery improved from 74% to 82%. These findings demonstrate that low-cost Lean–Digital tools can improve logistics reliability in food-distribution SMEs.

1 Introduction

The food logistics sector plays a relevant role in the Peruvian economy, as the food industry represents 26.2% of manufacturing GDP. However, food-distribution SMEs continue to face structural limitations related to manual operations, low digital adoption, insufficient process standardisation and limited transport planning. These conditions affect logistics service levels, especially in companies that distribute non-perishable food products to institutional and private clients. Regional evidence indicates that logistics service levels in Latin America, measured through indicators such as OTIF, seldom exceed 75%, while global benchmarks frequently surpass 85% [1].

In this study, logistics service level is measured through the On-Time In-Full indicator, which evaluates the percentage of customer orders delivered in the correct quantity and within the agreed delivery window. Previous studies indicate that the absence of standardised warehouse procedures increases variability, reduces inventory accuracy and affects order reliability [2]. In addition, poor coordination between warehousing and transportation can extend lead times and reduce service performance in food-sector SMEs [3].

The case company reported an OTIF of 65.4% from 910 deliveries processed in 2024, of which only 608 were delivered complete and on time. Monthly OTIF performance ranged from 62.3% to 66.1%, showing persistent underperformance. The OTIF decomposition showed that In-Full reached 68%, while On-Time reached 74%, indicating that the main deficiencies were related to order completeness, picking accuracy, documentation control and delivery punctuality.

The initial diagnosis showed that the company operates with weekly planning, ten daily deliveries and approximately 130 institutional delivery points within a ten-day operating window. A Value Stream Mapping analysis identified a total process time of 70 minutes per standard order and 4.03 days of accumulated waiting time, mainly caused by delays in quality inspection and dispatch planning. Root cause analysis identified three dominant causes of the low OTIF level: picking errors from non-standardised manual procedures (36%), documentation errors from manual validation and inconsistent records (27%), and inefficient routing from empirical route planning (24%).

Existing literature provides partial solutions to these problems. Standard Work and Lean warehousing tools reduce variability in manual picking processes [4]. Digital Poka-Yoke systems prevent documentation and data-entry errors through automated validation mechanisms [5]. Vehicle Routing Problem models improve transport efficiency by optimising delivery sequences under operational constraints [6], [7]. Other studies have also shown that Lean warehousing, RFID, IoT, barcode-based systems and cluster-first route second approaches can improve OTIF, traceability and delivery planning [8], [9], [10]. However, these approaches are often applied separately. Therefore, this research proposes an integrated Lean 4.0 and VRP-based model composed of Standard Work, Digital Poka-Yoke and route optimisation to improve OTIF in a food-distribution SME.

2. Methodology

The dependent variable of this study was the On-Time In-Full (OTIF) indicator. The independent variables were Standard Work in picking, Digital Poka-Yoke for barcode-based validation, and a VRP-based route planning module. The research followed an applied improvement design combining diagnosis, pilot testing and discrete-event simulation.

The unit of analysis was the customer order. The population consisted of 910 orders processed during 2024, from which a representative sample of 271 orders was calculated using a 95% confidence level, a 5% margin of error and maximum variability. In addition, a pilot test involving 60 orders was conducted to estimate TO-BE operational parameters.

The diagnosis was developed through historical data review, direct observation, process mapping, Value Stream Mapping, Ishikawa diagrams and Pareto analysis. The standard institutional order was defined through Pareto analysis, where the eight most representative products concentrated more than 80% of the annual distributed volume. These products were used as the operational reference for analysing picking workload, order preparation and distribution performance, consistent with previous logistics improvement studies [11], [12].

Table 1. Key variables and measurement criteria

Variable	Measurement criterion	Purpose
OTIF	Complete and on-time orders / total orders	Measures the overall logistics service level
Picking cycle time	Time required to prepare one standard order	Evaluates the impact of Standard Work
Picking errors	Orders with preparation errors / total orders	Measures order preparation reliability
Documentation errors	Documents with inconsistencies / total documents	Evaluates Digital Poka-Yoke effectiveness
On-time delivery	Orders delivered within the agreed window / total orders	Measures VRP-based delivery punctuality

The proposed model integrates three components. First, Standard Work was applied to optimise picking. A Work Combination Chart identified multiple trips, manual counting and high physical effort, with an AS-IS cycle time of 2374 seconds per standard order. Through ECRS analysis, unnecessary return trips, fatigue pauses, redundant checks and manual verification were eliminated or simplified, reducing the target cycle time to 890 seconds [4], [11].

Second, a Digital Poka-Yoke system was developed in AppSheet. Operators scanned product barcodes and validated them against the digital order before continuing. If the product did not match the assigned item, the application blocked the next step. The same logic was applied to quantity control, delivery confirmation, digital signature and receiver data registration, following digital error-proofing principles supported by barcode, RFID-like validation and IoT-enabled control mechanisms [8], [9], [13].

Third, a VRP-based route planning module was implemented in Python using Google OR-Tools. The fleet included two vans with 1200 kg capacity and two trucks with 2500 kg capacity. The model was formulated as a Capacitated Vehicle Routing Problem, ensuring that each customer was visited once, each vehicle started and ended at the warehouse, and vehicle capacity was not exceeded. A cluster-first, route second logic was used to calculate the optimal delivery sequence [6], [14], [15].

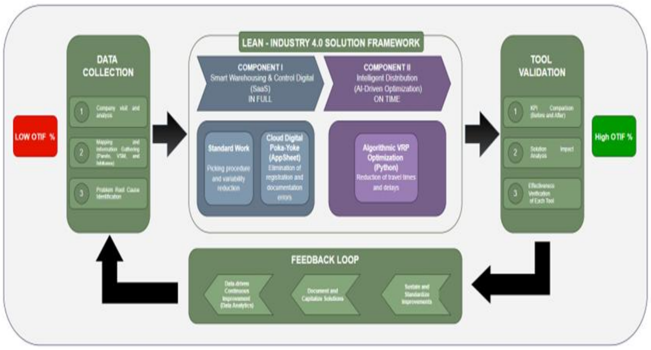

Figure 1 Proposed model.

The validation combined a six-week pilot and Arena Simulation v16. The AS-IS model replicated the logistics process from reception to delivery, and Input Analyzer was used to fit operational distributions. The AS-IS model showed an average cycle time of 155.20 minutes per order, with a standard deviation of 25.50 minutes and a 95% confidence interval from 151.10 to 159.30 minutes. The TO-BE model incorporated pilot-derived parameters: standardised picking time, digital validation logic and VRP-optimised transport times. Ten simulation replications were used, exceeding the minimum of eight replications required at a 95% confidence level and a 5% error margin.

3 Results

3.1 Diagnosis and root cause analysis

The initial diagnosis confirmed that the company's OTIF level was 65.4%, below the national average of 69%, the regional benchmark of 70–75% and the international reference level above 85%. From the 910 orders analysed, 315 orders did not meet the complete or on-time delivery condition. The monthly results showed persistent underperformance, indicating that the problem was structural rather than occasional [1], [3].

The Value Stream Mapping analysis identified several operational inefficiencies. The process showed a total operating time of 70 minutes per standard order and 4.03 days of accumulated waiting time. The main sources of delay were quality inspection and dispatch planning. The comparison with a takt time of 48 minutes per delivery showed that the system lacked synchronisation between warehouse preparation and distribution planning, a condition frequently associated with insufficient process standardisation and weak warehouse control [2], [7], [12].

The OTIF decomposition showed that In-Full reached 68%, while On-Time reached 74%. This six-percentage-point gap indicated that the most critical deficiencies were associated with order completeness, picking accuracy and documentation validation. The Ishikawa and Pareto analyses confirmed that the main root causes were lack of standardised picking procedures, manual and ineffective validation of guides and records, and manual route planning without optimisation [4], [5], [6].

The problem tree summarises the causal structure behind the low OTIF performance. It shows how non-standardised picking, manual documentation control and empirical route planning generate incomplete orders, delivery delays and economic losses, justifying the selection of Standard Work, Digital Poka-Yoke and VRP optimisation as improvement components.

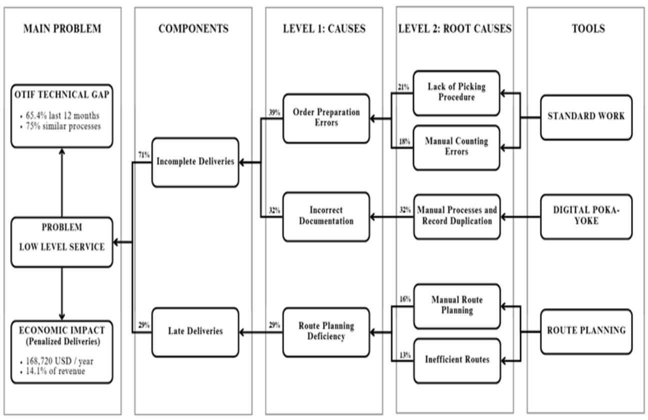

Figure 2. Root Cause Problem Tree.

3.2 Standard work implementation

The Standard Work intervention focused on reducing picking variability and eliminating unnecessary movements, following Lean warehousing approaches that emphasise repeatable task sequences, visual control and standardised execution to improve order accuracy [2], [4], [11]. In the AS-IS scenario, operators performed repeated trips between storage locations and the dispatch area, resulting in an inefficient flow and high physical effort. The initial spaghetti diagram confirmed multiple return movements, while the Work Combination Chart identified 30 microactivities and a total picking cycle time of 2374 seconds per standard order.

The ECRS analysis revealed several improvement opportunities, consistent with Lean improvement principles applied to warehouse process standardisation [4], [7]. Return and unloading activities accounted for 1027 seconds, equivalent to 43% of the total cycle time, and were eliminated through the use of a picking cart and a single-route picking method. The fatigue pause was removed by reducing manual load carrying, and the final manual verification was replaced by barcode-based validation. In addition, the picking route was reorganised into a standard sequence, and the loading method was simplified by placing heavier products at the bottom and lighter products on top.

The improved method reduced the process to 20 standardised activities. As a result, the TO-BE picking cycle time decreased to 890 seconds, compared with 2374 seconds in the AS-IS condition, representing a 62% reduction. The redesigned method also generated a positive operational gap relative to the takt time of 2304 seconds, creating a margin of 1414 seconds per cycle. These results indicate that the new process became more stable, efficient and capable of meeting operational demand, confirming the role of Standard Work in reducing variability in manual logistics processes [2], [11].

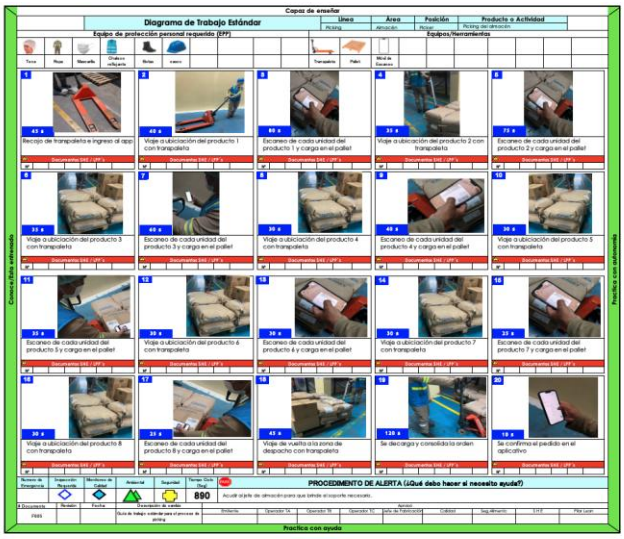

Figure 3 Standard Work Board.

The Standard Work Board summarises the redesigned picking process, including the standard sequence, activity times, visual controls, PPE requirements and target cycle time. It served as a practical guide for operator training and helped ensure process consistency during the pilot implementation.

3.3 Digital Poka-Yoke implementation

The Digital Poka-Yoke was designed to prevent picking, quantity and documentation errors throughout the order fulfilment process, following digital error-proofing principles based on barcode validation and automatic blocking of inconsistent records [5], [13]. The AppSheet application included role-based access, product catalogues, order details, picking validation, delivery validation and digital signature. During picking, operators were required to scan the correct product barcode before increasing the registered quantity. If the scanned code did not match the required product, the action was blocked. Once the required quantity was reached, the scan button was automatically hidden, preventing overpicking.

The system also controlled the delivery stage. Delivery documents and customer signatures could only be generated when all required products had been validated and the delivered quantities matched the order. This logic linked the physical process with the digital record, ensuring that documentation could not be completed if any product or quantity discrepancy remained unresolved. This approach is consistent with RFID- and IoT-enabled traceability mechanisms used to improve warehouse data accuracy [8], [9].

The pilot test was conducted over one week and covered 60 orders, 142 total items, four picking operators, two delivery workers and one warehouse manager. The complete flow was evaluated from picking and digital validation to distribution and final delivery signature. The results showed a substantial reduction in operational errors. Incorrect product errors decreased from 11.20% to 0%, overcounting or shortages decreased from 18.70% to 3.10%, and reprocessing cases fell from 14 to 2 per week. In the documentation stage, incomplete or inconsistent delivery records decreased from 9.50% to 0%, receiver data errors decreased from 7.00% to 1.60%, and physical delivery record losses decreased from two cases per week to zero. These results support the role of digital validation mechanisms in improving data integrity and reducing manual errors [5], [13].

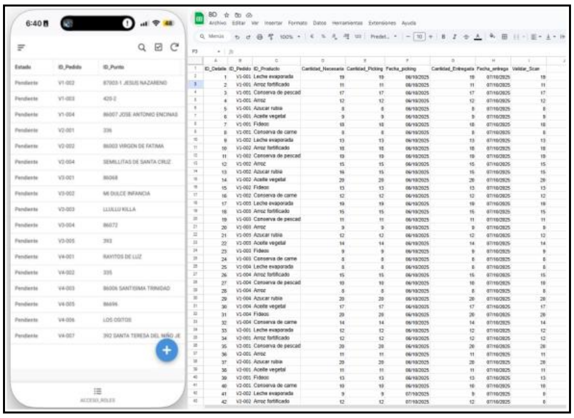

Figure 4. Digital Poka-Yoke Implementation for Order Packing Verification.

The figure illustrates the AppSheet-based validation system, including barcode scanning, synchronisation with the live database and field application during order packing and delivery. It shows how digital verification connected physical execution with real-time records, improving traceability and significantly reducing picking and documentation errors.

3.4 VRP-based route planning implementation

The VRP module addressed the route-planning deficiencies affecting the On-Time component of OTIF. In the AS-IS scenario, route assignment was based on empirical criteria, generating unnecessary travel distance, route deviations and high variability in delivery times, which are commonly reported problems in urban logistics systems [6]. The transport analysis showed that non-OTIF orders travelled between 2% and 13% more kilometres than OTIF orders, with an average deviation of 8%. These additional distances increased fuel consumption and logistics costs.

The proposed route planning model was developed in Python using Google OR-Tools to solve a capacitated vehicle routing problem. The algorithm considered the company’s fleet, composed of two vans with 1200 kg capacity and two trucks with 2500 kg capacity, as well as the delivery demand associated with the institutional distribution schedule. The model minimised total distance travelled while ensuring that each customer was visited once, each vehicle started and ended at the warehouse, and vehicle capacity constraints were satisfied, in line with VRP approaches focused on distance, time and capacity optimisation [10], [14], [15].
The routing results were exported to an Excel file containing route sequences, daily summaries, client data and global performance indicators. A Google Maps visualisation was then generated to validate the route sequence with the operations team and confirm its practical feasibility. The pilot showed that on-time delivery improved from 74% to 82%, mainly due to better route sequencing, lower distance variability and more efficient use of available vehicle capacity. This outcome is consistent with recent applications of food-delivery routing and cluster-first route-second strategies [16], [17].

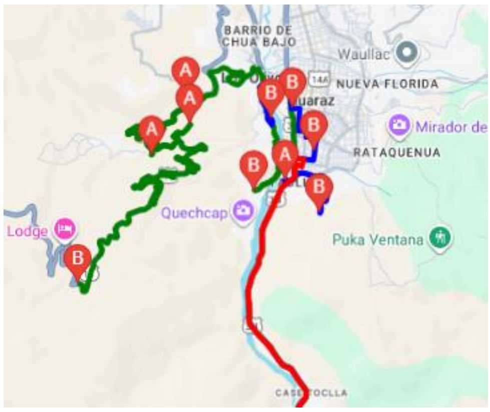

Figure 5 Visualization of routes.

The figure presents the optimised delivery routes generated with Python and Google OR-Tools and validated through Google Maps. It illustrates the improved sequencing of delivery points and supports the observed increase in punctuality and the reduction of unnecessary travel distance during the pilot.

3.5 Arena simulation results

The AS-IS simulation represented the logistics process from order arrival to final delivery, following simulation-based validation approaches commonly used to evaluate Lean logistics and warehouse improvement models [7], [11]. The model included reception, storage, quality control, dispatch planning, picking, loading, transport and delivery. Documentation errors were modelled through decision modules that redirected orders to reprocessing or classified them as incomplete. Picking variability was represented using a Weibull distribution, while transport was modelled as a separate process affecting the On-Time component.

The TO-BE model incorporated the improvements generated by the three proposed components. For picking, the process delay was adjusted to the standardised time of 890 seconds. For documentation, the error-checking logic was modified to reflect the blocking effect of the Digital Poka-Yoke system. For transportation, travel times were updated according to the optimised values obtained from the VRP module. This integration of process standardisation, digital validation and optimised routing supports a Lean–Digital improvement logic for service-level enhancement [5], [10], [13].
The simulation results showed a clear improvement in overall system performance. The average total cycle time decreased from 155 to 129 minutes, representing a 16.7% reduction. The standard deviation also decreased from 25.50 to 15.40 minutes, indicating a more stable and predictable logistics flow. At the process level, picking time decreased from 45 to 14.83 minutes, with a standard deviation of 1.50 minutes, confirming the effect of Standard Work and digital validation on operational stability [2], [4], [13].

A paired t-test comparing AS-IS and TO-BE total cycle times showed an estimated mean difference of 26.00 minutes. The 95% confidence interval ranged from 22.5 to 29.5 minutes and did not include zero, confirming that the proposed model significantly reduced total cycle time. In addition, the variance comparison for picking produced a ratio of 10.32, indicating that the AS-IS process was more than ten times more variable than the improved process.

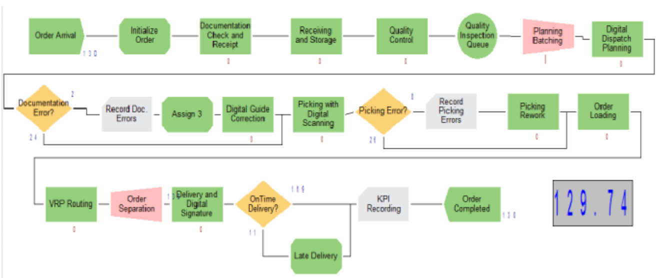

Figure 6 Simulation Model in Arena.

The figure shows the Arena model used to represent the AS-IS and TO-BE logistics processes. It illustrates the main process flow, decision points and operational stages incorporated into the simulation to evaluate the impact of the proposed improvements on service level and cycle time.

Table 2 Performance comparison between AS-IS and TO-BE scenarios

Indicator	AS-IS	TO-BE	Variation
OTIF	65.40%	83.00%	+17.6 pp
Picking productivity	500 pkg/h-h	620 pkg/h-h	24.00%
Picking error rate	10.00%	1.00%	−9.0 pp
Documentation error rate	27.00%	3.00%	−24.0 pp
On-time delivery	74.00%	82.00%	+8.0 pp
Total cycle time	155 min	129 min	−16.7%
Picking cycle time	2374 s	890 s	−62.5%

The results confirm that the integrated model improved both OTIF components. The Standard Work intervention reduced picking time and process variability. The Digital Poka-Yoke reduced documentation inconsistencies by preventing the process from advancing when product or quantity mismatches occurred. The VRP module improved delivery punctuality by replacing empirical planning with algorithm-based route sequencing.

4 Conclusion

The implementation of the integrated Lean 4.0 and VRP-based model improved the logistics service level of the studied food-distribution SME. The initial diagnosis showed an OTIF of 65.4%, mainly affected by picking errors, documentation mistakes and empirical route planning. To address these causes, the proposed model integrated three complementary tools: Standard Work, Digital Poka-Yoke and VRP-based route planning.

The Standard Work component reduced picking cycle time from 2374 to 890 seconds by eliminating unnecessary movements, simplifying manual tasks and establishing a fixed picking sequence. The Digital Poka-Yoke developed in AppSheet reduced documentation errors from 27% to 3% through barcode-based validation before dispatch and delivery confirmation. The VRP module improved on-time delivery from 74% to 82% by optimising route sequences according to vehicle capacity and delivery locations. As a result, OTIF increased from 65.4% to 83.0%.

The Arena simulation confirmed the operational impact of the proposal. Total cycle time decreased from 155 to 129 minutes, while the variability of the picking process was significantly reduced. The paired t-test confirmed a statistically significant reduction of 26 minutes in total cycle time, and the variance comparison showed that the AS-IS picking process was more than ten times more variable than the improved process.

From an economic perspective, the project proved feasible, generating a positive NPV of S/ 12,912.35, an IRR of 58%, a Benefit-Cost ratio of 1.83 and a payback period of 2.8 months. Overall, this study provides a replicable Lean–Digital framework for food-distribution SMEs, extending previous research on Lean warehousing, digital traceability and route optimisation [7], [8], [10]. Future research should evaluate the long-term implementation of the model and explore real-time traffic data, IoT-enabled monitoring and adaptive routing mechanisms [18], [19], [20].

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6 References

[1] Arabelen, L., Kaya, H.T.: 'Assessment of logistics service quality dimensions: A qualitative approach', Journal of Shipping and Trade, 2021, 6, pp. 1–15.

[2] Acevedo-Aybar, R., Jáuregui-Alfaro, F., Quiroz-Flores, J.C.: 'Standardization of warehouse processes to improve inventory accuracy', International Journal of Productivity and Performance Management, 2024, 73, pp. 450–470.

[3] Canales-Huaman, D.S., Gamio-Valdivia, K.G., Quiroz-Flores, J.C.: 'Integrated Lean Logistics–Warehousing model to reduce Lead Time in an SME of food sector'. Proc. IEIM 2022, Barcelona, Spain, 2022.

[4] Carhuas-Cuyubamba, K.: 'Standard Work and 5S to improve productivity in the picking process', Industrial Data, 2025, 28, pp. 75–88.

[5] Romero, L., Balderas, P.P., Macías, A.M.: 'Digital Poka-Yoke in manufacturing: A review of recent applications', Procedia CIRP, 2022, 107, pp. 112–117.

[6] Cheng, C., Yang, Y., Li, X.: 'Vehicle routing problem applications in urban logistics: A systematic review', Transportation Research Part E, 2022, 161, 102714.

[7] Vasquez-Quispe, M., Calcina-Flores, A., Quiroz-Flores, J.C., Collao-Diaz, M.: 'Implementing Lean Warehousing model to increase On Time and In Full of an SME commercial company'. Proc. ICIEA-EU 2023, Rome, Italy, 2023.

[8] Deepa, N., et al.: 'IoT-based smart warehouse management system using RFID', Measurement: Sensors, 2024, 32, 101034.

[9] Ngaboyimbere, K.: 'The impact of RFID technology on warehouse management', International Journal of Logistics Systems and Management, 2021, 38, pp. 345–362.

[10] Bührmann, J., Bruwer, R.: 'Vehicle routing problem with time windows: A cluster-first, route-second approach', Operations Research Perspectives, 2021, 8, 100189.

[11] Valdivia, A.D., Rentería, G.S., Flores, A.: 'Implementation of 5S, SLP, and Standard Work in a warehouse in Metropolitan Lima: Improvement of OTIF orders'. Proc. MSIE 2024, Bangkok, Thailand, 2024.

[12] Cerquera Pérez, L., De la Cruz Jauregui, G., Lopez Cabrera, M., Cespedes Blanco, C., Raymundo Ibañez, C.: 'Improvement of the storage and inventory management system for grocery stores', LACCEI Proceedings, 2024, pp. 1–10.

[13] Haswika, A., Pujotomo, D., Promea, S.N.W.: 'Integration of IoT and Poka-Yoke for quality control in manual assembly lines', IEEE Access, 2024, 12, pp. 15430–15442.

[14] Bektas, T., Erdogan, G., Ropke, S.: 'The Pollution-Routing Problem', Transportation Research Part B, 2011, 45, pp. 1232–1250.

[15] Ghasemi, P., Hemmaty, H., Pourghader Chobar, A., Heidar, M.R., Keramati, M.: 'A multi-objective and multi-level model for location-routing problem in the supply chain based on the customer's time window', Journal of Applied Research on Industrial Engineering, 2023, 10, pp. 412–426.

[16] Thipparthy, K.R., Khalaf, M.I., Yogi, K.S., Ofori-Amanfo, P.: 'Optimizing delivery routes for sustainable food delivery for multiple food items per order', Discover Sustainability, 2024, 5, 122.

[17] Poohoi, B., et al.: 'Cluster-first route-second for the vehicle routing problem: A case study in Thailand', Transportation Research Interdisciplinary Perspectives, 2024, 23, 100980.

[18] Deng, Y., Yan, Y., Chow, A.H.F., Zhou, Z., Ying, C., Kuo, Y.H.: 'A proximal policy optimization approach for food delivery problem with reassignment due to order cancellation', Expert Systems with Applications, 2024, 258, 125045.

[19] Jagtap, A., García-García, G., Rahimifard, S.: 'Optimization of the food supply chain through IoT and digital technologies', Journal of Cleaner Production, 2021, 283, 124633.

[20] Solari, F., Lysova, N., Romagnoli, G., Montanari, R., Bottani, E.: 'Insights from 20 years (2004–2023) of supply chain disruption research: Trends and future directions', Sustainability, 2024, 16, 7530.