Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Development of Artificial Intelligence Powered Zero Defect System Strategy for Production Management to Optimize Randomized Defect Monitoring with Centralized Monitoring System

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ARTICLE INFO

Received: 18 Oct 2024

Revised: 10 Nov 2024

Accepted: 28 Dec 2024

ABSTRACT

In the era of Artificial Intelligence, production management can get benefit from automated dispatch control. In case of an electrical control panel dispatch system, production management strategy involves integrating control panels into a broader system for managing and tracking the production of industrial electrical equipment, using software and hardware for real-time monitoring, dispatching, and overall production process control. This system aims to enhance production efficiency, ensure timely delivery, and maintain product quality by providing a centralized command and control interface for the entire panel manufacturing workflow. However, it is important to monitor and control the decentralized tracking to achieve the zero-defect deliveries. Hence, proposed research focuses on the Artificial Intelligence strategic development for order management to route optimization with randomized defect monitoring with centralized monitoring system.

Keywords: Zero defect logistic, Artificial Intelligence, Wireless monitoring, Product safety

1. INTRODUCTION

To achieve a zero-defect dispatch system for electrical control panels, a company must implement robust quality management throughout the manufacturing process, not just at the final stage [1]. This is based on Philip Crosby's principle of "doing it right the first time". The dispatch system is the final quality gate that confirms all upstream processes have been followed correctly before the product is delivered to the customer [2]. To err is human, but to err in the day and age of technology directly results in the loss of business and growth opportunities. The scope of this loss becomes even greater in the context of the logistics industry. Being largely dependent on its human resources, the industry is more prone to slips, lapses, and mistakes. With increasing adoption of technology, however, the industry has been eliminating such logistical bottlenecks and is rapidly making inbound and outbound logistics operations seamless through automation [3].

The nature of operational jobs in logistics entails repetitive tasks, exhaustive operations, and inflexible conditions. These factors directly result in human-related errors and can cause a significant depreciation in quality and productivity, especially as fatigue comes into play towards the end of the shift [4]. Moreover, with a high churn in manpower, training remains a constant challenge. Bringing automation into the logistics process has a twofold effect. Firstly, it reduces the dependency on human resources by deploying automation solutions which minimize human intervention. Secondly, the same system can be altered to perform a range of operations in almost no time by updating

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software mode and configurations. This, when compared to the workforce training that usually precedes such functional changes, results in highly flexible and efficient operations [5,6]. Moreover, the existing workforce can be trained to use automated systems easily through digital media such as videos, tests & mock drills.

1.1 Zero-defect dispatch systems

Prevention over inspection: Focus on preventing defects from occurring during the design and manufacturing stages, rather than just detecting and correcting them at the end.

Conformance to requirements: A defect is any failure to meet customer and design requirements. Your system should ensure the final product strictly conforms to all specifications.

Accountability: Every employee should be responsible for the quality of their work. This fosters a culture where quality is a shared goal, not just the quality assurance team's job.

Measurement and financial impact: Measure quality by the cost of non-conformance (waste, rework, customer dissatisfaction). This financial metric highlights the value of the zero-defect approach.

2. LITERATURE REVIEW

Recent advances in quality manufacturing research have focused on the industrial landing of Zero-defect Manufacturing (ZDM) which is aiming toward a more precise, robust, and sustainable production paradigm. Cyber-physical system (CPS) is a critical framework and low-rank representation (LRR) is the method which has widely used in computer vision, signal processing and other research areas [7].

Contemporary firms rely heavily on the effectiveness of their supply chain management. Modern supply chains are complicated and unpredictable, and traditional methods frequently find it difficult to adjust to these factors. Increasing supply chain efficiency through improved supplier performance, demand prediction, inventory optimization, and streamlined logistics processes may be achieved by utilizing sophisticated data analytics and machine learning approaches. The goal must be to create optimization frameworks and prediction models that can support well-informed decision making and supply chain operational excellence [8].

This review paper investigates the critical role of human factors (HF) in achieving Zero Defect Manufacturing (ZDM) within the context of Industry 5.0. Through a comprehensive analysis of relevant scientific studies from scientific databases Scopus, key attributes contributing to ZDM success are identified, including employee training, workplace culture, effective communication, and the use of assistive tools [9].

The report from the European Commission on Industry 5.0 emphasizes that human-centric is a key pillar in building a more resilient industry and is vital to incorporate the human component into the manufacturing sector. However, we did not find any publications that explain what human-centric ZDM is, nor what the roles of humans are in advancing ZDM [10].

Author suggested a step-by-step practical implementation guide for achieving zero defects in modern manufacturing facilities. While considering the links with various ZDM strategies, author’s guidelines can be applied to both new and existing production systems. The suggested method has been tested with an industrial example that concerns the manufacturing of an electronics board by the author in the case of a European semiconductors manufacturer[11]. Author reviewed different monitoring techniques of large photovoltaic (PV) plants. They can be categorized into cameras or non-cameras-based techniques which both yield complementary information. Indeed, the study shows that up-today, there is no sensing technique which is adequate to operate in all conditions or to satisfy all possible constraints [12]. So, this can be considered as a research gap for the proposed research.

Furthermore, to embrace agility and deliver a rich portfolio of services to the industrial sector, industrial automation based on digital connectedness will challenge the traditional digital boundaries among industrial systems [13]. The flow of data created and collected by various actors in the manufacturing value chain will have to break these barriers in order to allow for the full-scale digital collaboration among production entities, ensuring at the same time multi-layer optimization. Additionally, sustainable manufacturing with zero defects and zero waste is one of the top priorities of manufacturers these days [14].

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Today, there is a lack of broadened approach and methodology to support them from the processes' efficiency perspective. To fulfill this gap, the purpose of this paper is to apply the Six Sigma method as a support in last mile delivery management. Six Sigma method plays important role in production systems processes management. However, it could be useful in much wider perspective, including transport and logistics processes. The Authors emphasize that the Six Sigma method could be efficient approach in the last mile delivery processes' analysis in the context of their efficiency [15].

Since the late 1960s, Zero Defect (ZD) has been one of the quality-improvement objectives for accomplishing manufacturing quality. As semiconductor manufacturing technologies advance, semiconductor manufacturing processes are becoming more and more sophisticated [16]. However, in today's era it is important to manage ZD in case of manufacturing / production, transportation, installation till commissioning. Further to that, ZD can be under the umbrella of centralized control system for remote monitoring.

3. PROPOSED METHODOLOGY

Today, technology has also reduced the dependency on legacy logistics techniques which were used for route planning in outbound logistics. With advanced navigation and real-time traffic analysis, companies can identify optimum routes in order to make on-time deliveries and attain higher capacity utilization. The technological infrastructure is also making it possible to make on-the-fly route amendments and addition of workload to an existing route, something which was not possible with previous techniques.

Modern industrial systems rely heavily on control panel boxes to house and manage critical electronic components. Ensuring the accuracy, completeness, and quality of these panels is vital to operational safety, efficiency, and compliance. Proposed study provides a new AI-powered inspection strategy that leverages automatic inspection of each panel.

Fig. 1 show the proposed AI-Zero-Defect methodology which mitigates and manages risk ensuring delivery of successful projects on time and on budget. For the proposed methodology, we assumed that product is in optimum functional condition with 100% quality control at the time of dispatch.

The proposed model also suggests the post delivery perks for shipping company driver to motivate safe logistics and re-booking database can be maintained. The proposed model incorporates with even vehicle-road alignment to understand and store the road condition, vehicle condition and accordingly routs can be suggested automatically.

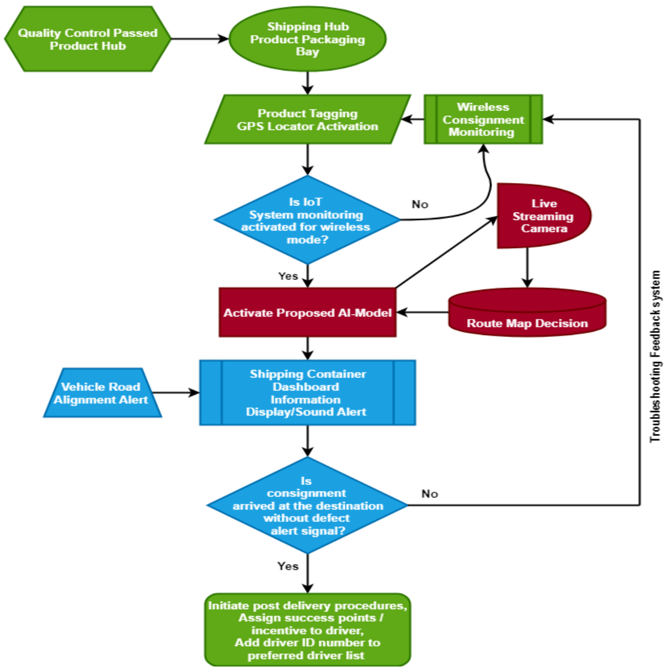

Fig. 1: Proposed Methodology (Generated by the Researcher)

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As shown in Fig.1 above, we modeled cumulative processes to achieve zero-defect state by the automation of processes involved in the supply chain management.The journey to a zero-defect dispatch begins on the shop floor and hence proposed study initiates from manufacturing unit.

Supplier material inspection: Establish a strict incoming inspection process for all components, including breakers, wiring, and bus bars. Validate that supplier materials meet quality standards to prevent issues from entering the production line.

Design for manufacturability: Work closely with engineering to design panels that are easy to build correctly. Identify and mitigate potential failure modes early in the design phase using tools like Failure Mode and Effects Analysis.

Mistake-proofing: Implement simple mechanical or automated controls to make it impossible for operators to make certain errors, such as using the wrong fasteners or missing a critical step.

Layered audits: Conduct regular, structured quality audits at every stage of assembly. This ensures adherence to standard work instructions and catches deviations early.

Before the panel is approved for dispatch, a multi-layered inspection confirms all standards have been met.

Comprehensive panel checklist: Use a detailed, documented checklist to verify every aspect of the panel, including:

- **Physical and visual inspection**: Check for any visible damage, cleanliness, proper labeling, and correct component placement.
- **Wiring and connections**: Ensure all wire connections are tight and properly terminated. Use torque-marking for critical connections to confirm they are secured to the correct specification.
- **Component verification**: Confirm all components, ratings, and fuse types match the approved bill of materials and design drawings.
- **Grounding and bonding**: Verify that the earthing connections are tight and the panel is correctly bonded.
- **Factory Acceptance Testing (FAT)**: Conduct a complete functional test to simulate operational conditions. This includes:
- **Electrical testing**: Perform insulation resistance tests, continuity checks, and voltage tests to ensure there are no short circuits or open connections.
- **Operational checks**: Test all circuit breakers, switches, meters, and indication lamps to confirm they operate as designed.
- **Final documentation review**: The dispatch team should verify that all required documentation including test reports, drawings, manuals, and warranty information is included and correct.

4. RESULT AND ANALYSIS

Based on the proposed methodology, we analyzed the outcome by post-delivery analysis. We considered following elements as a sub-processes.

- **Customer feedback loop**: Establish a system to collect customer feedback post-delivery. This helps identify latent issues and areas for improvement in the manufacturing or dispatch process.
- **Root cause analysis (RCA)**: For any reported defect, perform a thorough RCA using tools like the "5 Whys" to identify the systemic issue that caused it. This prevents the problem from recurring.
- **Quality data analysis**: Collect and analyze data from all inspection stages and field feedback. Use this data to continuously refine and improve manufacturing and quality control processes.

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For proposed AI-model methodology analysis, initially we recorded defect prone logistic incident data for electric control panel consignment for year 2022-2023 and recorded that there were 5 defect incidents out of 20 number of consignment. The data analysis result represented in following Fig. 2.

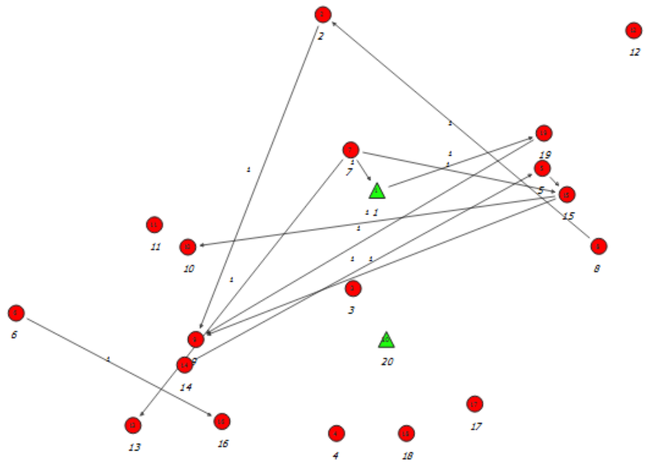

Fig. 2: Product defect analysis without proposed AI-Zero-Defect methodology (Generated by the Researcher)

Further, we collected data for consignment with count of 40 and tested with the proposed AI-model which incorporates the geo tagging for whole consignment, suggesting real-time route for safe journey and sensors for individual product package which alerts the shaking of the package which in turn alerts driver of the shipping container. The AI-model analysis with consideration of the proposed methodology is shown in following Fig. 3. Hence, result shows that proposed methodology is able to stable the defects.

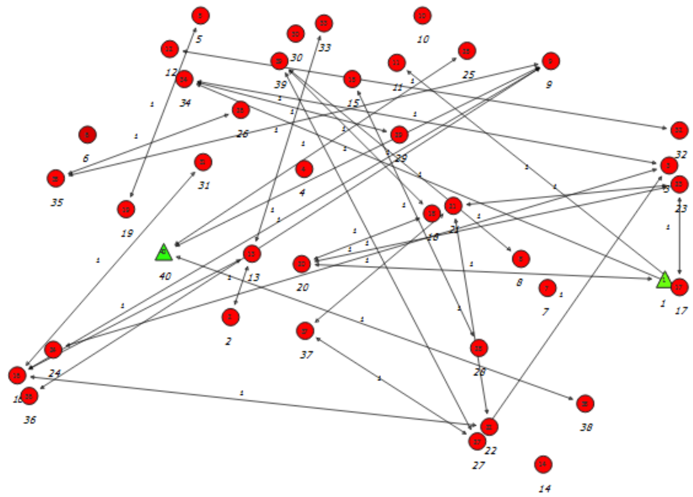

Fig. 3: Product defect analysis with proposed AI-Zero-Defect methodology (Generated by the Researcher)

However, there is a practical difficulty may arise in case of sealed container as driver cannot open the container. Hence, we suggest the flexible mounting of AI-cameras which can be access remotely on the driver dashboard. With this end-to end methodology consideration, promising results for optimization of randomized defect monitoring with centralized monitoring system are shown in Fig. 4. This shows that there is no single package left without monitoring the product journey from manufacturing hub till client location.

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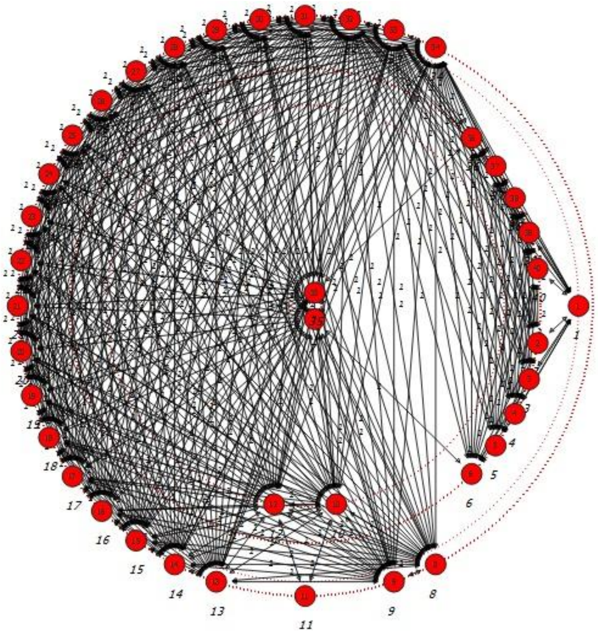

Fig. 4: Proposed AI-Zero-Defect model analysis (Generated by the Researcher)

We conducted adjacency matrix analysis for 40 products for accidental defect analysis and Fig.5 shows the diagonal elements which interprets that no single product is damaged during the transportation. While there are like hood of incidences initially which is monitored and corrective action has been taken.

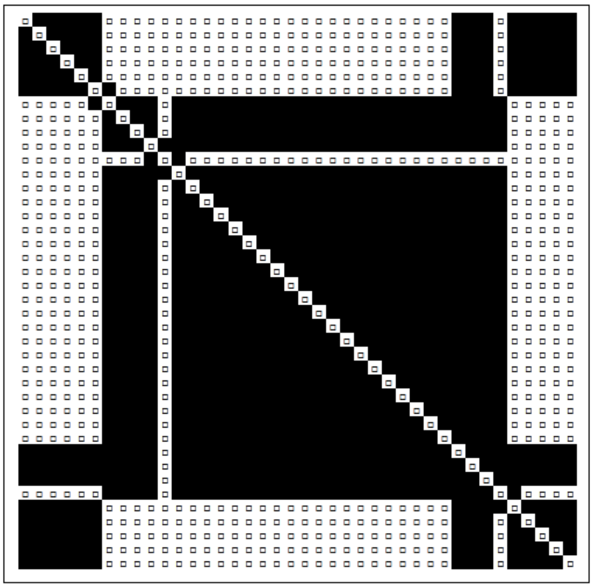

Fig. 5: Adjacency matrix showing zero defects logistic

Apart from the proposed technical system, we identified the success elements which can be very crucial. The proposed methodology is successful by additionally focusing on preventing damage during transit.

- **Secure packaging**: Use custom pallets, reinforced crating, and internal bracing to protect the panel from shock and vibration. Use moisture-absorbing packets if necessary to prevent corrosion.
- **Final inspection sign-off**: A dedicated dispatcher or quality control officer performs a final review of the packaged panel to ensure no details were missed. They will affix a tamper-evident seal or a signed-off tag to the package.

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- **Real-time tracking**: Use GPS and RFID tags to track the delivery, monitor for unauthorized stops, and ensure the panel arrives on schedule.
- **Logistics automation**: Integrate warehouse management and Enterprise Resource Planning (ERP) systems to ensure accurate picking, packing, and shipping data, preventing documentation errors and also geo-tagging the control panel parcels.

5. CONCLUSIONS

Track and trace is a key issue in the logistics industry. For zero defect logistics, technologies can enables real time tracking of delivery vehicles and real time updates of delivery attempts along with products' safety status which lowers the overall cost. Moreover by the proposed methodology, the relevant data can constantly update on a central server, accessible for analysis. Proposed AI-model can help to identify deviations and exceptions in the supply line of a package. It is also possible to independently track real time location of critical packages through wireless tags/geo-location points, product specific monitoring etc. The proposed study can be helpful for industries to provide additional safety and tracking for seamless supply chain management incorporating Management 5.0.

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Journal of Information Systems Engineering and Management
2024, 9(4s)
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