

Case Study: Application of QR Codes to Develop a Storage System for Pipe Spools in an Erection Yard

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Abstract

This research focuses on improving the efficiency of Pipe Spool management within an erection yard to mitigate delays in item retrieval, a critical factor previously hindering the master project schedule. The researcher implemented two primary strategies: 1) the implementation of a Standard Layout, which involved redesigning the storage area into organized sections with clearly defined zone identification; and 2) the integration of QR Code technology combined with Pipe Spool identification stickers to enable rapid data access and precise tracking of storage locations. The results demonstrate a significant reduction in operational lead time, with retrieval times decreasing from a range of 4–24 hours per item to 1.1 hours. Furthermore, the system achieved a 100% success rate based on established Key Performance Indicators (KPIs). In terms of cost efficiency, the improved management system eliminated the necessity for re-fabricating lost spools, ensuring the installation schedule remained on track and preventing unnecessary project expenditures.

Keywords

Pipe Spool Management, Warehouse Layout, QR Code System, Operational Efficiency, Lead Time Reduction

1. Introduction

The petroleum and petrochemical industries are highly complex and demand stringent safety standards, with the piping system serving as a vital component for fluid transportation (American Piping Products, 2021). During the construction of offshore platforms, pipes must undergo cutting, fitting, welding, and inspection processes to become finished components known as "Pipe Spools". These spools are uniquely identified by a Stencil Mark Number and are stored in an open lay-down area called the Erection Yard, awaiting withdrawal for module installation according to the master schedule. Proper storage management and facility layout are crucial to prevent material damage, avoid contamination between different materials, and ensure a smooth operational flow (Octal Steel, 2022).

However, managing and transporting Pipe Spools within the Erection Yard using traditional manual systems frequently leads to issues that delay the project's master schedule. The primary problem is the excessive time required to locate materials, which often takes more than 4 hours per request. This issue fundamentally stems from

a lack of effective facility layout planning and clear storage positioning policies (Vistable GmbH, 2024). Furthermore, the absence of an accurate traceability system results in redundant costs due to the unnecessary re-fabrication of spools presumed to be lost. Such delays and operational limitations act as a critical "bottleneck" that obstructs throughput (Goldratt, 1984), causing a significant "waste of waiting" in the construction workflow (Lucidchart Content Team, 2023).

To systematically address these challenges, this research proposes the application of Quick Response (QR) Code technology integrated with a Grid Layout Design. QR codes not only possess high error-correction capabilities that withstand harsh industrial environments (Denso Wave Incorporated, 2023), but they also serve as a Passive Internet of Things (IoT) gateway, converting physical objects into digital footprints (Cisco Systems, Inc., 2023). This enables real-time digital mapping and location tracking while minimizing human errors associated with manual data entry. The primary objective of this study is to implement an integrated location tracking system to reduce the Pipe Spool search time to less than 4 hours. Ultimately, this implementation aims to enhance picking accuracy, ensure timely delivery to the erection department, and mitigate the risk of delays impacting the overall project schedule

2. Literature Review

In the study "Development of Pipe Spool Storage System in Erection Yard with QR Codes", the researcher collected relevant theories, principles, and research to guide the analysis of the problem and design the storage area and the identification of the Pipe Spool, including the storage location, to be effective

2.1 Industrial Pipes Types and Storage Management

This research examines the characteristics and specific storage requirements of various pipe materials, which are fundamental for establishing effective zoning within the Erection Yard. Carbon steel pipes, while structurally robust, are highly susceptible to rust and require preventive storage measures such as end caps and sleepers to avoid direct ground contact (American Piping Products, 2021). Conversely, stainless steel pipes, renowned for their corrosion resistance, demand strict segregation; they must never be in direct physical contact with carbon steel to prevent galvanic corrosion and contamination (Octal Steel, 2022). Additionally, high-value materials like nickel alloy and duplex pipes necessitate precise tracking systems to prevent costly losses. The storage and handling of these materials must adhere to international identification standards, such as ASTM and ASME B31.3, ensuring accurate traceability back to their material certificates.

2.2 Logistics and Supply Chain Management

To effectively manage the flow of Pipe Spools, this study incorporates logistics theories, focusing particularly on the "7 R's" principle. This principle is essential for accurate delivery: Right Product, Right Quantity, Right Condition, Right Place, and Right Time. However, traditional yard management often encounters severe operational limitations. To analyze this, the research applies the Theory of Constraints (TOC) proposed by Goldratt (1984). TOC posits that a system's overall performance is dictated by its weakest link, or "bottleneck". In the context of this study, the excessive "searching time" for pipes acts as a critical bottleneck that delays the master installation schedule. Addressing this specific constraint is vital to increasing the project's overall throughput.

2.3 Facility Layout & Location Assignment

A primary challenge in managing an Erection Yard is its vast, open layout lacking distinct reference points. Therefore, this research explores the Grid Layout Design (Vistable GmbH, 2024). This concept involves overlaying a virtual grid onto the physical yard, subdividing the area into Zones, Rows, and Grids to assign specific "addresses" to components. This structured layout is implemented alongside a Randomized Storage policy, which allows operators to place components in any available grid slot to maximize space utilization. However, theoretical frameworks explicitly state that the success of randomized storage relies entirely on a highly accurate tracking system to meticulously record the exact coordinates of where each pipe is stored.

2.4 QR Code Technology and the Internet of Things (IoT)

To support the randomized storage strategy, this study investigates the application of QR Codes as a location identification tool. A distinct advantage of QR Codes is their "Finder Patterns" which enable 360-degree (omni-directional) scanning, making them highly efficient for pipes placed at varying angles. Furthermore, the research utilizes Reed-Solomon Error Correction technology, specifically selecting Level Q (25%) and Level H (30%)

(Denso Wave Incorporated, 2023). These advanced levels ensure high resilience, allowing the codes to be read accurately despite exposure to harsh construction environments, dust, oil stains, or scratches. In terms of systems engineering, the QR Code functions as a "Passive IoT" device. It serves as a gateway to digitize physical objects (digital footprint), enabling the real-time mapping of storage coordinates and seamless status updates to the central database (Cisco Systems, Inc., 2023).

2.5 The PDCA Cycle

To drive concrete and continuous improvement, the researcher utilizes the Deming Cycle, or the PDCA (Plan-Do-Check-Act) Cycle, as the core operational framework (ASQ, 2022). This methodology involves four systematic stages: "Plan" to analyze current issues and design the grid layout; "Do" to generate QR Codes and implement the new storage protocols in the actual yard; "Check" to measure and statistically compare retrieval times before and after the intervention; and "Act" to standardize the successful processes by developing Standard Operating Procedures (SOPs). This cycle ensures that the developed system is systematically tested, implemented, and continuously evaluated for optimal performance

2.6 Related Literature

A review of related literature provides strong empirical support for this methodology. A study by Khunsit and Supharyagul (2025) demonstrated that integrating QR Code applications into inventory control within the pharmaceutical industry significantly enhanced operational efficiency. Their findings revealed that QR Code technology reduced the time required for picking and searching processes by 86.7%. Furthermore, it effectively eliminated human errors, increasing inventory counting accuracy from 85% to 99%. These results perfectly align with the hypothesis of this study, confirming that integrating QR Code technology with spatial coordinate mapping can successfully resolve searching delays and elevate the overall efficiency of Pipe Spool storage management.

3. Methods

This research aims to enhance the efficiency of pipe spool storage and retrieval in the Erection Yard by implementing QR code technology integrated with a grid layout system. An experimental field research approach was employed, utilizing a pre-test/post-test design to evaluate performance improvements by measuring search time reduction and inventory accuracy (Figure 1).

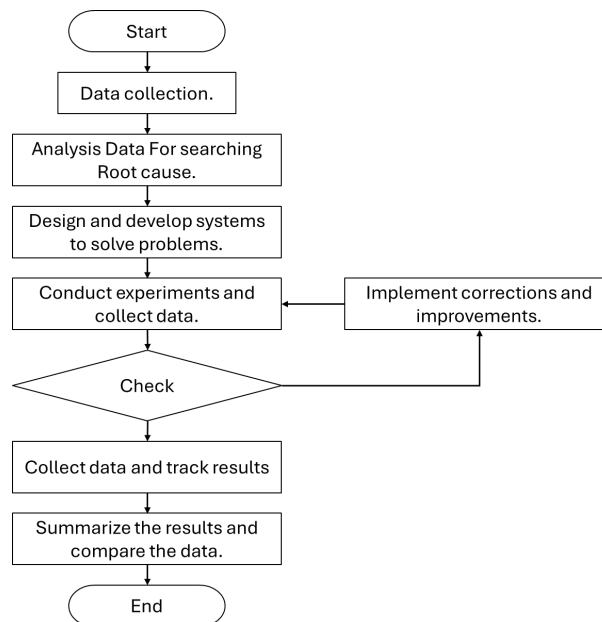


Figure 1. Research method

3.1 Population and Sample

The research was conducted at the Erection Yard of an oil pipeline construction project operated by Company "ABC". The sample consisted of 1,945 Pipe Spools that were processed through the storage system. To accurately measure the system's impact, data collection was conducted over an 8-month period, divided into two distinct phases: 4 months of recording the traditional manual retrieval process (pre-improvement baseline) in Figure 2. and 4 months of recording the newly implemented QR code system (post-improvement), Show the impact details that occurred in the pipe spool storage process

Item	Year	Month	Pipe Spools Status		Impact Details (Before)				Search Time Average
			Receiving	Distributed	Delay	Not found	Pipe spool damaged	Wrong Identification	Hrs.
1	2024	June	482.00	455.00	408.00	27.00	47.00	14.00	8:04
2	2024	July	486.00	468.00	411.00	18.00	31.00	3.00	7:32
3	2024	August	506.00	479.00	459.00	27.00	21.00	22.00	7:48
4	2024	September	471.00	439.00	385.00	32.00	16.00	17.00	7:59
Accumulated			1,945.00	1,841.00	1,663.00	104.00	115.00	56.00	7:50
					Delay	Not found	Pipe spool damaged	Wrong Identification	Time Average
					85.50%	5.35%	5.91%	2.88%	7:50

Figure 2. Number of pipes collected and impact details Occurred in the Pipe Spool storage process (legacy system prior to renovation).

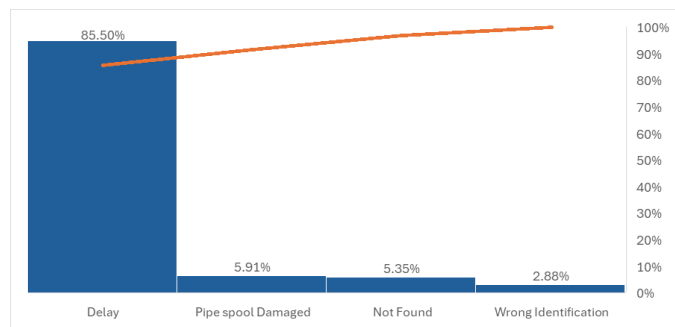


Figure. 3 The Pareto Chart shows the impact details that occurred in the pipe spool storage process (the previous system before the improvement).

From Figure 3, the Pareto Chart shows the impact in detail. The graph clearly shows that the main problem that has the greatest impact on the process is the delay in finding the workpiece. Delay accounted for 85.50 percent, followed by Damaged at 5.91 percent and Not Found at 5.35 percent, respectively. The data from this graph is used as an important reference point for the researchers to focus on solving the problem of delays.

3.2 Research Instruments

The implementation utilized a combination of hardware and software instruments. Hardware components included smartphones and tablets for omni-directional scanning, a centralized computer for database management, and industrial label printers capable of generating weather-resistant QR code stickers. The primary software utilized was the "Scan IT to Office" application show in Figure 4., which served as the operational interface for real-time data entry and spatial mapping.



Figure 4. Application: Scan IT to Office(left) interface of Application(right)

3.3 Research Procedure

The researcher applied the Deming Cycle, or the PDCA (Plan-Do-Check-Act) Cycle, as the core operational framework to drive continuous improvement. The in-depth procedures are as follows:

Plan In the Plan phase, the researcher initiated an As-Is Analysis by surveying the actual site operations, interviewing relevant department managers, and recording the manual searching time to establish baseline data. Utilizing a Fishbone Diagram in Figure 5.

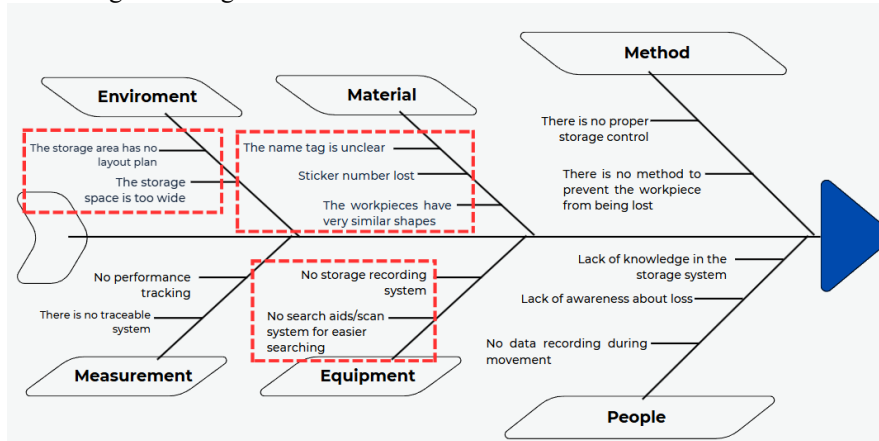


Figure 5. Fishbone Diagram

the analysis revealed that the primary causes of delay were the identical physical appearances of the components and the lack of clear location reference points. Consequently, a new system was designed, which included developing a Grid Layout Plan as Figure 6. that subdivided the yard into specific Zones, Rows, and Grids. This was paired with a QR Code data architecture designed as Figure 7. to encapsulate essential spool details and their designated storage coordinates.



Figure 6. New storage yard layout

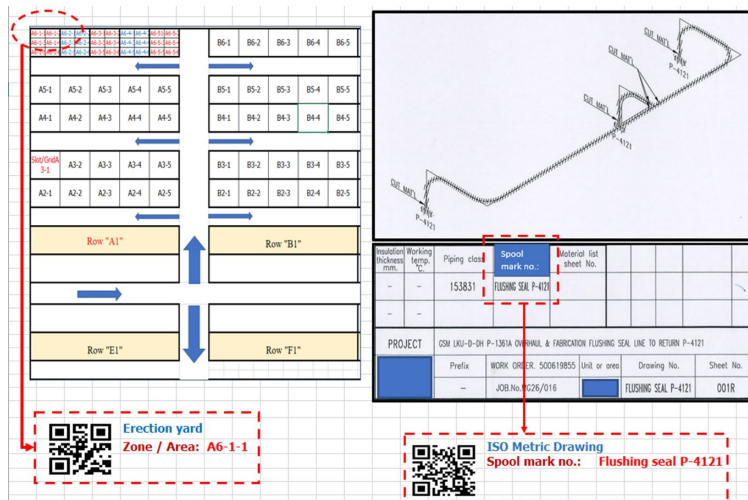


Figure 7. Erection Yard Storage Designation Format and Spool Mark Number Designation Format

Do During the Do phase, physical site preparation was conducted by demarcating the storage boundaries and installing Address Signage. For material tagging, the fabrication department attached QR code stickers to two strategic locations—the outer pipe wall as Figure 8. and the inner flange as Figure 9.—to prevent impact damage during transportation. The system operated under a Randomized Storage policy, allowing operators to place the pipes in any available space. However, they were required to use a mobile application to scan the QR code on the pipe alongside the location signage to instantly perform "Digital Mapping" and update the coordinates into the central database.



Figure 8. Mounting Location QR Code Sticker outer pipe wall

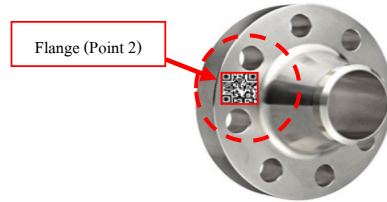


Figure 9. Mounting Location QR Code Sticker inner flange

Importing data and storing data into the system will start with the smart phone scanning the QR code at the pipe spool and then scanning it at the pole. Location labels to map data into the database. The procedure is as shown in Figure 10. The placement can be placed at any point using the Randomized Storage method, but it must be saved to the system every time.

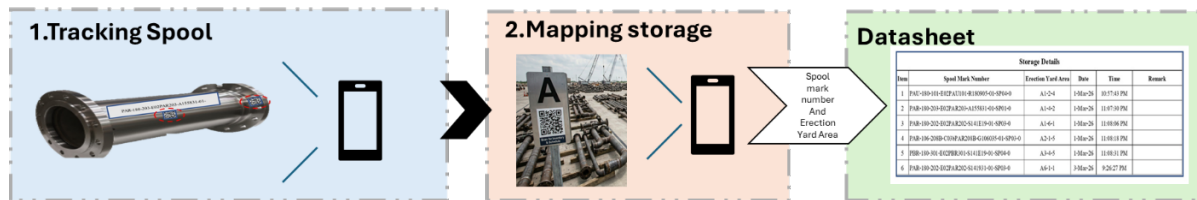


Figure 10. The digital mapping process utilizing the "Scan IT to Office" mobile application for real-time location data entry.

Check In the Check phase, the researcher conducted a Trial Run to simulate real-world retrieval requests from the erection department. The process involved searching for the coordinates via the database, navigating to the specified location, and scanning the QR code to verify the correct item (Verification). Throughout this process, the actual searching times and any operational errors were meticulously recorded so they could be evaluated against the baseline data of the traditional system.

Act (Analysis & Standardization) Finally, in the Act phase, all collected data was statistically analyzed to compare average retrieval times and system accuracy. Once it was confirmed that the system achieved its efficiency targets, the researcher developed a Standard Operating Procedure (SOP) to ensure that all warehouse personnel utilized the QR code system consistently. Furthermore, any operational bottlenecks or issues identified during the trial were documented as recommendations for future system enhancements.

3.4 Data analysis

To scientifically quantify the operational improvement between the traditional manual system and the proposed digital tracking system, descriptive statistics were applied. The primary metrics and their corresponding mathematical equations are detailed as follows:

Mean The arithmetic mean was utilized to calculate the central tendency of the searching time required per Pipe Spool. The equation is expressed as

$$\bar{x} = \frac{\sum x}{n}$$

Where \bar{x} represents the average searching time per spool, $\sum X$ is the summation of all individual retrieval times recorded, and n denotes the total number of samples (1,954 Pipe Spools) evaluated in the study.

Percentage Change To explicitly evaluate the efficiency gained, a percentage change formula was utilized. This metric compares the baseline retrieval time against the post-improvement retrieval time to determine the exact proportion of time saved. The equation is formulated as

$$\text{Percentage Change} = \frac{\text{Time}_{\text{before}} - \text{Time}_{\text{after}}}{\text{Time}_{\text{before}}} \times 100$$

Where $\text{Time}_{\text{before}}$ represents the average retrieval time using the traditional manual system (recorded at 470 minutes or 7 hours and 50 minutes), and $\text{Time}_{\text{after}}$ indicates the significantly reduced time achieved through the QR Code system (recorded at 66 minutes or 1 hour and 6 minutes). The difference is multiplied by 100 to express the operational efficiency gained as a percentage.

4. Result

The transition from a traditional manual recording system to a Digital Tracking System, integrating QR Code technology with a Grid Layout Design, yielded significant operational improvements in managing the Erection Yard. The results can be categorized into three primary performance metrics:

4.1 Time Efficiency

The implementation of the digital mapping system dramatically reduced the operational bottleneck caused by searching delays. Prior to the improvement, the average searching time for a Pipe Spool was 7 hours and 50 minutes (470 minutes) per unit (Figure 11- Figure 12). Following the system implementation, the average searching time was significantly reduced to 1 hour and 6 minutes (66 minutes) per unit. This represents an 85.95% reduction in retrieval time, successfully achieving the project’s primary objective of restricting the search duration to under 4 hours this result show as Table 1.

Table 1. Result of Time Efficiency

Evaluation Metrics	Baseline (Manual System)	Post-Improvement (Digital Mapping)	Efficiency Gained / Reduction
the average searching time	7 hours 50 minutes (per spool)	1 hours 6 minutes (per spool)	85.95% Reduction (Saved 6 hours 44 minutes per spool)

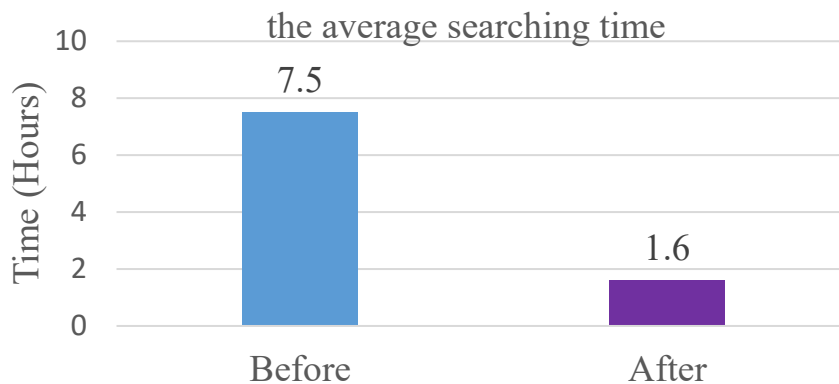


Figure 11. Result of Time Efficiency

4.2 Inventory Accuracy and Error Reduction

The statistical analysis demonstrates a substantial enhancement in inventory quality. The critical issue of "Not Found" items, which previously accounted for 5.35% of operational errors and led to redundant re-fabrication costs, was entirely eliminated (reduced to 0%). Furthermore, the error rate for "Wrong Identification" decreased drastically from 2.88% to 0.16%. The precise location tracking also minimized unnecessary material handling and movement, which consequently reduced the rate of "Damaged" spools from 5.91% to 0.89% show as Table 2.

Table 2. Result of Inventory Accuracy and Error Reduction

Evaluation Metrics	Baseline (Manual System)	Post-Improvement (Digital Mapping)	Efficiency Gained / Reduction
"Not Found" Error Rate	5.35%	0%	Reduced to 0% (100% elimination of missing items)
"Damaged" Spool Rate	5.91%	0.89%	5.02%Reduction (Minimized unnecessary material handling and impact)
"Wrong Identification" Rate	2.88%	0.16%	2.72%Reduction (Significant decrease in human error)

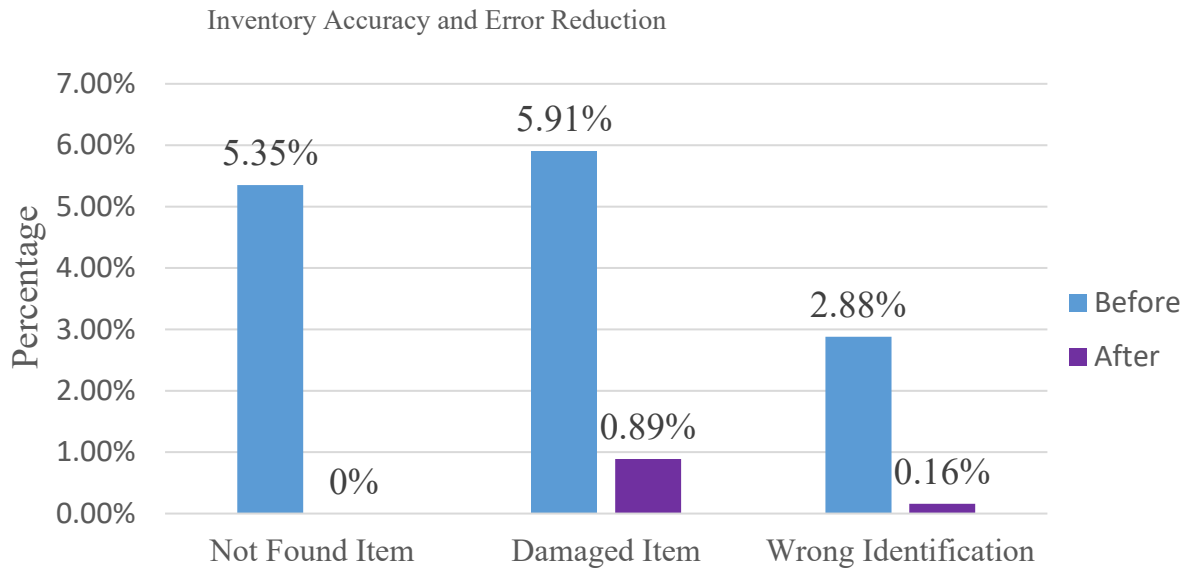


Figure 12. Result of Inventory Accuracy and Error Reduction

4.3 System Visibility and Traceability

The utilization of Level Q (25%) and Level H (30%) QR Codes ensured high data recovery rates despite the harsh, dusty environment of the Erection Yard. By scanning these robust QR codes via a mobile application, the physical components were successfully transformed into digital footprints. This enabled a centralized management system where supervisors could monitor real-time spatial data and establish 100% traceability for every spool without relying on manual paper-based reports.

5. Conclusion and Future work

5.1 Conclusion

This study demonstrates that the integration of QR Code technology and systematic Grid Layout planning provides a highly effective solution for managing large-scale, open-air storage facilities. By assigning specific "virtual addresses" to physical components and utilizing randomized storage policies, the Erection Yard overcame its severe searching delays. The new system not only achieved a 100% picking accuracy for previously "Not Found" items but also eliminated hidden costs associated with workflow interruptions and the unnecessary re-fabrication

of misplaced Pipe Spools. Ultimately, this research validates that digitizing material tracking is a critical process improvement for heavy industries and complex construction projects.

5.2 Future Work

Based on the operational findings, the following recommendations are proposed for future system enhancements:

- **Offline Capabilities:** Future applications should incorporate an offline data entry feature to accommodate areas within the construction site that experience unstable internet connectivity.
- **BIM Integration:** To elevate visual management, the spatial coordinates (Digital Mapping) should be integrated with Building Information Modeling (BIM) software. This would provide the erection team with a 3D visual dashboard indicating which materials are "Ready for Erection."
- **System Expansion:** The proven framework of this tracking system can be scaled and applied to efficiently manage other critical construction components, such as industrial valves or small machinery, facilitating comprehensive project-wide asset management.

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Biographies

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Somporn Phuangpan holds a Bachelor's degree in Production (Welding and Fabrication) from Pathumwan Institute of Technology and is currently pursuing a Master of Engineering in Systems Engineering at Suranaree University of Technology.

He has extensive experience in QA/QC for oil pipelines and crude oil storage tanks. His current focus is on applying digital technology and systems engineering to improve warehouse management. Specifically, his research explores using QR code systems in Pipe Erection Yards to better track pipe spools and storage locations. This system aims to reduce search time and make operations significantly faster and more efficient.