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Advancing Pipeline Integrity Monitoring through GIS Mobile Applications

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Abstract

The frequent field inspection and rapid incident response are critical processes for safety and reliability of pipeline infrastructure. Conventional practices such as paper-based checklists and post-field data entry involve high rates of human mistakes, delayed flow of information, limited situational awareness, and slow response for field incidents. This study evaluates a digitalized workflow implemented through a field-oriented Geographic Information System (GIS) that integrates collected field data through GIS mobile applications with notification and workflow management systems. The system was deployed to cover the frequent safety inspection for hundreds of site locations on a pipeline network system. After one year of implementation, compared to manual approach, the digitalized workflow has achieved 400% increase in the total number of the conducted checklists, 94% reduction of non-visited sites per week, and 90% decrease of the time required to resolve negative observations. Finally, the system has proved the elimination of human mistakes and provided instant responses for field incidents.

Keywords: Pipeline Inspection; Integrity Monitoring; Geographical Information Systems; GIS Mobile; Digital Checklist

1. Introduction

Saudi Arabia has thousands of Kilometers of a sophisticated upstream and downstream pipeline network system. To ensure safety and reliability of these assets, regular field inspections are mandatory to verify the integrity of pipe walls, valves, supports, coatings, and ancillary instrumentation [1]. Traditional inspection processes rely on paper checklists, post-field data entry, and later data storing into enterprise GIS databases [2]. This manual workflow jeopardizes both the safety and efficiency of the inspection process. The manual data entry is prone to transcription errors, missing data, or unreadable handwriting [2]. The general findings across many field studies confirmed that the manual approach is vulnerable to 8-15% of human transcription errors.

The rapid advancement and diffusion of smartphone and tablet devices, combined with high-speed cellular and satellite connectivity, makes it feasible to replace paper-based inspection checklists with GIS-enabled mobile solutions [3, 4]. This research introduces a digitalized workflow based on GIS mobile applications to streamline the manual process of the pipeline field inspection. The developed system enables pipeline field operators to perform inspection and verification processes digitally, makes the collected data available instantly for analysis, and link the collected data with a notification and workflow management system to expedite response to field incidents.

The main objective of this research is to explore how GIS mobile solutions have been used to optimize the process of pipeline inspection. Most existing solutions focus on a single aspect, such as mobile data capture [5], synchronization with geospatial data repository, or sensor-driven alarm management [6]. This research addresses this gap by focusing on how the GIS mobile can be integrated with other systems to save time and increase efficiency of pipeline inspection by eliminating post-field data entry and increasing number of conducted checklists. The paper shows that how the GIS-

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based system can improve inspection safety and reliability by ensuring engagement of workers at the worksite locations of critical activities, track compliance in real time, and respond automatically to negative observations.

2. Literature Review

2.1. Advantages of GIS Mobile Apps

GIS mobile refers to extending traditional GIS to mobile devices used by field personnel to visualize, capture, and analyze spatially referenced data. GIS mobile apps integrate technologies like GPS, camera, and wireless networks for real-time location intelligence [6,7]. This integration provides an opportunity for field operators to perform crucial field tasks such as field data collection, asset management, and navigation. GIS mobile apps can integrate with other backend systems such as ERP (Enterprise Resources Management) or CMMS (Computerized Maintenance Management Systems) to ensure seamless data flow [7,8]. Leverage mobility in the field is one of the main advantages of GIS mobile apps, in which the field workers have access to mapping services that enable them to search, locate, and take field notes on mobile devices. Field operators can use these applications offline and seamlessly synchronize data once connectivity is restored [5,6,9]. GIS-enabled mobile apps are increasingly providing an effective alternative through digital checklists. These applications convert paper forms into smart, digital forms by incorporating geospatial data, automatic validation, and multimedia capabilities, turning them into dynamic, interactive workflows [2,6].

2.2. Benefits of Digital Checklists

Field digital checklists are electronic versions of traditional paper-based inspection lists, used by field staff to carry out tasks consistently and in accordance with established procedures [2,6]. Unlike paper-based forms, digital checklists can integrate with mobile or tablet-based systems, enabling real-time data capture, validation, and transmission directly from the field [2,10]. Transition from paper to digital checklists improves field inspection processes in different aspects. Reduction of human errors is one of the most significant benefits for digital forms. The digital checklists incorporate automated validation rules to ensure validity of entered values, avoiding missing fields, and minimizing human errors [2,11]. Digital checklists provide traceability advantage, which links between each checklist and the user who completed it, resulting in a clear audit trail for the inspection process. Using digital checklists provides real-time data synchronization through uploading collected data to a central database once the form is completed. The real-time data synchronization supports faster decision-making and prevents operational delays of safety issues [2,5,10].

2.3. Optimizing Pipeline Field Inspection with GIS Mobile

In the oil and gas industry, field inspections are a regular but critical practice. These inspections play a crucial role in preventing incidents like leaks, corrosion, or equipment failures, which can result in environmental damage, financial costs, or operations disruption [12]. As the industry continues to evolve through digital transformation, understanding the crucial role of field inspections becomes essential for ensuring operational excellence and long-term asset integrity [13]. Pipeline operations require precise coordination between field personnel, office management, and control centers. Managing thousands of kilometers of a sophisticated pipeline network across diverse terrains requires efficient data management and real-time spatial awareness [14,15]. GIS mobile technology has emerged as a game-changer in achieving these goals, allowing field teams to access, edit, and analyze pipeline data in real time while in the field. This capability enhances operational efficiency and helps minimize downtime [16]. A study conducted across various upstream operations revealed that implementing digital checklists led to a 25% reduction in inspection time and enhanced adherence to safety protocols by more than 40% [17].

2.4. Application of GIS Mobile in Pipeline Management

Mobile GIS applications enable field inspectors to identify the exact location of pipeline assets, review their maintenance records, and add new inspection data directly in the field. This real-time data flow can help in maintaining up-to-date and precise asset records [5]. GIS mobile tools can overlay real-time events such as pipeline leak, pressure drops or flow anomalies onto digital maps, allowing rapid response at the incident location [18]. This capability accelerates response efforts and enhances coordination between field crews and control centers [19]. Field operators can use mobile GIS in planning optimum routes for environmental compliance. They can identify sensitive ecological zones, evaluate terrain, and adjust maintenance routes accordingly. This approach supports compliance with regulations and helps reduce environmental impact [20]. Access to real-time geospatial data gives field workers the ability to make well-informed decisions on the spot, without having to return to the office or rely on back-end support. Supervisors and engineers can visualize field activities in real time, leading to more effective planning and better allocation of resources [5,18]. The GIS mobile apps provide simplified navigation and offline capabilities that can help field operators access and maintain oil & gas pipeline segments that are located in remote or low-connectivity areas [16,21,22].

2.5. The Role of GIS Mobile in Pipeline Incident Response

GIS mobile has become a central component of a responsive and data-driven incident management strategy [23]. Identifying the location of the incident precisely is a key factor in responding to pipeline incidents to prevent or mitigate losses [24]. GIS mobile applications leverage GPS and real-time data acquisition from geospatial databases to detect and locate anomalies such as pressure drops, flow imbalances, or temperature fluctuations [25]. This level of spatial accuracy significantly reduces the time needed to dispatch the appropriate response team to initiate corrective actions [19]. During an incident, responders need to rapidly evaluate the impacted pipeline section, including its material details, previous maintenance history, and any environmentally sensitive areas nearby [26]. Overlaying incident contextual information on digital maps through GIS mobile apps can help field personnel determine the appropriate actions, the type of intervention, and the required resources [27,28]. Mobile GIS facilitates communication between field operators and control centers, which enhances situational awareness and accelerates decision-making [23]. The staff in the control rooms can update incident status, modify response strategies, and coordinate with emergency services based on the received data from the field crews, which may include voice notes, photos, and incident logs [23]. According to the European Emergency Number Association (2024) [17], using mobile GIS can expedite resolving incidents 35% faster than the industry average.

3. Methodology

The project has started with designing a comprehensive system that aims to digitalize the manual paper-based inspection process for oil & gas pipeline systems. The design of the system focused on achieving the main objectives of the project, which include reducing processing time and increase productivity, improving review and quality assurance, enhancing analysis and reporting functionalities, and accelerating response for incidents. The project phases consisted of software and hardware acquisition, data preparation, dashboard system development, notification and workflow system integration, and data collection.

3.1. Software and Hardware Acquisition

The required software included the mobile application that will be used by pipeline field operators to collect inspection data digitally. ESRI ArcGIS Survey123 was selected as an off-the-shelf solution for field data collection. This GIS mobile application has the required capabilities such as dynamic form builder, easy data collection, working offline, and integration with other business systems. During the software acquisition process, another acquisition process for the required tablet devices was initiated. The number of required tablets and mobile software licenses was calculated based on the number of field users who will move from using paper-based inspection forms to the new system.

3.2. Data Preparation

The data preparation process started with standardizing the various paper forms for all pipeline units into one digital form. This step was important to have the same data structure for all units. The advantages of standardizing inspection forms include reducing time for building and updating digital forms, allowing for comprehensive analysis and statistics, and facilitating maintenance and technical support. The digital form was created by using XLSForm as standard format for creating survey logical forms. The digital form was published on the GIS platforms after testing it by designated users. The field operators were granted access to the published digital form. The authorized form users were allowed to install the ArcGIS Survey123 mobile application on their tablet devices to access the digital form to start data collection.

Since the inspection process is carried out at specific locations (critical sites) along the pipeline network system. Each pipeline unit sent a list of the critical sites that belong to this unit. The critical sites information included the location name, description, organization code, and the geodetic coordinates of the location in WGS84 UTM projected coordinate system. A feature layer was created in the GIS database to store spatial data of the critical sites. The GIS analysis tools were used to create another feature layer to represent a buffer area of 100m around each critical site location. The buffer layer is required for overlay analysis to ensure that all survey observations were collected at the right location. A new map was created to contain the form of observation layer, the critical site layer, and the buffer layer of the critical sites.

3.3. Dashboard System Development

Developing dashboard systems aim to enable technical engineers and supervisors in the control center to track and monitor the progress of the pipeline safety inspection process. The system components include a map viewer to show the location and information of pipeline network, collected inspection forms, critical sites, and the buffer layer of the critical sites. The system includes another representation for the collected data in a tabular format. The dashboard users can use the table to search for specific data, query the data based on specific criteria, and export data. The dashboard system provides numerical statistics and charts that enable users to monitor the progress of the inspection process based on specific criteria. The statistics display information about the total number of collected forms, visited and non-visited sites, negative observations, etc. The dashboard system has the flexibility to show only the data for specific unit or during a specific period of time. The system was customized by using ArcGIS JavaScript APIs.

3.4. Notification and workflow System Integration

Reducing the response time for field incidents and negative observations requires integrating the field collection process with a notification and workflow management system. The integration component includes a module that runs automatically with digital forms submission. The module checks the form information and sends a notification email to the supervisor of the field operator if the submitted form contains negative observations. The notification email includes all information about the negative observations that the email receiver may need to take the proper action. In case of critical incidents such as pipeline leaks, the module automatically creates an incident ticket and assigns it to designated people in addition to sending notifications. This integration ensures a real-time awareness of incidents, which enables office management to take proper action as quickly as possible to mitigate the risk of the incident. Figure 1 shows the system components and workflow.

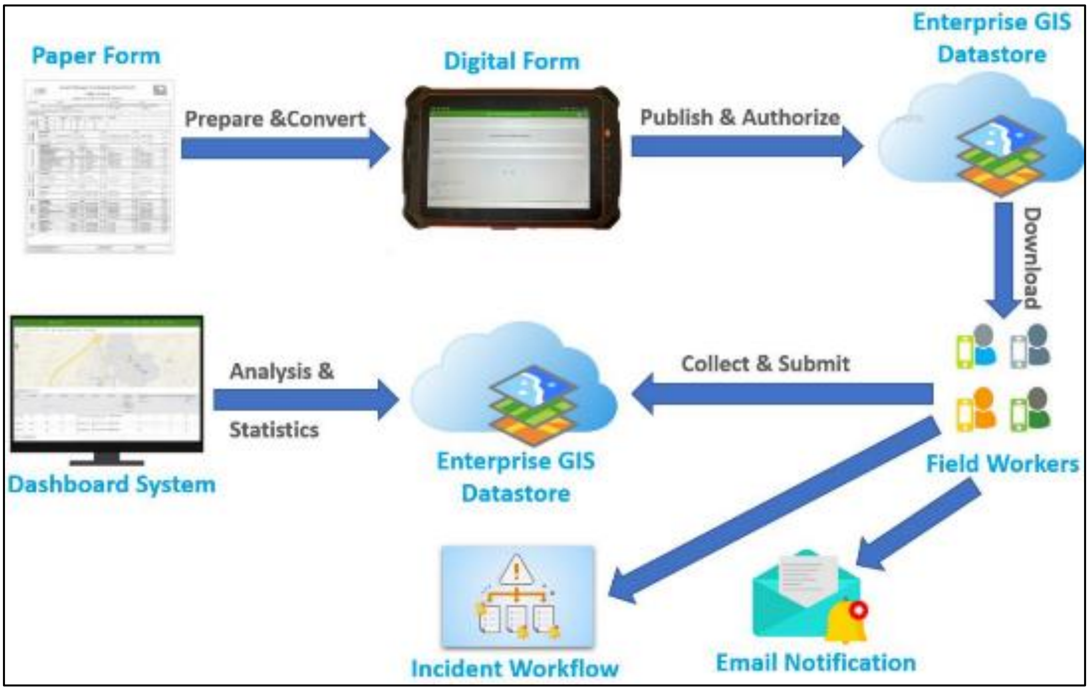

Figure 1 System Components and Workflow

4. Results

The GIS mobile application was deployed on more than 100 tablet devices in June 2024. Authorized field operators were granted access to the pipeline safety inspection form, and they began collecting data in July 2024. During the first month of implementation, the users were provided many awareness sessions for how to use the application properly even if they are not connected to the Internet. The users encountered some technical issues in the beginning such as setting up the GIS platform configuration, enabling location service on the device, and account sign-in issues. After resolving the issues, the users were able to use the mobile application smoothly without facing business disruption issues.

In conjunction with deploying the mobile field application, the dashboard system was deployed to the control center team to enable them to track and monitor the progress of the field inspection work. The control center team is using the system daily to create different types of reports and charts. Also, the integration of the mobile field application with the corporate email system and the workflow management system was implemented. The supervisors started to receive notifications for critical negative observations upon submission of the digital form. The designated technical people started to receive assigned incident tickets in their inbox to take the proper corrective actions with a complete follow-up workflow to ensure resolving the issue within a certain time. Figure 2 shows a screenshot of the dashboard system.

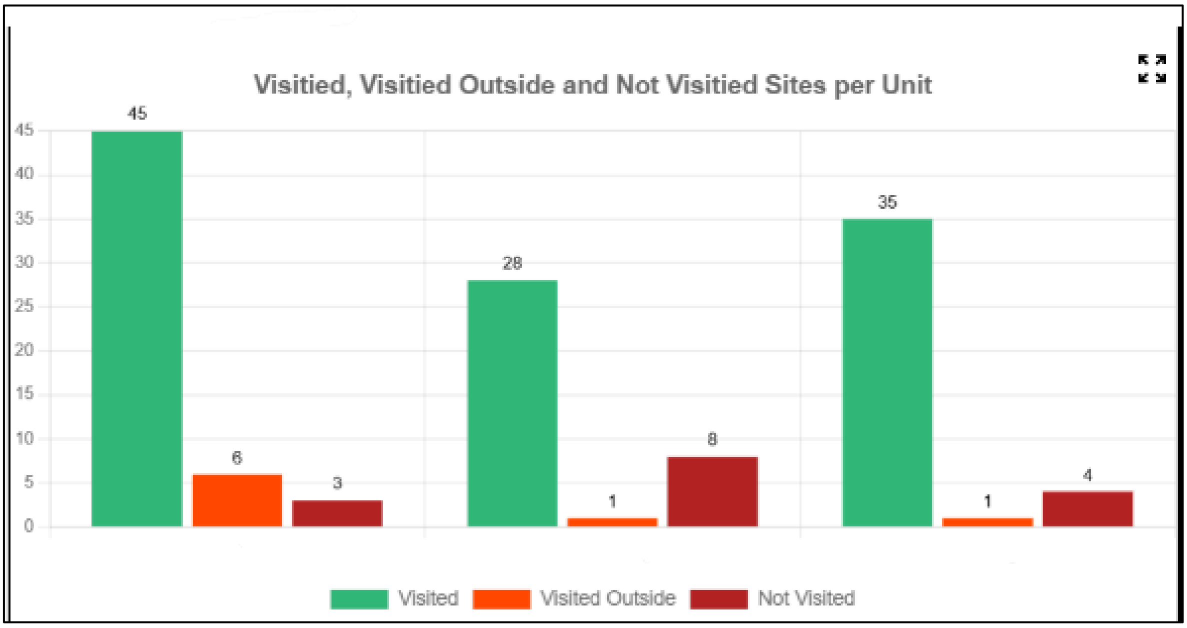

Figure 2 System Dashboard

In July 2025, one year after implementation of the system, the historical data for one year showed that the number of the conducted forms increased from approximately 8000 manual paper forms/year to more than 32,000 digital forms/year. The non-visited sites indicator is one of the main indicators for pipeline inspection processes. This indicator shows the number of sites that were not inspected during the week. The results showed that the average number of non-visited sites was reduced from 510 sites to 263 sites per week. The number of duplicated negative observations is an important indicator for tracking the response to negative observations. This indicator shows the negative issues that are repeated in two consecutive weeks without resolution. The results showed that the average number of duplicated negative observations was reduced from 71 forms to 40 forms per week. The response for pipeline incidents ranged between 2 to 4 hours that includes the time of discovering and reporting the incidents. The results showed that the system reduced the response time to few minutes with the help of notification and workflow management system. Table 1 shows a comparison between manual and digital checklists performance indicators.

Table 1 A comparison between manual and digital checklists performance

Indicator	Business Value	Manual Checklists	Digital Checklists	Percentage
Number of Checklists (year)	Productivity	8000	32,000	400%
Non-visited Sites (week)	Quality Assurance	510	263	94%
Duplicated Negative Observations (week)	Workflow Optimization	71	40	77%
Incident Response Time	Response Management	2-4 hours	Few minutes	>200 %

5. Discussions

Shifting from a paper-based inspection process to a mobile GIS-enabled digital form system produced significant improvements across several key performance indicators (KPIs) that are directly linked to pipeline safety and operational efficiency. The findings in Table 1 confirmed the capabilities of digital tools such as mobile GIS to increase productivity through eliminating manual paperwork limitations, which resulted in 400% increase in productivity. This finding aligns with AlShammari et al. (2022)'s findings that confirmed the reduction of transcription time when using digital checklists compared to manual paper checklists. The weekly average of non-visited sites fell by 94% as the GIS system helped supervisors assign non-visited sites to the nearest available field operators and apply a real-time task allocation. The observed reduction aligns with the 30–45% average gains reported in other GIS-driven inspection programs (Zhang et al. 2021). The average of duplicated negative observations was reduced by 77% because the digital system provides analytical dashboards to highlight recurring problem areas, notification reminders, and close-loop workflows to ensure completion of resolving issues. The response time for pipeline incidents (discovery + reporting) was reduced to a few minutes from 2 to 4 hours. The digital system enables the technical engineers in the control center to get instant geo-tagged information about the incident, including location, photos, and description. The automated notification engine and the integrated workflow management system enable control center engineers to compress the decision-making cycle and take the corrective actions within a few minutes.

6. Conclusion

The transition from a paper-based inspection workflow to a mobile GIS-enabled digital checklist system has demonstrated enhancement of pipeline safety and operational efficiency across pipeline departments. By significantly increasing the productivity of field operators, reducing the average of non-visited sites, lowering duplicated negative observations, and cutting incident response times from hours to minutes, the solution demonstrated that mobile GIS-enabled tools can play a central role in preserving pipeline integrity and operational resilience. The system's ability to capture high quality, georeferenced data in real time creates a robust foundation for advanced analytics and predictive maintenance initiatives to mitigate potential hazards.

The observed improvements validate the strategic direction of adopting intelligent, location-aware tools for critical infrastructure management and set up a solid foundation for future innovations. Field digital checklists represent a relatively simple but powerful step in the broader digitalization of field operations. By reducing errors, enhancing traceability, and enabling real-time data flow, they contribute significantly to operational excellence. This aligns with Saudi Arabia strategic objectives for accelerating digital transformation and achieving operational excellence goals.

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