The Development of a BIM-enabled Inspection Management System for Maintenance Diagnoses of Oil and Gas Plants

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Abstract –

Current inspection process has productivity issues, such as double handing information, time-consuming data aggregation, lack of information transparency and so on. About inspections for plant maintenance, site managers encounter difficulties in getting global pictures tracing a significant amount of inspection information at management perspective. The decision-making is based on paper-based schedules and updated progress of them, which lacks information reliability and change flexibility. The purpose of the research-industry cooperation is to determine how the integration of inspection management and Building Information Modelling (BIM) influences the performance of the plant inspection and maintenance processes. The research team developed the integration among an online inspection management portal, a mobile client application and an existing BIM platform, Navisworks™, in this study. By using the developed system, the information of inspection tasks, including daily status reports, schedules, and task assignments, can be linked with BIM for better visualization, communication and asset life cycle management. Site managers are able to view the inspection processes through 4D simulation identifying particular inspection tasks and time duration of their interests. The outcomes of a pilot study conducted through industrial partners shows positive comments, such as reducing time spent on aggregating inspection information, going paperless and increasing real-time inspection visibility for managers to make corresponding decisions.

Keywords –

Building Information Modelling; Inspection; Plant life extension; Maintenance

1 Introduction

Inspection is one of the most essential processes [4] in identifying potential issues affecting the execution of process plants in current maintenance practice. There are different purposes for conducting inspections of a plant, such as quality control of under-constructing plant modules, pipe corrosion detection and replacement, functionality analysis of plant instruments, pre-determination of the requirement for shutdown maintenances and so on. Each of these requires accurate and efficient evaluations, a perpetual cycle of inspections and capital renewal actions [3] in order to make the maintenance diagnoses with sufficient supportive evidences and to be judged to maintain the serviceability of the plant facility. It usually requires a significant amount of field crews' efforts, management and effective inspection tools to accomplish such missions, especially in a large-scaled and complex facility.

As can be seen in state-of-the-art inspection processes, many issues exist and obstacle the productivity gained at every stage of processes. The transformation of the inspection information is a manual process between the locations of site offices and fields, which results in data aggregation problems, such as double handling information, misinterpretation, human errors and risks of document loss. These problems sometimes let the inspection be seriously dragged on. In addition, error and insufficient information increases the difficulty for managers to make flexible and appropriate decisions, resulting in cost blowout and significant delay in the completion of the inspection tasks. Furthermore, current inspection practice lacks the information transparency among site managers and field crews, increasing the difficulty of communication and the opportunities to get global pictures of the entire inspection statuses simultaneously. The above-mentioned issues need to be solved urgently given the circumstance that the complexity of current project is getting higher and higher these days.

Previous research work focuses on improving current inspection processes through the innovations at management and technical aspects. Take technologies adoption for an instance, Choi and Park [8] designed and implemented a field inspection management system based on wireless sensor networks (WSN). Yang *et al*. [9] conducted an application research on the intellectual inspection system of transmission line based on the mobile information platform. Regarding management innovations, Akanni and Alonge [5] proposed an effective implementation of risk based inspection (RBI) approach in asset integrity management of oil and gas facilities.

An observation from the previous research work shows that researchers are working on integrating emerging technologies to create a digitalized environment for reducing the use of paper-based documentary and manual effort of processing. Besides potential hardware that can be used to facilitate current inspections, new considerations of management also help improve their efficiency and effectiveness. However, the way to view and organize the information for a large-scaled and complex project still requires managers' effort in comparing and discovering deviations among planned and actual information. There should be an intuitive approach to show clear status of the entire process and facilitate appropriate decisions to be made for further maintenances actions and predictions.

To further eliminate the above-mentioned issues between current inspection systems and their users, the researchers introduce Building Information Modelling (BIM) technologies to be integrated as a user interaction layer for providing sufficient visualization capabilities to site managers. BIM is utilized in the entire life cycle of a facility which contains various information potentially benefits to discover the progress issues of the inspection. The extra information, such as cost, existing schedules and component properties, can be further referenced by managers to easily perform the inspection data comparisons and organizations. The objective of this research-industrial cooperation is to develop a BIM-enabled inspection management system so that site managers can have better communication and understanding of the status of the inspections, through the visualization of the 3D models. It is expected to help create a paper-less environment minimizing data aggregation error and waste, and to provide necessary information for further decision making.

The rest of sections are written as the follows: Section 2 describes a typical inspection process and its critical decision points needed to be aware of; Section 3 is written to introduce the architecture of the proposed BIM-enabled inspection system. The BIM-enabled functionalities are presented as well; Section 4 shows the pilot study of the research and the summary of the discussion with industrial partners regarding the use of the proposed system; Finally, section 5 presents the conclusion and potential future work of this study.

2 Inspection Process

Considering a typical inspection process, it always comes out with a decision about whether maintenance actions are needed depending on the result of the inspection. After a consultation with industrial experts, a general and complete life cycle of a typical inspection process is summarized and can be seen as Figure 1. It goes through six stages: Planning, Execution, Review and Engineering, Implementation, Examination, and Closeout. At the beginning stage, it always needs to plan inspection tasks based on the facility's maintenance strategy. The tasks will be scheduled and issued for execution. In cases of oil and gas plants' inspections, these stages always represent a significant amount of planning effort, large scaled survey activities and frequent coordination in order not to influence with the oil and gas production processes. It can be even a decision for the preparation of a shutdown maintenance which closes the entire plant for essential process components' repair and replacement.

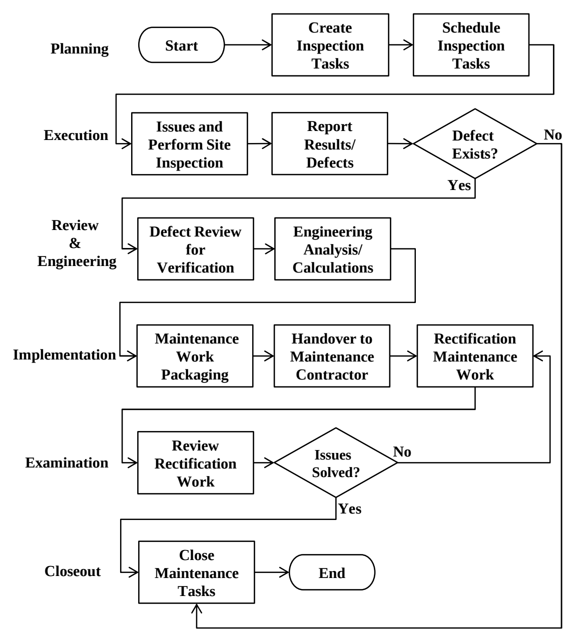

Figure 1. A general life cycle of the inspection process for infrastructures, buildings and industrial facilities

After the execution of the planned inspection task, here comes to the first decision point: is any defect or urgent fatal discovered and needed to be responded immediately? It the answer is *No*, the inspection task is considered to be completed and closed. Otherwise, a review process should be adopt with more verification, engineering analysis and calculation in order to identify the properties of the defect in more details and for scoping necessary maintenance tasks.

After the maintenance work packages are defined and scheduled, the developed maintenance tasks will be contracted and the rectification will be executed. The following review process is heading to the second decision point: have the issues discovered during the inspection task been solved through the maintenance actions? If it has been judged as a *Yes*, consider the maintenance task is done and the case will be closed. If it is not the case, further rectification is necessary in order to fix remaining problems.

As can be seen in the above-mentioned process, the entire inspection process is a complex mission with a considerable amount of effort expected on planning, coordination, judgement, communication and verification [3]. It is especially difficult to be well-managed in a complicated and large-scaled facility like oil and gas plant [6, 7]. Thus, BIM, as a management data base with visualization capabilities, is integrated to serve for the better communication among decision makers. It is done by providing visualizations of the entire inspection situations, coordinative functions of the inspection management and historical inspection simulations. These features can enhance the efficiency and effective of the inspection process during Planning, Review and Engineering, and Examination stages. A BIM-enabled inspection system is proposed and developed in this study. The following section describes its overall architecture and elaborates its' functions for better management.

3 BIM-enabled Inspection System

In this study, a BIM-enabled inspection system which integrates a BIM visualization platform, Navisworks™ [1], a web-based inspection management portal, Inspectivity Portal™, and a mobile inspection application, Inspectivity Go™, [2] has been developed. Multiple inspection managers can access the inspection information through the web interface and see the visualization results on the BIM platforms of their own computers simultaneously, as long as the system keeps the data synchronized. The details of the developed system architecture and functionalities can be referred to the following two sub-sections:

3.1 System Architecture

The overall system architecture is illustrated as Figure 2. Basically, the system can be divided into three main modules: Web-based management, Mobile computing and Visualization module. The web-based management module is the foundation of the inspection system, which contains two sub-modules: Inspection and Issue management sub-module.

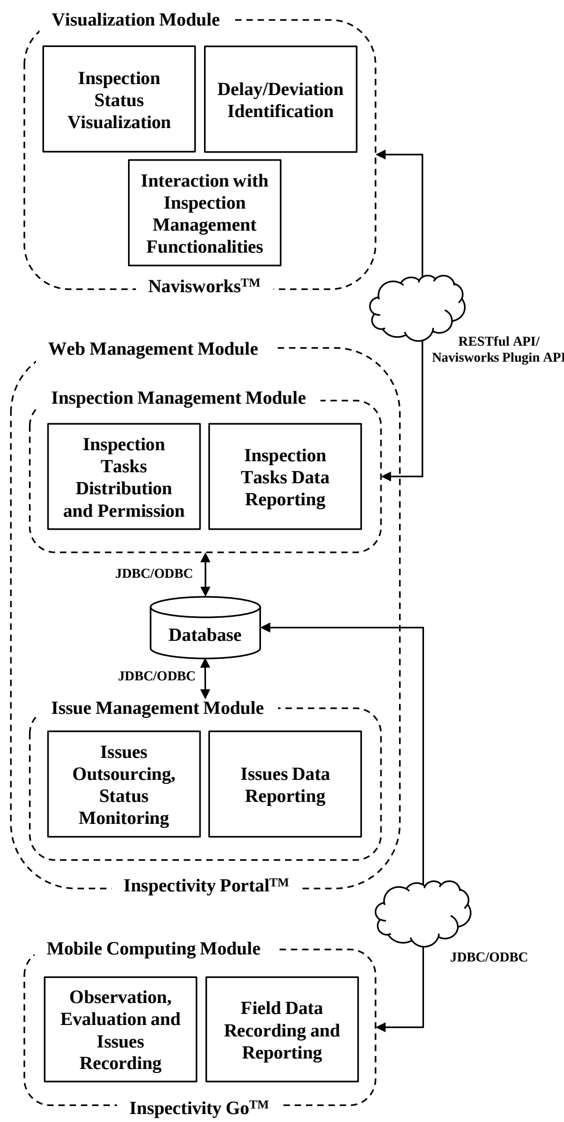

Figure 2. System architecture of the developed BIM-enabled inspection management system

The inspection management sub-module is a web portal allowing user to coordinate every inspection tasks. The coordination options include creating, assigning, approving, modifying and monitoring inspection tasks through web-based interface; As for the issue management sub-module, it basically shares the same information of a database with the inspection management sub-module. Once an issue has been raised and reported through mobile computing module used at field, the work flow of handling the issue can be created through this sub-module and the created process will be tracked and updated once any further examination been conducted. Both of the sub-modules can be accessed through Internet by office computers for site managers or planners to know the latest information of the inspection.

Mobile computing module is an application installed in mobile devices, such as tablets, which can be utilized by site inspectors to perform any inspection and examination tasks. Firstly, the field inspectors need to download the information of the inspection tasks assigned to them, from the web-based management module to their mobile application. The list of inspection tasks is varies depending on the assignments and different login authorizations for the individual field inspector. Once any latest assignment is announced, the notification messages will be sent out to the account which is already logged in. The application further provides inspection related functions, such as inspection form editing, check option designing, field photo capturing, annotating and commenting and so on, for field inspectors to record the inspection results. Those results can be uploaded to the database and update the information to the web-based management module, once the field inspectors have headed back to the office or any places with Internet capacities.

By utilizing the above-mentioned two main modules, the data of inspection tasks can be transferred digitally which reduces potential manual error of data collection and organization. However, it still lacks interpretabilities for better communication among managers to make effective decisions. Due to all the format of the information is in text- or list-based, it is difficult to get a global picture without significant effort on data referencing and comparing, in order to determine what the appropriate maintenance action the managers should go for at the next step. Regarding the effective visualization which helps managers to create maintenance plans with more confidents, the study is particularly focused on the development of the connection between the web-based management module and visualization module.

The visualization module is developed on an existing BIM platform to show the 3D facility model related to inspections in the virtual environment. The facility information is also associated with the corresponding components on the model. Furthermore, schedule information linked between different work activities and corresponded components are also provided. Thus, the inspection status of different components can be easily retrieved by calling RESTful web application programming interface (API) [10] to synchronize the latest information from the web-based management module. It is also easy to identify any delay or deviation of inspection tasks by comparing the planned schedule with the actual reported one.

For the implementation of the system in this study, the researchers utilized commercial software, Inspectivity Portal™ and Go™, as the web-based management module and the mobile computing module individually. They are all synchronized with the same database. As for the visualization module, the researchers utilized Autodesk Navisworks™ as the BIM platform and developed a plugin by using Navisworks plugin API and RESTful web API to communicate with the Inspectivity Portal™. The details of the BIM-enabled functionalities can be seen in the following sub-section.

3.2 BIM-enabled Functionalities

The purpose of integrating BIM capabilities in the visualization module of the system is to increase the data interpretabilities and communications during decision-making processes. The overall BIM-enabled functionalities contain three main sets of functions: (1) data synchronization, (2) status identification and animation, and (3) task manipulation. They are elaborated accordingly in the following sub-sections:

3.2.1 Data Synchronization

Data synchronization functions help user connect the relationships between the component of 3D geometrical facility and its related inspection task in the inspection management sub-module. It can be demonstrated in Figure 3 and 4. Figure 3 shows the user interface of the inspection management sub-module. As can be seen in the figure, a tree hierarchy of the facility's components (left-side of the figure) is generated. It is referenced to the uploaded information of 3D components. It executes in real-time by pressing a menu item of the plugin (as can be seen in Figure 4) and a batch uploading process can be executed. By generating the tree hierarchy automatically, user can plan and create related inspection tasks on the individual item on the tree, including the detail task descriptions, schedule, assignee, and supervisors.

The defined inspection tasks can be further performed by field crews through the use of mobile computing module to report the latest outcomes back to the inspection management sub-module. Once the inspection results are captured at sites, the data will be uploaded as long as crews go back to the office and submit it with Internet capability. It is a necessary procedure similar with that of manual reporting approach instead of the higher accuracy and efficiency. It helps rapid reactions against urgent task changes. Figure 4 shows the user interface of the visualization module. As can be seen in the figure, detail inspection information (properties and outcomes) from the inspection management sub-module can be further downloaded to the visualization module, and updated and displayed as properties of the 3D components (right-side of the figure). In addition, related inspection schedule of the corresponding component can also be generated automatically (bottom of the figure).

It should be noted that in this study the synchronization is dominated by the information from the inspection management sub-module. BIM models and inspection tasks are bounded by identifiers and cannot be modified by normal users. The proper approach in handling synchronization issues is expected and will be investigated in the future studies.

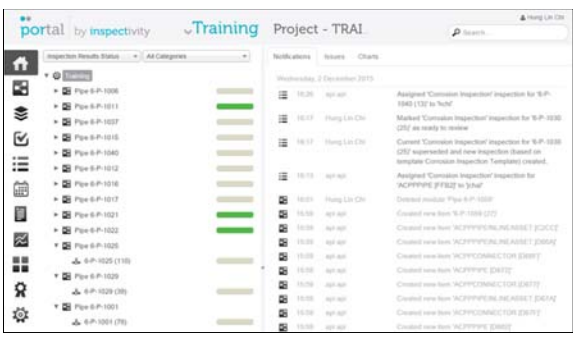

Figure 3. The user interface of the inspection management sub-module (Inspectivity Portal™)

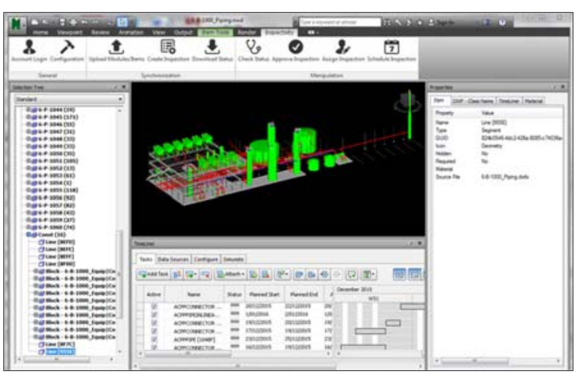

Figure 4. The user interface of the BIM visualization module (Navisworks™)

3.2.2 Status Identification and Animation

Once all the latest inspection information is synchronized with the corresponding ones in the visualization module, typical BIM simulation functions become useful. As can be seen in Figure 5, color-coded inspection statuses of different pipes in an oil and gas plant are presented based on the synchronized data. It is easy for user to click on any color-coded component and get its related inspection details right away on the properties list (right side of the user interface shown in Figure 5).

For example, managers may want to check the delay reasons if there is a task wasn't finished on time. It can be done by simply comparing the actual progress with the planned inspection schedule. It should be noted that the researchers defined a set of general inspection statuses in the plugin: Draft, Review, Assignable, Assigned, In Progress, In Progress at Field, Performed, Completed and Archived. As shown in Figure 6, different inspection tasks show their status in different colors at the specific tracking period. The representative colors of different inspection status can be edited through configuration function as shown in the right side of Figure 6.

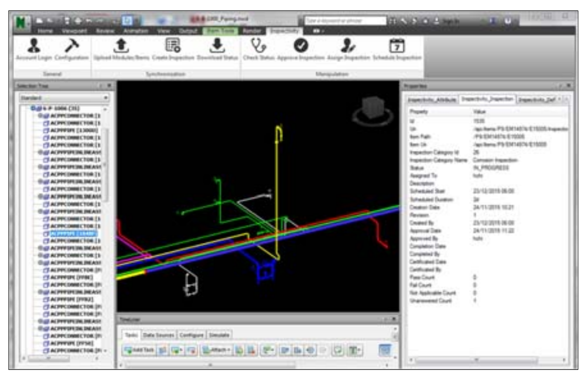

Figure 5. The color-coded inspection statuses of different pipes in an oil and gas plant

Besides showing the overall inspection status to users, a 4D (3D plus schedule) animation function is implemented to show the different inspection status with time goes by. It also helps managers evaluate how reliable the current inspection plans against actual implementations at field, which would facilitates re-planning process to be performed on the web-based management module or modifications in the visualization module right away. The re-planning process of inspection tasks allows better control of the inspection efficiency and reflects actual situations of field activities. The re-planning functions are described in the next sub-section.

It should be noted that only CAD representations of the existing oil and gas facility could be enough for the status identification because of the sufficient information of geometrical visualization. However, further related information for supporting decision-making, such as cost analysis of maintenance, quantity information and animation, which BIM can provide would better achieve the goals of inspection monitoring. This is the reason why the researchers adopt BIM platform in the proposed system development.

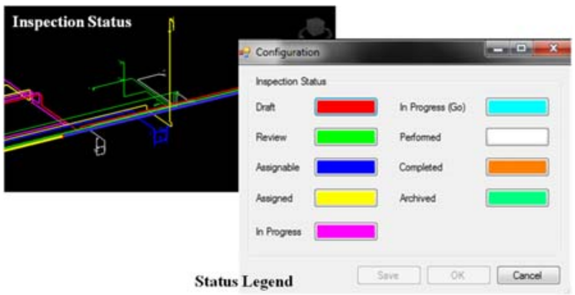

Figure 6. The configuration of the color-coded inspection status

3.2.3 Task Manipulation

In the visualization module, partial inspection management functions have been realized for modifying the details of inspection tasks, as the same ones in the inspection management sub-module. It is implemented because managers may need to rapidly re-plan the current inspection tasks based on the actual inspection progress reported from fields. These inspection management functions include approving certain inspection tasks, assigning them to related field crews, and re-scheduling specific tasks. Approving inspection tasks is a function that helps perform quick reactions while managers observed any permission haven't been dealt with. It can be observed by viewing the visualization of inspection statuses; Assigning function is designed with similar intentions, which speeds up the inspection progress when the similar delays in the work arrangement are discovered; As for the re-scheduling of inspection tasks (as shown in Figure 7), manager can easily reference to the current progress of the specific task and evaluate the actual inspection effort, to adjust its schedule plan. It would help better control the field resources and shorten the actual inspection duration of finishing all tasks, which will benefit to complex and large-scaled inspection events such as the preparation of the shutdown maintenance.

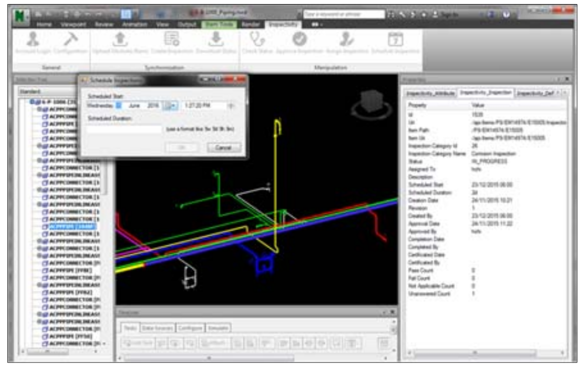

Figure 7. The re-scheduling function for the specific inspection task

All BIM-enabled functionalities have been implemented and packaged as a plugin on Navisworks^{TM} platform. Different roles of project crews in the inspection management process require different account with different authorities to access this plugin. The plugin can be logged in by users and provide different functions depending on what role the user is, such as inspection manager, inspector, site crews, supervisors and so on.

After the implementation of the proposed system, the next section describes the details of a pilot study through a discussion with industrial partners. Some comments from the industrial partners regarding the use of the proposed system have been presented as well.

4 Pilot Study and Discussion

For evaluating the usefulness of the proposed BIM-enabled inspection system, the researchers have conducted a pilot study by (1) cooperating with a software company professionalized in the inspection management of the oil and gas plant; (2) introducing the developed system to an oil and gas industrial company and (3) seeking for their professional comments regarding the adoption feasibility of the system in practice.

The oil and gas company is currently executing a life extension project for a 30+ years old Liquefied Natural Gas (LNG) plant. In this project, a significant amount of inspection tasks involving establish of scaffoldings, utilization of corrosion detection instruments and massive evaluations are planned and scheduled. And the inspection activities are performed simultaneously with the regular LNG production processes. So the inspection task can only be executed in one limited region at one time, trying to minimize effects to the production. Therefore, accurate and flexible inspection plans and effective task monitoring are very important for the project so that the time and cost spent on inspections can be optimized for further maintenance processes.

By presenting the developed system to industrial inspection managers, the following comments and benefits has been summarized and identified:

- *Data aggregation approach of the proposed system is efficient and effective*: Inspection managers generally agree that the proposed system is useful to create a paper-less environment which eliminated the potential information loss and error during the data aggregation processes. In the conventional way, field crews need to collect and remember all inspection information and record them through papers, photos and computers manually. The system helps reduce the chances of encountering uncertain situations such as double handling the data, manual input error and documents missing.
- *Status identification of the proposed system help support decision making*: Inspection managers used to identify all the inspection statuses and display them with different colors on the 3D model, just as what the developed system did instead of the entire process is manual. It usually takes time in weeks to come out with a decent drawing for decision makings. With the use of the system, the time spent on the view generation can be significantly reduced and it will indeed buy more reaction time while the actual situation going far from the expectation.
- *More configurations of the inspection status are needed*: Inspection managers suggest that the function of the status identification and animation should be extended, so that users can define the names of different inspection status by themselves to include different outcomes of the inspection. In a pipe inspection task, for example, managers would like to know how serious the corrosion condition of a specific segment of the pipe is and how the corrosions will grow with time through the collected historical data. It can facilitate making decisions for prioritizing the maintenance work sequence due to the limited budget. The growing pattern of the corrosion can be also a good reference to be considered in further predictive maintenance considerations.
- *Issue management also requires visualization capabilities*: Regarding the issues discovered during inspection processes, it is also necessary to keep tracking the progress of the corresponding maintenance. Inspection managers suggest a new synchronization function to be realized for monitoring when the issues can be solved and how to do so, by viewing the global view of the issues' status in the system. Technically, such function can be implemented by cooperating with the software company to provide another RESTful web API for the issue management sub-module. It can be then integrated into the current developed plugin. However, how to make the data structure of inspection tasks co-existing with that of issues and to be visualized individually still needs further design effort and examinations.
- *Further validation is required as well as the experimental adoption*: In despite of positive feedbacks received in the discussion, inspection managers raised several concerns to be noted, such as culture changes of implementing new technologies among field crews against the conventional approaches. The actual benefit of the developed system must be identified through more evaluations in practice, in order to validate the expectations summarized from the discussion. It should be done at the next stage of the study.

5 Summary and Conclusion

A BIM-enabled inspection management system is developed in this study in order to increase the productivity of inspection tasks and get better control of uncertainties. The developed system contains three main modules: web-based management, mobile computing and visualization module. They are sharing the same database and can be synchronized or linked through web API. A plugin in the BIM platform, Navisworks™, is developed to support the visualization module. It also provides three sets of functions: data synchronization, status identification and animation, and task manipulation for users to easily get ideas about inspection details. Pilot study including discussions with inspection experts, from an oil and gas industrial partner, has been conducted and the feedbacks are generally good for the feasibility assessment of the system adoption in practice.

The contributions of the research-industry coordination include that: (1) the proposed approach extended BIM visualization capacities, such as color-coded status identification and 4D animations, from oil and gas plant planning and construction stages to maintenance and operation stages; (2) the system provides efficiency and effectiveness in inspection data aggregations as well as inspection status tracking. In addition, it helps managers know the deviations of inspection tasks rapidly in order for better communication and decision making; (3) through this study, BIM model will have inspection information as another dimension of the management, which facilitates the asset management at the entire life cycle of the oil and gas facility in the future.

For the future plan of the research-industry cooperation, evaluations will be conducted in order to further validate the true values of the developed system. Quantitative results collected in a simulated inspection environment will be used to support the claims in this study. Furthermore, the developed system will be integrated with more features based on the comments provided from the industrial partners, such as adding issues' status monitoring functions, historical data animation functions for inspection outcomes, the freedom of naming different inspection status and so on.

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References

[1] Autodesk Navisworks | Project Planning. On-line: http://www.autodesk.com.au/products/navisworks/overview, Accessed: 15/03/2016.

[2] Inspectivity Commissioning Completion Software. On-line: http://www.inspectivity.com, Accessed: 15/03/2016.

[3] Hegazy T. and Gad W. Dynamic System for Prioritizing and Accelerating Inspections to Support Capital Renewal of Buildings. *Journal of Computing in Civil Engineering*, 29(5): 04014058, 2015.

[4] Laofor C. and Peansupap V. Defect Detection and Quantification System to Support Subjective Visual Quality Inspection via a Digital Image Processing: A Tiling Work Case Study. *Automation in Construction*, 24: 160-174, 2012.

[5] Akanni J. and Alonge O. Effective Implementation of Risk Based Inspection (RBI) Approach in Asset Integrity Management of Oil and Gas Facilities. In *Proceeding of ASME 2015 Pressure Vessels and Piping Conference*, Boston, MA, 2015.

[6] Chandima Ratnayake R. M. Challenges in Inspection Planning for Maintenance of Static Mechanical Equipment on Ageing Oil and Gas Production Plants: The State of the Art. In *Proceeding of ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering*, Rio de Janeiro, Brazil, 2012.

[7] PharmOut White Paper: 10 Common GMP Challenges Facing Maintenance Departments in Pharmaceutical Plants. On-line: https://pharmout.net/downloads/white-paper-10-problems-with-pharma-plant-maintenance.pdf, Accessed: 24/05/2016.

[8] Choi S. H. and Park H. K. Design and Implementation of a Field Inspection Management System Based on Wireless Sensor Networks. *International Journal of Distributed Sensor Networks*, 2014:1-4, 2014.

[9] Yang Z. W., Yi W. and Jin Y. Application Research on the Intellectual Inspection System of Transmission Line Based on the "Mobile Information Platform." *Applied Mechanics and Materials*, 596: 719-722, 2014.

[10] Pautasso C., Wilde E. and Alarcon R. *REST: Advanced Research Topics and Practical Applications*. Springer-Verlag, New York, 2014.