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The Engineering Inspectors and Work Piece Matching Algorithms Based on Multiple Criteria

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Abstract— One of the key processes of the engineering inspection project is the ability to form the engineering inspection team quickly. The basic WBS-EI Matching Algorithm based on cost consideration was presented by W. Bovenizer [7]. This paper presents the extension of this algorithm to cover multiple criteria. The system will automatically run the matching algorithm to find the inspection team satisfying certain criteria including budget, location of engineering inspectors, and minimum number of engineering inspectors. This would provide more flexibility in forming the team satisfying the contract requirements.

Keywords-Engineering inspection team, work pieces and engineering inspectors matching algorithms, location of inspectors.

I. INTRODUCTION

Quality Assurance is process oriented and focuses on defect prevention, while Quality Control is product oriented and focuses on defect identification. QA/QC is the combination of quality assurance, the process or set of processes used to measure and assure the quality of a product, and quality control, the process of ensuring products and services to meet consumer expectations, and mandatory regulatory requirements. The field of QA/QC covers a multitude of industries and processes. However, there are common structures and procedures normally recognized and followed when implementing QA/QC requirements for materials and equipment manufactured for major and critical industries the 10 most important being: Oil & Gas, Upstream & downstream, Onshore and off shore, Nuclear Plant, Petrochemical, Power generation including renewables, Railways , Shipbuilding, Automobile, Aero-space, Military, Civil infrastructure.

There is a vast amount of government regulation and customer specification covering the processes of QA/QC. Also, many certifying organizations. This paper relates to the provision of QA/QC services for material or equipment as purchaser, or on behalf of the purchaser which usually are managed according to the requirements of ISO 9001-2015 and ISO 17020-2012, the former being a general management system and the latter being specifically to cover the implementation of QA/QC inspections and controls.

ISO 17020-2012 requires full traceability of management, documentation and operational activities. In the event of a quality problem or product failure, full traceability can identify and isolate the affected product or practice and facilitate correction according to prescribed procedure, as well as providing historical data in the event of some future accident or failure after the material or equipment is in use. Such as say a pressure vessel failure at a refinery resulting in explosion, fire, and loss of life. In such circumstance, full traceability of the QA/QC records can provide vital information in establishing the root causes.

Conducting QA/QC Inspection services to ensure that processes and products meet the customer's requirements and specifications normally follows a pattern; as noted above this basic pattern is mostly common for different types of project and in different industries.

The reason why it is common is because the manufacturing/engineering disciplines for different materials and components are common. For example, a centrifugal pump for a power plant will be basically the same as for an oil rig or a gold mine or a nuclear plant. Of course, there can be differences of specification due to different operating conditions but the basic manufacturing/engineering discipline is the same. Engineering disciplines as applicable to conducting typical QA/QC as related to this research fall into separate groups, the main groups broadly cover: Mechanical, Rotating, Welding, Electrical, Instrumentation, Coatings. Some engineers conducting QA/QC activities may be multi-disciplined and specialized disciplined engineers might be called upon if necessary.

II. Research Problem

The engineering inspection process is the execution of the QA/QC to prevent defects by identifying the possible defects as inspected. This mostly relies on the experience and integrity of the inspectors. The proposed inspectors need to be approved by the Client, the portfolio of the inspectors is sometimes not well kept and updated in a systematic manner. For a large multi-phase third party QA/QC project, a large number of inspectors must be identified, qualified, and selected based on the matching of previous experience in similar type of inspection work, and on the availability, and the cost associated with hiring that person. It is a complex process. Current situation is that this process is generally done based on the familiarity of the persons to be commissioned. The client has no way to access the qualification data online since no system is designed to support that in the most transparent and trustworthy manner.

In order to improve this process dramatically, the new system to support the selection, matching of experience and work scope, the recording of accomplishments, the rating of the experience and skill level all need to be re-designed with process improvement in mind. Here are a number of issues that need to be incorporated in the new design [7].

- The selection process of inspectors matching the work piece and the budget allocated
- Receipt of all details and documentation from client, Drawings, specifications, Inspection and testing plans, reporting instructions etc.
- The work breakdown structure (WBS) and qualification of each item or group of items in the WBS
- Issue of assignment instructions
- Coordination and control of the activities at the vendor
- Receipt, control and distribution of Reports
- Coordination and management of any Non-conformity issues until resolution
- Coordination and management of any client related issue or complaint until resolution

All of the above processes are usually supported by the Inspection agency's data systems and procedures and the purpose of this research is to propose a more efficient system in selecting and matching the inspectors and the work pieces.

Significance of this Problem, the third-party inspection for QA/QC of large infrastructure projects is an essential part of the modern business paradigm that cannot be neglected since the public safety is of the utmost concern and the investment must be protected, not allowing any defects to cause damage to life, property and reputation. This research aims at improving the efficiency of the inspection agency in identifying the qualified inspectors for a project. The system to be developed will provide the following benefits:

1) It will strengthen the practices of the engineering inspection industry.
2) The infrastructure projects can demand all the inspection agencies to deploy a similar system for transparency and efficiency.
3) A new class of inspectors can be trained to understand the new system and therefore, the QA/QC inspection industry can grow in Thailand and overseas market.
4) It will increase competitiveness as the system deploys the cutting-edge technology and innovative design idea.
5) Derivative products can be designed to support other engineering disciplines that require simalar project management.

III. Previous Work

In this paper we provide a brief overview of some of the research work in the area of SQM. Research papers specific to the engineering inspection industry are very limited. In particular, little if any previous research about the process or procedures to facilitate the contract finalization, the allocation of workforce, the fulfillment of contract, the transparency of the third-party inspection company, the project owner and the inspectors who perform the actual inspection work in accordance to the work breakdown structure of the project. Most research papers relate to the EPC industry. Consequently, our survey will be limited in scope to touch upon certain aspects of quality management in the EPC industry as relevant in certain degree to our engineering inspection industry.

The Study by Yoshua Neuman [1] is very relevant as can be seen from the following taken from it's Introduction and Objectives sections; it evaluates the most effective processes and practices for ensuring "that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications and that they are delivered to the project site without any need for rework." The relevancy of the EPC project [1] can be noted in the reports on research being investigating how to achieve zero rework through effective supplier quality surveillance practices. However, the paper does not identify or suggest methodology or procedures to rectify this situation or to suggest a system which would provide control and traceability. The issue of the management of supplier quality within the construction industry was studied by Rufaidah Al Maian [2].The researchers aim to determine the effective practices for SQM in the construction industry to ensure that the supplied materials are produced and fabricated without any need for rework by supervising the suppliers, full time or part time, to ensure that they are meeting the project quality requirements,

Inspection effort tracking, and Muhammad Arsalan Farooq, Randolph Kirchain, Henriqueta Novoa, Antonio Araujo[3] studied the cost of quality by evaluating cost-quality trade-offs for inspection strategies of manufacturing. The problem of the role of third-party agency in FPSO/FSO EPCIC project, was studied by Vijay Kumar [4]. This research relates to roles and practices of the Third-Party Agencies providing Quality Services as required for the EPIC (Engineering Procurement Construction & Installation) of FSO (Floating Storage & Offloading Vessels). However, the values can also be generally applied to the majority of On-shore, Off-shore Oil & Gas and other EPIC projects.

For the aspect of optimization and minimum costing, a number of researches using heuristics algorithm will be presented here to give an overview of various techniques that can be employed to get the solution. The paper, Cost-Based Query Optimization via AI Planning [6] examines the complications of engendering AI programmed query plans considering and utilizing the major contemporary planning improvements of recent times. The Paper puts forward an innovative encoding which supports the classification of join-order query planning as a (near) delete-free planning problem; concentrating particularly on the difficulty of cost related join-order augmentation. The investigations validate the efficacy of AI planning methods for effective query plan production.

IV. WBS-EI Matching Algorithm and Business Processes

The basic WBS-EI Matching Algorithm was presented in [7]. It is presented here so to understand the extension of this algorithm to cover multiple criteria including location, and margin, the number of EI to be selected.

The following variables and assumption will be made. Assume that the ABC company signed a contract C. Contract C has given a budget of B USD, project location G. The Contract C has a Work Breakdown Structure (WBS) consisting of M elements in the set work pieces in WBS {W1, W2,..,WM}. Let us further assume that there are N Engineering Inspector represented by the set EI= {E1, E2..., EN}. Each Ei is characterized by a rate Ri, the competency qualification CQ 1, CQ2, …CQ3 …., CQk , Job Rating JR, and each Ei has a capacity , Ci, in terms of the number of WBS that can be assigned to Ei. Each WBS is qualified by the manhour estimate, mh; skill qualification, SkillEI() needed SQ 1, SQ2, …SQ3 …., SQk

WBS-Engineering Inspector Matching Methods and Criteria: The system will automatically run the matching algorithm to find the inspection team satisfying certain criteria. In this sections, three such algorithms will be represented.

- WBS-EI Matching Algorithm based on budget criteria.
- WBS-EI Matching Algorithm based on budget criteria and location of EIs.
- WBS-EI Matching Algorithm Based on budget criteria and minimum no. of EIs.

1) *WBS – EI Matching Algorithm (Auto Selection-based on budget criteria)*

Objective: Given a set of WBS, find a set of EI that cover WBS such that

*(Sum (Wj.mh*EIi.rate), for all j and i) <= B*
And skill qualifications, the location, the job rating are satisfied
Let Cap.EI(j) be the current assigned work pieces to EI (j)
Initially Cap.EI(j) = 1 , for all j
Let i be the index of work piece in WBS from 1 to M
j be the index of EI members from 1 to N
i =1
TotalBudgetSofar = 0
Do while (i <= M)
j=1
Do while (j <=N)
CapLoop : If Skill.EI (j) = SQ.W(i) then W(i) in array WW(); Cap.EI(j) = Cap.EI(j) + 1
if CapMax.EI(j) > Cap.EI(j) then take EI(j) from the EISet and goto CapLoop
Then use that member
Do k= 1 to CapMax.EI(j)
*Cost.EI(j) = Mh.WW (k) * rate.EI(j)*
End
totalcost sofar= totalcostsofar + Cost.EI(i)
If totalcostsofar>project.budget and i< M then goto A
If totalcostsofar=project.budget and i = M then goto B
If totalcostsofar<project.budget and i = M then goto C
If totalcostsofar>project.budget and i = M then goto D
A: Not success (Budget exceeded, need to fulfil (M-i) items)
B: Success (Margin = 0)
C: Success(Margin= Project.budget – Totalbusgetsofar)
D: Semi Success (Margin is off by one person's cost)
j=j+1
End
i=i+1
End

2) *WBS – EI Matching Algorithm* (Auto Selection-based on budget criteria and location of inspectors)

Objective: Given a set of WBS, find a set of EI that cover WBS such that

*(Sum (Wj.mh*Ei.rate), for all j and i) <= B and each element of EI is within k kilometers from the work site)*
Assuming that skill qualifications and job rating are satisfied
Let i be the index of WBS from 1 to M

Let j be the index of Engineering Inspector members from 1 to N
i =1
TotalBudgetSofar = 0
Do while (i <= M)
j=1
Do while (j <=N)
If travel.distant.(GPS.E(j)-GPS.Worksite)<=k kilometer Then do
If skill.EI(j) = SQ.EI(i)
If currentCapacity Cap.EI(j) > CapMax(j) then update , assign WBS.W (i) to EI(j) , update currentCapacity Cap.E(j), if CurrentCapacity Cap.E(j) = CapMax(j) then mark E(j) as un-assignable since it has reached the maximum capacity.
Then use that member
*Cost EI(i) = Mh.E(j) * rate.EI(i)*
Totalcost sofar= totalcostsofar + cost.EI(i)
If totalcostsofar > project.budget and I < M then goto A
If totalcostsofar = project.budget and I = M then goto B
If totalcost sofar < project budget and I = M then goto C
If totalcostsofar > project.budget and I = M then goto D
A: Not success(Budget exceeded, need to fulfil (M-i) items
B: Success (Margin = 0)
C: Success (Margin = Project.budget – Totalbusgetsofar)
D: Semi Success (Margin is off by one person's cost)
End
j=j+1
End
i=i+1
End

3) *WBS – EI Matching Algorithm (Auto Selection-based on budget criteria and minimum number of engineering inspection members)*

Objective:
*Given a set of WBS, find a set of EI that cover WBS such that (Sum (Wj.mh*Ei.rate), for all j and i) <= B and use minimum number of inspectors)*
Assuming that skill qualifications and job rating are satisfied
Let i be the index of work pieces in WBS from 1 to M
Let j be the index of Engineering Inspector members from 1 to N
i =1
TotalBudgetSofar = 0
Case 1: sum (MaxCap.EI(j)>=2) > = M then ok
Case 2: sum(MaxCap.EI(j)>=2) < M then need additional number of EI(j), L = M-sum(C(j)>=2)
Preprocessing : j=1;sum=0; do while (j <=M) ; if MaxCap.EI(j) >1 then do sum= sum + MaxCap.EI(j); j=j+1; end;
Case 1: Do while (i <= M)
If MaxCap.EI(j) >=1 then do
j=1
Do while (j <=N)
If skill.EI(j) = SQ.WBS.W(i)
If currentCapacity Cap.EI(j) > MaxCap.EI(j) then update, assign WBS.W (i) to EI(j) , update currentCapacity Cap.EI(j), if CurrentCapacity Cap.EI(j) = MaxCap.EI(j) then mark EI(j) as un-assignable since it has reached the maximum capacity.
Then use that member
*Cost E(i) = Mh.E(j) * rate.E(i) Totalcost sofar = totalcostsofar + cost.E(i)*
If totalcostsofar > project.budget and I < M then goto A
If totalcostsofar = project.budget and I = M then goto B
If totalcost sofar < project budget and I = M then goto C
If totalcostsofar > project.budget and I = M then goto D
A: Not success (Budget exceeded, need to fulfil (M-i) items
B: Success (Margin = 0)
C: Success (Margin = Projectbudget – Totalbudgetsofar)
D: Semi Success (Margin is off by one person's cost)
j=j+1
End
i=i+1
End
If sum > = M then the number of assigned inpectors = sum;
If sum < M then need to find another M-sum inspectors.
Case 2:
Update WBS, EI
M=L
Do while (i <= M)
j=1
Do while (j <=N)
If skill.EI(j) = SQ.WBS.W (i)
Then use that member
*Cost E(i) = Mh.E(j) * rate.E(i)*
Totalcost sofar= totalcostsofar + cost.E(i)
If totalcostsofar > project.budget and I < M then goto A
If totalcostsofar = project.budget and I = M then goto B
If totalcost sofar < project budget and I = M then goto C
If totalcostsofar > project.budget and I = M then goto D
A: Not success (Budget exceeded, need to fulfil (M-i) items
B: Success (Margin = 0)
C: Success (Margin = Project.budget – Totalbusgetsofar)
D: Semi Success (Margin is off by one person's cost)
j=j+1
End
i=i+1
End

In this section, three WBS-EI Matching Algorithms were presented. The application of these algorithm is to identify the engineering inspectors to work in a project with a number of work pieces, each requiring different skill set and quality rating, time to complete and the rate of the engineering inspector to carry out the task. In [7],

the basic WBS-EI matching algorithm with profit margin criteria was evaluated against the output from manual procedures. It was found that the WBS-EI Matching algorithm consistently outperformed the manual procedure in forming an inspection team based on the budget criteria.

V. CONCLUSION

In automating part of the engineering inspection work under the framework SQM, the key process of securing the contract and later execution is to form an engineering inspector team that can deliver the inspection work within the agreed budget. Currently, the selection of team members is based on familiarity and browsing through the resumes to determine if an inspector is qualified or not. The selection of inspectors matching the requirements of each of the WBS is done systematically through the proposed algorithms as outlined in Section IV Auto Selection: The system will automatically run the matching algorithm to find the inspection team based on budget criteria, or based on location criteria, or based on minimum member of inspector criteria.

The algorithmic process will enable a project manager to quickly form a team that can deliver the work within the budget and satisfies many other constraints that can be specified. Experiments were designed with three data sets to evaluate the performance of the algorithm against the manual procedures in selecting engineering inspectors matching the work pieces. The performance based on the total budget needed to carry out the inspection work is used as key performance indicator. The outcome is that the algorithm performs much better than the manual procedure in terms of total manpower expenses.

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