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# The Engineering Inspector – Work Piece Matching Algorithm for Setting up Minimum Cost Engineering Inspection Team

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*Abstract*— The Quality Assurance (QA) and Quality Control (QC) for materials and manufactured equipment purchased and destined for use in different industries as well as their assembly, fabrication, integration and commissioning as functioning entities such as Refineries, Power Plants, Nuclear facilities, Ships, Oil Rigs etc. is a highly complex, specialized and critical undertaking which unless performed to prescribed and controlled levels and extent can result in calamitous HSE consequences with danger to life, the environment as well as financial loss. This research describes the practices and planning required to effectively manage the QA/QC process in terms of finding the right engineering inspection team algorithmically; this is a new approach to securely deliver the cost-effective aspect of QA/QC. Cost being a fundamental and mandatory component of QA/QC business. This can be achieved by securing the key elements of the process which have to include; the selection of the inspection personnel, the identification of the required specifications and design parameters, the control of reporting, maintenance of data, contractual conditions and requirements as related to QA/QC, control of budget. Currently, often the control of these processes is compartmentalized and based on familiarity of personnel and fragmented systems. This dissertation proposes that the processes can be controlled systematically through the proposed algorithms. The algorithmic process will allow management to effectively form work groups that will control and deliver the work processes within budget satisfying the QA/QC requirements. Experiments were conducted to compare the results of using the manual procedures and the proposed WBS-EI Matching algorithm to find the inspectors for a set of work pieces (WBS) with minimum cost or budget. The algorithm produced results far superior to manual procedures. There are many variations of the matching algorithm proposed in this research providing a broader possibility to maximize the profit in many different situations.

***Keywords- QA/QC; engineering inspection; matching algorithm; minimum cost***

## I. INTRODUCTION

The Quality Assurance (QA) and Quality Control (QC) for materials and manufactured equipment purchased and destined for use in different industries as well as their assembly, fabrication, integration and commissioning as functioning entities such as Refineries, Power Plants, Nuclear facilities, Ships, Oil Rigs etc. is a highly complex, specialized and critical undertaking which unless performed to prescribed and controlled levels and extent can result in calamitous HSE consequences with danger to life, the environment as well as financial loss. The QA/QC process is realized by means of engineering inspection. Engineers who perform the actual QA/QC Inspection activities at the Vendor locations where the materials and equipment are manufactured, known as Inspectors. These Inspectors are often contracted directly by the inspection agencies on a free-lance contract basis or can be their own staff members [1-3]

The inspectors must have experience and integrity to complete the assignment. Currently, 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.

Certifying and Inspection Companies such as TÜV Rheinland, TÜV Nord, Intertek, Velosi, Phoenix QC, JIC, Incok etc. known as Inspection Agencies. These are

contracted by the EPCs to provide certifying and QA/QC services related to the materials and equipment procured. Inspection Agencies are also contracted directly by the end users to monitor and control the QA/QC activities being provided to them by the EPCs. As noted, there are many aspects of QA/QC functions and services relating to different aspects of the EPC process. The inspection and related processes are based on the Quality Management System (QMS) processes according to the requirements of ISO 9001-2015 and ISO 17020-2012, can be illustrated in Figure 1.

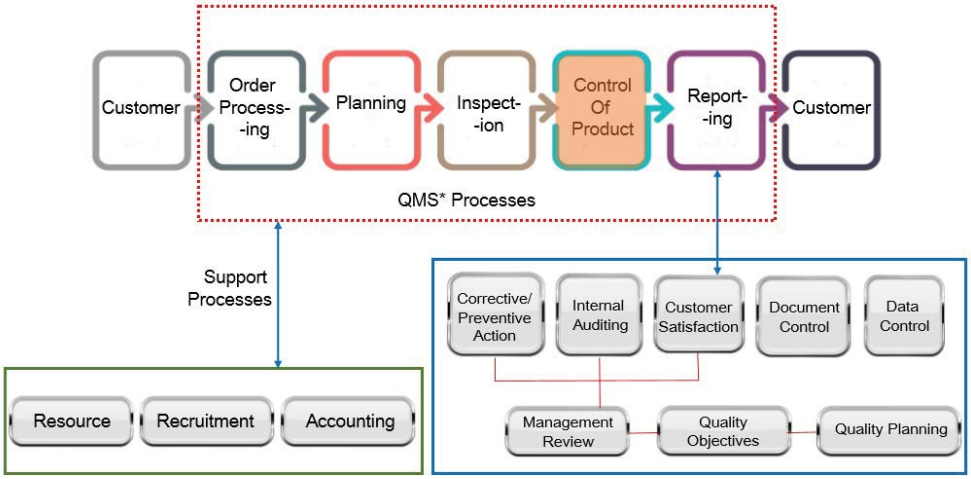


Figure 1. Quality Management System for Engineering Inspection Project.

## II. Selection, Proposal and Approval of Inspectors

The third-party inspection for QA/QC of large infrastructure projects are an essential part of 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.

The requirement is to select and propose the most local, suitably qualified and experienced personnel for the given assignment's technical and general requirements. Individual clients have differing selection requirements, a fact which could be additional to inspection agency's standard practice. The inspection agency must ensure that a proposed inspector meets such before proposing any candidate. It is generally the case that Clients review and approve the resumes of Candidates before awarding any service contract or assignment.

However, this paper concentrates on algorithmically setting up of the inspection team as related to the work breakdown structures of the project in terms of cost and manpower skill and experience attributes. This approach has not been addressed by existing published papers.

The inspection process workflow is given in Figure 2 within the context of QMS. The processes involving the project work breakdown structure (WBS) and finding the inspectors who have the skill and experience to perform the inspection work for a WBS successfully is a time-consuming work for large inspection projects. Moreover, currently, this matching process is carried out manually. In order to improve the efficiency of this selection and matching process, we will propose the Engineering WBS-Engineering Inspector (EI) Matching algorithm with a minimum cost criteria.


Figure 2. The Inspection Process Workflow

In Figure 2, the process in step 2 and step 3, need to estimate the cost of carrying the contract. The initial estimate as the inspectors are selected and qualified. The details estimate as needed to finalize the proposal in Step 3 need to form the inspection team from the detailed WBS work pieces. Section 3 will present the algorithms to carry out these complex tasks.

## III. The Manual Process of Selecting the Inspectors

*1) For the expertise of the inspectors, and types of inspections the following disciplines and categories have to be considered:*

- Mechanical (steel fabrication, pressure equipment, piping, storage tank)
- Welding, NDT
- Electrical Equipment
- Instrumental Equipment
- Coating & Painting
- Offshore & Sub-Sea Materials and Equipment
- Product Quality Inspections
- Cargo Loading/Offloading Services
- Goods Inspection Services: Visual Inspection, Dimensional Inspection, Quality Control Document Review, Quantity Inspection, Packing & Marking Inspection, Loading Inspection
- Other: Shop Inspection, pre-shipment inspection, Commodity Inspections, Vendor Inspection Services, Acceptance testing, Final Inspection.

*2) Evaluation of Working Knowledge of Industry Codes and Standards: To meet client's needs agancies conduct evaluation against the following codes and standards: ASME, ASTM, ANSI, AWS, TEMA, NACE, SSPC, UNI-EN, IEC, DIN, ISO, API, ASNT, IEEE, NEC, NEMA, BS, MSS, CSA, CGSB, BGAS, BOSIET and others (including equivalent local standards)*

*3) Certifications:* We have to check for certain certificates as required by the client such as for NDT, ASME, PED, SET, OPSC, IRCA, SSIC, BOSIET, NACE, API, CSWIP, HUET, ISO, AWS, IIW and others (including equivalent local national standards/regulations as appropriate)

*4) Expediting:* When expediting is part of the WBS an extensive and proven record of experience in expediting of various disciplines is required, technical qualification and experience is considered an advantage but is secondary to the expediting experience.

*5) Age and Physical Condition*

### A. Acceptance and Approval Process

After evaluation according to the criteria above, if satisfied, the coordinator/proposal dept. shall include the candidates' details in the inspector database. The approval of the candidate for all assignments will be recorded by the member of the technical staff or manager that sanctioned the candidate as approved. If required by client, a Field Personnel Approval Record Form can be generated and issued as a scan or hard copy for clients' reference. The approved candidates' certification and associated documents are stored in the system, this being considered the primary document repository. Generally, every three months the Technical Manager will review data base and check completeness of inspectors' registration.

*1)* An inquiry with job details is received from the client.

*2)* The coordinator identifies the type of work, location, dates & frequency and discipline

*3)* The coordinator refers to a world map showing locations of Vendors and inspectors as well as the location and discipline of qualified inspectors in the database. Each inspector has gone through a qualification process before being eligible to be selected. There is a questionnaire and an established procedure as to how the qualification process is managed.

*4)* The coordinator selects inspectors, considering their discipline, location, cost and previous work experience with their rating for previous assignments carried out. (On completion of every work piece the performance of the inspector is evaluated, rated and recorded in the database). The policy is to select the nearest (by location) suitably qualified by discipline and experience and cost-effective candidates. Regarding cost it may be that there is already an agreed rate structure with the client or it may be that it has to be proposed on a case by case basis.

*5)* Cost of the inspector is either 1) hourly rate for all travel, working and reporting time with any previously agreed other expenses such as overnight hotel costs etc. if applicable being paid at cost. 2) fixed day rate including all travel working and reporting time 3) day rate with additional overtime rate if working hours exceed 8 or 10 hours, 4) monthly all-inclusive rate for resident assignments 5) a permutation or combination of these.

*6)* Rates charged to clients may be on the same basis as for the inspectors; after evaluation on the probable inspector cost in some cases in order to increase margin the coordinator may negotiate a day rate with the inspector and an hourly rate with the client.

*7)* The coordinator calculates the travel time and distance for each candidate, for say 95% of assignments the inspector will use his own car and be paid on mileage basis

*8)* Having identified suitable candidates the number of which will vary depending on discipline and locations of prospective candidates in or near to that location but will typically be between one and four, the coordinator will email each candidate advising them of the type of work, location, dates & frequency and request them to advise their availability.

*9)* Once available candidates are identified the coordinator will send their CVs' (Qualified inspectors CVs and qualification certification is kept in the data base) with details of location and cost as described above. Depending on the work factors between one and 4 candidates will be typically proposed.

*10)* The client will choose their preferred candidate and confirm that the work may proceed. In some cases, a backup inspector may also be approved in case of sickness etc. of the principle inspector.

### *B. The Number of Work Pieces for An Inspector*

The nature of the work will vary according to the engineering discipline so Mechanical, Electrical, etc. it's very rare to mix disciplines , therefore if the assignment requires inspection of different disciplines it may be necessary to send 2 or more but this is rare, It would also be very rare for one inspector to visit 2 or more separate vendors/ manufacturers in one day but if it should happen that he visited 2 then that would be 2 work pieces. Considering that the definition of a work piece/assignment is the sale of man days, weeks or months some typical cases below:

*a) Case1:* A single visit to a vendor for one day by one inspector for one specific work scope, so one work piece, this is the most common. Say 65 %.

*b) Case 2*: In the event that an Inspector is assigned to cover all the inspections required during the manufacture of equipment this may be over a period of time say one month to 18 months or more. At the beginning the inspection points will be identified and agreed between the client the vendor and the inspector. A schedule of inspections is drawn up known as an Inspection and Test Plan (ITP) The inspector will then be required to attend the inspection points agreed in the ITP over the period of manufacturing and testing. This may typically be between 10 to fifty visits. Therefore 10 to 50 work pieces. This is fairly common say 25%.

*c) Case 3:* It may be decided that the Inspector should attend at the vendor/manufacture's location every day during the manufacturing process and the rates be on a monthly Resident basis as described above. Therefore, one work piece. This is less common say 10%.

## IV. The Engineering Inspection Team Forming Algorithm (EITF)

Before presenting the algorithm, 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 work pieces in the set {W1, W2,...,WM}. Let us further assume that there are N Engineering Inspector (EI) represented by the EISet {EI1, EI2..., EIN}. Each Ei is characterized by a rate Ri, the skill competency qualification Skill 1, Skill2, …Skill3 …., Skillk, Job Rating JR, and Each EIi has a capacity, CapMaxi, in terms of the maximum number work pieces of WBS that can be assigned to EIi. Each work piece, in WBS is qualified by the manhour estimate, mh; skill qualification needed SQ 1, SQ2, …SQ3 …., SQk.

*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*
*hen 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*

## V. Experiment and Validation

In order to validate the use of WBS-EI matching algorithm during the pre-project execution. Basically, in this phase it is to setup the final manpower for the projects, setup the budget, and payment, mobilize the support team. Our objective in designing the WBS-EI matching algorithm is to speed up the contract finalization and mobilization. At the same time, it is fruitful to ensure that the perspective of the users is on the positive side.

For the experiment, we first design a prototype of the system. For this prototype we implement only a simplified model of the WBS-EI algorithm. The functionalities implemented would give the minimum expense for the set of work pieces in WBS and the set of EI. We design the experiment with three set of data: Data Set 1 comprising 200 engineering inspectors, 46 work pieces, Data Set 2: comprising 200 engineering inspectors, 100 work pieces, Data Set 3: 200 engineering inspectors, 140 work pieces. The manual process used in selecting the engineering inspectors for a set of n work pieces is described in Section 3.

| | WBS-EI Matching Algorithm | Manual 1 | Manual 2 |
|---|---|---|---|
| Data Set 1<br>200 EI, 46 WBS | 41,652 | 84,838 | 82,254 |
| % increase | | 103.68 % | 97.48 % |
| Data Set 2<br>200 EI, 100 WBS | 101,162 | 194,542 | 193,820 |
| % increase | | 92.31 % | 91.59 % |
| Data Set 3<br>200 EI, 140 WBS | 151,096 | 250,341 | 239,240 |
| % increase | | 65.68 % | 58.34 % |

Figure 3. Comparisons of the budgets between using WBS-EI Matching Algorithm and the manual selection procedure.

The results from running the Data Set 1 on the WBS-EI Matching algorithm in selecting engineering inspectors to work for 46 work pieces is clearly shows that it is superior to the manual procedures in selecting the qualified engineering inspectors in terms of budget. The main reason is that the manual process is to browse through a lot of documents to screen for qualified inspectors also it is cumbersome to identify the one with lowest rate and also qualified to perform the specified inspection task. Data Sets 2 and 3 with increasing number of work pieces shows consistently the increase of budget in using the manual procedures. The percentage increase in budget ranging from 58.34% to 103.68%. Hence, it is clearly shown that the proposed algorithm performs better than existing manual procedures.

## VI. Conclusion

In automating part of the engineering inspection work under the framework SQM, the key process of securing the contract and execution later 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 inspector data to determine if an inspector is qualified or not. Then the rate of the inspector will come to play to compute the accumulated expense. Therefore, most frequently there is little time to really identify the qualified inspector with lower rate.

In this research we propose an algorithm that facilitates the selection of inspectors matching the requirements of each of the work pieces of WBS with minimum cost criteria. The algorithmic process will enable a project manager to quickly form a team that can deliver the work. The application of this algorithm is during the initial pre-contract phase to estimate the cost of man-month for a project under consideration.

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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