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**MULTIVARIATE APPROACH TO BENCHMARKING QUALITY PREDICTION PARAMETERS IN BUILDING MAINTENANCE WORKS**

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**Abstract**

Observing quality etiquette on maintenance work is of essence when satisfying clients' requirement is a priority. However, the quality etiquette comes in the form of framework and benchmarks. This study has therefore presented succinctly, multivariate approach to benchmarking quality prediction parameters in building maintenance works. The study used sixty-three (63) questionnaires retrieved which contains information on benchmarked parameters. The study used factor analysis to reduce the parameters to a sizeable number based on their coefficient and Eigen value. Resultant factors were used to dissect quality into quality dichotomies; the zero defect, medium quality and high quality work status. The model would assist building maintenance practitioners in quality monitoring on building maintenance works.

**Key words:** Benchmark, Quality, Multi-variable, Rotation, Prediction.

**Introduction:**

Quality system formulating and compliance enforcement at all facets of works in construction industry have been areas with increased attention worldwide, over the decades. This has resulted in the awareness about finished products quality assurance in the construction industry, the kind that provides clients' satisfaction and value on money invested (Chan & Tan, 2009; Roston and Amer 2006). Quality issues often arise from clients' needs and specification, these often formed the basis of supervision as work progresses on construction sites (Lings, 2005; Bamisile, 2004). Likewise, clause on compliance with specified quality standard is often stated in building projects' contract documents, commencing from brief stage to project commission stage, which has in no way different from other sectors of the economy. This fact has therefore turned formulating quality policy statement to a global best practice. However, certain school of thought believes quality to be work-state dependent, that quality can be described as conformity with specified instructions as project progresses. Bamisile (2004) and Oakland (1984) submitted that quality is fulfillment of specified requirements. Another school of thought viewed quality from fitness for purpose point of view, that quality can be termed item of work that is rightly formed to perform intended purpose (Chan & Tam, 2000). Similarly, in another submission, quality can be seen from the perspective of agreement between goal, clients and builder (Fan 1999; Abdel-Rasek et al; 2001).

However, non alignment with the goals in facilities maintenance that formed the direction through which various plans and strategy should be driven could be linked to various failures often recorded in building maintenance sector. Huge monetary resource goes into maintenance annually without lasting solution proffered, which is often revealed through reworks. This trend however could be attributed to absence of standard procedure to be followed in facility maintenance. To this end this study is set at developing a model for parameter that should be follow to ensure quality maintenance work in Nigeria. sThere are institutions responsible for enforcement of standard and procedure, such as Standard Organization of Nigeria (SON), British Standard Institutions (BSI) in Great Britain including International Organization for Standardization ISO. BSI in 1979 issued BS 5750 'Quality system' ISO rolled out, ISO 9000 in 1987, all these are quality documents. Oladokun and Adegbenjo (2008) submitted that standard Organization of Nigeria officially adopted ISO 9000 for quality management in Nigeria, and since then widely publicized training workshop had been staged in an attempt to create awareness. The structure and component of the ISO 9000 did not adequately provide framework to address detail aspect of quality problem in construction industry. However, introduction of National Building code in August 2006 provided a silver lining out of the cloud of the problem, by providing a conceptual framework upon which quality issues in building maintenance works can be based. Since then, there has been no attempt at modeling the concept mathematically, which could provide a platform for further development and research, in aspect of quality monitoring in facility maintenance in Nigeria. To this end therefore, this study is set at developing a model of parameters that could be used as working guide in ensuring quality of facility maintenance operations, and a real improvement in maintenance sector of Nigerian Construction Industry.

**Review of Related Works:**

A number of researches have been carried out in the direction of finding out detail about factors affecting quality of works in built environment and generating model to describe related assumptions. Ling (1990) developed quality assurance procedures manual, which summarizes essential tips in quality assurance in construction works. Amusan et al; (2012a) described the role of building material manufacturers in quality assurance in building; the study identified the unethical practices in the construction industry in relation with effect on quality and safety. Similarly, Cham and Tam (2000) produced a model containing 77 sub-factors from six main factors in predicting quality performance of building projects in Hong Kong. Furthermore, Oladokun and Adelakun (2008) Amusan et al; (2012b) generated a quality model that attempt at describing existing relationship among project parameters, it states that: Quality = 5.20 + 0.50 (project management) action of project team) + 0.80 (effectiveness of the construction team leader) + 0.30 (client emphasis on time). In El-Dosouky and Sulaiman (2001), a model based on average weighted score of site staff, project execution, site layout, subcontractor, equipment, labor material, contract and design was generated. This generated model was described as suitable for use on Egyptian construction projects. A model for predicting quality of building projects in Singapore was developed by Ling (2005). The study suggested parameters that could be used in enforcing quality in building projects; it also identified the variables that affect quality scores of project in Singapore projects such as design -bid- build (DBB) and design build (DB) project. Lastly, Rustom and Amer (2006) modeled factors affecting quality of works in Gaza strip, using two different perspectives (i) Stepwise multiple regression analysis and factor analysis.

**Research Methods:**

A platform was set for the research through comprehensive literature search to establish the current state of knowledge in order to put the work into proper perspective. Random sampling technique was used to gather information from population of site managers, project directors, construction managers, maintenance engineer and facility manager. One hundred questionnaires were administered and sixty three were returned and used for the analysis. Samples of respondents were taken from Lagos state, Ogun state, Abuja (F.C.T.) and Portharcourt. These locations were chosen as a result of high concentration of construction activities taking place there. The distributed questionnaire was designed in Likert scale 1 to 5, the respondent were requested to express their opinion in the degree tabulated on the questionnaires. A scale 1 to 5 was adopted, with 1 representing "strongly disagree (SD)" 2 – being disagree (D) 3 – being neither agree nor disagree (N), 5- being strongly agree (SA).

Agreement index of the respondents was generated using the relation M.A.I = 5S.A + 4A + 3S.D + 2D + 1N/5(S.A+ A+S.D+D+N) $M.A.I = \frac{1}{N\sum Aij}(\sum Aij)$ where M.A.I = Mean Agreement Index

A= Agreement variable i = Lower boundary, j = Upper boundary

N = Frequency of Variable Σ = Summation Notation.

Total maintenance operation management (TMOM) is advocated in this study. TMOM would enable total management of all aspects of building maintenance operation. TMOM covers the technical and management aspect of maintenance operation. In TMOM presented in this context, the following parameters were presented in Likert scale structure for ease of response by respondents; quality policy, communication, work environment, personnel management, performance monitoring, budgeting, resource allocation among others. Information on the parameters is presented in Likert scale 1 to 5 on the questionnaires used in data collation on the set parameters.

**Model Development**

Different researchers have used diverse methods to generate model to measure quality of construction operation carried out. Chan and Tam (2000) used combination of multiple regression analysis and factor analysis. Roston and Amer (2006) adopted weighted average, factor analysis, Pareto and stepwise multiple regression analysis. Also, Abdel Rasaq et al; (2001); Ling (2005) used calculated Pearson's correlation coefficient, and weighted average approach. However for the purpose of this work, this research work adopted combination of stepwise multiple regression methods and factor analysis for data reduction. The response from questionnaire was loaded onto the statistical package for social science students (SPSS) software, the factors were subjected to factor rotation so as to ensure emergence of stable criteria which would be used in modeling and represent relationship among the thirty-nine variables regarded as ability parameters. The resultant factors were then subjected to stepwise multiple regression analysis to establish pattern of relationships among them.

**Factor Extraction:**

Percentage of total variance obtained from each of the independent variables (the thirty-nine (39) variables (sub factors affecting quality) were examined). Each variable was standardized to have variance of 1, while total variance was given by the sum of each variable which totaled thirty-nine (39). Chan and Tam (2000), Ruston and Amer (2006) adopted two approaches to determine the factors to be included in the model. They used Screeplot and Eigen value approach, Chan and Tam (2000) submitted that in Eigen value approach, only variable with Eigen value greater than one (1) should be included in the model formation. In screeplot approach, there is differential relationship pattern among variables; there is always a distinct demarcation between large variables on steep slope and gradual trailing off scores of the rest variables. This usually occurs at the variable, where K is the true number of variables Chan and Tam (2000). However, this study adopted Eigen value and regression coefficient approach as shown in Table 9. Eighty-two percent of (82%) the total variance is attributed to the first 20 variables where these variables have an Eigen value greater than 1. Other twelve (12) variables account for only about 38.25% of the total variance. This shows that a model with 20 factors should be robust enough to represent the data

**Factors Rotation**

Factors rotation is used to identify the relationship of individual variables to the set of common factor synthesized; Oblim rotation can be used to achieve this. Therefore, Oblim rotation approach was adopted. On the other hand, Rostom and Amer (2006), used variance rotation methods, and were able to discover each variable with a single factor. Table 9 shows the relationship of the variables to the common factors, the new factors and elements related to each factor. The new set of twenty (20) factors that emerged after rotation is presented in Table 10.

**Analysis of Results and Discussions** .

Analysis of the sixty-three (63) collated questionnaires is scheduled in Tables 1 to 10 in this section. Table 1 presents information about quality policy, it revolves around the following items; maintenance policy details, employee involvement in decision making, communication of standard expected of work done, formulation of quality assurance team and periodic retrospective check on successful implementation of quality policy. Clearly defining maintenance policy to be used was ranked first ($1^{st}$ )

 

among the five (5) variables with mean index score(MIS) value 0.92. Open communication of expected standard of work and quality policy, retrospective check on success of maintenance policy implemented was scored with MIS value 0.91 respectively. Implications of these results points to the relevance of clearly defining quality policy to the employee, setting up the enforcement and assurance team that will drive the quality vision and periodic review of success achieved. All these are essentials of formulating, benchmarking and quality assurance on construction works.

Table 2 illustrates responses on communication, authority and responsibility, convening meeting on quality issues periodically was scored high with MIS value 1.00, establishing line of command scores 0.89, effective communication of information about maintenance quality to personnel scores 0.88 while responsibility delegation has MIS value of 0.88.

The outcome implies that convening periodic meeting where maintenance issues would be discussed would enable effective communication and understanding by all and sundry. Also, line of command need to be put in place, this would likewise facilitates responsibility delegation for an effective leadership. Work environment related issues were presented in Table 3, creating a work environment that conforms to international standard was rated high with MIS value 0.9, provision of adequate ventilation first aid and personal protective items were scored next with MIS value of 0.91. Likewise, provision of incentives to enhance productivity has MIS scored 0.91. In the modern day, creating a conducive environment that stimulates productivity is highly essential. It is often regarded as an incentive that produces satisfying effects. Therefore creating an environment with state of art work tools, first aid materials and personal protective devices has capacity to stimulate workers at performing maximally.

Table 4 presents related factors on manpower, training and development. Organizing workshop, conference for workers were strongly advocated and tagged with MIS value 0.96; organizing refresher courses on job-place quality assurance scored 0.93, while mechanization of production process with automated tools scored MIS value 0.92. Sometimes, mechanizing production process improves process quality, introduction of new tools would warrant setting up refresher courses. In addition, knowledge upgrade through seminar, conference, workshop among others increases quality and value of personnel.

Moreover, Table 5 contains information on measurement and precision as a benchmark for quality measurement. Placing emphasis on getting quality work done once and at a time was scored on MIS scale 0.92 closely followed with periodic measurement of quality index on the work done with MIS value of 0.92. Ascertaining the frequency of rework also scored MIS value 0.92. This factor is also one of the quality parameters to measure quality of work done. The greater the amount of returned job and breakdowns after maintenance the lower the quality of product being turned out to consumer. However, placing emphasis on getting quality job done once and all the time is an important issue in maintenance, this would reduce rate of rework and brightens customers' hope. This can be achieved through periodic measuring of product quality index.

Furthermore, Table 6 illustrates analysis on performance monitoring. Performance monitoring on the maintenance operation carried out is of importance, this could be achieved through use of conventional techniques, teaching personnel on how to enhance their performance, teaching art of personal fault recognition and assessing extent of maintenance work done. The use of conventional methods of performance monitoring was ranked high with MIS value 0.91, teaching personnel art of failure recognition scores 0.91, replacing human based inspection method with conventional methods has MIS score 0.88 while noting frequency of corrective operation as performance index was scored 0.88.

In Table 7, factors on resource allocation and budgeting was scheduled, setting up budget for routine maintenance has MIS value 0.90; resources to be allocated for works in every fiscal year has MIS value 0.86. Benchmarking fund for maintenance work at every fiscal year is highly essential, it will enable avoiding excessive spending and facilitate budgeting, and it would as well help in routine and periodic financial check.

Table 8 presents component of quality cost objective. Minimizing expenditure to maximize profit has MIS value 0.59, having maintenance expenditure base on machine, equipment age and utilization has MIS value 0.89 while allowing contingency allowance tools, incidentals with bias for internal and external failure has MIS value 0.90. Quality cost objective of any organization should make provision for minimizing expenditure while maximizing profit and economic situation of machine and tools.

Moreover, in Table 9, Factor rotation analysis was conducted on thirty-two (32) factors; this was reduced to a sizeable number. The co-efficient of the factor was used to select resultant factors that could be used as benchmarked parameters. Correlation co-efficient and Eigen-value were used in selecting the best factor. After rotation, variables with coefficient greater than 0.43 were preliminarily selected, the factors were later sized and selection parameters benchmarked to coefficient value 0.75 to Eigen value of 1.00. Extracted values were scheduled in Table 10. Table 10 presents the extracted coefficients of the factors; this action reduced the factors from 32 to 20 factors, with strong Regression coefficients and Eigen values. Factors $F_1$, $F_{22}$, $F_6$, $F_{11}$, $F_{14}$ and $F_{21}$ emerged as favorable factors that constitutes benchmarked parameters. Factor 22 ($F_{22}$) was tagged with two (2) variables; $F_1$ with 3 variables, $F_6$ (3-variables); $F_{11}$(3-variables); $F_{14}$(4-variables) and $F_{21}$ with five(5) variables. This forms the nucleus of benchmarked quality parameters as presented in Fig 1.

In Fig.1, quality parameters were benchmarked into three (3) quality dichotomies, namely: zero defect, medium quality and high quality. Zero defects occur when there is near-zero defect situations. The benchmarked quotient for this status is 1.00. Medium quality is the second dichotomy; medium is benchmarked to occur at 80% quality. Five (5) factors were tagged coded as Zero defect factors, these factors when observed would guaranteed zero defect, the factors includes: F1( $QP_3$-Clearly communicating standard and operation quality of maintenance work; $QP_4$- Formulating quality assurance policy and $QP_5$- Periodic retrospective check on successful implementation of quality policy. Also, $CAR_3$- Setting up of quality implementation committee; $CAR_4$-Delegation of responsibility and $CAR_5$- Establishing lines of command. Similarly, $MTD_1$, $MTD_2$ and $MTD_4$ are tagged as factors to be taken into consideration in ensuring zero defects. $MTD_1$ Factor recommends skill workers' sufficiency in maintenance operations; $MTD_2$-Organizing workshop and conference for workers; $MTD_4$-Rotational job-bits for workers and mastering of craftsmanship.

Furthermore, $F_{14}$ factors includes $MTD_3$,$MTD_5$, $WE_4$ and $QCO_2$. $MTD_3$- Setting up refresher course for personnel, $MTD_5$- Mechanization of production process, $WE_4$-Man-machine convenience, QC-Allocating maintenance fund based on machine-tool age. `

Lastly, $F_{21}$ is another factor for zero defect products. It consist of five (5) subfactors; $PM_5$,$RAB_1$,$RAB_2$, $RAB_4$ and $QCO_1$. $PM_5$- Noting frequency of corrective operation as index of performance monitoring, $RAB_1$-Allocating resources for emergencies; $RAB_4$- Progressive auditions of operations and $QC_1$-Minimizing expenditure to maximize profit.

**Conclusions and Recommendations**

The study has presented a framework for benchmarking quality in maintenance operations. Quality parameters have been benchmarked into three dichotomies: the zero defect parameters; 80% quality parameter (tagged medium quality) while the third group is 90% quality parameters (tagged high quality). Therefore, when zero defect is desired, the following parameters subsists:$F_1$, $F_6$, $F_{11}$, $F_{14}$ and $F_{21}$. If Medium quality (80% quality) is desirable the following parameters are applicable; $F_6$, $F_{11}$, $F_{14}$ and $F_{21}$. However, high quality job would be achieved with the following parameters: $F_{22}$, $F_{11}$, $WE_4$ and $F_{21}$ combination of one or more of the parameter would facilitate quality work in maintenance operation. The model would help maintenance practitioners in formulating framework for quality conformance in maintenance work. The study has the capability of contributing to the body of knowledge in the area of quality management in building maintenance operations this study can also form a platform for further studies and working guide in quality prediction of different aspects of construction works.

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Table 1: Analysis of Response on Total Maintenance Operation Management (T.M.O.M.) structure.

**List of Tables**

**Table 1: Quality Policy**

| **Quality Policy** | Total | MIS | Rank |
|---|---|---|---|
| 1.Policy of maintenance method to be used should be clearly defined | 52 | Val | 1 |
| 2. Employee should be involved in decision making. | 62 | 0.92 | 5 |
| 3. Standard of works and operational quality should be clearly communicated. | 55 | 0.85 | 3 |
| 4. Quality assurance team should be formulated. | 55 | 0.91 | 1 |
| 5. Period retrospective check on successful implementation essential. | 57 | 0.92 | 3 |
| | | 0.91 | |

**Table 2: Communication, Authority and Responsibility**.

| **Communication, Authority and Responsibility**. | Total | MIS Val | Rank |
|---|---|---|---|
| 1. There should be effective communication of information on work quality standard to the maintenance personnel. | 61 | 0.88 | 3 |
| 2. Management should convey meeting on quality in maintenance issue periodically. | 57 | 1.00 | 1 |
| 3. Policy implementation committee need to be established | | | |
| 4. Delegation of responsibility is essential for over operation success | 59 | 0.54 | 5 |
| 5. Establishing line of command is essential. | 57 | 0.88 | 3 |
| | 54 | 0.89 | 2 |

**Table 3: Work Environment**

| **Work Environment** | Total | MIS | Rank |
|---|---|---|---|
| 1. Work environment should conform to international standard. | 45 | 0.92 | 1 |
| 2. Adequate ventilation, first aid and personal protective items should be available | 55 | 0.91 | 2 |
| 3. Work schedule should be flexible to minimize error and accident. | 43 | 0.88 | 4 |
| 4. Man-machine convenience should be given consideration | 45 | 0.86 | 5 |
| 5. Provision of incentive to enhance productivity. | 55 | 0.91 | 2 |

 

**Table 4: Manpower Training and Development**

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| | Manpower Training and Development | Total | MIS Val | Rank |
|---|---|---|---|---|
| | 1. Skill workers should be sufficient in companies/ organizations maintenance operations. | 44 | 0.86 | 5 |
| | 2. Workshop, Conference should be organized for workers (essential for on-job development). | 43<br>43 | 0.96<br>0.93 | 1<br>2 |
| | 3. Rotational of job-bits for workers job-experience universality | 43 | 0.89 | 4 |
| | **4.** Mechanization of production processes operation | 48 | 0.92 | 2 |

**Table 5: Measurement and Precision**

| E | Measurement and Precision | Total | MIS Val | Rank |
|---|---|---|---|---|
| | 1. Emphasis is usually on getting the work done correctly once and always | 34 | | 5 |
| | 2. Periodic measurement of maintenance quality management. | 46 | | 3 |
| | 3. Item repaired last long before developing faults. | 42 | | 4 |
| | 4. Fault developing period on maintained items are as follows: | 47 | | 2 |
| | Below 5 months. | 48 | 0.50 | 1 |
| | 5-10 months. | | 0.55 | |
| | 10 months and above | | 0.85 | |

**Table 6 : Performance Monitoring**

| F | Performance Monitoring | Total | MIs Val | Rank |
|---|---|---|---|---|
| | 1. Conventional method of detecting faults should be in place. | 59 | 0.88 | 3 |
| | 2. Human-based inspection method should give way to conventional method | 65 | 0.80 | 2 |
| | 3. Personnel should be taught fault recognition techniques. | 55 | 0.91 | 5 |
| | 4. Personnel should be taught ways of assessing maintenance works done. | 56 | 0.90 | 4 |
| | **5.** Frequency of corrective operation (rework) should be noted as performance index | 71 | 0.88 | 1 |

**Table 7: Resource Allocation Budgeting**

| G | Resource Allocation Budgeting | Total | MIS | Rank |
|---|---|---|---|---|
| | 1 Resource should be allocated for works in every fiscal years. | 50 | Val | 2 |
| | 2 Financial allocation should exist for emergencies. | 40 | 0.86 | 4 |
| | 3 There should be budget for routine maintenances. | 48 | 0.74 | 1 |
| | 4 Progressive auditioning of operations. | 51 | 0.90 | 2 |
| | | | 0.86 | |

 

**Table 8: Quality Cost Objective.**

| H | Quality Cost Objective. | Total | MIS | Rank |
|---|---|---|---|---|
| | 1 Minimizing Expenditure to maximize profit. | 45 | Val | |
| | 2 Having maintenance expenditure base on machine/equipment age/utilization | 50 | 0.59 | 3 |
| | 3 Allowing contingencies for tools and incidental: internals and external failure | 50 | 0.85 | 2 |
| | | | 0.90 | 1 |

| **Variables** | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** | **F7** | **F8** | **F9** | **F10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **QP1** | **1.00** | | | | | | | | | |
| **QP2** | | **1.00** | | | | | | | | |
| **QP3** | 1.00 | | **1.00** | | | | | | | |
| **QP4** | 1.00 | | 1.00 | **1.00** | | | | | | |
| **QP5** | | | | | **1.00** | | | | | |
| **CAR2** | | 0.43 | | | | | **1.00** | | | |
| **CAR3** | | | | | | | | **1.00** | | |
| **CAR4** | | 0.43 | | | | | | 0.87 | **1.00** | |
| **CAR5** | | | | | | | | | 0.91 | **1.00** |
| | **F11** | **F12** | **F13** | **F14** | **F15** | **F16** | **F17** | **F18** | **F19** | **F20** |
| **WE1** | **1.00** | | | | | | | | | |
| **WE2** | | **1.00** | | | | | | | | |
| **WE3** | | | **1.00** | | | | | | | |
| **WE4** | 0.52 | | 0.91 | **1.00** | | | | | | |
| **WE5** | | | | | **1.00** | | | | | |
| **MTD1** | 0.74 | | 0.91 | | | **1.00** | | | | |
| **MTD2** | 0.82 | | | | | | **1.00** | | | |
| **MTD3** | | | | 1.00 | 1.00 | | | **1.00** | | |
| **MTD4** | 1.00 | 0.52 | 0.91 | | | 0.82 | | | **1.00** | |
| **MTD5** | | | 0.49 | 0.82 | | | 0.82 | 0.93 | 0.82 | **1.00** |
| | **F21** | **F22** | **F23** | **F24** | **F25** | **F26** | **F27** | **F28** | **F29** | **F30** |
| **PM1** | **1.00** | | | | | | | | | |
| **PM2** | | **1.00** | | | | | | | | |
| **PM3** | | 0.57 | **1.00** | | | | | | | |
| **PM4** | | | | **1.00** | | | | | | |
| **PM5** | 1.00 | | | | **1.00** | | | | | |
| **RAB1** | 0.82 | 0.91 | | 0.58 | | **1.00** | | | | |
| **RAB2** | | | 0.91 | | | | **1.00** | | | |
| **RAB3** | | | | 0.52 | 0.52 | | | **1.00** | | |
| **RAB4** | 0.82 | | | 0.58 | 0.58 | 0.82 | | | **1.00** | |
| **QCO1** | 1.00 | 1.00 | | | | | | | | **1.00** |
| **QCO2** | | 0.57 | | 0.57 | 1.00 | | 0.58 | | 0.85 | 0.57 |
| **QCO3** | | 0.90 | 0.91 | 0.52 | | | | | 1.00 | |

**Table 9: Factor Rotation of Quality Parameters**

**Table 10: Extracted Factors Coefficients**

| **FACTORS** | | | | | |
|---|---|---|---|---|---|
| **F22** | **RAB2**(0.91) | QC3(0.91) | ------------ | | |
| **F1** | **QP3** (1.00) | QP4(1.00) | QP5(1.00) | | |
| **F6** | CAR3(0.87) | CAR4(1.00) | CARS(0.91) | | |
| **F11** | MTD1(0.74) | MTD2(0.82) | MTD4(1.00) | --------------- | |
| **F14** | MTD3(1.00) | MTD5(0.82) | WE4(0.91) | QCO2(1.00) | ------------- |
| **F21** | PM5(1.00) | RAB1(0.82) | RAB2(0.91) | RAB4(0.82) | QC01(1.00) |

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Benchmarked Quality Parameters

Zero Defect: $1F_1 + 1F_6 + 1F_{11} + 1F_{14} + F_{21}$

80 % Medium Quality: $0.87F_6 + 0.8F_{11} + 0.82\ F_{14} + 0.82\ F_{21}$

90% High Quality: $0.91F_{22} + 0.91F_{11} + 0.9WE_4 + 0.91F_{21}$

Fig. 1 Benchmarked Quality Parameters