A New Framework for Measuring the Quality of Engineering Education System using SEI-CMM approach – (E^2-CMM)

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ABSTRACT

We propose a maturity model for computing education which is inspired by the Capability Maturity Model (CMM) used in software engineering. Similar to CMM, the Capability Maturity Model for Engineering Education System (E^2-CMM) can be used to rate educational sector according to their capability to deliver high quality education on a five level scale. Furthermore, E^2-CMM can be used in order to improve an institution's capability by implementing the best practices and organizational changes it describes. In this paper we explore a maturity model suitable for educational sector to improve the standard and quality of an educational system. For this purpose we have selected SEI-CMM as our base model for developing E2-CMM framework, which can be used for continuous process and quality assessment in education sector. Finally, this paper concludes with a brief discussion on the capability assessment and rating methodology that can be used for ranking the level of maturity of the educational organization.

KEYWORDS

ISO 9001:2000, CMM, education process improvement, accreditation, quality model, maturity model.

1. INTRODUCTION

Managing quality in the education context should be handled differently from that of manufacturing or service industries [16]. The quality management models practiced by the business world have been adapted and applied to the education sector. In fact, quality in education should begin at the school level [14]. For example, the Total Quality Management (TQM) philosophy has been applied to schools and colleges in the UK, USA, and in Asian countries such as Malaysia [13] [2]. However, the education sector is not entirely comfortable with the TQM approach [2].. Alternatively, educational sector can use the quality practices such as the European Foundation for Quality Management (EFQM) excellence model, ISO 9000, Malcolm Baldrige National Quality Award to improve performance. Even the most popular service quality methodology, SERVQUAL [20], is also used to measure the quality in the education context. The models and concepts, such as EFQM, Singapore Quality Award (SQA), School Excellence Model (SEM) and Malcolm Baldrige National Quality Award (MBNQA), are widely applied to educational institutions. These models embrace the philosophy of TQM which has been modified for the education environment. Many educational institutions are realizing the benefits of these quality models, and extensive research has been done in this area to investigate the school performances in relation to the quality management philosophy.

DOI : 10.5121/ijsea.2011.2103

It is worth noting that the ISO quality standard does not refer to the product or services delivered instead to the production and administrative processes that produce them. It should also be noted that ISO only produces the standards but does not verify compliance to it [1]. . It is also quite possible that an organization at a relatively low maturity level in the CMM scale gets qualified for an ISO. An ISO 9000 certificate for an education and training organization provides " assurance the it is well organized and that the outcomes of programmes and courses meet the intended goals and needs of the users, however, it does not necessarily guarantee that the content of these courses and programmers meet particular educational standards[23].

2. LITERATURE SURVEY

Education in general and high education in particular represents too process oriented, intangible, and multiple - stakeholders' situation. Most of the performance measurement systems of higher educational institutions do not reflect the full range of interested stakeholders and are not easily linked to the strategic and quality management. Therefore, cullen et al. [7] propose the use of a balanced scorecard approach in order to reinforce the importance of managing rather than just monitoring performance. Garvetson [8] confirms the importance of the expectations of key stakeholders in the educational process. Avdjieva and Wilson [1] suggest, Higher Education Institutions (HEIs) are now required to become learning organizations, where internal stakeholders also interpret and assess the quality of higher education provision.

As a result, many higher education institutions are looking towards the adoption of ISO9000 standard [9] for quality improvement in higher education and total quality management (TQM) practices in order to achieve quality goals. International Organization for Standardization (ISO) published guidelines for the application of ISO9001-2000 in education sector [9]. The best-known maturity model is the Software Capability Maturity Model (SW-CMM) [5] from Carnegie Mellon university, although there are many CMM-like models that exist in industry; System Engineering Capability Maturity Model (SE-CMM), Software Acquisition Capability Maturity Model (SA- CMM), System Engineering Capability Assessment Model, EIA/IS 731System Engineering Capability Model, System Security Engineering CMM, FAA Integrated CMM, IEEE/EIA 12207, ISO/IEC 15288, ISO/IEC 15504 and ESI Project Framework [9]. Although these maturity models are not without their inherent limitations, they focus on one particular area of knowledge and ignore the rest. For example SEI's CMM focus on improving processes in an organization but ignores the people and staff development.

3. OVERVIEW OF E^2-CMM MODEL

E^2-CMM is a five-level model to evaluate the maturity of an engineering education process and to provide educational practices. It is a framework that describes the key elements of an effective education process, and it serves as a guide for improving education practices, including planning, administration, academics, engineering, management, and education maintenance. Such practices help an educational organization to set goals for scheduling, cost, functionality, and quality. Education process maturity implies that the organization's processes are well defined, managed, controlled and effective. E^2-CMM maturity levels define a scale for measuring the maturity of an educational process. Achieving a maturity level, results in an increase in the capability of the educational process. Figure 1. depicts the basic structure of E^2-CMM.

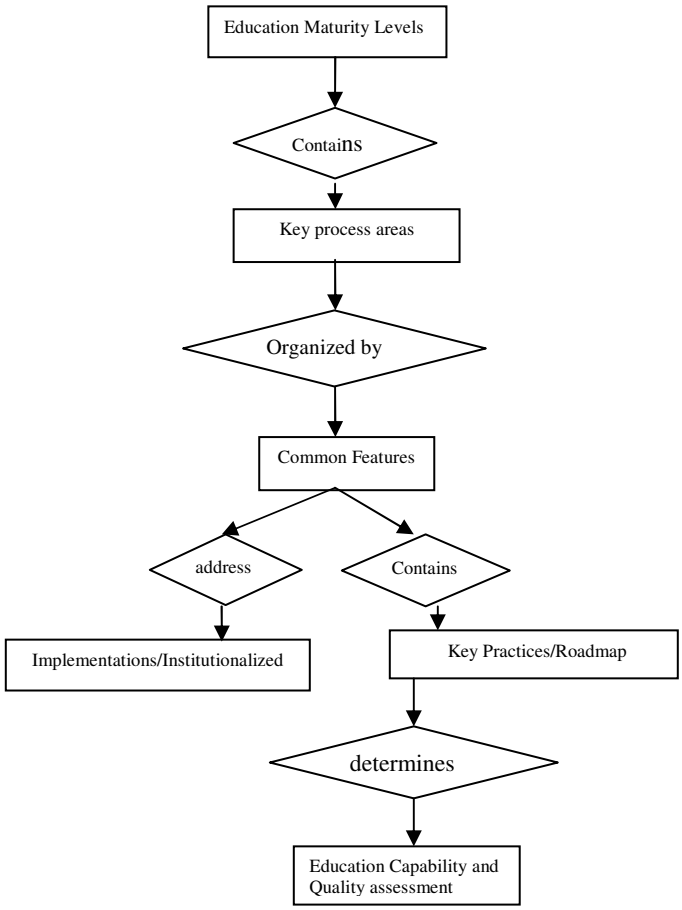

Figure 1, Basic structure of E^2-CMM

The structure of E^2-CMM consists of six components:

1. Maturity Levels: Each maturity level indicates education process capabilities expected at that level.

2. Process Capabilities: Process capabilities describe a range of expected results achieved by Implementing and managing the educational process.

3. Key Process Areas: Each maturity level includes a number of key process areas, and each process area defines a group of related activities called Key practices that together achieve a set of goals defined for that level.

4. Goals: Goals are key practices associated with a key process area, and also they signify the scope, boundaries, and intent of the key process area. The practices are used to determine if the educational organization has implemented the key process area.

5. Key Practices: Key practices describe activities and infrastructure needed to effectively implement and institutionalize a key process area**.**

The E^2-CMM is composed of five incremental maturity levels by which an educational organization establishes and improves its standard and quality. The structure of EQW maturity model has 5 levels of maturity. Except for level 0, each maturity level is decomposed into several key process areas, which indicates the areas an education system should focus on to improve its level. Key process area identifies the issues that must be

addressed to achieve a maturity level. Each key process area identifies a cluster of related activities that, when performed collectively, achieve a set of goals considered important for enhancing education process capability. The E^2-CMM maturity levels, it key process areas and key practices are illustrated as in Table 1.

Level 0: Initial

Educational process is characterized as adhoc and occasionally even chaotic. Few processes are defined and success depends on individual effort and heroics. At this level, the educational organization has a less stable education process and management practices. The process is "ad hoc" and changes as work progresses. All aspects of the process are unpredictable. This level has no key process areas.

Level 1: Repeatable

Basic education management processes are established to tract activities like Requirements, planning, teaching and learning practices and standards. At this level, the focus is on education process planning, management, tracking, and the implementation of procedure and policies. The objective of this level is to establish an effective education management process that allows the organization to "repeat" successful practices and procedures used on earlier projects.

Level 2: Defined

This level focuses on the educational organization's defined standard process, including administration, academic and management processes. The education process for both management and technical activities is documented, standardized and integrated into a standard process. The activities are stable and repeatable and are implemented throughout the educational sector.

Level 3: Refined

The various processes like teaching and learning, curriculum, R&D etc are fine tuned to adhere to the stated standards and procedures. Finally the organization has set up an internal quality accreditation system called Internal Quality Assurance Cell (IQAC).

Level 4: Quantifiable Matured Process

Detailed measures of the education process and system quality are collected. Both the education
process and products are quantitatively and quantitatively understood and controlled. This level focuses on productivity, quality, assessment, and continuous process improvement of the educational system. Measurements are established for both qualitative and quantitative assessment and evaluation of education processes and products. At this level, the organization is capable of predicting quality trends within quantitative bounds.

Table 1. E^2-CMM

LEVELS	KEY PROCESS AREAS (KPA's)	KEY PRACTICES/ROADMAP
LEVEL 0: (INITIAL)	**KPA-0-1:** Adhoc process	• No EQW as such • Traditional methods • Departmental starting

LEVEL 1: (REPEATABLE)	**KPA-1-1:** Resource Management	• Provision of resources in the educational organization. • Human/Software/Hardware resources in the educational organization • Infrastructure in the educational organization • Work environment in the educational organization • Computers as learning resources • Library as learning resources
	KPA-1-2: Financial resource, allocation and utilization	• Budget allocated to institution and utilization(recurring and non-recurring) • Budget allocated to department and utilization(recurring and non-recurring)
	KPA-1-3: Physical facilities	• Well equipped laboratories with modern facilities • Academic, residential and recreational facilities • Aesthetic views of faculties • Training in a well equipped communication labs • Opportunities for campus training and placement • Effective classroom management
	KPA-1-4: Learning Resources	• Sufficient qualified local teaching staff members are hired for teaching the courses. • Detailed course materials are provided by educational tutors. • Course materials provided are comprehensive. • Sufficient teaching staffs with extensive industry experiences are available to teach students. • Providing students with adequate electronic access to its library. • Course materials are posted effectively on the university's webpage. (e-learning) • Marked assignments with proper feedback and comments are returned promptly to students.
	KPA-1-5: Course Curriculum	• The prescribed degree curriculum is updated systematically. • Courses offered are of the same quality as the courses offered at the linking university. • The degree program is delivered and assessed in English. • The course content is updated with the latest technology and business scope. • Coursework problems to be solved by students are real-life work related problems. • Faculties are given opportunity to provide input to the development of course curriculum.
	KPA-1-6: Administrative Support	• Day and night lectures and practical classes are conducted. • There are appropriate administrative arrangements to secure student feedback and to respond to students' feedback. • The administrative and records management system maintains student records effectively. • Adequate student services are provided by the college. • Administrative services are provided efficiently. • Transcripts and degree certificates are issued promptly by the linking university to graduating students
	KPA-1-7: Leadership	• Input into the development of assignments and examination papers by the teaching staff are adequate. • The responsibility for marking and moderation of students' scripts by the college tutors and linking university staff and external examiners is appropriate. • Educational leaders make their vision and goals clear to all. • Academic and management staffs demonstrate a shared responsibility for ensuring the provision of quality

		engineering education to students. • The engineering degree education is clearly linked to the growth of engineering industries locally and globally. • The collaboration link between the institutions is strong. • The excellence of engineering education is promoted to all.
	KPA-1-8: Staff and Students relationship	• Staffs meet with students privately to gather their views and address their concerns. • Staffs play active roles in addressing students' requests. • Staffs give prompt responses to students' requests. • Students receive prompt, individualized attention from college tutors. • Staffs motivate students to excel. • There is open and honest communication among all Staffs and Students.
	KPA-1-9: Management and organization skills	• Plan and organize tasks efficiently and effectively. • Able to work under minimal supervision. • Able to brainstorm ideas in groups. • Have the capacity to work within deadlines. • Development in study skills in preparing for examination. • Development in academic skill. • Development in management skill.
	KPA-1-10: Communication and social skills	• Take initiative to explore opportunities and develop new ideas. • Have acquired good oral communication skills. • Able to speak and write good English. • Have acquired good report writing skill
	KPA-1-11: Teamwork	• Learn to work in teams. • Able to contribute multidisciplinary viewpoints.
	KPA-1-12: Human Resources(faculty and staff)	• Student faculty ratio, experience, turnover, qualification. • Participation of faculty in development activities. • Impact of faculty development initiatives. • Analysis and follow-up for performance appraisal. • Service rules, pay package etc. • Strength and Skill set of supporting staff. • Skill up-gradation of supporting staff.
	KPA-1-13: Human Resources(students)	• Students admission • Academic results • Performance in competitive examinations • Placements.
	KPA-1-14: Management Responsibility	• Management commitment in the educational organization. • Customer focus in the educational organization • Quality policy in the educational organization • Planning. • Responsibility, authority, and communication. • Management review in education sector • Instilling sense of pride and commitment through able leadership, participation, management and motivational measures. • Funds mobilization. • Rewards and recognition for performers of guidance for non performance • Delegation of authority and responsibility.
	KPA-1-15: Product realization.	• Planning of product(student) realization in the educational organization • Customer- related processes • Design and/or development • Production and service operation.

		• Control of monitoring and measuring devices in the educational organization.
	KPA-1-16: Measurement, analysis and improvement	• General guidance in the educational organization. • Monitoring and measurement • Control of non conformity product in the educational organization • Analysis of data in the educational organization.
	KPA-1-17: Educational Change Management	• Goal orientation and decision making • Organization structure power and functions • Perspective planning. • Human power planning and recruitment. • Performance appraisal • Staff development programmes. • Resource Mobilization. • Finance management.
	KPA-1-18: Teaching-Learning and assessment practices	• Delivery of syllabus. • Content beyond syllabus • Continuous evaluation • Student-centered learning • Teaching staffs are able to effectively implement good pedagogical practices. • Staffs have strong theoretical and practical knowledge of their subjects. • Staffs give helpful comment and feedback to students. • Staffs are able to facilitate group discussion. • Students feedback
LEVEL 2: (DEFINED - FORMAL EFFORT)	**KPA-2-1:** Educational subcontract management	• Signing MOU with well accredited organization.
	KPA-2-2: Educational organization process focus	• Focus on the teaching-learning process • Focus on faculty and staff work systems • Focus on faculty and staff learning and motivation. • Focus on faculty and staff well being and satisfaction. • Focus on student, stakeholders and market knowledge • Focus on student and stakeholder relationship and satisfaction.
	KPA-2-3: Student support and progression	• Student profile. • Student progression. • Student support. • Student activities.
	KPA-2-4: Supplementary practices	• Extra and co-curricular activities. • Personality development initiatives • Entrepreneurship development • Alumni interaction. • Ethics. • Student's publication.
	KPA-2-5: Healthy practices	• Total Quality Management • Innovations • Value based education • Social responsibilities and citizenship role • Overall development • Institutional ambience and initiatives
	KPA-2-6: Strategy planning	• Strategy development • Strategy deployment
	KPA-2-7: Opportunities for knowledge up-gradation	• Attending and conducting seminars', conference, and workshops • Training for teachers including communication skills • Sufficient new addition of books, encyclopedia and journals

		• Fast and reliability IT services • Computational facilities, laboratory modernized, software etc • Continuing education and outreach activities
	KPA-2-8: Learning outcomes	• Training on state of the art technology • Practical orientation in education • Adaptability to model techniques • Design of course structure based on job requirements • Problems solving skills • Sense of social obligation
	KPA-2-9: Technical Competencies	• Apply mathematics, science and engineering knowledge in modeling and analyzing engineering problems. • Use software simulation tools to analyze engineering problems and develop solutions to the problems. • Use test and measurement equipment to design, conduct experiments and analyze experimental data. • Use given specifications for designing an engineering system. • Design alternative systems based on criteria provided.
	KPA-2-10: Technology driven teaching aids	• Modern visual instruments like OHP's, LCD's, Videos, Films etc in the classrooms • Prototype, physical models, simulations and animated models etc. • Virtual classroom facilities
	KPA-2-11: Generic Competencies	• Learn about professional engineering ethics. • Integrate and apply technical advice to technical problems. • Understand the impact of engineering on local and global business and economics. • Able to undertake problem identification, formulation and develop solution to problem. • Understand the needs of the engineering industry and community as a whole. • Able to demonstrate quality-assurance criteria in relation to engineering practice. • Demonstrate continuous learning to overcome the obsolescence of changing technologies. • Have developed lifelong learning skills. • Aware of the impact of global environmental changes on the development of engineering.
LEVEL 3: **(REFINED)**	**KPA-3-1:** Teaching – Learning and Evaluation.	• Admission process. • Catering to diverse needs • Teaching-learning process • Teacher quality • Evaluation of teaching • Evaluation of learning • Evaluation reforms
	KPA-3-2: Research, Consultancy and Extension	• Promotion of research • Consultancy • Extension activities / Continuing education. • Participation in extension • Linkages (MOU's etc) • Budget for in-house (R & D activities)/ • Sponsored research projects • Publications / Patent etc
	KPA-3-3: Redefining educational quality in terms of outcomes	• In calculating a value system in student • Fostering global competencies among students • Quest for excellence • Empowerment of team like working environment
	KPA-3-4:	• Curriculum aspects.

	Internal Quality Assurance Cell (IQAC)	• Teaching, learning and evaluation. • Research, consultancy and extension • Infrastructure and learning resources • Student support and progression • Organization and management
	KPA-3-5: Process management	• Organization and management • Learning – centered process • Support processes and organization.
	KPA-3-6: personality development	• Encouragement for sport games and cultural activities. • Enhancement of knowledge • Adherence to schedule • Extra academic activities • Recognition of the student
	KPA-3-7: Academics	• Adequacy of subject teachers • Available regularly for student's consultation. • Close supervision of students work • Expertise in subjects and well organized lectures • Good communication skills of academic staff.
	KPA-3-8: Industry Institute Interface	• Industrial visits and training for students and faculties • Industrial consultancy and collaborative project work • Technology development and transfer
	KPA-3-9: Responsiveness	• Prompt service of service departments • Courteousness and willing to help • Cleanliness, orderliness, systematic and methodical • Transparency of official procedures, norms and rules • Adequate facilities infrastructure to render service
LEVEL 4: (QUANTIFIABLE - MATURED PROCESS)	**KPA-4-1:** Organizational performance results	• Student learning results • Student and stakeholders focused results • Budgetary, financial and market focus • Faculty and staff results. • Organization effectiveness results • Leadership and social responsibility result.
	KPA-4-2: Quantitative and qualitative focus on teaching and learning	• Constantly updating teaching and learning process with current needs and technology. • Bridging the gap between curriculum content and teaching and learning process • Avoid proactive and reactive risk affecting the quality of education
	KPA-4-3: Measurement Analysis and knowledge mgt.	• Measurement, analysis and review of organizational performance • Information and knowledge management
	KPA-4-4: Maturity and stability of the institution	• Curriculum content • Record for employment of graduation • Feedback mechanism. • Student performance and progression • Continuously validating the organization performance
	KPA-4-5: Educational Quality Assurance	• Use of statistical process control for educational system • External accreditation • Delegated involvement (foreigners) • Audit of quality system • Cause and effect analysis • Peer review of educational quality process • Technology driven teaching aids • Continuous validating the system.
	KPA-4-6: Continuous Evaluation System	• Performance monitoring through class tests, quizzes, assignments, mini-projects, examinations etc • Provision of time slots in academic, curricula for counseling, advising and discussions

		• Timely evaluation of students work in a fair and transparent manner • Development of study materials and hand outs.

4. EDUCATIONAL CAPABILITY ASSESSMENT

Education Capability Assessment can be carried out by preparing a checklist consisting of Key process areas and Key practices. As illustrated in Figure 2, conducting an appraisal focuses on:

- Collecting and recording data with respect to educational practices and implementation in the form of notes.
- Consolidating data into a manageable set of observations, determining their validity as findings, and their coverage of the assessment scope.
- Using those findings to produce ratings of the appraised entity's educational process with respect to the E^2 - CMM.

The assessment conduct phase results in a set of appraisal outputs which include both findings and ratings.

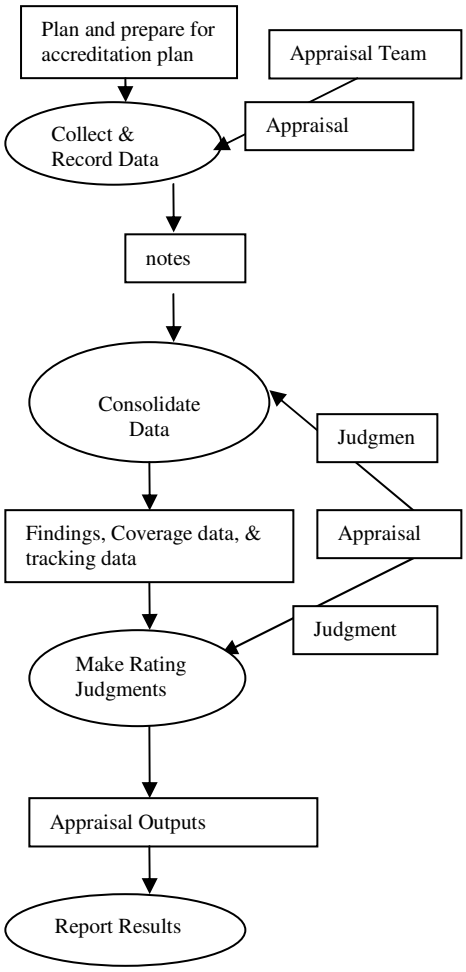

Figure 2: Appraisal process

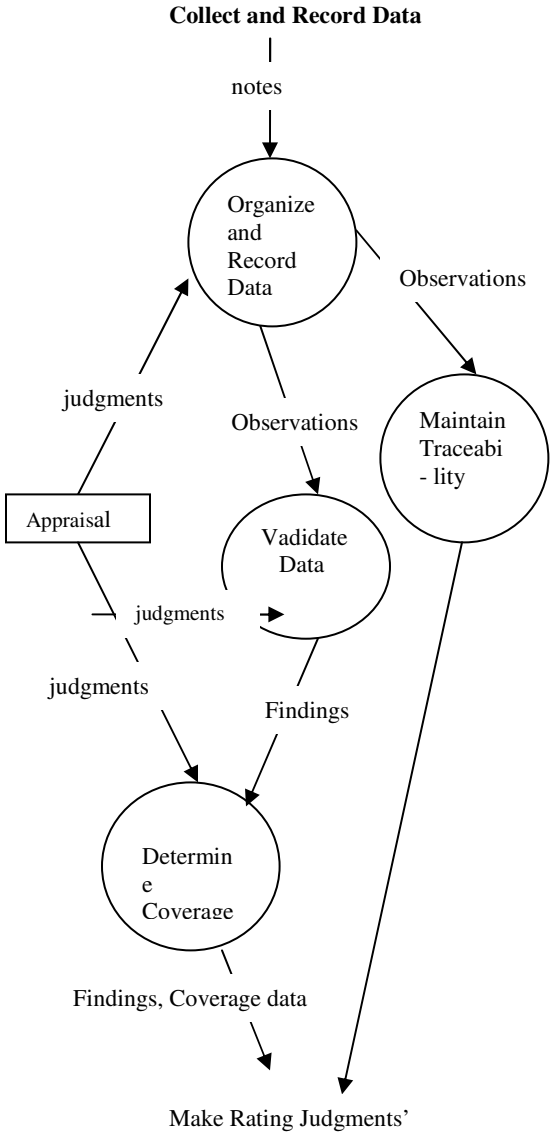

Figure: 3 – Consolidate Data

As illustrated in Fig-3, consolidating data of educational process includes:

- Transforming notes from data collection sessions of education process into a set of observations and categorizing them relative to the E^2 - CMM.
- Determining that these observations are valid findings.
- Determining the extent to which the findings provide adequate coverage of the scope of the appraisal and adjusting data collection plans accordingly.
- Maintaining traceability among observations, findings, and ultimately ratings

Generally significant data will take one of the following forms:

• Evidence of implementation of E^2 - CMM key practices.
• Evidence of alternative practices which meet E^2 - CMM KPA.
• Evidence of education process strengths unrelated to the E^2 - CMM.
• Evidence of absence of E^2 - CMM key practices.

4.1 Rating Scale

The rating of E^2 - CMM consists of maturity level rating scale which is of a five integral levels (1 - 5) as described in the E^2 – CMM framework. The appraisal method shall define a rating process using the following rating values:
• A KPA is satisfied if this aspect of the E^2 - CMM is implemented and institutionalized either as defined in the E^2 – CMM, or with an adequate alternative.
• A KPA is unsatisfied if there are significant weaknesses in the appraised entity's implementation or institutionalization of this aspect of the E^2 - CMM, as defined, and no adequate alternative is in place.
• A KPA or goal is not applicable if the KPA is not applicable in the organization's environment.
• A KPA or goal is not rated if the associated appraisal findings do not meet coverage criteria or if this aspect of the CMM falls outside the scope of the appraisal.

4.2 When Ratings Can Be Performed

Appraisal method shall define a rating process which specifies that:
• An appraisal team can rate a KPA when valid observations related to the Key practices are met.
• An appraisal team can rate a KPA when it has rated each of the associated Key practices.
• An appraisal team can determine a maturity level rating once it has rated all of the KPA's within that level and each level below.
Rating Sequence: Ratings are determined in a hierarchical fashion as illustrated by the rating sequence in fig. The rating of any given CMM component is dependent on ratings of the more detailed CMM components, if any. In particular:
• Maturity level ratings depend exclusively on KPA ratings. For example, rating of maturity level 3 requires that all KPA's within levels 2 and 3 be satisfied or not applicable.
• KPA ratings depend on the ratings of the goals. An appraisal team cannot rate a KPA satisfied if any goals are unsatisfied. As illustrated in Figure: 4, ratings are determined in a hierarchical fashion.

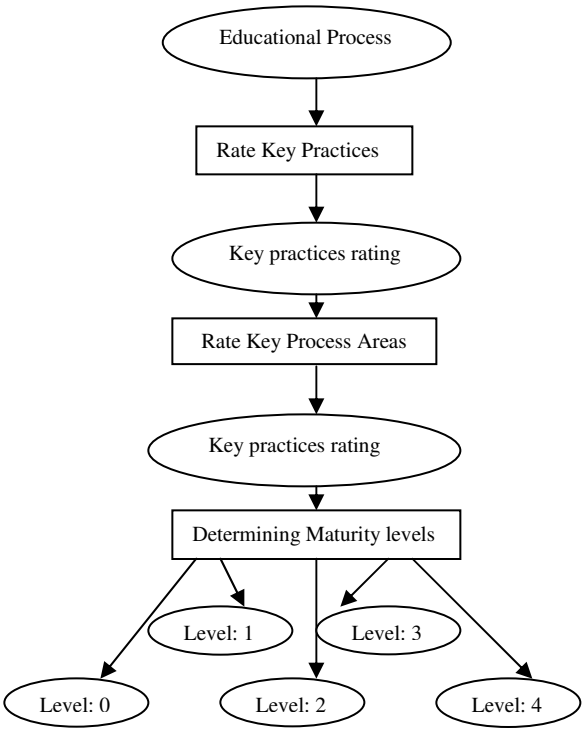

Figure 4. Rating Sequence

4.3 Rating Methodology

a. Judge Satisfaction of KPA's

The appraisal method shall define a rating process which specifies that each KPA is rated in accordance with the following rules:

• Rate the KPA "satisfied" if all of the Key practices are rated "satisfied."
• Rate the KPA "unsatisfied" if any Key practices are rated as "unsatisfied."
• Rate the KPA "not applicable" if the Key practices is not applicable in the organization's environment.
• Rate the KPA "not rated" if any of the Key practices are rated "not rated" or if the KPA falls outside the scope of the appraisal.

b. Determine Maturity Level

The appraisal method shall define a rating process which specifies that maturity level, if determined, is determined in accordance with the following rules:

• A maturity level is satisfied if all KPA's within that level and each lower level are satisfied or not applicable.

5. RELATED WORK.

As there are different meaning and interpretations of quality, there are different models of quality assurance as well. Across the world, institutions follow different models of quality assurance; particularly country specific and institution specific models. These models are mostly process oriented and emphasize on the development of a quality assurance system. There are five popular models of quality assurance: Baldrige Criteria, ISO 9000-2000, CMM,

Six Sigma and total quality management. In addition to these models, there are other accreditation models like ABET, NBA, NAAC, AB of ICAR and DEC.

6. FUTURE WORK AND CONCLUSION

This paper presents a new E^2 – CMM framework that can be used for assessing the maturity level of an educational organization. This model can be further tuned and optimized. Instead of applying ISO, this model can be used in assessing the standard and quality of educational system. Further, this model can be implemented using Formal or Ontology technique. Finally the metrics parameter and methodology of E^2 - CMM can be formulated using statistical approach, fuzzy logic or neural networks.

In this paper, we have proposed a Capability Maturity Model for Engineering Education, which helps in improving the practices of key educational processes and contribute to enhance the overall quality education. The five levels of maturity provides a finer grained measure of comparison that the binary accreditation designation (0 – not accredited, 1 – accredited), thus facilitating the process of articulation between institutions at the same level and giving an encouraging assessment of institutions, instead of an all-or-nothing accreditation decision, the programs starts at level 0. Managing quality in higher education institution is not similar to business and industry. Thus in this model, emphasize is based on 'management for quality' rather than 'management of quantity'. This E^2 – CMM model can be used for continuously evaluating the education process which serves as the mantra for effective accreditation of higher education system. Finally, it is concluded that quality assurance is not the destination, but a journey to continuously improve the higher education system

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