Evaluating the Individual Scientist, Engineer, and Technologist: A Review of Practices and Suggested Framework

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Abstract

Measuring the performance of scientists, engineers, and technologists is a daunting task due to the nature of the job they perform and the absence of common work standards. Presenting this material in an engineering management class can be, therefore, confusing and controversial. This paper will seek to develop a review of industry practice in using five present performance appraisal types relative to scientists, engineers, and technologists; review a new innovation in individual performance appraisals, the individual balanced scorecard; and identify factors important to a successful performance assessment program for scientists, engineers, and technologists.

I. An Introduction to the Problem and Report Objectives

It starts with the prescribed form sent to each engineering manager with the little check boxes and a No. 2 pencil. The manager begins, "On a scale from one to five evaluate the engineer's problem-solving ability." Immediately the manager struggles to remember key instances in the last year where the engineer exhibited good or poor problem-solving abilities. Remembering none, the manager decides to rate the engineer a 3.5 based on no recent memory of odious or pernicious errors in judgement. The performance appraisal process has begun.

The performance appraisal is a well-recognized and established feature in modern corporate climates. Although many companies espouse a belief in systems thinking, the individual performance appraisal is a cornerstone of American management [1]. A survey by the Wyatt Company, a Washington consulting firm, found less than half of employees evaluated liked the process and the reviewers were even less satisfied [2].

Measuring the performance of scientists, engineers, and technologists is a more daunting task due to the nature of the job they perform and the absence of common work standards [3,4]. A. Schainblatt states, "There are no currently used systems for measuring the productivity of scientific and engineering groups without substantial flaws. Nor does the literature on productivity measurement offer encouragement that suitable systems will soon be available" [5]. This makes the topic of performance appraisal a particularly difficult and controversial portion of an engineering management course. This paper will seek to develop a review of industry practice in using five present performance appraisal types relative to scientists, engineers, and technologists; review a new innovation in individual performance appraisals, the individual balanced scorecard; and identify factors important to a successful performance assessment program for scientists, engineers, and technologists. The purpose of such a review is to

provide material suitable for presentation in an engineering management course at the graduate level and to provide instructors and students of engineering management a framework to evaluate variations of performance evaluation formats.

II. Performance Evaluation Definitions and Types

The literature is imprecise concerning definitions of performance appraisals and for defining the technical function. It will be necessary to clarify these terms in a course of engineering management for discussion purposes before undertaking a review of relevant types of performance appraisals.

II. A. Operational Definitions

Before undertaking a discourse in the measurement of individual engineers and scientists, it will be beneficial to define the terms: performance assessment, performance appraisal, scientists, engineers, and technologists.

II. A. 1. Performance Assessment

According to Berk, "Performance assessment is the process of gathering data by systematic observation for making decisions about an individual" [6]. He notes five key elements in this definition:

- performance assessment is a process, not a single measure or event;
- an emphasis exists on data gathering with many instruments;
- the data represent the information from systematic observation;
- the data are used to make decisions that provide the form and substance of the assessment; and
- the focus of the assessment is the individual [6].

Performance evaluation is a synonymous term for performance assessment. The assessment of the individual is conducted in terms of the job requirements of knowledge, skills, and aptitudes gathered through job analysis [7].

II. A. 2. Performance Appraisal

According to Cascio, "Performance appraisal is the systematic description of the job-relevant strengths and weaknesses with and between employees" [8]. Although similar to the definition above, this paper will use this definition of performance appraisal because of its focus on the systematic description of the employee. A performance appraisal is distinguished from performance assessment by its focus on the description and its omission of the job analysis and data gathering. Performance appraisal may be seen as the rating or measurement of the employee based upon a performance assessment system.

II. A. 3. Scientists, Engineers, and Technologists

For the purposes of this paper, scientists, engineers, and technologists are defined according to their roles in business and industry. Scientists are interested in the study of particular aspects of the universe. They may be involved in pure research into the nature of things or may have a directed interest into the innovation or breakthrough necessary to create a new product or service. Generally speaking, a scientist's interests lie in the "why" of the world [9]. While a scientist is interested in the "why," engineers and technologists are interested in the "how" of

things. Engineers apply mathematical and scientific principles in creation of useful products and services [9]. Technologists use existing technologies and systems to build or refine products or services [9]. For all these groups, the creative and innovative process involved in doing their work causes difficulty in establishing standards of work performance. The technical function within an organization will encompass all the jobs defined as scientists, engineers, and technologists.

II. B. Purpose and Types of Performance Assessments

There are numerous ways to evaluate employee work performance discussed in the literature. Many graduate engineering management students will be familiar with Deming and his beliefs that the individual performance appraisal should be eliminated. The review of literature and practice tend to show the performance appraisal can serve many useful purposes. These purposes, as part of the total performance assessment, are discussed in the next section. The subsequent sections will explain and discuss five different types of performance appraisals.

II. B. 1. Purposes for Performance Appraisals

W. Edwards Deming and some of his followers have been enthusiastic about eliminating the individual performance appraisal, because they find it is detrimental to the system view of the organization and does not properly consider individual variation in measurement data [10,11]. Deming even goes so far as to label appraisals as the third Deadly Disease of Companies of the Western World [10]. A summary of Deming's charges is presented in Table 1.

Appraisals nourish short-term focus and performance	Appraisals feed rivalry and politics that are detrimental to organizational goals.
Appraisals build fear of management into the system.	Appraisals anger and embitter employees.
Appraisals demolish teamwork.	Appraisals and ratings are unfair as they ascribe system variation to individuals.
Appraisals increase variability in job performance.	Appraisal rewards performance within the system instead of improving the system.

Table 1. Deming's Exhortations Against Appraisals

Cardy and others assert the performance appraisal can be designed without the problematic flaws that lead to Deming's criticisms [12,13]. Such an appraisal, properly designed, can serve several purposes for the employer and employee [12]. These are summarized in Table 2.

Employer's Perspective	Employee's Perspective
Individual differences in employees do affect organizational goals.	Feedback is desired and needed.
Documentation from appraisals may be needed for legal defense.	Improvement requires feedback and appraisal.
Appraisal help rationalize bonuses or merit.	A sense of fairness demands individual differences be recognized and good performance rewarded.
Appraisals can operationalize strategic goals and relate them to individual performance.	Appraisal and recognition can motivate an employee to better performance.
The appraisal is part of a valid performance assessment.	
Appraisals can include teams as its focus.	

Table 2. Cardy's Purposes for Performance Appraisals

The performance appraisal can also be used in training and development efforts to assess potential and identify needs [14].

II. B. 2. Five Types of Performance Appraisals
Creativity and individual application influence the specific content and method of the performance appraisal; however, there are five major types of appraisals relevant to scientists, engineers, and technologists found in the literature.

II. B. 2. a. Employee Ranking
Employee ranking is a popular method of evaluating employee performance by directly comparing all employees performing a similar job for a single unit or single supervisor [15]. Employees are simply given an ordinal rank relative to their co-workers. Jacobs notes two fundamental flaws with such a system: 1)it is inherently ordinal and 2)it compares overall performance in a single measure [15]. Due to ranking the best employee as the first or top standard, no actual measure of performance against job requirements is known. This system assumes the best employee must be doing the correct job for the organization. Secondly, since only one measure is made, rank, measures of job efficiency, compliance to process standards, etc. are not individually considered.

This type of system has its noted problems. Employees at Houston Power and Light were divided into four categories by rank with "1" being the best performers and "4" being the worst. Employees were so upset with the system that many took to wearing t-shirts printed with the slogan: "Don't Ask Me – I'm a 3" [16]. Employees at Enron Corporation were equally upset with such a program [16]. The ranking system is sometimes employed by companies seeking to reduce their workforces. Sun Microsystems, Dell Computer, Intel, and Cisco Systems are notable firms using similar methods to reduce employee numbers [17].

The literature does not report the ranking system to be in wide use for the evaluation of scientists, engineers, and technologists; however, many engineers have informally reported the use of such a system in the face of budget constraints, reductions in force, or limited promotion availability. This would seem credible, since approximately one-fourth of Fortune 100 companies queried as part of a Cornell University research study stated the main performance appraisal system for professionals was supplemented by forced ranking. This supplement was primarily done in conjunction with salary decisions [14]. Professional staff was defined by the survey as salaried, exempt employees exclusive of management and would include scientists, engineers, and technologists. Other research has indicated the use of ranking can influence other types of appraisal systems through rater bias by rating good workers lower to distribute finite resources over a larger population [18].

II. B. 2. b. Graphical Rating Scales
Graphical rating scales use a numerical or symbolic rating continuum to analyze work performance in key categories [15]. Using a job analysis, several important areas are identified relative to performance. To evaluate the employee, the rater places the observed job performance in the important area along the continuum. For example, an engineer of average project management capability may be scored a "3" on a scale of "1" being best to "5" being

poorest. The scale may also be symbolic as "A, B, C, D, & F." The graphical rating scale may also include verbal anchors like "Unsatisfactory to Exceptional" [15].

The survey of Fortune 100 companies conducted by Cornell University researchers indicates graphical rating scales are used by 23% of the companies for their professional staff [14]. An older study of sixty-nine research laboratories indicated graphical rating scales were used by a vast majority [19].

A report by Murphy indicated a criticism of graphical ratings is the tendency of managers to assign a uniform rating. Murphy's report studied Merck & Co, Inc. from 1978 through 1989. Merck managers assigned a rating from 1, poor, to 5, best, based on overall performance. For appraisals during 1984 and 1985, 97.76% of the employees received a 3 or 4 appraisal rating [20]. The Cornell University researchers found 77% of their respondents' professional employees rated at the comparable 3 or 4 level [14].

Another shortcoming of the graphical rating is its inherent reliance on the rater's subjective analysis of the work performance behaviors observed and their translation to the rating scale. An article published by Rice summarizing performance appraisal research indicates the rater can be biased by certain factors like occupational sex stereotyping, race, halo effect, and categorization. Occupational sex stereotyping was found to occur as women working in traditionally-male-dominated jobs usually received lower ratings than men. Racial bias has revealed a pattern of white supervisors tending to favor African-Americans. Bias due to halo effect occurs when well-liked or compliant employees are rated higher than their co-workers. Finally, bias is shown to occur when the supervisor categorizes the overall performance of the employee and uses this to influence the important job factors ratings. Categorization has even shown to elicit false memories of job performance that would justify the rating [21]. Due to this subjectivity, several companies are being sued over performance appraisal ratings. Microsoft, Ford, and Conoco are battling lawsuits alleging discrimination against women, African-Americans, and older white males [22].

II. B. 2. c. Behavioral Based Rating Systems

To eliminate some subjectivity, Smith and Kendall introduced behavior expectation scales [23]. Using job analysis, several behaviors of job performance are categorized into job performance content areas. The behaviors are then sequenced within the category by effectiveness in achieving the job content objective. These behaviors may be observable behaviors, other examples of actual behaviors, or summarized statements of the behavior. The appraisal consists of the rater recalling examples of the employee's performance according to content area and comparing the actual examples to the content area behaviors. The closest comparison, in the rater's opinion, places the employee within the sequenced continuum of content area attainment [24]. For example, an engineering content area may include project financial management. Sequenced observable behavioral examples may be represented by the example in Table 3.

5	Prepares budget and management reports for major projects (> $1MM). Makes decision to influence project timing and budget.
4	Prepares budget for some portion of major projects. Reports time & effort of sub unit to project manager. Prepares budget and management reports for moderate projects ($40M to $1MM)
3	Reports time & effort to project manager or leader. Influences budget decisions for some portion of major project. Prepares budget and management reports for minor projects (< $40M).
2	Reports time & effort to project manager. Reports expenditures and accruals to leader. Assists with budget preparation and management reports for moderate and minor projects.
1	Reports time & effort to leader.

Table 3. Example of Behavioral Observation Scale

The supervisor recalls examples of the engineer's work for the past period and matches it to the closest corresponding behavior in the scale to determine the appropriate rating.

No Fortune 100 companies in the Cornell study indicated using behavioral based appraisal with professional staff, although there was significant usage of such scales for non-exempt personnel [14]. Several companies are reported, however, to base performance appraisals on observable behaviors of their scientists and engineering staff. Such performance measures tend to focus on counts of publications, number of patents, or citations of work by others [4].

II. B. 2. d. Forced-Choice Appraisal Systems

The forced-choice appraisal format asks the rater to select one statement from a set of statements that best describe the employee. The statements are arranged so that the forced selection of one requires the rater to describe in some detail the performance of the employee. Arrangements are made so the statements have equal appeal but describe job effectiveness unequally [15]. Forced-choice formats are used to eliminate subjectivity by eliminating the rater's ability to select all very low statements or very high statements. The appraisal is a derived rating from the choices selected by the rater.

As a derived rating, the unanticipated score may be hard for the supervisor to explain during a feedback interview [15]. A surprising result also causes this technique to raise questions of credibility, and the rater can develop a resentment to the appraisal due to loss of control [8]. Additionally, as might be expected, this technique requires considerable preparation and investment [15].

South reported the development of a forced-choice appraisal for engineers called the Engineer Performance Description Form. Developed and used by a nationally known company, the form consisted of thirty-five pairs of statements used to derive an overall score, and thirteen sets of six statements used to derive six category scores. The appraisal described the engineer's work according to six categories:

- communication,
- relating to others,
- administrative ability,
- motivation,

- technical knowledge and ability, and
- self-sufficiency [25].

South later studied the ability of this appraisal to be deliberately biased by the rater either higher or lower. The reported raw scores could be varied by only 18%, since the raters could not accurately predict the final rating from the set of forced-choices [26].

II. B. 2. e. Management by Objective, MBO

Management by objective is a performance appraisal process that requires employees and supervisors to negotiate and agree upon a set of measurable objectives for the employee that will become the measurement standard for the appraisal period [27]. It is desirable the negotiation process will lead to objectives that will forward organizational goals. Since the objectives are measurable according to agreed upon systems, the employee can ascertain at any time progress toward or accomplishment of the objectives.

Management by objectives has many critics, most notable Dr. Deming. Deming and other categorize MBO as:

- short sighted, focusing on only one appraisal period;
- focused too much on numerical, easily-measured, non-critical objectives;
- using past data as a predictor of future performance without regard to markets and customers;
- seeking to control people instead of systems;
- relying on innovation and technology for system improvement instead of continual improvement; and
- inevitably resulting in suboptimization [28].

Although maligned and criticized, the Cornell research indicated MBO is used by 70% of Fortune 100 companies to evaluate professional staff [14]. MBO can be a powerful tool for organizational alignment, communication, and goal setting. In practice, however, claims of unfairness can center upon the individuality of the objectives [21]. While one researcher may have only one patent application resulting in millions of dollars of product sales towards a goal of three, another may have four worthless applications toward a goal of two. This example shows the difficulty in setting and evaluating measurable goals.

MBO as applied to scientists, engineers, and technologists can have suboptimizing effects. In an effort to set measurable objectives some researchers and engineers have opted for measurement according to quantity of writing, number of designs sent to production, and square feet of drawings completed. These goals, although measurable and exhibiting productivity, may not consider quality or customer needs in their measurement.

III. The Balanced Scorecard

Kaplan and Norton presented a relatively new concept of measuring organizational and individual performance in 1996. Their concept of the balanced scorecard is based upon a set of measures used to translate the performance of the company towards achievement of strategic

goals. The balanced scorecard was developed for organizations, but it is now being proposed as an individual performance measure also.

III.A. The Balanced Scorecard for Organizations

Using the strategic goals and mission of the company, the balanced scorecard attempts to enumerate and measure several key indicators of strategic performance for an organization. Kaplan and Norton also expand the use of the balanced scorecard from a simple measurement and control tool to a planning, goal setting, communication, and learning instrument. The balanced scorecard is comprised of four key sections:

- financial perspective,
- customer perspective,
- internal-business-process perspective, and
- learning and growth perspective.

The perspectives are sequentially examined with reference to the key strategies for the company using a cause-and-effect hypothesis. This hypothesis being that financial results are derived from proper market target and strategies. These markets are exploited with excellent internal processes that are delivered by exceptional staff [29].

After the company has determined its mission, values, and strategy, it should examine the key financial indicators that would indicate the company is performing well. If a company is to be price competitive, then measures of productivity, return on capital employed (ROCE), or manufacturing cost would be appropriate indicators of success. Another company, however, concerned with growing market share in the high technology sector may find revenue growth, market share, and cost of new product introduction more appropriate measures [29].

In order to achieve the previously defined financial goals of the organization, the company must consider how and where the company will compete. This means determining who the customers are, their specific market needs, and how the company will strive to target those markets. These indicators may be on time delivery performance, partnerships, turnkey operations capability, or customer loyalty [29].

The internal-business-process perspectives seeks to find the key, critical processes the organization must master to meet the customer demands, grow the target market, and deliver on the financial results. These measures may speak directly to the company's technical function as its research and development engineers bring new processes or products to market. They may also deal with traditional measures of inventory mix, inventory turns, or process cycle time [29].

Finally, the company must examine the infrastructure of organization and staff necessary to deliver the processes. Measurements in this category evaluate whether the correct staff, organization, and systems are in place, how satisfied the staff is, and staff and system effectiveness [29].

The four perspectives represent a mix of lagging and leading indicators of performance. While the financial perspective and certain customer perspective measures mainly indicates past

performance, infrastructure, staffing, and internal business process development are mainly future oriented.

III. B. The Balanced Scorecard for Individuals

Kaplan and Norton followed up on their original work in the *Balanced Scorecard* with *The Strategy-Focused Organization*. Devoting an entire chapter to the subject, they assert the employee can and must be involved with individual objectives aligned with the organizational strategy. They differentiate their approach to the individual balanced scorecard from MBO by noting that MBO uses objectives set within the context of departmental functioning and departmental goals. The individual balanced scorecard uses wider organizational goals stemming from strategic planning and uses the cause-and-effect hypothesis of sequential formulation to find key indicators of performance [30].

Kaplan and Norton note the use of the individual balanced scorecard by an oil exploration group comprised mainly of engineers, project managers, and technologists. Each employee carried a small card with the important corporate objectives on the left. The center contained the business unit's objectives that would enable the corporate objectives. The right was reserved for the employee to write in personal and team objectives aligned with the middle and left sections [29].

Technologists in Nova Scotia Power similarly set individual objectives. Employee objectives are set using the following:

- each individual must have one objective and measure for each of the four perspectives;
- no more than fifteen measures;
- the employee's scorecard must support the supervisor's scorecard;
- the scorecard must mix lag and lead indicators;
- all supervisors and managers must include an objective and measure related to coaching, counseling, or employee development;
- each scorecard must include an objective and measure in support of a partner business unit; and
- all changes must be agreed to by employees and supervisors [30].

IV. Factors Influencing Successful Performance Appraisals

Regardless of the controversy, inadequacies, and detractors, research does indicate the performance appraisal for scientists, engineers, and technologists can be an effective management tool. The inclusion of performance evaluation is, therefore, an integral portion of the engineering management class. The next sections will develop this notion and provide a look at factors the instructor should stress that are found to effect successful appraisals.

IV. A. Performance Appraisal as an Effective Management Tool

Job satisfaction measured by grievances, strikes, and resignations can be shown to correlate very strongly with production costs and labor productivity [31]. Blau conducted a longitudinal study of medical technologists' job satisfaction. The regression analysis of nine factors for job satisfaction corrected for prior satisfaction, individual differences, and organizational factors, showed a remarkably high influence on job satisfaction by performance appraisal satisfaction

[32]. Additionally, motivation to improve job performance was found to be highly correlated to appraisal participation through a meta-analysis of twenty-seven studies [33].

These research findings would tend to indicate the performance appraisal does influence job satisfaction and motivation. Further, job satisfaction does influence productivity and organizational costs. The instructor of engineering management can validly alleged the productivity of the engineering department is affected by a performance evaluation method.

IV. B. Factors Influencing Performance Appraisal Success

An engineering management instructor should carefully emphasize the nature of an organization to express individuality in applying any of the aforementioned performance evaluation methods. While the student may recognize aspects of a performance evaluation method in the particular way an organization measures its scientists, engineers, and technologists, each organization will likely adapt methods to meet specific organizational goals. The literature, however, tends to reflect three, common, clear factors influencing performance appraisal success. These factors are a proper job analysis, alignment of individual goals with organizational goals, and employee participation in the performance assessment process.

IV. B. 1. Job Analysis

From the preceding discussion in Sections II and III concerning types of performance appraisals, clearly employees resent forced rankings and comparisons the most. Notably, employee rankings are the only method mentioned in use to evaluate scientists, engineers, and technologists that do not rely upon some level of job analysis. Much of literature resentment concerning performance appraisal is the tendency to not identify or reward the good and poor performers with tangible or feedback results [2, 14, 15, 21]. This is often the case, as noted earlier, in a system of constrained resources and rewards where ranking influences rating poor workers high and good workers low.

The job analysis is confounded by the nature of the technical function to be non-routine, non-repetitive, and creative. This requires keen involvement of the employee and supervisor to adequately refine the operational definitions that will comprise the job performed. Students of engineering management may recognize the job analysis as a conference proceeding the performance appraisal where employees and managers discuss the job, its objectives, and measures of success. Reaching a commonality of objectives and measures will require open communications and a high level of employee involvement.

IV. B. 2. Objective Alignment

Cawley, Keeping, and Levy suggest that employee participation in performance appraisals causes the employee to become more focused on organization motives because of the social context in which they find themselves [33]. Folger, Konovsky, and Cropanzano view the performance appraisal process in terms of a "due process metaphor" of organizational justice. By this view, they see the performance appraisal not in terms of psychometric scales, but apply a broader view of individual interaction within the organization goals [34]. Accordingly, this social view places the individual in a group context with a need for participation and fairness.

Silverman's book review of Mohrman, Resnick-West, and Lawler's *Designing Performance Appraisal Systems: Aligning Appraisals and Organizational Realities* echoes the assessment process needs to be tied to the organizational objectives [35]. Moravec also advocates an organizational approach to determination of individual objectives [36].

The scientist, engineer, or technologist should feel a sense of contribution to the organization's goals. This places the individual's participation as part of a group effort in achievement. The engineering management student should recognize and evaluate the level of input and communication the individual employee has in recommending, establishing, and aligning individual objectives with organizational performance. Engineering management instructors should emphasize this alignment as a key element in countering Deming's exhortations on management by objective and performance appraisals.

IV. B. 3. Employee Participation

Very credible and substantial correlation is made by Cawley, Keeping, and Levy between employee participation in the performance appraisal and appraisal successful reactions. Specifically, they identified a strong correlation between "value-expressive" and "instrumental" employee participation and good employee reactions to the appraisal. Their term "value-expressive" encompasses the ability of the employee to be heard and express views about the appraisal. "Instrumental" participation involved the ability of the employee to influence the process or the evaluation [34]. Blau also notes the perception of fairness within Folger's social justice context as influential on appraisal success [32]. If the appraisal is fair, the employee is satisfied regardless of rating.

McDowell notes that scientific and technical communicators prefer an involved, problem-solving approach to the appraisal process [37]. In this, scientific and technical communicators were more satisfied with appraisals based on participation and employee input.

Participation was also found to further organizational goals. Waite, Newman, and Krzystofiak found by regression that "progressive" appraisal methods result in higher attainment of quality goals for the organization. Progressive methods were generally defined to include participative workplace practices [38].

Engineering management courses can easily substantiate this conclusion from the two previous elements of successful appraisals. It should be emphasized, however, the nature of the scientist, engineer, and technologist to be creative problem solvers lends itself to involvement at all levels of the performance evaluation. Not only should employees be involved in establishing aligned objectives, but they should also contribute to the development of the process, instruments of measurement, and evaluation of the system's results.

V. Conclusions

The performance appraisal for scientists, engineers, and technologists can be a daunting and hated process for the employee and the reviewer. Similarly, it presents a challenge to the engineering management instructor to accurately and validly cover the topic in a course in engineering management. It is also a useful and perhaps needed feedback tool for individual

improvement and organizational improvement. It can also represent a seed of contention and distrust. Differentiating successful evaluation programs from disastrous programs can be difficult. This paper has attempted to provide some framework for such a differentiation in assessment and appraisal.

This paper has also presented five pertinent appraisals for scientists, engineers, and technologists with their benefits and problems. It has also presented a new technique that is gaining greater attention. Despite Deming's alarms, many authors and researchers believe the appraisal and assessment, properly designed, can serve a useful and necessary purpose in an organization's technical function.

The performance appraisal of scientists, engineers, and technologists is a mainstay of engineering management and of such courses. It is hoped this paper has provided some insight and much need course material where little is to be found and where great controversy can exist.

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