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INDUSTRIAL FACILITY QUALITY PERSPECTIVES IN OWNER ORGANIZATIONS

by

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Title: Industrial Facility Quality Perspectives in Owner Organizations

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1. **Abstract:** In this paper, a definition for industrial facility quality and a quality measurement technique are proposed. Owner attitudes toward plant quality are measured in an exploratory study of 17 industrial facilities. Three sub-populations within owner organizations are identified (Operations, Strategic, and Project Management) and attitude differences between them are interpreted. Two quality indices based on subjective evaluations are presented which enable the comparison of plants on the basis of summary statistics. The indices are validated based on correlations with an objective representational measure. The implications of these results for owner organizations as well as engineering and construction contractors are discussed.

2. **Subject:** We define industrial facility quality as owner satisfaction with the plant after it has been in operation for at least six months. 29 plant characteristics are used to approximate this concept of quality and elucidate the differences in subjective attitudes about plant quality in the owner organization. The differences are explored as potential areas to gain competitive advantage. We develop summary quality indices which can be used to compare plants of different types. The plant is viewed as the product of the facility development process.

3. **Objectives/Benefits:** In 1991, owners spent over $16 billion in construction costs alone on new industrial facilities [Dodge, 1992]. This research seeks to provide a measurement tool to give EPC firms feedback on the performance of the facilities they develop. They can benchmark their own performance in achieving customer satisfaction from project to project, or track the performance of implementing quality improvement programs. Owners can use the tool to understand the different quality priorities that exist with the organization, and to target areas for improvement. Items demonstrating high importance and low satisfaction can be targeted as areas of potential competitive advantage. The plant managers' summary quality indices will be used in a forthcoming paper to evaluate the impact of technical and organizational integration in the facility development process on plant quality.

4. **Methodology:** 17 industrial process facilities were included in this study. They ranged from $10 million to $1 billion, and included power generation plants (6), pulp and paper (4), chemical manufacturing (4), water and waste

water treatment (2), and hardware manufacturing (1). All were located in North America. 53 managers and operations personnel in the owner organizations of these facilities contributed questionnaire and interview data regarding plant quality. Semantic differential rating scales were an important component of the measurement procedure. Statistical techniques were used to analyze the data.

5. **Results:** We found evidence to support the working hypothesis that there are perhaps three or more categorizable perspectives of industrial facility quality in owner organizations, each with distinct priorities and standards of performance. These owner categories are project management, strategic, and operations. Project management demonstrates significantly higher satisfaction levels with plants than do the other two groups. We pinpointed several facility characteristics that demonstrated high importance and low satisfaction ratings within the groups, which indicate potential areas of competitive advantage. We identified one "objective" measure, the ratio of actual to planned production capacity, that is suitable for comparing plants of different types, but limited in its ability to represent broader aspects of the customer satisfaction definition of facility quality. We developed two summary quality indices that do tap these broader aspects, and as expected, they correlate modestly with the "objective" measure.

6. **Research Status:** This paper will be followed by a companion paper exploring the impact of facility development process integration on the quality of these 17 facilities. Next, an in-depth longitudinal study of two plants is proposed, from the mechanical completion stage through the first few months of operation. This will enrich our understanding of pertinent quality and process variables, and enable us to refine the measurement techniques. Then, to rigorously test our hypotheses and enable the generalization of the results, we should pursue a study of about 30 plants. They should be selected randomly from the population of all industrial process plants in the U.S. that had commenced operation between 6 and 18 months prior to the study.

   The measurement technique developed in this paper, though not validated with a generalizable sample as described above, is easy to use and understand by people in EPC and owner organizations. These organizations could adapt and refine the measurement technique to suit their own emphases.

INDUSTRIAL FACILITY QUALITY PERSPECTIVES IN OWNER ORGANIZATIONS

Kelly Jean Fergusson[1] and Paul Teicholz[2]

ABSTRACT

Empirical measurement techniques to evaluate industrial facility quality are sparse in the literature. This gap invites exploration by researchers. In this paper, a definition for industrial facility quality and a quality measurement technique are proposed. Owner attitudes toward plant quality are measured in an exploratory study of 17 industrial facilities. Three sub-populations within owner organizations are identified and attitude differences between them are interpreted. Two quality indices are presented which enable the comparison of plants on the basis of single summary statistics. The indices are validated based on correlations with a representational measure. The implications of these results for owner organizations as well as engineering and construction contractors are discussed.

INTRODUCTION

It is the responsibility of the owner organization to communicate its expectations to the engineering and construction professionals that design and construct its industrial facilities [ASCE, 1988]. However, the expectations of people within the owner organization can vary dramatically depending on their individual functions and roles. This diversity in perspectives can result in some groups being very satisfied with a particular project's outcome, while others are not.

Understanding the differences between these owner groups and their viewpoints of facility quality is important to both owner organizations and providers of engineering and construction services. In 1991, owners spent over $16 billion in construction costs alone on new industrial facilities [Dodge, 1992], and so they need to both understand and communicate their expectations effectively to get the best value for their investment. Engineering and construction professionals provide their services in an extremely competitive marketplace with low margins. Thus, they need to recognize what constitutes a satisfactory standard of performance for each type of customer in order to deliver a quality product that will bring repeat business, positive word-of-mouth referrals and build a strong reputation in the industry.

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This paper describes the findings of an exploratory study of attitudes of 53 managers and operations personnel in owner organizations regarding the quality of 17 industrial facilities. In a forthcoming companion paper, the authors will discuss the impact of technical and organizational project integration on the quality of these industrial facilities. This paper starts with a general definition of product quality. Next, methods developed in the social sciences to measure attitudes are reviewed and adapted to this application. A wide range of quality parameters are proposed, and owners' importance and satisfaction ratings of these parameters are presented. Three sub-populations within the owner organization are identified and the differences in attitudes between them are highlighted. Methods to combine each respondent's data into single summary statistics are presented and supported. By demonstrating the wide applicability of these techniques and their ability to uncover interesting and useful results, this study aims to contribute to the evolution of our industry's quality paradigm from *specification conformance* to include *satisfaction of owner needs* by providing a tool with which to measure progress toward this goal.

BACKGROUND

"Quality" is a popular term in the engineering and construction industry today. Each company, and indeed, each person, has a favorite definition. There are hundreds of quality consultants and philosophers, and hundreds of books and articles. How does one make sense of this mountain of information?

Two simple models shown in Figure 1 may be used to help us categorize and analyze quality definitions and programs: Dumas' progressive four-step hierarchy [Dumas, 1989], and Garvin's five category classification system. [Garvin, 1984]

4. It develops new capabilities

3. It satisfies the customer

2. It works (meets requirements)

1. It has extra features

Figure 1a.
Dumas' Hierarchy of Quality Definitions [Dumas, 1989]

Transcendent approach
Product-based approach
User-based approach
Manufacturing-based approach
Value-based approach

Figure 1b.
Garvin's Five Approaches to Defining Quality [Garvin, 1984]

These two models are useful frameworks for categorizing the wide variety of quality literature in industry and academia today. Dumas' "It satisfies the customer" definition and Garvin's "user-based approach" are similar and are adopted as the definition of quality in this study.

Dumas' framework (Figure 1a) relates successive definitions of product quality to an industry's or company's competitiveness. Periodically, an upheaval occurs within a company or industry which causes advancement to the next level. Progressing to a higher level expands the definition of quality without supplanting lower levels. At the most primitive level, "quality" means the inclusion of *extra features*. An example of this from the American automobile industry is Sloan's strategy of sustaining customer interest by annually changing features such as styling, layout, dashboard components, etc. [Womack et al., 1990]. At the second level, *it works*, quality is defined as conformance to specifications. This is the operational definition for most A/E/C firms in business today [Burati, 1987] [Davis, K., 1987], and remains a vital area to improve. At the third level, the definition expands to include a focus on the customer; *it satisfies*. Meeting customer and user expectations in terms of durability, reliability, or life cycle value for the initial investment are objectives for companies or industries operating at this level. Finally, the very best companies offer products which anticipate or exceed customer expectations and thereby help *develop* customers by enhancing customer competitiveness and profitability.

Crosby's "zero-defects" philosophy [Crosby, 1979] and Juran's "conformance quality" [Juran, 1974] fit at the second level, while Juran's "fitness for use" [Juran, 1974] belongs at the third level. Deming's "Out of the Crisis" [Deming, 1982] is a general prescriptive approach to achieving a transition from the second to the third level.

Garvin's system is composed of five approaches to quality definitions as shown in Figure 1b. In the *Transcendent* approach developed by philosophers, quality is an undefinable characteristic like beauty which we can only recognize by experience. The *Product-based* approach defines quality as a measurable attribute of a product, for example high quality rugs have a high number of knots or stitches per square inch. This definition is useful when all customers agree that a single attribute is the most important. The *User-based* definition recognizes that each person has different needs and expectations. Individuals attach weights to each quality characteristic of a product, and the highest quality product is one that maximally satisfies the individual user. This approach is popular among marketing people. The *Manufacturing-based* approach emphasizes conformance to requirements rather than user satisfaction and is prevalent in engineering and manufacturing departments. In the *Value-based* approach, quality is acceptable performance at an affordable price. Garvin emphasizes the need for companies to cultivate differing perspectives of quality in order to produce high quality products.

To demonstrate the pitfall of not cultivating differing perspectives by overemphasizing *manufacturing-based* quality at the expense of *user-based* quality, Garvin cites Ishikawa's example of a Japanese paper manufacturer who:

> "discovered that [the strength and tear characteristics of] its newsprint rolls failed to satisfy customers even though they met the Japanese Industrial Standard. Conformance was excellent, reflecting a manufacturing-based approach to quality, but

acceptance was poor. Other rolls of newsprint, however, generated no customer complaints even though they failed to meet the standard." [Ishikawa, 1984 as cited by Garvin, 1984]

By focusing just on the manufacturing-based approach the company created unhappy customers. A more robust view of quality that included the user-based approach soon put an end to the complaints.

Certainly the reader can envision parallels in the engineering and construction industry today, in which facility characteristics meet a specification, but fail to meet an owner's needs or expectations. This is not to say that extra features and conformance to requirements are not essential components of the definition of facility quality, but that customer satisfaction must be added to the industry's conception of quality if it is to remain competitive through the 1990s and beyond.

POINT OF DEPARTURE OF RESEARCH

Traditionally, the industrial facility engineering and construction industry has operated in line with Dumas' *it works* (conformance to requirements) and Garvin's *manufacturing-based* definitions of quality. However, owner dissatisfaction with cost-effectiveness of engineering and construction services [BRT, 1983] and the losses of Engineering, Procurement and Construction (EPC) firms in international competitiveness [Wiggins, 1988] have prompted many EPC companies to start adding Dumas' *it satisfies* (customer satisfaction) and Garvin's *user-based* approach to their operative definition of quality.

The above definitions suggest the use of customer satisfaction with a completed facility to measure its relative merit. Such measurement could provide valuable feedback to consumers as well as providers of industrial facilities regarding the strengths and weaknesses of both facility and project performance.

Prior work on measuring quality in the engineering and construction industry has focused on the quality of the facility development *process* : planning, engineering, constructing, and start-up. The Construction Industry Institute's (CII) work has primarily focused on quality of the process using the conformance quality definition in measuring the costs and causes of rework and prevention of errors [Davis, K., 1987] [Burati, 1987] [Josephson, 1989]. Other work adopts user-based quality definitions, and emphasizes project success [Ashley, 1987] [Salimbene, 1986], or total quality management of the process [Matthews, 1989].

Work which views the facility *as a product* includes [Sanvido,1990] which identifies a facility as the prime output of the facility planning/ engineering/ construction process. In the context of facility performance many articles that have appeared in the Journal of Performance of Constructed Facilities analyze specific building component failures. [Hadipriono,1990] uses fuzzy set concepts to quantify qualitative assessments of facility component performance.

[Preiser] discusses the impact of office and housing facility characteristics on the productivity of the occupants. [Mohsini, 1989] proposes that performance of a building can be maximized by adjusting the relative bargaining powers of participants in the process. Finally, numerous papers were presented at the symposium on Overall Facility Performance in Toronto, Canada which viewed the facility as a product [Davis, G., 1990]. Although the facilities addressed in these papers are limited to office and laboratory buildings, a number of guidelines for possible performance measures are discussed. Especially relevant is [Stokols, 1990], a study in which a 4-point Likert scale is used to obtain workers' evaluative attitudes about attributes of their work environment such as "Comfort of your chair", "Conversational privacy", and "Availability of electrical outlets".

As evident in the above discussion, empirical measurement techniques to evaluate industrial facility quality are sparse in the literature. This gap invites exploration by researchers. The current study partially addresses this gap by contributing a new measurement technique of the industrial facility as a product based on *it satisfies* and *user-based* (customer satisfaction) definitions of quality. The results obtained from using the technique can be used by both owners and providers of industrial facilities to refine and achieve their strategic business goals.

MEASUREMENT OF CUSTOMER SATISFACTION

But how can customer satisfaction be measured? Traditional attributes that engineers are accustomed to measuring such as dimension, weight, ductility, cost and duration cannot be easily translated to the realm of measuring human attitudes. Instead, we may defer to expertise developed in the fields of sociology and psychology on attitude measurement.

[Dawes, 1985] gives an enlightened overview of the many approaches to attitude measurement, distinguishing between representational and nonrepresentational techniques. Representational methods include magnitude techniques such as Thurstone's paired comparisons [Thurstone, 1928], interlocking techniques such as Guttman scaling [Guttman, 1944], proximity techniques, and unfolding techniques. These techniques attempt to represent both the orders and specific consistent distances on a scale between different observed behaviors or objects. On the other hand, nonrepresentational measurement is not based on the assumption of consistent distances between points on a scale . For example, the interpreted distance between 2 and 3 on a Likert scale (nonrepresentational) may vary from person to person and may be influenced by the item being measured. In contrast, the difference between 2 and 3 ounces on a balance scale (representational) is consistent regardless of who performs the measurement and what type of item is being measured on the scale.

Importantly, nonrepresentational measures, like representational ones, have been shown to demonstrate both internal and external predictability. Internal predictability refers to the ability to replicate results on similar scale, and external predictability is the capacity to "predict dissimilar behaviors (e.g. from rating scale responses to voting). Hence the basis for all measurement is empirical prediction." [Dawes, 1985, pg. 512] [Seiler 1970] concludes that the external predictability of representational (Thurstone scale) versus nonrepresentational (Likert Scale) is comparable. Indeed, Likert himself argued, and other studies have verified, that his scale meets or surpasses the reliability of the Thurstone method with greatly reduced effort and fewer statistical assumptions [Likert, 1932] [Seiler 1970].

The semantic differential technique is a heavily used nonrepresentational measurement method in the fields of sociology and psychology. [Osgood et al, 1957] developed the semantic differential as a by-product of investigating semantic meaning. They determined that simple equal-appearing-interval rating scales with bi-polar adjectives as anchors (e.g. good-bad, hot-cold, beautiful-ugly) could be used to capture the meaning of semantic objects. Furthermore, they identified three clear dimensions of meaning: 1) evaluative, 2) potency and 3) activity. Pure rating scales along these dimensions (such as good-bad for evaluative, powerful-powerless for potency, and active-passive for activity) can economically and reliably capture the essence of a person's attitude about an object [Heise, 1970]. Developed in the 1950s, semantic differential rating scales soon became enormously popular among attitude researchers [Summers, 1970], and continue in their popularity today.

The evolution and refinement of attitude measurement evident in the above discussion forms the basis for this study's implementation of the measurement of customer attitudes discussed in the next section.

IMPLEMENTATION OF QUALITY AND MEASUREMENT CONCEPTS

To measure attitudes about industrial facility quality, the semantic differential scale was chosen for this study because of its simplicity and flexibility. As [Ventre, 1990, pg. 19] points out, there is a tradeoff between elegance of measurement and the applicability of a measurement method. One of the goals of this study is to produce results that are immediately applicable to current practice by EPC professionals and facility owners. A straightforward, easily understandable technique is required in this context, even if the trade-off involves the possible introduction of some random error into the data. The semantic differential scale introduces some error into the data by assuming a linear scale, rather than an ordinal scale. At worst, this type of error will cause us to find a statistically non-significant result when a true effect exists in reality (Type II error). This is therefore a very conservative approach, as [Bohrnstedt, 1970, pg. 80] attests:

> "By assuming interval measurement where only ordinal measurement exists, some measurement errors will occur. The result of errors generally is the attenuation of relations among variables. That is, one's

apparent results will be more attenuated than they are in reality. Thus, it is unlikely that the decision to assume interval measurement when it does not exist will lead to the spurious overestimation of results."

It was recognized at the inception of this study that the concept of industrial facility quality was highly complex and composed of many underlying factors. Indeed, [Garvin, 1984] identifies no less than eight dimensions of manufactured product quality: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. Although our concept of industrial facility quality does not necessarily align with Garvin's eight dimensions, it is made even more complex by the fact that there are several, perhaps many, customers of a single facility, each with different priorities.

The strategy for capturing this complexity is based on the notion that each individual has a different conception of industrial facility quality as shown schematically in Figure 2, which is an adaptation of a Venn Diagram [Tabachnick, 1989]. The concept of quality for each person is shown as a large circle. Overlapping the large circle are ovals representing facility characteristics. The fraction of the circle's area that is overlapped by each oval is an indication of how important that characteristic is to the person's overall concept of the facility's quality.

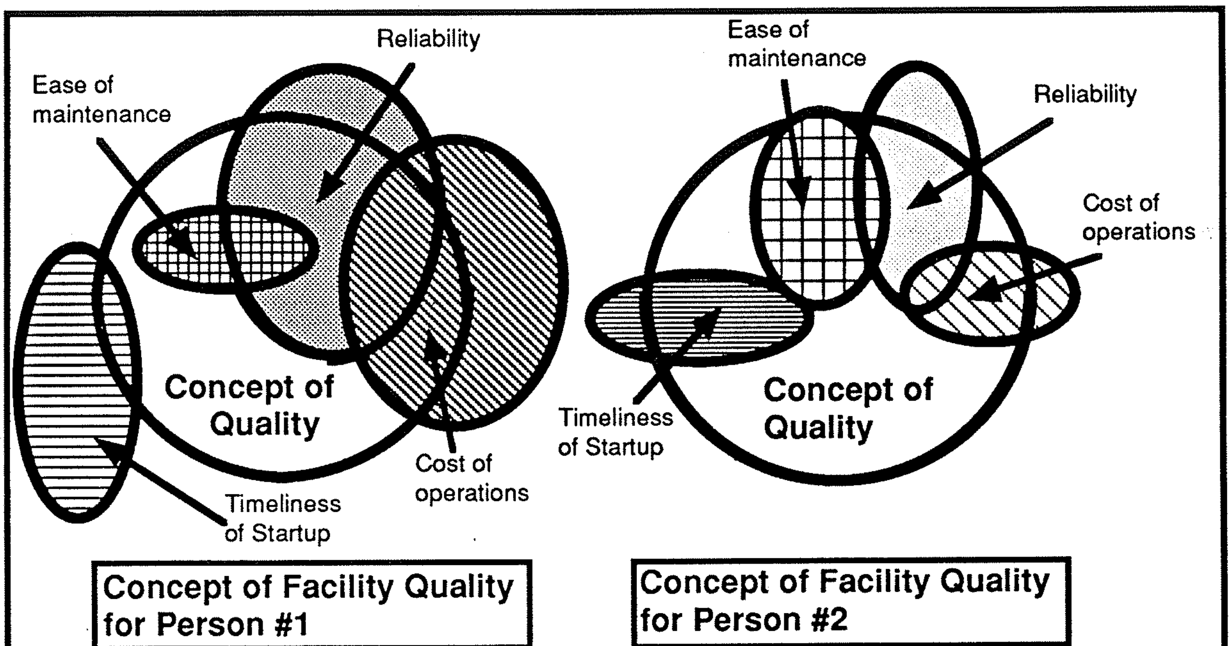

Figure 2. Schematic Representation of Concept of Quality.
Each large circle represents a hypothetical individual's concept of industrial facility quality. Ovals represent facility characteristics which comprise that individual's concept. The fraction of a circle's area that is overlapped by each oval indicates how important that characteristic is to the person's overall concept of facility quality.

Theoretically, some characteristics may overlap and vary in consistent ways from person to person, indicating dimensions of an underlying structure of the concept of quality. For example, variables that measure similar aspects of a plant such as plant safety, healthfulness of worker environment, and comfort of worker environment might be grouped into a dimension called "operator well-being" based on correlations between the items. Similarly, durability, ease of maintenance, and adequacy of warranty might cluster into a "maintainability" dimension. This is speculation, however. Identifying the actual underlying dimensions of facility quality and whether or not they match Garvin's eight dimensions is beyond the scope of this study and might be a topic of future research.

To implement a measurement system, a list of 32 facility characteristics represented by phrases used to analyze and discuss facility quality were derived from the literature and discussions with industry professionals. These became the quality characteristics (semantic objects) that were rated by survey participants. They are presented in Table A, along with the variable names used in the analyses.

Two semantic differential rating scales were constructed for each characteristic as shown in Figure 3. One rating scale measured the evaluative dimension of the characteristic (low satisfaction-high satisfaction), and the other measured the potency of the characteristic (low importance-high importance). Since an industrial facility is inanimate, the action dimension of meaning was deemed irrelevant so was not measured. To visualize this in terms of Figure 2, the importance dimension is the relative size of each oval. The satisfaction dimension is pattern intensity, where a perfectly satisfying characteristic is completely black. For example, "ease of maintenance" is more important to person #2 than to person #1, but person #1 is more satisfied with "ease of maintenance" than person #2. Statistical variance of importance items can be thought of as the diversity in oval sizes from person to person on the same characteristic. Similarly, statistical variance of satisfaction items is the diversity of pattern intensities from person to person on the same characteristic. Statistical correlation between two characteristics is consistency in the relative size of the two ovals from person to person for importance characteristics, or consistency in the relative pattern intensities from person to person on satisfaction characteristics.

Profitability of Plant

Importance Scale					Satisfaction Scale				
1	2	3	4	5	1	2	3	4	5
(low)				(high)	(low)				(high)

Figure 3. Two Semantic Differential Scales for the Semantic Object "Profitability of Plant".
Respondents in owner organizations rated 32 semantic objects such as "Profitability of Plant" on the importance and satisfaction scales shown above. The importance scale measures the potency dimension of the object's meaning, while the satisfaction scale measures the evaluative dimension of meaning.

FACILITY QUALITY CHARACTERISTIC (SEMANTIC OBJECT)	VARIABLE NAME
1. Timeliness of start-up	STARTUP
2. Meeting production output specifications	PRODUCT
3. Capital cost (including design, construction, and start-up)	CAPCOST
4. Profitability of plant	PROFIT
5. Cost of operating (excluding energy cost)	OPCOST
6. Energy cost for operating	ENCOST
7. Adaptability to changing owner/operator needs	ADAPT
8. Control systems providing industrial process feedback	DCS
9. Meeting emissions requirements (all waste types)	ALLWASTE
10. Meeting emissions requirements under all operating conditions (e.g. varying loads)	LOADWASTE
11. Flexibility to meet more stringent emissions requirements	FLEXWASTE
12. Flexibility to use alternative fuel types*	FLEXFUEL
13. Adequate warranty	WARR
14. Flexibility of major systems for expansion	FLEXEXPAN
15. Useful operations and training manual	MANUAL
16. Training of operators during start-up	TRAINING
17. Ease of operating (e.g. operation of machinery by less experienced workers)	OPEASE
18. Healthfulness of worker environment	HEALTH
19. Comfort of worker environment	COMFORT
20. Safety	SAFETY
21. Security (proprietary processes, materials, assets, etc.)	SECURE
22. Storage space	STORAGE
23. Reliability of major systems	RELIAB
24. Durability of major materials	DURAB
25. Cost of maintenance	MNTCOST
26. Ease of maintenance (accessibility of equipment, clearances around equipment)	MNTEASE
27. Ability to predict failures of major components	PREDICT
28. Ability to avoid catastrophic failure of major components	CATASTR
29. Equipment replacement cost **	EQCOST
30. Cost of cleaning	CLNCOST
31. Ease of cleaning	CLNEASE
32. Public image portrayed by facility ***	ARCHIMAG

* There were many missing values on this item, so it was omitted from the analysis.
**This item was ambiguous to respondents, so it was omitted from the analysis.
*** Although we decided to omit this item from the survey instrument, it was a popular write-in item so it will be included in future studies. It is not included in the analysis.

Table A. Quality Characteristics Rated by Survey Participants. 32 facility characteristics used to analyze and discuss facility quality were culled from the literature and discussions with industry professionals. These characteristics are intended to represent the concept of facility quality. Respondents in owner organizations rated their facility on each of these items.

Seventeen (17) industrial facilities were selected for inclusion in the analysis. The facilities had all been operating for between nine months and six years, and had initial capital costs between $10 million and $1 billion U.S. dollars. They represented a variety of process industries: power and co-generation plants (6), chemical manufacturing (4), pulp and paper (4), water and waste water treatment (2), and hardware manufacturing (1). The population is heterogeneous in the sense that five industries are represented, yet homogeneous in the sense that they are all industrial facilities. The heterogeneous nature precludes us from using narrow objective data such as availability or start-up duration to compare the plants directly because each industry has unique norms for these measures. However, the homogeneous nature enables us to apply the rating scale measurement technique outlined above.

The plants were selected by contacts within owner and engineering companies. In most cases, each contact selected two projects in which his[3] company had been involved. In order to guard against the tendency for people to "show off" only their best projects and to ensure variance in the data, the contact was requested to provide what he judged to be one higher quality plant, and one lower quality plant. Contacts had either expressed a prior interest in participating in the study, or had been contacted because of their company's affiliation with the Center for Integrated Facility Engineering (CIFE) at Stanford and thus were inclined to permit the researcher access to their organization and information. Typically, the contact provided the researcher with the names of two people in the owner organization: an owner representative that had been involved in the project, as well as the chief operator of the plant (operations manager, production manager, etc.). After interviews with these two people, snowball sampling (i.e. using members of a special population to identify others of that population) [Kish, 1965] was used to obtain, typically, between zero and three more respondents per facility.

RESULTS

Our results in four main areas can give industry professionals insight into quality attitudes in the owner organization. These are 1) group distinctions, 2) attitude differences between groups, 3) construction of summary quality indices and 4) correlation of objective data with summary indices. Statistics were computed using [Statview, 1991] and the Statistical Package for the Social Sciences [SPSS, 1990] computer packages.

1) Group Distinctions

When this research was conceived, we assumed that there was one and only one “customer” or “owner” viewpoint of facility quality. However, during the course of data gathering, it became apparent that people with different roles in the owner organizations often have substantially different definitions of facility quality. Specifically, after completing interviews for the first few projects in the study, we hypothesized that project managers were more satisfied with the plants than other people in the owner organization.

As a working hypothesis, we have classified people in the owner organization post-hoc into 3 groups, Project Management (n=12), Strategic (n=8), and Operations (n=33), defined as follows:

Owner - Project Management

From year to year, the full time responsibilities of a person in this category involve facility engineering or construction, and the person’s financial accountability for the facility tapers off at mechanical completion. The person

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[3] All contacts were men.

typically begins working on a new facility project when the current one is complete.

Owner - Strategic
The Strategic person has financial responsibility for the plant, and may oversee operations of more than one plant. This person contributes to the strategic technical and/or business direction of the company, and typically has depth of experience in operations of more than one plant. The financial accountably of people in both this group and the next typically increases at mechanical completion.

Owner - Operations
People in this category currently oversee one plant at most, and work on day-to-day production operations. Future studies may distinguish between the senior operations manager of the facility and the other supervisors and workers included in this category.

A summary of the raw data categorized by these groups is presented in Appendix A.

To test whether attitudes about facility quality are reliably different between the three groups, ANOVAs (ANalysis Of VAriance) were used to determine the differences in group means, μ, of the 29 facility quality items, such as profitability of plant, meeting production output specifications, etc.[4] Because this is an exploratory study with relatively unrefined measurement techniques, a relatively high significance level of $p<.10$ was chosen for this analysis.

The null hypotheses are that there is no difference between the three groups' mean scores on each item: $\mu 1=\mu 2=\mu 3$. Based on the F-statistic, we reject the null hypothesis for 4 of the 29 importance comparisons and 10 of the 29 satisfaction comparisons, as shown in Table B, below.

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[4] ANOVA enables us to avoid one aspect of the problem of multiple comparisons because only 29 comparisons are made for importance and satisfaction measurements of each characteristic rather than the 87 that would be required using the t-test of mean differences. However, 29 is still a large number of comparisons. If these variables were independent, we could use Bonferroni's adjustment to reduce the probability level, p. However, the variables are not independent, so the problem of multiple comparisons remains an unresolved issue for this study.

Item type:	Significant F-statistic Totals:
Importance items	4 of 29
Satisfaction items	10 of 29
Total significant items	14 of 58

Table B. Number of Significant ($p<.10$) Mean Differences in Facility Characteristics.
For each of the 29 importance and 29 satisfaction items, we used ANOVA to compare the means of the respondents' scores between owner groups. The null hypotheses are that there is no difference between the three groups' mean scores on each item: $\mu1=\mu2=\mu3$. Based on the F-statistic, we reject the null hypothesis for 14 of the 58 tests.

Although these significant F-statistics tell us that differences between means exist, they do not specifically tell us between which groups the differences exist. To determine specifically which groups exhibit these differences, the Least Significant Difference (LSD) statistic [Ostle, 1988] is used on these 14 items. Based on the LSD statistic, 6 importance differences and 17 satisfaction differences were obtained, as shown in Table C, below. These differences are detailed in Figure 4 in the next section.

Comparisons: / Item type:	Proj. Mgmt. vs. Operations	Proj. Mgmt. vs. Strategic	Operations vs. Strategic	Significant LSD totals:
Importance items:	3	1	2	3+1+2 = 6
Satisfaction items:	8	8	1	8+8+1=17
Significant LSD totals:	11	9	3	11+9+3=23

Table C: Number of Significant ($p<.10$) Specific Group Differences in Facility Characteristics Between Three Owner Groups.
After obtaining a significant F-statistic indicating that at least two of the three means are different, we perform an LSD test on that comparison to obtain the details of the difference. For example, the F-test may tell us that the statement $\mu1=\mu2=\mu3$ is false. The LSD test can tell us specifically that $\mu2\neq\mu3$. The table indicates that of the 14 variables for which $\mu1=\mu2=\mu3$ was false, 11 demonstrated a significant difference between the Project Management and Operations groups, 9 demonstrated a difference between the Project Management and Strategic groups, and 3 demonstrated a difference between the Operations and Strategic viewpoints.

These test results show that although there are few importance differences between the groups, there are substantial differences in satisfaction levels between Project Management and both the Operations and Strategic groups. The number of satisfaction differences, 8 of 29 for the Project Management vs. Operations relationship, and 8 of 29 for the Project Management vs. Strategic relationship indicate that these groups have significantly different definitions of industrial facility quality. Project Management has different standards than the other two groups. These results were confirmed by two sign tests comparing Project Management mean satisfaction with the 29 items to Strategic and Operations means, respectively. The null hypothesis is that there is no difference in satisfaction between the two pairs of groups, and the alternative hypothesis is that Project Management means exceed those of the other two groups. These results are displayed in Table D, below.

Comparisons:	Proj. Mgmt. mean is greater than Operations mean	Proj. Mgmt. mean is greater than Strategic mean
Number of sign differences:	27 of 29**	24 of 29**

** indicates significance at $p<.001$; $p = (n! / ((n-m)!m!)) / 2^n$.

Table D. Sign Tests for the Differences in Satisfaction Item Means for Project Management Compared to Operations and Strategic Groups. Project Management means exceeded Operations means for 27 of the 29 satisfaction items, and exceeded Strategic means for 24 of the 29 satisfaction items. We conclude that Project Management has a significantly difference definition of industrial facility quality than Strategic and Operations.

However, the differences in satisfaction means between the Strategic and Operations groups are few compared to the differences in means between either of these two groups and the Project Management group. Therefore, although the differences between Strategic and Operations should be highlighted and discussed, it may be appropriate in future analyses to combine Strategic and Operations people into a single "Permanent Facility Responsibility" group.

In addition to testing the differences between means, the correlation between the 29 satisfaction means for each group was explored using a permutation test. The purpose of the test was to discover whether the homogeneity of attitudes within each group is greater than within the sample as a whole. In other words, do people's attitudes differ distinctively by groups, or are attitudes just different in general? To answer this question, an SPSS program was written to see if the correlation within groups was greater than the correlation between groups. The program first calculated the correlation coefficient between the three pairs of groups: project management vs. strategic, project management vs. operations, and strategic vs. operations. Next, three simulated groups were created by randomly sampling subjects (without replacement) from the total sample. Again, correlation coefficients of the satisfaction means were computed for each of the three pairs of groups. One thousand sets of simulated coefficients were calculated, and these simulated coefficients were compared to the actual coefficients. When the actual coefficient was less than the simulated coefficient, the groups' attitudes were deemed different. The p value is the number of times divided by 1000 that the actual value exceeded the simulated value.

Although none of these comparisons reached significance, the greatest difference in attitude was between Strategic and Project Management viewpoints. Please refer to the first author's doctorate dissertation (forthcoming) for a further discussion of this procedure.

A striking feature of the data is the much higher satisfaction values given by the project management group as compared to the strategic and operations groups.

Comparing each group's overall mean of the means of the 29 items ("baseline") indicates whether or not scale interpretation is the same or different between groups, as shown in Table E. Looking only at the .42 and .44 differences in the baseline of the satisfaction scores, one might suspect that the project management people have a general optimism that causes them to interpret the semantic differential scale differently than the people in the other two groups. However, the fact that the project management group's baseline for the importance items is virtually the same as the other two groups suggests that the people in all three groups do indeed have a similar psychological interpretation of the scale. Thus, the large differences in satisfaction between the project management group and the operations and strategic groups can be interpreted as real differences rather than as artifacts of scale interpretation.

Groups: Baseline type:	Proj. Mgmt. vs. Operations	Proj. Mgmt. vs. Strategic	Operations vs. Strategic
Mean of means on satisfaction items:	3.80 vs. 3.38 **.42** difference	3.80 vs. 3.36 **.44** difference	3.38 vs. 3.36 **.02** difference
Mean of means on importance items:	3.85 vs. 3.97 **-.12** difference	3.85 vs. 3.94 **-.09** difference	3.97 vs. 3.90 **.07** difference

Table F: Rating Scale Baseline Comparison Between Three Owner Groups Are the large differences in satisfaction scale baselines (.42 and .44) between Project Management and the other two groups due to innate optimism or real differences in satisfaction? The baseline differences appear to be due to actual satisfaction differences because there are only small differences between the groups' importance scale baselines. This indicates the respondents in all groups have similar psychological interpretations of the scales.

2) Attitude Differences Between Three Groups

Given the working hypothesis that these three distinct viewpoints regarding satisfaction with facility quality exist in the owner organization, the differences between them will now be examined in more depth. Based on the F-test, the significant ANOVA results comparing group means on each facility characteristic that were summarized in Tables B and C are now presented in detail in Figure 4. Note that because of our hypothesis that project management means would exceed operations and strategic means of satisfaction scores, one-tailed tests were performed in these cases. However, the importance comparisons between all groups and the satisfaction comparisons between the operations and strategic groups were performed using two-tailed tests because there was no prior expectation as to whether one group would exceed another.

Statistically significant differences on the basis of the Least Significant Difference (LSD) statistic are indicated by one asterisk (*) for $p<.10$ and two asterisks (**) for $p<.05$ at the end of the bars in Figure 4. The items are positioned from left to right in rank order of importance based on the means of all 53 responses for each item.

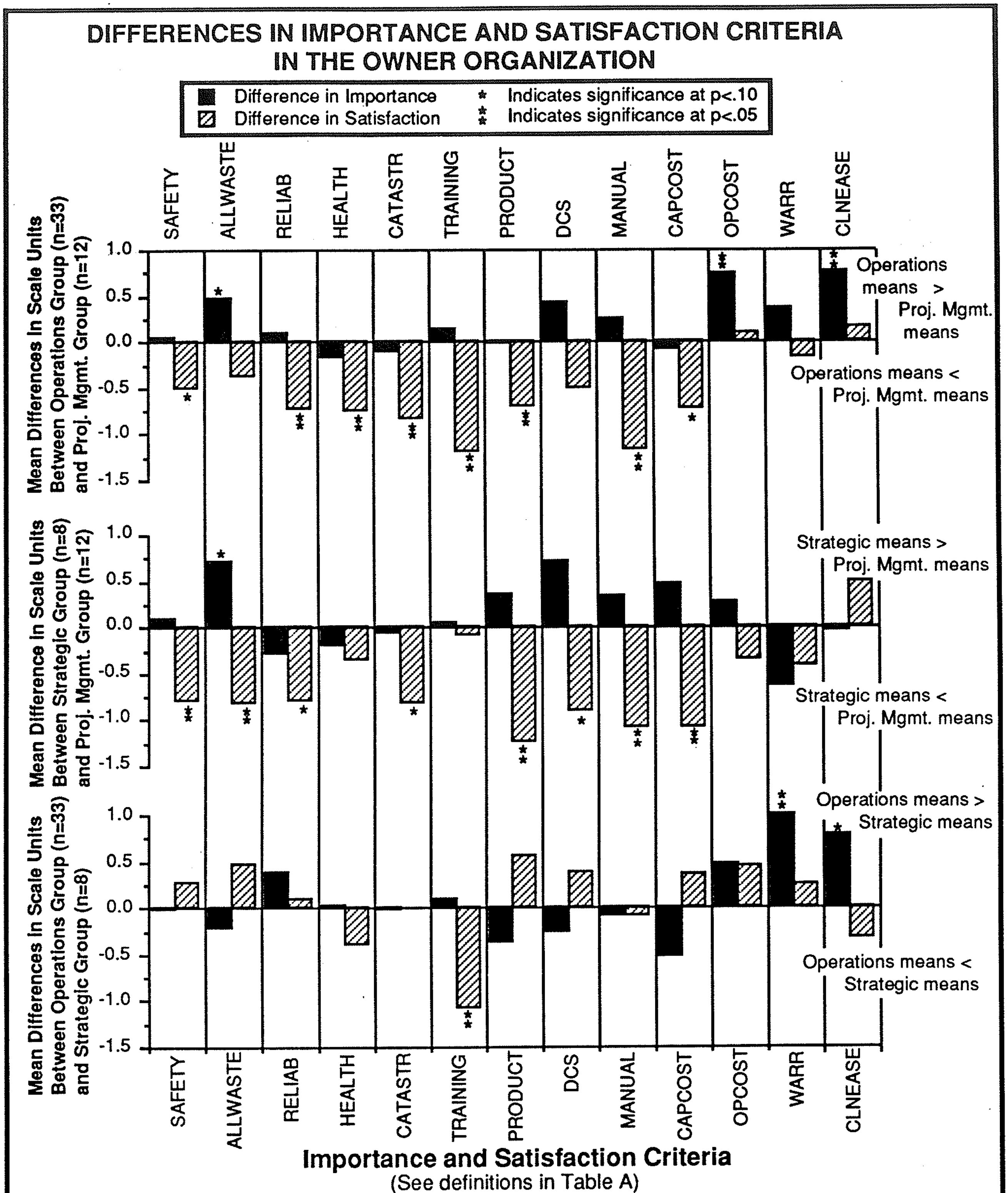

Figure 4. Differences in Importance and Satisfaction Criteria in the Owner Organization. Each of the three horizontal bar charts compares two owner groups. For example, the top bar chart compares Operations with Project Management. Each black bar show the difference in the two groups' importance means on a single variable. Likewise, the striped bars show differences in satisfaction.

Operations Group vs. Project Management Group: As shown in the upper bar chart in Figure 4, there are three facility characteristics that are more *important* (shown by *'s at the end of the *black* bars) to operations personnel than to project management in this study. The operations group places a greater *importance* on the ability to meet emissions requirements for all waste types, cost of operating, and ease of cleaning.

Meeting environmental regulations is obviously of great concern from the operations perspective because of the combined potential of public safety consequences, heavy regulatory fines and detrimental public relations that could result from non compliance. Cost of operating is likewise more important to the operations group, perhaps because these people are accountable for setting and meeting operations budgets. Ease of cleaning, though not relatively as important as many other characteristics, is of understandable concern in maintaining "housekeeping" standards and a safe working environment.

Though not shown in Figure 4 because the item did not quite reach statistical significance, owner project managers rated timeliness of startup much higher in importance than did the operations group. This is a reasonable result because project management people are generally focused on schedule deadlines, whereas operations personnel, knowing that they are responsible for the plant on a permanent basis, tend to focus their concerns on the long term operating capability of the plant.

Operations has a lower average *satisfaction* level (shown by *'s at the end of the *striped* bars) than project management on 8 items. These are plant safety, plant reliability, healthfulness of worker environment, the ability to avoid catastrophic failure of major components, training of operators, the ability to meet production output specifications, useful operations and maintenance (O & M) manual, and capital cost.

Plant safety, healthfulness of worker environment, and the ability to avoid catastrophic failure might be termed "operator well-being" variables. Operations people are less satisfied than project management on these items, perhaps because being on site, they have found themselves at greater personal risk when failures do indeed occur. We might group training and O & M manual together as "how-to" variables. It is rather alarming that the people responsible for running these enormous, complex facilities have low satisfaction with the "how-to" operations instruction they receive at turnover. Plant reliability and meeting production specifications, two items measuring the basic functionality of the plant, also demonstrate significantly lower satisfaction levels for the operations groups relative to project management, perhaps due to an over-optimistic perception by project management regarding the performance of the plants they deliver to their internal customers. Lower satisfaction with capital cost may indicate a concern with value received for the money.

Storage space was an "almost significant" item for which operator satisfaction again was lower than project management satisfaction. While being a rather low importance item overall, it is mentioned here because it surfaced time and again during interviews as an item that had received little attention during design but that now was a persistent, irritating problem.

Strategic Group vs. Project Management Group: As with the operations perspective, the strategic perspective varies significantly from project management. The middle bar chart in Figure 4 shows that meeting emission requirements for all waste types is more *important* to strategic personnel than to project management in this study. Being responsible for the plant's business performance, strategic people understand the true magnitude of the costs that can be associated with environmental non compliance.

Strategic people have a statistically significant lower level of *satisfaction* than project management with respect to eight facility characteristics. In addition to seven items in common with the Project Management vs. Operations differences (plant safety, meeting emissions requirements for all waste types, plant reliability, the ability to avoid catastrophic failure of major components, meeting production output specifications, useful operations and maintenance (O & M) manual, and capital cost), the eighth item is Distributed Control Systems (DCS). These items are indicated by asterisks (*) at the ends of the *striped* bars of the middle bar chart in Figure 4.

Project management's markedly higher satisfaction with critical items such as reliability and ability to meet production output specifications may indicate a misperception regarding the actual performance of the plant. In addition, as plant complexity continues to increase, the DCS has become more and more essential to plant operation by guiding optimization of industrial process performance and reducing labor requirements. However, the strategic perspective is much less satisfied with DCS than project management, perhaps because these systems do not perform to expectations. The gap between the two groups on plant safety and the usefulness of the operations and maintenance manual may exist because these items are difficult to judge from the shorter-term project management perspective. The lower satisfaction of the strategic perspective than the project management perspective with capital cost may indicate the strategic person's desire to achieve a better return on investment, while project management's goal is to meet budget objectives.

Taken together, the differences in satisfaction described above suggest that owner project managers may not have an accurate conception of the performance of the new facilities that they "deliver" to their organization. Project managers are the owner organization's crucial liaison with the larger facility development team which includes engineering, vendor, construction, regulatory, and other organizations. Owner project managers communicate the priorities of the owner organization as a whole. It is therefore essential that they develop a deep, sensitive understanding of what constitutes satisfaction in the eyes of the people in their organizations that have long-term financial accountability and operations responsibilities for these facilities.

For the projects in this study, the most frequent number of post start-up reviews per project to provide feedback to the project team was zero. If one or more post-start-up reviews were held, they typically focused on *project* performance rather than *facility* performance. These meetings are typically held shortly after start-up, with operations and strategic representatives often not even present. In addition, because project managers are typically extremely valuable personnel in the owner organization, as soon as mechanical completion is accomplished they are often transferred to the next capital project in progress. Under these circumstances, it is not surprising that project managers' perceptions of facility quality are typically focused on the "front end" of the facility life cycle rather than being aligned with the perceptions of others in their organization.

Operations Group vs. Strategic Group: The operations group gives a significantly higher weight to the *importance* of adequate warranty and ease of cleaning than the strategic group. Operations people bear the responsibility of keeping the plant running on a day-to-day basis. When something goes awry, they are responsible for get things running smoothly again. It is thus not surprising that they exceed the strategic group with respect to equipment warranty expectations. And ease of cleaning, while not a particularly important item, does contribute to a safer, more pleasant working environment.

The only significant difference in *satisfaction* averages between these two groups involves training of operators. While all three groups concur on the *importance* of operator training, operations people themselves are very dissatisfied. Table F, below, portrays items ranked high in importance and low in satisfaction based on item means within each group. Note that operator training has the very largest difference in rank order of all the facility characteristics.

The items shown in Table F have possible implications for both owner organizations and EPC firms. These areas of high importance and low satisfaction to the owner organization may be very productive areas in which to focus improvement efforts in order to achieve an edge over competitors. Particularly, training of operators and useful operations and maintenance manuals are two areas where gains could be made with relatively little effort. Meeting emissions requirements is an area where owner companies may have more practical expertise and know more about future requirements than typical engineering organizations. Therefore, one strategy for improving customer satisfaction in this area would be to pro-actively tap the expertise existing within the owner organization. Reliability is also a prime target, since it is a high importance, low satisfaction item for all three groups.

Operations Viewpoint			Strategic Viewpoint			Project Mgmt. Viewpoint		
Facility Quality Characteristic	Import -ance Rank	Satis- faction Rank	Facility Quality Characteristic	Import -ance Rank	Satis- faction Rank	Facility Quality Characteristic	Import -ance Rank	Satis- faction Rank
Reliability	3	15	Mtg emissions requirements (all operating conditions)	3	18	Reliability	4	9
Training of Operators during Startup	7	29	Meeting Production Output Specifications	4	21	Profitability of Plant	11	19
Profitability of Plant	9	16	Profitability of Plant	5	23	Ease of Maintenance	12	22
Useful O & M Manual	13	30	Distributed Control System	9	24	Cost of Maintenance	14	27
Cost of Maintenance	16	24	Reliability	10	17	Ability to predict failure of major components	15	24
Warranty	18	25	Capital Cost	12	25			
			Useful O & M Manual	16	29			

Table F. Facility Characteristics Ranked High in Importance and Low in Satisfaction by Three Groups in the Owner Organization.
This table is divided into three main vertical sections, one for each of the owner groups. The items listed in this chart are areas in which competitive advantage might be gained by organizations demonstrating superior competence. Note that all three owner groups show plant reliability as a high importance, low satisfaction item.

3) Defining Summary Indices For Facility Quality Assessment

Indices are used extensively in the social sciences to provide convenient, powerful, and reliable summaries of measured data. The Cost-of-Living Index and the Dow-Jones Index are examples of well-known indices.

The development of summary indices that incorporate the most relevant information regarding facility quality will allow managers to compare varied, complex facilities on a simple, straightforward basis. In addition, these summary indices could be used as dependent variables to assess the impact of various facility development strategies on the outcome of the product.

We have developed two such indices based on the data gathered in this study. The first is a simple additive index, in which we sum each individual's standardized scores of six facility characteristics ranked as among the twelve most important, on average, by all the respondents. The formula for the Additive Satisfaction Index is:

Additive Satisfaction Index

$$QA_k = S_{kSafety} + S_{kReliab} + S_{kCatastr} + S_{kDCS} + S_{kTraining} + S_{kProduct}$$

Where:
QA is the kth individual's additive satisfaction index score
S is the kth individual's standardized satisfaction rating for the indicated item

The Cronbach's alpha statistic indicates the level of random noise or error in the data comprising an index. It is calculated based on inter-correlations between the items. The statistic ranges between O and 1, and larger numbers indicate less error. Cronbach's alpha for the Additive Satisfaction Index is 0.77, which indicates that this is a reliable, interpretable index [Cronbach, 1951].

The second index uses a weighted sum of an individual's scores on all the facility characteristics as follows:

Weighted Sum Satisfaction Index

$$QW_k = \frac{\sum_{i=1}^{i=29} S_{ik} I_{ik}}{\sum_{i=1}^{i=29} I_{ik}}$$

Where:
QW is the the kth individual's weighted satisfaction index score
S is the kth individual's Satisfaction rating for item i
I is the kth individual's Importance rating for item i

Although this index has the advantage of incorporating all the semantic differential information provided by the respondent, multiplication of I and S has the drawback of creating a second order error term in QW. It is not possible to calculate the Cronbach's alpha statistic for the Weighted Sum Satisfaction Index because it cannot be decomposed into additive components.

4) Correlation of Objective Data with Summary Indices

[Dawes, 1985, pg. 540] recommends the validation of nonrepresentational measures by significant correlation with representational measures. In this study we collected "objective" representational data on percent availability, startup duration, and ratio of actual production to planned capacity. Percent availability is defined as hours of uptime/(uptime+unscheduled downtime) for the most recent year. Startup (SU) duration is defined as the period in days from mechanical completion to sustainable commercial production. Availability and startup duration appear to be industry dependent, as demonstrated by the test of mean difference for these measures by industry using ANOVA as presented in Table G.

The results in Table G indicate that percent availability and startup duration measures are not suitable for index validation because the data collected using these measures differ significantly between industries. For example, the average availability for power plants is 98.1% and the average for chemical plants is 86.9%. Because of the large difference between these means,

Group:	Availability mean	Availability Std. Dev.	SU Duration mean (days)	SU Duration Std. Dev. (days)
Chemical (n=4)	86.9%	03.2%	47.0	16.9
Power (n=5) (n=6)#	98.1%	02.3%	139.8	94.7
Pulp & Paper (n=3)	96.2%	03.9%	12.3	15.7

Comparison:	Availability[5] mean difference	SU Duration mean difference (days)
Chemical vs. Power	*-11.2%	*-92.8
Chemical vs. Pulp & Paper	*- 9.3%	34.7
Power vs. Pulp & Paper	- 1.9%	*127.5

n=5 for percent availability and n=6 for startup duration comparisons.
* indicates significant differences between industries at $p<.10$ for LSD statistic.

Table G. One Factor ANOVAs of Percent Availability and Startup (SU) Duration by Industry Type.
This table shows than neither Percent Availability nor Startup Duration are suitable measures for comparing facility quality across different types of facilities. Each of these two measures vary distinctively by industry type.
Ho: $\mu_1=\mu_2=\mu_3$. Availability is not related to industry type. Reject, $p<.002$, $F=16.03$
Ho: $\mu_1=\mu_2=\mu_3$. Duration is not related to industry type. Reject, $p<.05$, $F=4.28$

comparing the plants on the basis of availability would be like comparing apples to oranges. However, the third representational measure, the ratio of actual production to planned capacity, is not significantly related to industry type and so may be used for index validation.

In general terms the ratio of actual production to planned capacity may be thought of as measuring whether "the plant we bought is producing as much as we thought it could produce". To the extent that this concept is similar to the concept of quality as customer satisfaction with the 29 plant characteristics, we can expect the two indices to correlate with the this ratio. Obviously, however, there is much more to facility quality than the concept that the ratio attempts to represent. For example, crucial facility characteristics such as plant safety, operator training, and maintainability are unrelated to the ratio. In addition, using the ratio as a quality indicator could give misleading results because it does not account for planned extra capacity which could be a crucial component of a strategic business plan. Therefore, we can expect a significant modest correlation but not a high correlation between the ratio and the two indices.

This expectation is borne out by the correlation tests shown in Table H. The actual production figure was obtained from the operations manager of the facility. The planned capacity figure was obtained from the engineering project manager. There were three cases with missing values (leaving 17-3=14 cases)

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[5] Because availability is a proportion, a test for mean differences between proportions is more appropriate here than ANOVA. However, to avoid overburdoning the reader with too many different types of statistical tests, the more conservative ANOVA is presented.

and one outlier, a power plant, leaving 13 cases to analyze. The Additive Satisfaction Index and the Weighted Sum Satisfaction Index for the operations manager was used for each of the facilities.

Including Outlier	r	z_r	σ_{corr}	z	p	r^2
Additive Index vs. Actual/Planned (n=14)	.503	.553	.302	1.83	p < .05	.25
Weighted Sum Index vs. Actual/Planned (n=14)	.501	.551	.302	1.83	p < .05	.25

Excluding Outlier	r	z_r	σ_{corr}	z	p	r^2
Additive Index vs. Actual/Planned (n=13)	.488	.536	.316	1.68	p < .05	.24
Weighted Sum Index vs. Actual/Planned (n=13)	.325	.337	.316	1.07	p < .15 not sig.	.10

r = correlation coefficient.

z_r =unbiased correlation coefficient with
normal distribution =.5ln((1+r)/(1-r)) [Ostle, 1988, pg. 246]

σ_{corr} = standard deviation of correlation = $1/(n-3)^{.5}$

z = standardized score with normal distribution= z_r / σ_{corr}

p = probability of Type I error

r^2 = explained variance

Table H. Correlations Between Proposed Quality Indices and Ratio of Actual Production to Planned Capacity

In order to validate the proposed Additive Quality Index and Weighted Sum Quality Index, we correlate them against a representational measure, the ratio of actual to planned production. Because the indices and the ratio measure different, though related concepts, we expect only a moderate correlation coefficient (r).

Ho: The quality indices and the actual/planned ratio are uncorrelated.
Reject for 3 out of four cases at p<.10.

As expected, there is a significant modest correlation between the indices and the ratio of actual production to planned capacity. The r^2 values for the Additive Satisfaction Index indicate that about 25% of the variance in the index can be explained by the ratio variable.

Interestingly, both indices perform well when the outlier is included in the analysis, suggesting that the indices might be valid for a greater range of facility quality than was included in this study. However, because of the potential of outliers to inordinately influence results [Belsley, 1980], the conservative strategy is to eliminate the outlier. In this case the Weighted Sum Satisfaction Index is not significantly correlated with the ratio of actual production to planned capacity. (It is also possible that the hardware manufacturing plant could be considered an outlier because of its conceptual difference with the other plants with respect to their emphasis on chemical and physical processes rather than a manufacturing process.) These correlations are shown in Figure 5 and Figure 6 which respectively plot the Additive Satisfaction Index and the Weighted Sum Satisfaction Index against the ratio of actual production to planned capacity.

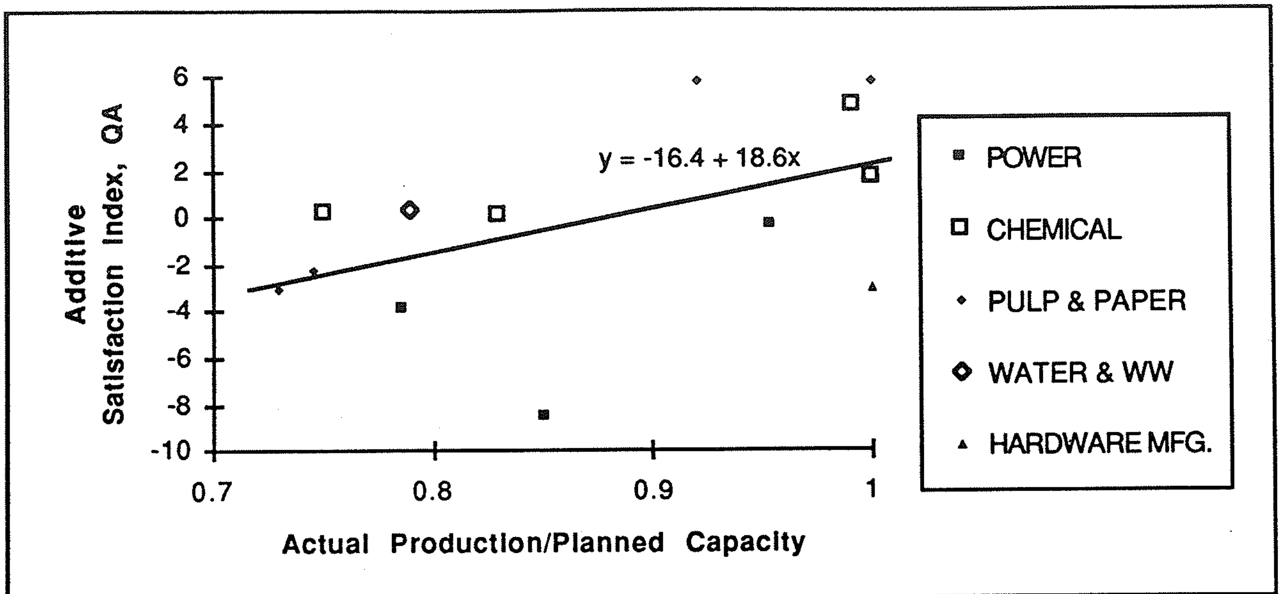


Figure 5. Regression of Additive Satisfaction Quality Index with Ratio of Actual Production to Planned Capacity Excluding outlier (13 cases). $r^2 = .24$

The plant manager provided the actual production information, and the engineering project manager provided the planned capacity. The Additive Satisfaction Index is comprised of the plant manager's standardized satisfaction scores for plant safety, reliability, ability to avoid catastrophic error, DCS, operator training, and meeting production output specifications.

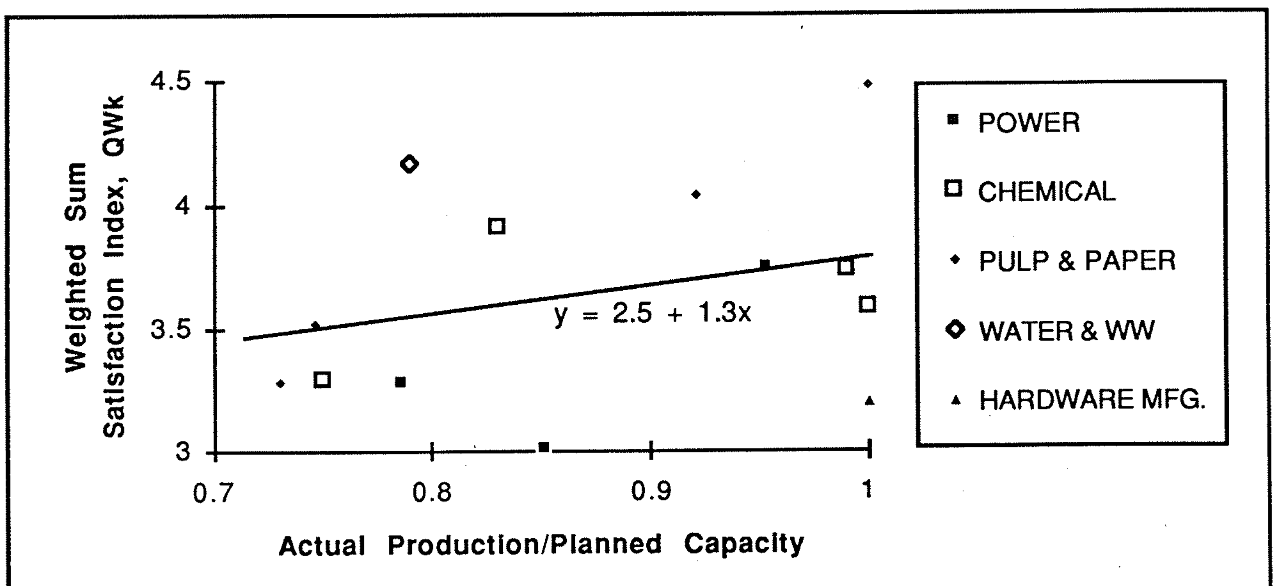


Figure 6. Regression of Weighted Satisfaction Quality Index with Ratio of Actual Production to Planned Capacity Excluding outlier (13 cases). $r^2 = .10$

As in the previous figure, the plant manager provided the actual production information, and the engineering project manager provided the planned capacity. The plant manager's Weighted Sum Quality Index is used in this graph.

The correlation of the summary quality indices with the ratio of actual production to planned capacity contributes to the validity of the indices. The indices can provide EPC professionals with useful information regarding industrial facility quality. In fact, we hypothesize that the indices tap much more of an individual's concept of industrial facility quality than the ratio measure because more aspects of facility quality are measured and combined.

CONCLUSIONS AND IMPLICATIONS

There are multiple viewpoints of industrial facility quality in owner organizations. Companies are broadening their operative definition of quality from requirement conformance to customer satisfaction. From a competitive standpoint, it is important to recognize who it is, exactly, that must be satisfied. This paper has demonstrated, from the perspective of evaluating facility quality, that there may be three or more types of customers in an owner organization, and that different types of customers have different priorities and levels of satisfaction with facility characteristics.

Project managers are more satisfied with the performance of the facilities they develop relative to others in their organization. Owner project managers have a much more optimistic view of the quality of facilities than people who work with these facilities on a day-to-day basis and are responsible for their profitability. However, project managers are typically the project participants that communicate the priorities and expectations of the owner organization to other project participants such as vendors and engineering and construction contractors. If the owner project manager does not have a clear understanding of the attitudes of the strategic and operations people towards completed facilities, then there is very little chance of producing a new facility that satisfies them in the long term, even if project-oriented objectives such as schedule, budget, and startup deadline are met.

Differences between the viewpoints highlight areas for improvement. Understanding the underlying causes of differences in attitude between the groups, such as those highlighted in Figure 4, may be an excellent way to pinpoint and resolve the conflicts in owner organization priorities that typically cause difficulties and change orders in project execution.

High importance and low satisfaction facility characteristics are opportunities for attaining competitive advantage. Facility characteristics which are consistently rated high in importance but low in satisfaction might be viewed as areas in which both owner and EPC firms could gain competitive advantage. EPC firms could differentiate their services on the basis of these items, and owners could likely improve their operations and profitability. Particularly, more in-depth equipment operation training programs and better equipment operations and maintenance manuals appear to be easily implementable goals. Improving plant reliability is another very important (though perhaps more difficult) goal. Even a fraction of a percentage point increase in process production could mean a welcome increase in profitability.

Improvements in assessing owner requirements, priorities, and expectations are needed in the facility development process. The observation that there are multiple viewpoints of quality in owner organizations has important implications for both EPC firms and the owners themselves. We hear over and over again from EPC firms about how poorly owner organizations communicate their priorities regarding new facilities. Owners complain about facility deficiencies after their completion. This study suggests that a very small investment in measuring and understanding these attitudes pro-actively could have tremendous payoffs. The payoff for EPC firms would be in achieving customer satisfaction and repeat business. The payoff for owner organizations would be the attainment of facilities that truly meet the expectations of *all* the stake holders in the owner organization, from maintenance personnel to the chief executive officer.

Attitude scales are a simple, easy-to-use measurement technique for assessing facility quality. This paper has demonstrated a rudimentary technique for measuring facility quality from the owner perspective. The method of using attitude scales we described is straightforward enough for owners and EPC firms to adapt to their own applications such as benchmarking for continuous process improvement. It is suitable for academic research because it allows the collection of meaningful data while potentially avoiding the necessity of gathering proprietary data.

The 29 facility characteristics presented approximate the concept of industrial facility quality. The 29 facility quality characteristics culled from industry professionals and the quality literature demonstrated an ability to uncover sensible, interesting and useful results. Write-in responses indicated that an "architectural image" item should be added as a facility characteristic in future studies. No other write-in item appeared more than once, which substantiates the validity of the 29 items as being representative. In a combined sense, they acceptably approximate the concept of facility quality for industrial process plants.

The ratio of actual production to planned capacity can be used to compare different types of facilities. We found only one "objective" representational measure, the ratio of actual production to planned capacity, to be appropriate for comparing facility performance. Other "objective" measures, while they may be appropriate for assessing facilities within single industries such as chemical manufacturing or power generation, cannot be used to compare the diverse collection of facility types represented in this study. The ratio measure, despite its inability to account for planned extra capacity, was useful in validating the summary indices of subjective, nonrepresentational measures.

Summary indices are a convenient basis for comparing industrial facilities as products of the EPC process. Owners could use these or modified indices to assess the quality of their own operating facilities. EPC firms could adapt the indices to assess their own performance in providing facilities that satisfy their range of customers in the owner organization, from the project management contacts they work with on a daily basis, to the division manager who will be responsible for the long-term profitability of the plant. Using the summary indices would allow both owners and EPC firms to track their improvement in producing quality facilities over the coming years.

FUTURE RESEARCH

In a forthcoming paper, we will relate factors in the facility development process used by the owner and EPC organization to the facility quality indices developed in this paper. This is an important topic to develop.

Further research is needed to improve on the measurement technique described in this paper. As an exploratory study, the goals of this research project were not to present a conclusive definition of facility quality or a perfected methodology, but rather to investigate ideas that may provide the basis for future, more thorough studies of quality, and from which we can start to refine our ideas on this important topic. Particularly, a better method of measuring importance, scales with finer granularity, more precise question wording, and a more balanced design are necessary. We wish to expand the detail of measurement of high importance, low satisfaction facility characteristics.

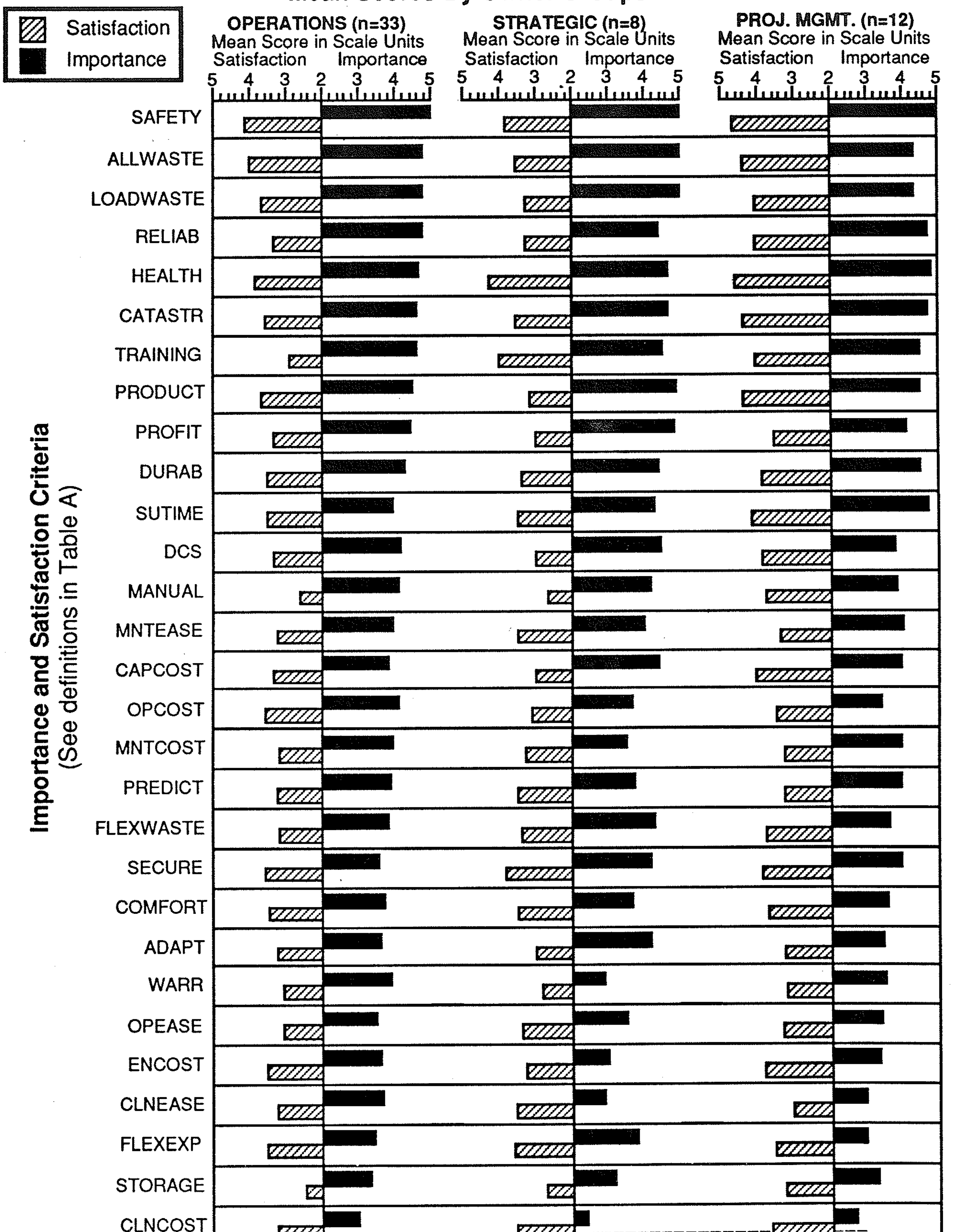
The distinctions between groups within the owner organization need further exploration. Of particular interest to industry may be a determination of the function(s) of the people within an owner organization who typically have the most say in choosing the contractor. These are the most important people to satisfy directly from a competitive standpoint. But certainly diffusion of opinion within the owner organization will influence these people as well.

Garvin identifies eight dimensions of product quality [Garvin, 1984]. With a larger sample of respondents from owner organizations, we should be able to use factor analysis and other statistical clustering techniques to determine whether industrial facilities fit Garvin's model.

The next step in this research program should be an in-depth longitudinal study of two plants, from the mechanical completion stage through the first few months of operation. This will enrich our understanding of pertinent quality and process variables, and enable us to refine the measurement techniques. In particular, additional objective measures will be explored.

In order to extend the applicability of this technique, future studies should attempt to sample the population of completed industrial facilities randomly for inclusion in the study. Although it is often difficult to obtain organizational access, this is not an unachievable goal. The payoff of generalizability of results would be well worth the effort.

APPENDIX A: SUMMARY OF FACILITY QUALITY RAW DATA
IMPORTANCE AND SATISFACTION CRITERIA IN THE OWNER ORGANIZATION
Mean Scores By Owner Groups



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Fluor Daniel, Inc.
General Electric
Gilroy Energy Company
HA Simons Ltd.
Howe Sound Pulp and Paper Company
ICF Kaiser Engineers
Mitsubishi
Owen Engineering and Project Management Consultants
Pacific Gas and Electric
Parsons & Whittemore
Rust Engineering Company and Rust International
Simons Eastern Consultants, Inc.
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Weyerhaeuser Paper Company
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