

Journal of

INDUSTRIAL TECHNOLOGY

Volume 22, Number 3 - July 2006 through September 2006

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Peer-Refereed Article

KEYWORD SEARCH

**Construction
Management
Manufacturing
Quality
Quality Control
Research**

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

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Introduction

This paper seeks to discover the current state-of-practice for quality initiatives in both the manufacturing and construction industries in the Midwestern United States. It provides a brief literature review of the current state-of-practice in both manufacturing and construction, and presents a statistical comparison of the two industries using a survey of manufacturing and construction companies.

When comparing manufacturing and construction, it is important not to overemphasize nor oversimplify their commonalities, as manufacturing is process dominated and construction is project dominated. However, there are similarities common to both industries. Two similarities and two differences in approach help distinguish the quality initiatives of these industries:

Similarities:

- Both industries exist to make products. Manufacturing tends to make the same product over and over, while construction makes a unique product, one at a time. This making of products provides opportunities for sharing experiences, research results, empirical evidence, etc., between these two industries.
- Both industries are part of the larger business community, seeking to survive, and striving to make a profit. Today, it is commonly accepted that profitability and survivability are driven by "cus-

tomers satisfaction." While not a new theme, to be sure, for either industry, "customer satisfaction" is now the dominant, most important consideration for setting company direction and assuring profitability in both industries. Readers should not be deceived by the perceived simplicity of the phrase, "customer satisfaction," because its contemporary definition encompasses the interests of all stakeholders: including but not limited to customers, clients, wholesalers, retailers, distributors, beneficiaries, internal and external users, and the general public. This definition of "customer" is a pervasive concept across our culture, embraced by both the manufacturing and construction communities.

Although other similarities could be identified, these are the two most important. The following sections present the distinctions between how the manufacturing and construction sectors approach quality management.

Differences

Quality in Manufacturing

Today, the quality function is a vital and well-developed discipline within most manufacturing organizations, having seen a great evolution over the last century, and continuing to improve today. Modern concepts of quality in manufacturing began with Frederick W. Taylor's introduction of "Scientific Management" principles in the late

1800's, which are still major factors in industry today. Later, statistical methods were developed and used by quality leaders, such as Shewhart, Deming, and Juran in the mid-1900's (Montgomery 2005). Deming's vision for quality took root and matured in post-World War II Japan, and later spread to the United States and around the world. The later half of the 1900's saw the spread of international quality standards and closed-loop quality systems, such as ISO, Six-Sigma, "5S," and Kaizen.

Today's modern manufacturing organization generally includes a sophisticated quality management system with components including statistical analysis, "design of experiments" methods using factorial analysis, gage repeatability and reproducibility, organized problem solving methods for individuals and teams, continuous improvement, and process and procedure documentation, just to name a few.

The development of a quality attitude and capability within both current employees and those planning to enter manufacturing is regarded as a high priority. Technology-based programs focused on manufacturing at colleges and universities often include significant study of quality control. Many institutions offer either a targeted option or a degree in quality. These areas of study usually relate to quality in the manufacturing environment, but are increasingly including other business sectors, such as the general business community and service industries.

Quality in Construction

Quality functions in construction are as diverse as the construction industry itself, which is commonly divided into residential, commercial, industrial, heavy, and highway. For most of the construction industry, quality requirements are established by several different stakeholders (owner, legal building requirements and codes, architect/engineer, international/national specifications, manufacturers, suppliers, etc.), but, the final arbiter is the owner (within legal bounds) who must balance

among the competing interests of a project's price, time, quality, and scope. However, the following paragraphs focus on quality management processes within the direct control of the constructor, not the owner, architect/engineer, supplier, materials' manufacturer, or code writer. Nonetheless, the constructors' quality initiatives may be, in part, dictated by the owner, as found in the contract (specifications).

Of the many inputs to the construction process, the constructor wields direct control over four distinct processes: work schedules, work procedures, equipment, and overhead operations; and indirect control over two distinct processes: materials and laborers (Aoieong, et al., 2002). Traditional monitoring techniques tend toward "hard" measures (cost and schedule), which are now used by most construction companies to evaluate performance on projects. Traditional techniques also include using formally trained and qualified skills (labor), following acceptance sampling, visual inspections, and testing processes.

Modern day quality initiatives in construction generally derive from the same sources credited with quality initiatives in manufacturing, Deming, Juran, etc. Therefore, TQM, ISO 9000, Baldrige, and Six-Sigma are found in the construction industry as well, receiving emphasis from such professional construction associations as the Partnership for Advancing Technology in Housing, the National Association of Home Builders, the Project Management Institute, the Construction Industry Institute, the American Society of Civil Engineers, and the Transportation Research Board, among others.

These professional construction associations recently concluded two major construction quality initiatives. Two important findings resulted:

- (1) Construction Industry Institute (1994b) found generally inadequate use of "soft" quality measures, such as customer satisfaction reviews, quality teams, quality planning, etc., in evaluating project success.

- (2) PATH (2003, pp. 6 & 7) characterized the quality management maturity of the construction industry, as follows:

- There is inconsistent application of quality standards in the industry.
- There are no complete and accepted quality performance standards.
- Customer expectations are different from constructor expectations.
- Inspections are inadequate for ensuring quality.

To summarize, the literature seems to indicate that quality in the construction industry is less mature than in the manufacturing industry. However, the literature does not contain a direct comparison of the two industries. To help explain these differences, quality initiatives in the manufacturing and construction curricula were explored.

Educational Differences

Colleges and universities typically include quality as an important topic in both manufacturing and construction curricula. In manufacturing technology programs, this subject is as well developed in the educational environment as it is in practice. Often manufacturing technology programs require one or two quality courses in their curriculum. The National Association of Industrial Technology (NAIT) includes Total Quality Management and Quality Control as two major topics that may be included in a NAIT accredited four-year degree (NAIT 2006). Course coverage often focuses on either statistical analysis methods or management of quality topics such as TQM, "5S," or Six Sigma. The topics and methods are well standardized and accepted as a major part of manufacturing technology programs.

Practical skills in quality are valued and often developed in manufacturing education by exposing students to realistic situations before they begin their careers (Kemenade & Garre, 2000). Interaction between industry and students is often accomplished through

class projects and internships involving real problems in industry. This helps students develop practical quality tools that will be valuable in a manufacturing career (Wheeler and Chambers 1992).

In construction, the importance of quality management education is well documented. According to the American Council for Construction Education (ACCE), the accrediting body for construction management educational programs, for ACCE-accredited four-year programs, quality should be a sub-topic covered under the broader topic of project management (ACCE 2006). The Construction Industry Institute (1994a) suggests four major topics for company-wide training of engineering and construction organizations: Executive Management Training, Quality Awareness Training, Quality Improvement Tools Training, and Team Skills Training. Jenkins (1999) suggests nine topics for the construction management classroom: (1) Why is Quality Control Important? (2) Submittal Data; (3) How to Check Incoming Materials; (4) Methods of Laying Out/Checking Work; (5) What to Look for When Inspecting Work; (6) Material and Equipment Compliance Tests; (7) When to Inspect Work; (8) Paperwork and Documentation; and (9) Quality Control Plans.

Although practical skills in quality are valued in the construction industry, many of the topics mentioned above are not taught in the typical construction classroom (Jenkins 1999). Most construction management programs relegate construction quality to a few weeks (or less) in a project or construction administration class, which typically includes little "real-world" problem solving.

Manufacturing and Construction Quality Comparison

Purpose of Study

The current state of the literature provides credible evidence that the construction industry lags behind the manufacturing industry's implementation of quality management systems.

Therefore, this study seeks to discover the current state-of-practice for quality initiatives in both the manufacturing and construction industry. Our hypothesis is that the manufacturing industry has a higher quality maturity than the construction industry.

Methodology

To test this supposition, the researchers created a 26-question, Web-based questionnaire. Manufacturers and contractors in the Midwestern United States were asked to complete the questionnaire. Following an initial email message to 230 manufacturers and contractors, and a follow-up telephone call, a total of 56 respondents completed the survey, 30 from manufacturing and 26 from construction.

The questionnaire laid out as follows: The first eight questions gather demographic information about the respondents and the respondents' companies, including information about the education of each respondent, the respondent's position in the company, and the type and size of the organization. The remaining questions (9 through 26) gather information related to the formal quality management system in the respondent's organization.

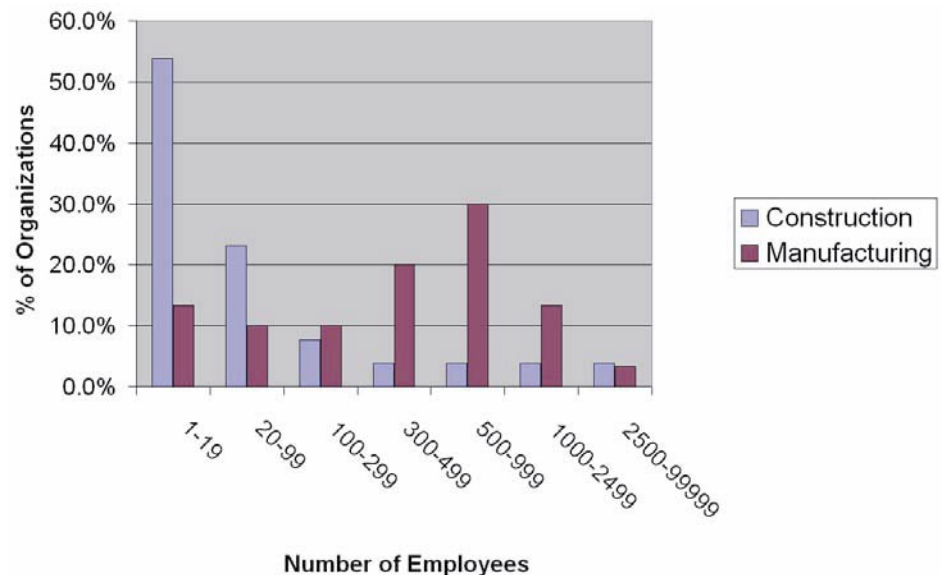
Findings of Comparison

Demographic Information

Of the 165 contractors originally contacted by email (addresses obtained from the Missouri Chapter of the Associated General Contractors), 26 responses were received for a response rate of 16%. The responding construction firms break down into 69% from the commercial sector, 18% from the residential sector, and 12% from heavy/highway. Of 65 manufacturing firms originally contacted by email (addresses were contained in an author-based professional network of Society of Manufacturing Engineers companies in and around Missouri), 30 responses were received for a response rate of 46%. The responding manufacturing firms break down into 63% who manufacture components, and the remaining who classify themselves as original equipment manufacturers.

Regarding relative size of organizations (Figure 1), 76% of construction participants have less than 100 employees, while 80% of manufacturing participants had over 300 employees. Ownership of these organizations also varied: Construction participants reporting 88% of these companies are privately-owned, 8% are publicly-owned corpo-

Figure 1. Size of Organizations



rations, and 4% were academic/educational institutions. Manufacturing participants, on the other hand, reported 50% of their companies are publicly-held corporations and 37% are privately-owned.

To further evaluate the organizational size differences, the statistical *t*-test was used to compare the mean of the size of manufacturing firms to the size of construction firms responding to the survey. The *t*-test uses the *t* statistic, given in the following equation, to test the difference between two-samples, in this case assuming unequal variance:

$$t = \frac{C_2 - C_1}{\sqrt{\frac{S_2^2}{m} + \frac{S_1^2}{n}}}, \text{ where}$$

- t* is the test statistic;
- C_2 is the observed mean value of the construction group;
- C_1 is the observed mean value of the manufacturing group;
- S_2 is the standard deviation of the construction group;
- m* is number of observations in the construction group;
- S_1 is the standard deviation of the manufacturing group; and
- n* is number of observations in the manufacturing group.

The *t*-statistic found a very high significant difference ($p = 5.6E -5 < 0.05$) between the sizes of the construction and manufacturing groups. This finding reveals a low statistical probability that the two means are from samples sharing the same mean value; in other words, the manufacturing and construction groups have statistically different size distributions.

The survey explored the educational background of participants from both construction and manufacturing. When asked to specify their highest level of formal training 27% of construction participants and 50% of manufacturing participants reported a four-year

bachelor's degree with either a technology or engineering focus. An additional 23% construction and 3% manufacturing reported a four-year bachelor's degree "other" than a technology or engineering focus. (This survey did not seek information on what specific type of degree was included in the "other" focus.) Additionally, the survey found that 23% of construction and 33% of manufacturing had pursued advanced degrees. Thus 74% from construction compared to 77% from manufacturing held no less than some type of four-year formal degree. However, there was a relative large difference in participants holding a two-year degree with a technology focus: 8% of construction participants compared to 23% manufacturing.

Participant years of service, to their respective industries, are shown in Figure 2. Of particular interest is the fact that 58% of construction participants and 63% of manufacturing reported experience of ten or more years. Using the *t*-test this time finds little significant difference between the two groups ($p = 0.33 > 0.05$); so here the two groups are likely to have equal years of service. Also note that in both groups, the number of years of service is lowest in the 5- to 15-year range, a fact that indicates that survey respondents are experienced individuals.

Analysis of Quality Initiative Responses

To evaluate the answers related to the quality initiative questions, the statistical *t*-test was used to compare responses from manufacturing firms to those from construction firms. Table 1 shows the results of the *t*-test. However, the *t* statistics in this table should be considered circumspect since the Shapiro-Wilk test for normality showed a low probability ($p < 0.05$) that many of the resulting answers were normally distributed (a requisite to using the *t*-test). So, a non-parametric rank-order analysis was also performed using the Kruskal-Wallis test, and is presented in Table 2, to further verify the validity of the *t*-statistic.

The Kruskal-Wallis test uses the "*H*" statistic as given below:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^I \frac{R_i^2}{n_i} - 3(N+1), \text{ where}$$

- H* is the test statistic;
- N* is the total number of observations;
- n_i is the number of observations in each group (manufacturing and construction);
- R_i is the rank sum in each group.

Figure 2. Participant Years of Service.

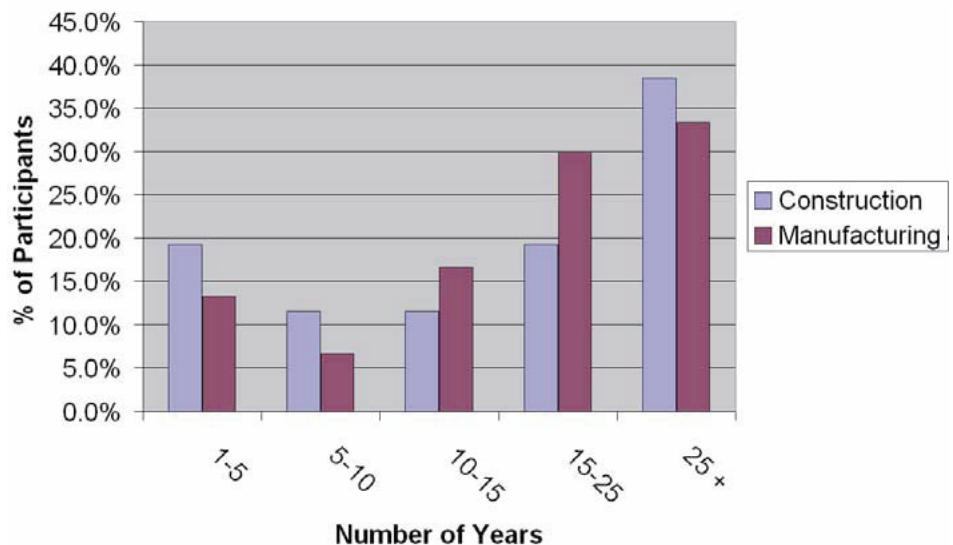


Table 2 shows that only question 19 (commitment to customer satisfaction) accepted under the *t*-test, should not be accepted per the Kruskal-Wallis Test.

The result for question 11 indicates that manufacturing personnel place much more emphasis on standardized quality management systems than do construction personnel. About 80% of manufacturing responses to question 11 were either "strongly agreed" or "agreed" (mean of 4.00), compared to only about 20% for construction (mean of 2.81); a statistically significant difference using both the *t*- and *H*-statistic at $p < 0.001$. This distinction is further highlighted in the results to question 12, where actual usage of internationally recognized standardized quality systems is examined: 65% of construction responses (mean of 0.37) indicated no current quality model is used versus only 7% of the manufacturers (mean of 2.64) indicated no quality model is in place (a statistically significant difference in both the *t*- and *H*-statistic at $p < 0.001$).

Most manufacturing responses indicate a structured quality system is used that includes self-audits and continuous improvement systems, such as ISO or Malcom Baldrige.

In question 22, respondents indicated that manufacturing organizations have well developed (mean of 3.79) applied statistical methods of quality control, as assumed, when compared to construction (mean of 3.12), a statistically significant difference using both the *t*- and *H*-statistic ($p < 0.05$). The results of question 24, indicates that manufacturing respondents (mean of 4.14) use actual metrics as feedback to process improvement more often than construction respondents (mean of 3.19), a statistically significant difference ($p < 0.01$).

The results (above) for Questions 11, 12, 22, and 24 seem to indicate that the construction industry (generally) has less standardized systems and documentation as compared to manu-

facturing. However, answers to other questions (below) do not support that conclusion. In fact, responses to several of the questions (below) indicate that many quality practices in construction and manufacturing companies are not different.

Questions 14 and 15, about long-range strategic planning and evaluating employee qualifications, respectively, seem to show that construction companies take a longer view on strategic planning and on evaluating employee qualifications than manufacturing companies. At first glance the means of 3.62 and 2.92 for construction and manufacturing, respectively, on question 14, and 3.77 and 2.92 for construction and manufacturing, respectively, on question 15, appear to be different. However, the *t*-statistic found no statistical significance in these values. In question 23, about frequency of data usage for discovery of opportunities, there was no significant difference in the *t*-statistic between construction

Table 1. Selected Results of Survey Using Parametric Procedures

Survey Question	Question	Mean ^a		Statistical Significance	<i>t</i> statistic ^c
11	In order to be effective a standardized quality management system is required.	4.00	2.81	$p < 0.001^b$	4.445
12	My organization uses internationally recognized quality system models.	2.64	0.37	$p < 0.001^b$	-5.103
14	My organization's long range strategic planning process looks into the future by this many years:	2.92	3.62	$p = 0.096$	-1.701
15	My organization takes steps to evaluate employee qualifications using certification, testing, etc.	3.69	3.77	$p = 0.760$	-0.307
16	My organization works with suppliers/subcontractors to identify and define quality assurance and conformance.	4.17	4.00	$p = 0.385$	0.876
18	My organization conducts customer perceptions studies/reviews to assess satisfaction.	3.90	3.46	$p = 0.164$	1.410
19	My organization's commitment to customer satisfaction.	2.86	3.46	$p = 0.031^b$	-2.222
21	My organization develops and adheres to written standard operating procedures for critical business processes.	2.56	2.73	$p = 0.030^b$	2.237
22	My organization gathers data & completes statistical analysis on critical processes or products.	3.79	3.12	$p = 0.030^*$	2.225
23	My organization's frequency of data review. (on a three-point Likert scale)	2.00	2.12	$p = 0.603$	-0.524
24	My organization uses actual metrics as feedback to process improvement.	4.14	3.19	$p = 0.003^b$	3.150
25	My organization uses a formalized, documented continuous improvement system.	3.79	3.19	$p = 0.056$	1.952

On a 5-point Likert scale, with 5 being the highest and 1 being the lowest.

^a Normality (skewness and kurtosis) was found to be within assumed limits.

^b Statistical significance at 5% or better ($< 5\%$) using analysis of variance techniques.

^c The *t*-statistic with one between group effect (manufacturing or construction).

(mean of 2.12) and manufacturing companies (mean of 2.00). Question 25, regarding documented continuous or formalized improvement strategy, found no statistical difference between construction responses (mean of 3.19) and manufacturing responses (mean of 3.79).

Questions 16 and 18, about organizational emphasis on an established customer satisfaction and supplier quality assurance, indicate that construction responses (mean of 4.00 for question 16, and 3.46 for question 18) are lower than manufacturing responses (mean of 4.17 for question 16, and 3.90 for question 18). Here again, though, these values are not statistically significant different using the *t*-statistic.

Finally, in question 19, addressing organization's commitment to customer satisfaction, a statistically significant difference between responses was found using the *t*-statistic ($p = 0.031$, manufacturing's mean of 2.86 versus construction's mean of 3.46). However,

as mentioned above, this is the only question where the Kruskal-Wallis *H*-statistic ($p = 0.058$) found that difference to be statistically insignificant.

Summary of Results

Overall the survey demonstrates a strong commitment by construction companies to strategic planning (question 14), employee qualifications, (question 15), and defining quality (question 16), with Likert scores all greater than 3.5. However, when asked about specific methods for gathering and analyzing data and using actual metrics for feedback (questions 11, 12, 22, and 24), construction companies indicate less emphasis in these areas with Likert scores < 3.2. These methods have been established as a primary means for developing and defining quality and planning techniques in manufacturing companies.

It is possible that construction companies place less importance on data analysis and metrics as a means for achieving quality and operations improve-

ments. There may be alternate methods for achieving high quality that are not well known outside the construction field. Further research is needed to determine whether other methods are being used to achieve these goals, and if so what specific techniques are being used.

Conclusions and Recommendations

The manufacturing industry has focused on developing and refining standardized quality and monitoring systems for several decades and that is supported by this survey's results. The results further indicate that manufacturing firms place more importance on these systems and actually use them far more than construction firms. This may be partially due to the number of smaller construction companies responding to this survey. Generally, smaller companies may not have the resources or willingness to develop and manage a standardized and formalized quality system. Both manufacturing and construction organizations place importance on customer

Table 2. Selected Statistical Results of Survey Using Nonparametric Procedures

Survey Question	Question	Mean Mfg.	Cons.	Statistical Significance	H-statistic ^b
11	In order to be effective a standardized quality management system is required.	4.00	2.81	$p < 0.001^a$	15.455
12	My organization uses internationally recognized quality system models.	2.64	0.37	$p < 0.001^a$	11.611
14	My organization's long range strategic planning process looks into the future by this many years:	2.92	3.62	$p = 0.427$	0.631
15	My organization takes steps to evaluate employee qualifications using certification, testing, etc.	3.69	3.77	$p = 0.770$	0.086
16	My organization works with suppliers/subcontractors to identify and define quality assurance and conformance.	4.17	4.00	$p = 0.517$	0.420
18	My organization conducts customer perceptions studies/reviews to assess satisfaction.	3.90	3.46	$p = 0.152$	2.051
19	My organization's commitment to customer satisfaction.	2.86	3.46	$p = 0.058$	3.596
21	My organization develops and adheres to written standard operating procedures for critical business processes.	2.56	2.73	$p = 0.022^a$	5.525
22	My organization gathers data & completes statistical analysis on critical processes or products.	3.79	3.12	$p = 0.024^*$	5.125
23	My organization's frequency of data review. (on a three-point Likert scale)	2.00	2.12	$p = 0.600$	0.276
24	My organization uses actual metrics as feedback to process improvement.	4.14	3.19	$p = 0.006^a$	7.459
25	My organization uses a formalized, documented continuous improvement system.	3.79	3.19	$p = 0.063$	3.445

On a 5-point Likert scale, with 5 being the highest and 1 being the lowest.

^a Statistical significance at 5% or better (< 5%) using chi-square distribution.

^b The H-statistic is assumed to be approximately distributed as Chi-squared with 1 degree of freedom.

satisfaction; however, the manufacturing firms tend to have a more clearly defined system in place to monitor customer perceptions.

Additional research is needed to determine what standardized quality systems are used in construction supplier/contractor selection and why this philosophy is not carried into other construction business and quality functions. Statistical analysis and metrics used in the construction industry would be of interest, as well. Compared to manufacturing, construction methods of statistical analysis and use of metrics are not commonly understood and should be examined through further research. Construction firms are using standardized quality systems and techniques in some areas and further research is needed to determine the need for and potential to further expand these methods throughout the organization.

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