Quantifying Levels of Wasted Time in Construction with Meta-Analysis

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Abstract: Quantifying the waste present in an operation is an important part of a number of performance improvement initiatives in the architecture engineering construction industry. Contemporary management approaches focus on waste minimization to reduce operating costs and to increase operating responsiveness and flexibility. In construction, studies have been conducted over the past 30 years as part of productivity-improvement efforts that have documented levels of wasted time in construction activities. This paper draws on the methodology of meta-analysis to provide a synthesis of the findings across all of these studies. The analysis reveals that an average of 49.6% of time in construction is devoted to wasteful activity, although this amount is widely varied. Among other things, these results demonstrate considerable potential for improvement in construction through initiatives that reduce levels of wasteful activity.

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Introduction

Wasteful activity interests those in the architecture engineering construction (AEC) industry who are concerned with improving operational performance. Wasteful activity absorbs resources without generating valuable product and purging waste from a process can improve levels of performance, enhance competitive advantage, and improve levels of profitability. Recently, interest in waste has heightened. Newly introduced management initiatives, like lean construction, focus on eliminating waste. Lean thinkers view a process as consisting of waste and value-adding (or conversion) components (Ohno 1988). Proponents of lean thinking argue that the reduction and elimination of waste rather than the enhancement of conversions ought to be the focus for improvement initiatives (Womack and Jones 1996). Important to the success of efforts to minimize waste is an understanding of the way waste is manifest in construction operations.

Waste has been studied in construction for some time. Past research has investigated the manner in which time is utilized by various construction operatives to provide an indication of the levels of wasteful activity in construction operations. These types of studies have been part of efforts to gage deficient practice and to improve productivity in construction for nearly 30 years. These studies provide an opportunity to better understand the levels of wasteful activity in construction.

This paper meta-analytically reviews the literature that has quantitatively reported levels of wasted time. Pooling the results of existing research provides a synthesized view of the quantitative character of waste. Despite the volume of existing research, there is little consensus of the typical levels of waste and the amount to which any of these levels vary in the presence of particular variables.

The body of literature indicates the disparate state of existing knowledge about the magnitude of wasted time. Meta-analysis provides a statistically rigorous means of drawing together the results of individual studies that have addressed a related set of research questions (Rosenthal 1991; Abelson 1995). A critique of meta-analysis is used to develop methods of data collection and data synthesis for this study.

This paper found that 49.6% of construction operative time is devoted to wasteful activity although this amount varies considerably. The results indicate considerable improvement potential in construction through waste reducing initiatives, such as those advocated by lean construction.

Background Review

Results from separate studies can be efficiently accumulated to generate a pooled average with meta-analysis. Quantitative levels of wasted time have been analyzed in an effort to improve productivity, yet there has been little assimilation of these findings. In this section, the body of productivity literature is assessed and the nature of meta-analysis is presented as an introduction to a detailed meta-analysis.

Productivity Analyses

Levels of wasted time have been investigated in productivity analyses with studies of time utilization and work sampling studies (Alarcón 1993). This information was designed to identify and expose areas where improvement could be made by ascertaining the proportions of time spent in nonproductive activity (i.e.,

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waste) (Oglesby et al. 1989). Despite extensive use being made of these types of studies, there has been little work to consolidate the findings, to pool the knowledge accumulated across these studies, or to identify longitudinal patterns through the results.

Early time utilization research tended to be concerned with demonstrating the efficacy of the technique (Peer and North 1971; Logcher and Collins 1978; Rogge and Tucker 1982; Baxendale 1987; Stevens 1987). By the time Oglesby et al. (1989) published their seminal text, *Productivity improvement in construction*, time utilization studies had become a prominent part of the armory of productivity analysts. Developing countries were also making use of time utilization studies (Olomolaiye et al. 1987; Parker et al. 1987). Liou and Borcherding (1986), Horner et al. (1987), Olomolaiye (1988, 1990), and Handa and Abdalla (1989) devoted their attention to exploring the links between time utilization levels and productivity levels with mixed conclusions. Time utilization studies were used to assess the effect of planning methods on productivity (Salim and Bernold 1994) and to demonstrate the relationship between safety and productivity (Alarcón and Ortíz 1995). Chan and Kumaraswamy (1995) explored the influence of productivity levels on project duration through time utilization studies. Finally, the infiltration of lean thinking into building project activity has rekindled the interest in time utilization studies (Serpell et al. 1995; Low and Chan 1997).

Thomas (1991) cast doubt on the value of using time utilization studies for productivity improvement when he suggested that the amount of time spent in direct work was unrelated to productivity. This work has been influential, but Thomas may have been a little hasty in the conclusions he drew from the study. This study was largely a revision of the results of past studies rather than a study on new data. The majority of the revised study highlighted weaknesses in previous studies that had indicated the existence of this relationship (Liou and Borcherding 1986; Handa and Abdalla 1989), and his own earlier study (Thomas et al. 1984). By questioning certain assumptions and adjusting for certain factors, Thomas diminished the significant correlations found in these studies and concluded no relationship was present. However, care is needed in interpreting the revised results. The reader must presume that the terms of the revised study now more accurately reflect reality than those of the previous studies. It is also important to remember that the failure to find a significant correlation does not conclusively mean that no relationship exists (Barnes 1994). It may well have been that other factors caused the failure to detect any significant relationship, such as chance or the possible presence of an intermediate variable (Grimm 1993). The way the studies (both previous and revised) were crafted, this possibility could not be discounted.

More recent work by Thomas and Napolitan (1995) and Thomas et al. (2003) better articulates the value of the analysis of the way time is utilized. These studies indicate the number of hours used inefficiently as part of the analysis of productivity. In these cases, time utilization is not used to substitute productivity analysis, but assists in understanding the sources of productivity problems (Thomas and Završki 1999).

There have been numerous studies in the literature concerning the levels of wasted time and the results of these studies provide a valuable indicator of wasteful practice in construction. A synthesis of these results is overdue. Such an analysis needs to be structured and replicable. Meta-analysis provides such a method.

Meta-Analyses

Meta-analysis provides a means for analyzing past time utilization level studies in order to glean a more comprehensive and coherent understanding of the quantitative character of time performance in construction.

Meta-analysis is "the analysis of analyses…the statistical analysis of a large collection of…results from individual studies for the purpose of integrating the findings" (Glass 1976, p. 3). It provides a critical and rigorous assessment that contrasts with the "casual, narrative discussions of research studies which [often] typify our attempts to make sense of the rapidly expanding research literature" (Glass 1976, p. 3). Meta-analysis offers a systematic means of integrating and accumulating the findings of individual studies to achieve an authoritative position regarding the issue under investigation (Hunt 1997, p. 8). It is used to discern trends, relationships, or average effect sizes where individual studies provide contradictory or insignificant findings. Gayle et al. (1994) used meta-analysis to educe, from a body of research that offered contrary evidence, the role that gender played in the adoption of conflict management strategies. Meta-analysis was used to ascertain a correlation between smoking and cancer across a series of studies that individually were unable to conclusively establish this link (Thomas 1998, p. 476). Meta-analysis now features in the fields of education, medicine, and management and in a growing scope of publications (Rosenthal 1991, p. 10; Hunt 1997, p. 13; Lyons 1998, p. 1).

Meta-analysis collects relevant statistics from individual studies and combines them to provide an average (Lyons 1998, p. 3). This average provides a more likely indication of the underlying population value than any individual study used to compose it, due to it being based on a much larger sized sample. The rigor of meta-analysis lies in the way statistics from studies are treated and the way the average is adjusted to improve its representativeness of the underlying population (Hedges and Olkin 1985, p. xv).

As with any research method, meta-analysis is not without its critics and detractors. Glass et al. (1981, p. 218) listed the four main challenges:

1. problems of comparing and aggregating studies that include different measuring techniques, definitions of variables, and subjects: that is, mixing "apples and oranges;"
2. uninterpretable results due to combining "poorly" designed studies with "good" studies;
3. bias in favor of significant findings as published research has a proclivity towards significant results: nonsignificant findings are rarely published; and
4. segmenting portions of a study to obtain multiple results gives the impression of greater reliability than really exists when the portions are treated as independent.The most effective means of tackling these concerns is to address them in the design and conduct of the investigation (Wolf 1986, p. 53). Consequently, variances between studies are assessed and moderator analysis is pursued where warranted, weightings are applied to individual studies to address varying quality, and the potential for bias in the findings is reviewed. These procedures form an integral part of the meta-analytic method used in this paper.

Method

The meta-analytic method adopted consists of search, coding, and statistical procedures to synthesize the findings of studies that have previously analyzed wasted time levels.

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Table 1. Basic Information on Studies

Reference	Author(s) of study	Year of publication	Publication status	Country where completed	Data gathering technique	Type of project(s) involved	Unit of analysis
A	Alarcón and Ortiz	1995	Report	Chile	Work sampling	Multistory cast in-place reinforced concrete	Nonspecific construction operations
B	Baxendale (p. 815)	1987	Conference proceedings	United Kingdom	Work sampling	Housing development; retail; factory	Multiple construction operations
C	Chan and Kumarasamy	1995	Journal	Hong Kong	Work sampling; continuous time lapse	Multistory cast in-place reinforced concrete	Tower cranes; concrete truckmixers
D	Chan and Kumarasamy	1995			Work sampling	Multistory cast in-place reinforced concrete	Formwork rigging; bar-bending; steel-fixing; concreting
—	Christian and Hachey	1995	Journal	United States	Multiple	Multistory cast in-place reinforced concrete	Concrete worker
E	Handa and Abdalla (p. 23)	1989	Journal	Canada	Work sampling	Medium density housing development	Framing operation—carpentry
F	Horner et al. (p. 678)	1987	Conference proceedings	United Kingdom	Direct measurement	Supermarkets; industrial; institutional; car park; office; health; water treatment	Concrete; steel reinforcement; formwork; brickwork activities
—	Lee et al. (p. 69)	1999	Conference proceedings	United States	Direct measurement	Hospital, university building	Steel erection
G	Liou and Borcherding (p. 94)	1986	Journal	United States	Work sampling	Nuclear power plant; fossil fuel power plant	Concreting
H	Logcher and Collins (p. 455)	1978	Journal	United States	Direct observation	Medium density buildings; new and renovated	Carpentry; tile laying activities
I	Low and Chan	1997	Book	Singapore	Direct observation	Multistory public housing apartments	Concreting activities
J	Low and Chan[a]	1997	Book	Singapore	Direct observation	Multistory condominium tower blocks	Insulation laying; bricklaying activities
K	Oglesby et al.	1989	Book	United States	Work sampling	Multiple project types	Multiple construction trades
L	Oglesby et al.	1989			Continuous time lapse	Multistory cast in-place reinforced concrete	Concreting crew
M	Olomolaiye et al. p. 319)	1987	Journal	Nigeria	Work sampling	Varied	Bricklaying, joinery; steel fixing activities
N	Olomolaiye (p. 8)	1990	Published report	United Kingdom	Work sampling	Varied	Bricklaying; joinery; steel fixing activities
O	Parker et al. (p. 842)	1987	Conference proceedings	Tanzania	Work sampling	Medium-density housing	Multiple construction trades
P	Peer and North	1971	Journal	Australia	Continuous time lapse	Multistory office building; institutional; supermarket; housing	Multiple construction operations
Q	Peer and North	1971				Multistory office building; institutional; supermarket; housing	Multiple types of equipment
R	Salim and Bernold (p. 733)	1994	Journal	United States	Work sampling	Mid-height multistory office building	Concrete reinforcement activities
S	Serpell et al. (p. 68)	1995	Conference proceedings	Chile	Work sampling	Multistory office; high density housing; commercial buildings	Multiple construction activities
T	Stevens (p. 707)	1987	Conference proceedings	United Kingdom	Work sampling	Medium and high density housing	Multiple construction operations
U	Rogge and Tucker (p. 595)	1982	Journal	United States	Work sampling	Nuclear power plant	Carpenters; electricians; ironworkers; pipefitters
V	Thomas	1991	Journal	United States	Work sampling	Nuclear power plant	Carpenters; electricians; pipefitters
W	Thomas	1991	Journal	United States	Work sampling	Nuclear power plant	Pipefitters
X	Thomas	1991	Journal	United States	Work sampling	Nuclear power plant	Nonspecific construction operations

[a]This study was subsequently published as a journal paper by Low and Tan (1998).

Search Procedures

An extensive search of construction and related literature was initiated by manual and computer searches. Each study was subjected to inclusion rules for aggregation. A study was included if: (1) it was an investigation that provided a statistical description of the data and (2) it reported enough information to enable aggregation of the statistical data.

The search procedures resulted in the location of 20 manuscripts with 26 relevant studies. Basic information regarding each study is found in Table 1. One other manuscript was identified but could not be obtained (Olomolaiye 1988). Of the studies acquired, two failed to provide sufficient statistical information to allow meta-analytic aggregation and hence were omitted (Christian and Hachey 1995; Lee et al.1999). The remaining 18 manuscripts with 24 separate studies were subjected to coding procedures.

Coding Procedures

Studies were coded using a definition of waste as "anything that is different from the minimum quantity of equipment, material, parts and labor time that is absolutely essential for production" (Alarcón 1995, p. 368). In some instances, this meant that some reclassification of the original studies' findings was needed. Some, like Oglesby et al. (1989), suggest the inclusion of 25% of essential contributory work as productive activity rather than unproductive (i.e., wasteful). Activity could be classified as effective, essential contributory, or ineffective work. The studies included in this review have adopted this classification system, although to varying degrees of detail, and with varying terminology. By the standard set above, both and all of essential contributory and ineffective work are wasteful, as neither add directly to the value of the product. Fortunately, sufficient detail was provided in the original studies to enable reclassification for consistency.

Where only effective time (or other terms used to refer to this category) was provided, then waste was calculated as 100% less that amount. Where effective time, contributory, and ineffective categories were provided, waste was calculated as the sum of the latter two. Where a more detailed categorization was provided, coding was completed to ensure the findings complied with the above definition.

Statistical Procedures

Descriptive statistics were collected from the various studies for inclusion in the meta-analysis and pooled using aggregation procedures. The aggregation procedures used are outlined in this section. The descriptive statistics collected provide estimates of the statistical nature of the variables of interest. Central tendency characteristics are conveyed by the arithmetic mean. The range, variance, and standard deviation provide indicators of the dispersion of the study results. The coefficient of skewness provides a measure of the symmetry of the frequency distribution of scores. Normally distributed frequencies have a coefficient of skewness of zero (Grimm 1993, p. 43). The sample population size and standard error provide an indication of levels of confidence in the accuracy of the studies and accordingly were used in the weighting procedures where appropriate.

The homogeneity of the results across the studies is evaluated by assessing the variances between the studies' means (Lyons 1998, p. 10). The chi-square test assesses the systematicity of the variation across the studies. The value obtained with the following equation is compared to a critical value [with degrees of freedom (df), of K-1 and alpha, (α) of 0.05] to determine whether the variances were significant:

$$\chi^2_w = \sum_i^K \frac{w_i}{\sum w_i}(\overline{x_i} - \overline{x_w})^2 \tag{1}$$

where χ^2_w=weighted chi-square test; K=number of included studies; w_i=weighting factor of the ith study, which is calculate by dividing the sample size (n_i) by the sample variance (s^2_i); $\overline{x_i}$ =mean of the ith sample; and $\overline{x_w}$=weighted pooled mean. The results of this test determine the adjustments made to the weighting procedures in the aggregation routines, how the pooled standard error statistic is computed, and directs the search for moderator variables.

Where there was systematic difference across the studies, as indicated by a significant chi-square result, the amount of this difference was estimated with the following equation. Frequently, these differences are a consequence of random effects. This is especially so in sampled data. Random effects relate to the presence of actions that bear little or no relationship to the subject of interest but which obscure detection of its true value (DerSimonian and Laird 1986). Taking into account random effects is a more conservative approach to estimating true underlying values than the commonly used fixed effects model. However, this approach has been demonstrated to yield superior estimates of true values (Sheehan and Gordon 1998)

$$\tau^2 = \max\left(0, \frac{\chi^2_w - (K-1)}{\sum w_i - \sum w_i^2 \Big/ \sum w_i}\right) \tag{2}$$

where τ^2=estimate of the size of the random effects; χ^2_w =weighted chi-square test; K=number of studies in the meta-analysis; and w_i=weighting factor of the ith sample, calculated as before.

Adjustment was then made for the estimated amount of the random effects through modification of the weighting factor with the following equation. The modified weighting factor was utilized in the subsequent equations where weighting was required

$$w_i \text{ is replaced with} \left(\frac{1}{w_i} + \tau^2\right)^{-1} \tag{3}$$

Overall averages were computed for each category of descriptive statistics to formulate the aggregated statistics. Both unweighted and weighted figures were reported for all statistics to enable comparison. Unweighted statistics were computed by averaging the respective statistic across the studies that provided them. Weighted statistics were computed with the following equations.

The weighted pooled mean was computed with the following equation:

$$\overline{x_{p_w}} = \frac{\sum (w_i \overline{x_i})}{\sum w_i} \tag{4}$$

where $\overline{x_{p_w}}$=weighted pooled mean; w_i=weighting factor of the ith sample; and $\overline{x_i}$=mean of the ith sample.

The weighted pooled standard deviation was computed with the following equation. Variance is (usually) the most amenable measure of dispersion to adjust for weighting. Subsequently, the variance reported in each study is used to compute the weighted pooled standard deviation, rather than the standard deviations

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$$s_{p_w} = \sqrt{\frac{\sum (n_i - 1)s^2 i}{\sum n_i - K}} \tag{5}$$

where s_{p_w}=weighted pooled standard deviation; n_i=number of subjects in the ith sample; $s^2{}_i$=variance of the ith sample; and K=number of studies in the meta-analysis.

The weighted pooled variance was computed by calculating the square of the weighted pooled standard deviation

$$s^2{}_{p_w} = (s_{p_w})^2 \tag{6}$$

where $s^2{}_{p_w}$=weighted pooled variance; and s_{p_w}=weighted pooled standard deviation.

The computation for the weighted pooled standard error of the mean is determined by whether the chi-square tested revealed a significant level of homogeneity across the studies or not. Where the test revealed an insignificant degree of variance, that is, insignificant variances, then the first equation is employed to aggregate the weighted pooled standard error of the mean, otherwise the second equation is used as follows:

$$s_{\bar{x}_{p_w}} = \frac{s_{p_w}}{\sqrt{K-2}} \tag{7a}$$

where $s_{\bar{x}_{p_w}}$ =weighted pooled standard error of the mean; s_{p_w} =weighted pooled standard deviation; and K=number of studies in the meta-analysis

$$s_{\bar{x}_{p_w}} = \frac{\sum n_i s_i}{\sum n_i \sqrt{K-2}} \tag{7b}$$

where $s_{\bar{x}_{p_w}}$ =weighted pooled standard error of the mean; n_i =number of subjects in the ith sample; s_i=standard deviation of the ith sample; and K=number of studies in the meta-analysis.

The weighted pooled coefficient of skewness was computed with the following equation;

$$\text{skew}_{p_w} = \frac{\sum (w_i \text{skew}_i)}{\sum w_i} \tag{8}$$

where skew_{p_w}=weighted pooled coefficient of skewness; w_i =weighting factor of the ith sample; and skew_i=coefficient of skewness for the ith sample.

The studies are analyzed for moderator variables when the chi-square test indicated significant variability across the studies. The analysis for moderator variables is performed to determine whether any factors were associated with variations in the size of the means (Wolf 1986, p. 34). The indication of insignificant levels of variability through the chi-square test presents a strong cause to conclude that no moderator variable is present in the data (Gayle et al. 1994, p. 15; Lyons 1998, p. 10). The detection of moderator variables can explain certain or varied levels of the subject matter.

Concerns that were frequently cited in the literature as being potentially problematic were used to guide the search for moderator variables. Coded in the studies to enable analysis was the country in which the study was conducted, the date of the study, the publication status, the data gathering technique, the type of building constructed, and the type of construction operative involved in the analysis.

All studies containing a particular variable were grouped and tested against the remainder of the population. A t-test, tested to a 95% confidence level, was used to discern whether there was a significant difference between the mean of the group containing the variable and that of the remainder of the population.

Bias in favor of significant findings was examined through the completion of fail-safe N computations with the following equation (Wolf 1986, p. 36):

$$N_{\text{fs}} = \frac{N(\bar{x} - \bar{x}_{\text{cri}})}{\bar{x}_{\text{cri}}} \tag{9}$$

where N_{fs}=number of additional studies; N=number of studies in the meta-analysis; $\bar{x}$=mean of the synthesized studies; and $\bar{x}_{\text{cri}}$ =criterion value selected that $\bar{x}$ would equal when the number N_{fs} were added to the meta-analysis. These computations provide a measure of robustness against claims of bias in favor of significant findings. They do so by calculating the number of additional studies possessing insignificant findings that are needed to diminish the magnitude of the mean found in the meta-analysis. Statements can then be made about the robustness of the found results. An insignificant finding for the purpose of the fail-safe N computations is a study that found no wasted time. The fail-safe N computations were completed on this basis.

Results

Overall findings revealed that the proportion of available time used in wasteful activity was 49.6% at a standard deviation of 11.9%. The summary of the descriptive statistics for each study is reported in Table 2. The pooled statistics, both weighted and unweighted, are presented in Table 3.

Significant Variances between Studies

The results of the chi-square test used to determine how to handle the variances between studies suggested significant levels of variance across the studies' means ($\chi^2=219.017, \text{df}=23, p<0.05$). Fig. 1 reports these results. Consequently, Equation (7b) was used to compute the standard error of the mean for wasted time reported in Table 3.

The significant chi-square result also affected the weighting used in pooling the studies. An estimate of the size of the random effects was calculated ($\tau^2=13.757$) and used to modify the weighting applied to individual statistics. Where weighting was used in the aggregating statistics to generate the results in Table 3, this modified weighting was employed.

Moderator Variables

Analysis for the presence of moderator variables was also pursued due to the significant chi-square result. Some significant differences in the tests for moderator variables were detected. The results of tests for moderator variables are recorded in Table 4. All tests were performed at the 95% significance level ($p<0.05$). Although groups of moderator variables were identified, as detailed below, this investigation did not seem to demonstrate consistent and definitive associations between any of the studied moderators and particular levels of waste.

The first of the moderator variable tests indicated a statistically significant difference in the pooled mean of studies from before 1990 to the pooled mean of studies from 1990 and after. Statistically significant differences were observed between studies published in conference proceedings and those published elsewhere.

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Table 2. Collation of Summary Statistics

Reference	Author(s) of study	Sample size[a]	Mean[b]	Range	Variance	Standard deviation	Standard error	Skewness
A	Alarcón and Ortiz (1995)	22	54.5	47.5–61.4	16.11	4.0	0.9	−0.02
B	Baxendale (1978)	20	49.0	29.0–63.0	72.25[c]	8.5[c]	2.0[c]	—
C	Chan and Kumarasamy (1995)	4	38.4	37.7–39.6	0.96	1.0	0.6	0.56
D	Chan and Kumarasamy (1995)	4	75.6	59.5–89.0	181.94	13.5	7.8	−0.36
E	Handa and Abdalla (1989)	18	33.6	26.7–39.5	15.47	3.9	1.0	0.03
F	Horner et al. (1987)	14	21.6	13.9–28.6	25.88	5.1	1.4	−0.28
G	Liou and Borcherding (1986)	45	67.0	46.5–82.0	59.44	7.7	1.2	—
H	Logcher and Collins (1978)	5	53.8	47.0–60.0	27.20	5.2	2.6	−0.04
I	Low and Chan (1997)	14	19.8	8.0–36.2	88.77	9.4	2.6	0.33
J	Low and Chan (1997)	18	59.3	16.5–83.7	470.29	21.7	5.3	−0.71
K	Oglesby et al. (1989)	16	63.9	54.0–73.0	47.40	6.9	1.8	−0.10
L	Oglesby et al. (1989)	12	49.2	30.0–75.0	241.97	15.6	4.7	0.60
M	Olomolaiye et al. (1987)	21	49.9	23.0–79.0	228.33	15.1	3.4	0.30
N	Olomolaiye (1990)	103	44.4	20.0–93.1	201.64	14.2	1.4	−100
O	Parker et al. (1987)	10	39.4	5.0–81.1	401.52	20.0	6.7	0.19
P	Peer and North (1971)	27	38.7	1.6–92.2	619.63	24.9	4.9	0.60
Q	Peer and North (1971)	28	30.8	0.0–62.2	481.27	21.9	4.2	−0.13
R	Salim and Bernold (1994)	4	62.3	45.5–75.2	197.76	14.1	8.1	−0.49
S	Serpell et al. (1995)	17	52.6	45.0–65.0	18.39	4.3	1.1	1.32
T	Stevens (1987)	8	55.4	41.0–71.0	85.70	9.3	3.5	−0.04
U	Rogge and Tucker (1982)	30	40.4	25.5–57.5	58.70	7.7	1.4	0.26
V	Thomas (1991)	46	71.6	55.9–82.9	39.37	6.3	0.9	−0.54
W	Thomas (1991)	22	58.8	44.5–69.2	55.10	7.4	1.6	−0.39
X	Thomas (1991)	127	67.7	—	34.93	5.9	0.5	—

[a]Sample size refers to the number of data points provided by the study.

[b]Values (other than sample size) are the percentages of available time devoted to wasteful activity.

[c]Although values were not provided in the original studies, values were estimated on the basis of the range being approximately four times the standard deviation.

A statistically significant difference was also detected between studies published in journals and those published elsewhere. Statistically significant differences were found between the means of the studies performed in Australia and those performed elsewhere. Such differences were also found between studies conducted in each of Canada, Chile, Singapore, the United Kingdom, the United States, and the mean of those conducted elsewhere in each respective instance. Statistically significant differences were also detected between studies whose data were collected by work sampling and studies whose data were collected by direct observation. Studies based on nuclear power projects possessed statistically significant differences when compared to all other types of projects. Statistically significant differences were ascertained between studies emphasizing plant utilization and those emphasizing labor time usage.

Tests could not be conducted for building types other than that for nuclear power plant projects or the type of operation. These variables were not isolated in the original studies and insufficient detail was recorded to permit their isolation in this analysis.

Patterns in the study characteristics revealed by the analysis for moderator variables enabled studies to be grouped into broad categories. Three groups were identified: that of studies performed in developing countries, that of studies conducted on nuclear power plant projects, and that of those excluded from these two. Table 5 reveals these categories and the associated means and confidence intervals.

Quality and Bias in Pooled Values

The computation of standard error provided an indication of the quality of each study and the confidence to be placed in the results. When combined with a confidence level coefficient, an interval is computed to provide a measure of the level of confidence to be placed in the result (Grimm 1993, p. 220). None of the

Table 3. Summary of Pooled Statistics

Statistical property	Weighted pooled value	Unweighted pooled value	Number of data points (n)	Number of studies (K)
Mean	49.6	49.9	635	24
Range	1.6–93.1	1.6–93.1	508	23
Variance	141.53	152.92	635	24
Standard deviation	11.9	12.4	635	24
Standard error	2.2	2.7	635	24
Skewness	0.03	0.005	443	21

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$\chi^2_{obt} = 219.017$

$\chi^2_{crit} = \chi^2(23)_{.05} = 35.172$

Since $\chi^2_{obt} > \chi^2_{crit}$ (219.017 > 35.172), it is concluded that there is a significant variance across the studies, $\chi^2 = 219.017$, $df = 23$, $p < .05$.

Fig. 1. Results of chi-square test performed to assess homogeneity of variance and to estimate size of random effects across studies

studies was omitted from the investigation, as all fell within tolerable limits for study quality. However, each study was weighted on the basis of sample size to ensure that the quality of the study did not unduly influence the results. A confidence interval for the wasted time studies of ±4.31 was calculated at the 95% level.

The results of the fail-safe *N* computations indicated the number of studies with insignificant results that need to be added to a sample to diminish the obtained result to a criterion level. These results are summarized in Table 6. In order to lower the aggregated mean from 49.6 to 34.7%, constituting a 30.0% change, ten studies, each with a mean of 0.0% wasted time, need to be added to the existing population of 24, representing a 41.7% change. In order to lower the aggregated mean to 24.8%, constituting a 50.0% change, 24 studies, each with a mean of 0.0% wasted time, need to be added to the existing population of 24, representing a 100.0% change. In order to lower the aggregated mean to 14.9%, constituting a 70.0% change, 56 studies, each with a mean of 0.0% wasted time, need to be added to the existing population of 24, representing a 233.3% change. These robust values are adequate to reject a claim of exaggeration.

Table 5. Confidence Intervals for Moderator Variable Groups

Group	Studies in group	Confidence interval at 95% level
Developing countries	A M O S	51.45±13.44
Nuclear power	G U V W X	61.47±7.46
Others	B C D E F H I J K L N P Q R T	43.29±7.54

Discussion

The investigation finding that the magnitude of wasted time in building projects is substantial at an average of 49.6%, although notably dispersed, is important. An earlier study by Horman and Kenley (1998) found slightly different results: a larger mean and narrower standard deviation. The results differed here due to the adoption of improved aggregation procedures. While the dispersion suggests that actual amounts vary, these remain, nonetheless, of considerable size despite the variety of situations and conditions over which they have been found.

The breadth of the aggregated range (1.6–93.1%) indicated widely dispersed data. This dispersal was also reflected in the standard deviation value of 11.9 (equating to a variance of 141.53). In a normal distribution, 99% of the data falls within ±2.5 s.d. (Naylor and Enticknap 1981, p. 55). This would equate to a range of 19.6–79.6, which, although narrower than the aggregated range, is still quite sizeable. The difference between the aggregated range and the standard range suggests that a number of data points were located in the extremities of the aggregated range. The dispersed nature of the data is also exhibited in a significant result for the chi-square test.

Table 4. Results from Tests for Moderator Variables (Using *t*-Test)

Variable	Category tested	Studies within category	Obtained *t* value ($t_{crit}=2.074, df=22, a=0.05$)	Difference between the means[a]
Date	Fulcrum at 1990[b]	B E F G H K L M O P Q T U	6.981	Significant
Publication status	Reports	A N	−0.022	Insignificant
	Conference	B F O S T	6.226	Significant
	Journals	C E G H M P Q R U V W X	−6.738	Significant
	Books	I J K L	1.426	Insignificant
Country	Australia	P Q	5.022	Significant
	Canada	E	16.213	Significant
	Chile	A S	−5.340	Significant
	Hong Kong (PRC)	C D	1.301	Insignificant
	Nigeria	M	−0.070	Insignificant
	Singapore	I J	5.678	Significant
	Tanzania	O	1.639	Insignificant
	United Kingdom	B F N T	8.884	Significant
	United States	G H K L R U V W X	−19.261	Significant
Data gathering technique	Sampling	A B D E G K M N O R S T U V W X	−10.290	Significant
	Direct	C F H I J L P Q	10.260	Significant
Building type	Nuclear projects	G U V W X	−17.676	Significant
Plant utilization versus labor time usage[c]		C Q	4.014	Signficant

[a]Tested at the 95% confidence level.

[b]Studies shown are those prior to 1990.

[c]Studies shown are those of plant utilization. Thus, all others relate to labor time usage.

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Table 6. Summary of *Fail-Safe N* Computations

Criterion value	% change from meta-analysis	N_{fs} (to nearest whole)	% change from meta-analysis
Mean=34.7	30.0	10	41.7
Mean=24.8	50.0	24	100.0
Mean=14.9	70.0	56	233.3

The data appear to be acceptably accurate in the context of characteristically dispersed data. The tolerable accuracy of the collected study statistics was already noted in the results. The confidence interval of 49.6±4.31% calculated at the 95% confidence level for the pooled data suggests soundness in the results. This interval denotes a bandwidth of 8.62% (45.3–53.9%) for the true mean with 95% confidence. This seems comparatively narrow in light of the dispersedness of the aggregated data (1.6–93.1%).

The aggregated coefficient of skewness, computed at 0.03, indicated that the data from the investigation are distributed (about the mean) symmetrically. Although a small positive skew was detected, this constituted a negligible amount in a context where skew ranging between ±0.50 can be treated as sufficiently symmetrical for most practical applications (Runyon and Haber 1991).

It is a notable finding in the meta-analysis that the population is almost symmetrical. The nature of, and other research into, construction time related properties, suggests the frequency of wasted time as positively skewed, that is, a greater number falling at a lower value than higher value. However, as AbouRizk and Halpin (1992) have also found, construction duration data respond and change due to many factors. Over small samples, it has been necessary to fit irregular Beta distributions to ensure an adequate fit for the modeled distribution function to overcome the problems presented by the irregularity of the data (AbouRizk et al. 1994). When considered over a large sample, it seems that peculiarities that skew frequencies balance themselves when it comes to wasted time. The findings of this meta-analysis present an alternative method to AbouRizk et al.'s approach, one that is admittedly loosely fitted, but which has the advantage of being founded on a large sample base.

The weighting processes ensured that the results of poor quality studies did not unduly influence the aggregated results. The impact of these processes was apparent when the weighted and unweighted values were compared, revealing that the latter were discernibly higher, albeit to a small extent.

The findings of the analysis of moderator variables suggested that the impact of factors that induce wasted time do so across varying situations and contexts, although patterns of behavior appeared to emerge. Even with differences detected in some of the moderator variables tested, the extent to which these influenced overall results remains unclear. Moreover, the definitiveness of their association with particular levels of waste requires further analysis.

One surprising result from the analysis for moderators was that studies completed in the US indicated significantly higher proportions of time wastage. However, further analysis reveals that this high figure may be associated more closely with the type of project, that of nuclear power projects, all of which came from the United States, than the country in which the study was completed.

The possibility of formulating three broad groups of moderators—developing countries, nuclear power projects, and others—suggested the presence of patterns in the moderator variables. This finding, although in need of care, was valuable because no patterns were apparent from the studies when treated individually.

The outcome of the investigation of moderator variables that projects are impacted by factors in a somewhat random fashion, lends some credence to the use of probability functions to emulate variable waste behavior in construction conditions. Analysis using techniques that approximate behavior in order to assess policy decisions on overall system performance is powerful yet rarely used in construction. One of the difficulties of using approximation techniques more widely for wasted time in construction has been a weak understanding of the quantitative character of its important elements. Some, like AbouRizk et al. (1994), Dawood (1998), and Kumaraswamy and Chan (1998), have utilized probability mechanisms to model variable phenomena. These approaches have been justified on grounds of intuition and with data from small samples. These can now be reinforced with empirical evidence from a much larger sample base with the results of this meta-analysis to provide much more convincing analysis and stronger results.

The fail-safe *N* computations demonstrated robustness against any potential claim of bias in favor of exaggerated findings.

The study of wasted time levels indicates two important aspects concerning the efficacy of the meta-analytic approach and the present state of construction management research. The first is that the rigor of past studies of wasted time is variable. In some cases, studies were poorly designed, in others, the results or statistics needed for comparison were not published. These deficiencies obstructed the meta-analytic review, but could not be avoided. Careful assessment permitted management of the influence that this variability exerts, but added greatly to the demands of the meta-analysis. The second is that construction management research is reaching a point where it needs to test existing models for replication, comparison, and validation to appraise what is currently known and to guide future efforts (Kenley 1998). In this context, meta-analysis exposes deficiencies in existing research practices and protocols and helps to develop rigor for future research.

The sizeable, yet dispersed, results of this study reflect the highly uncertain and complex nature of building projects and indicate how poor current initiatives are at managing the effects of these conditions. The size of the pooled waste level in construction activity indicates the potential for improvement through initiatives that minimize waste. As noted in the discussion of moderators, the quantitative character of this variable is supported by a large sample base that can be used to formulate simulation models. For instance, Horman (2000, p. 201) was able to use the results of this meta-analysis to model wasted time levels in order to assess possible performance improvements under waste minimization initiatives.

Conclusion

This meta-analysis of previous studies that have quantitatively reported the way time is utilized by construction operatives, provides an integrated measure of levels of wasteful activity in building projects. The disparity and incoherence among the sizeable number of existing studies was synthesized through the meta-analytic methodology.

The assimilated results indicate that building projects possess substantial, although widely varied, levels of waste. The review found that across a variety of circumstances and contexts, 49.6%

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of construction operative time was devoted to wasteful activity. The assimilated data varied considerably being characteristically dispersed (standard deviation 11.9%). Results covered a broad range of values (1.6–93.1%). The sizeable, yet dispersed, results reflect the highly uncertain and complex nature of building projects. They also indicate how poorly current initiatives are at managing the effects of these conditions.

The meta-analytical review of past studies to develop an assimilated view of waste in building projects makes an important contribution to research in this area. It confirmed that waste is substantial in building projects, although quite varied. It also provides a large empirical source of data to describe the quantitative characteristics of building project waste. This is valuable for further research initiatives such as simulation modeling, where this information can be utilized as input data. It indicates the potential performance improvements that are possible through waste minimization initiatives.

References

Abelson, R. P. (1995). *Statistics as principled argument*, Lawrence Erlbaum Associates, Hillsdale, N.J.

AbouRizk, S. M., and Halpin, D. W. (1992). "Statistical properties of construction duration data." *J. Constr. Eng. Manage.*, 118(3), 525–544.

AbouRizk, S. M., Halpin, D. W., and Wilson, J. R. (1994). "Fitting beta distributions based on sample data." *J. Constr. Eng. Manage.*, 120(2), 288–305.

Alarcón, L. F. (1993). "Modeling waste and performance in construction." *Proc., 1st Annual Conf. of the Int. Group for Lean Construction*, Espoo, Finland.

Alarcón, L. F. (1995). "Training field personnel to identify waste and improvement opportunities in construction." *Proc., 3rd Annual Conf. of the Int. Group for Lean Construction*, Albuquerque, N.M.

Alarcón, L. F., and Ortíz, R. (1995). "The relationship between productivity and safety in the construction site." *Research Rep.*, School of Engineering, Univ. Catolica de Chile, Santiago, Chile.

Barnes, J. W. (1994). *Statistical analysis for engineers and scientists*, McGraw–Hill, New York.

Baxendale, A. T. (1987). "Measuring site production by work sampling." *Proc., 5th CIB W65 Int. Symp. on the Organisation and Management of Construction: Managing Construction Worldwide*, Vol. 2, London, 812–822.

Chan, D. W. M., and Kumaraswamy, M. M. (1995). "A study of factors affecting construction durations in Hong Kong." *Constr. Manage. Econom.*, 13, 319–333.

Christian, J., and Hachey, D. (1995). "Effects of delay times on production rates in construction." *J. Constr. Eng. Manage.*, 121(1), 20–26.

Dawood, N. (1998). "Estimating project and activity duration: a risk management approach using network analysis." *Constr. Manage. Econom.*, 16, 41–48.

DerSimonian, R., and Laird, N. (1986). "Meta-analysis in clinical trials." *Control Clin. Trials*, 7, 177–188.

Gayle, B. M., Preiss, R. W., and Allen, M. (1994). "Gender Differences and the Use of Conflict Strategies." *Differences that make a difference: Examining the assumptions in gender research*, Turner, L. H., and Sterk, H. M., eds., Bergin & Garvey, Westport, Conn., 13–26.

Glass, G. (1976). "Primary, secondary and meta-analysis of research." *Educational researcher*, Vol. 5, American Educational Research Association, Washington, D.C., 351–379.

Glass, G. V., McGraw, B., and Smith, M. L. (1981). *Meta-analysis in social research*, Sage Publications, Beverly Hills, Calif.

Grimm, L. G. (1993). *Statistical applications for the behavioral sciences*, Wiley, New York.

Handa, V. K., and Abdalla, O. (1989). "Forecasting productivity by work sampling." *Constr. Manage. Econom.*, 7, 19–28.

Hedges, L. V., and Olkin, I. (1985). *Statistical methods for meta-analysis*, Academic, Orlando, Fla.

Horman, M. J. (2000). *Process dynamics: buffer management in building project operations*, PhD thesis, Univ. of Melbourne, Melbourne, Australia.

Horman, M., and Kenley, R. (1998). "Quantifying wasted time in construction." *Proc., Logistics Research Network Conf.*, Cranfield Univ., Cranfield, U.K., 429–441.

Horner, R. M. W., Talhouni, B. T., and Whitehead, R. C. (1987). "Measurement of factors affecting labour productivity on construction sites." *Proc., 5th CIB W65 Int. Symp. on the Organisation and Management of Construction: Managing Construction Worldwide*, Vol. 2, London, 669–680.

Hunt, M. (1997). *How science takes stock: The story of meta-analysis*, Russell Sage Foundation, New York.

Kenley, R. (1998). "The role of meta-analysis in construction management research." *Proc., 14th Annual ARCOM Conf.*, Vol. 1, Univ. of Reading, Reading, U.K., 31–38.

Kumaraswamy, M. M., and Chan, D. W. M. (1998). "Contributors to construction delays." *Constr. Manage. Econom.*, 16, 17–29.

Lee, S.-H., Diekmann, J. E., Songer, A. D., and Brown, H. (1999). "Identifying waste: applications of construction process analysis." *Proc., 7th Annual Conf. of the Int. Group for Lean Construction*, Univ. of California, Berkeley, Calif., 63–72.

Liou, F.-S., and Borcherding, J. D. (1986). "Work sampling can predict unit rate productivity." *J. Constr. Eng. Manage.*, 112(1), 90–103.

Logcher, R. D., and Collins, W. W. (1978). "Management impacts on labor productivity." *J. Constr. Div., Am. Soc. Civ. Eng.*, 104(4), 447–461.

Low, S. P., and Chan, Y. M. (1997). *Managing productivity in construction: JIT operations and measurement*, Ashgate, Aldershot, United Kingdom.

Low, S. P., and Tan, S. K. L. (1998). "How 'just-in-time' wastages can be quantified: case study of a private condominium project." *Constr. Manage. Econom.*, 16, 621–635.

Lyons, L. C. (1998). *Meta-analysis: Methods of accumulating results across research domains* 〈http://www1.monumental.cpm/solomon/MetaAnalysis.html/〉 (Nov. 10, 2000).

Naylor, G. F. K., and Enticknap, L. E. (1981). *Statistics simplified: An introduction for social scientists and others*, Harcourt Brace Jovanovich Group, Sydney, Australia.

Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). *Productivity improvement in construction*, McGraw–Hill, New York.

Ohno, T. (1988). *Toyota production system: Beyond large-scale production*, Productivity Press, Portland, Ore.

Olomolaiye, P. O. (1988). *An evaluation of bricklayers' motivation and productivity*, PhD thesis, Loughborough Univ. of Technology, Loughborough, United Kingdom.

Olomolaiye, P. O. (1990). "An evaluation of the relationships between bricklayers' motivation and productivity." *Constr. Manage. Econom.*, 8, 301–313.

Olomolaiye, P. O., Wahab, K. A., and Price, A. D. F. (1987). "Problems influencing craftsmen's productivity in Nigeria." *Build. Environ.*, 22(4), 317–323.

Parker, N. A., Lema, N. M., and Mlingwa, G. (1987). "An analysis of labour productivity in Tanzania." *Proc., 5th CIB W65 Int. Symp. on the Organisation and Management of Construction: Managing Construction Worldwide*, Vol. 2, London, 835–845.

Peer, S., and North, T. R. (1971). "Unproductive time in building operations." *Build. Forum*, 3(2), 39–48.

Rogge, D. F., and Tucker, R. L. (1982). "Foreman-delay surveys: work sampling and output." *J. Constr. Div., Am. Soc. Civ. Eng.*, 108(4), 592–604.

Rosenthal, R. (1991). *Meta-analytic procedures for social research*, Sage Publications, Newbury Park, Calif.

J. Constr. Eng. Manage., 2005, 131(1): 52-61

Runyon, R. P., and Haber, A. (1991). *Fundamentals of behavioral statistics*, 7th Ed., McGraw–Hill, New York.

Salim, M., and Bernold, L. E. (1994). "Effects of design-integrated process planning on productivity in rebar placement." *J. Constr. Eng. Manage.*, 120(4), 720–738.

Serpell, A., Venturi, A., and Contreras, J. (1995). "Characterization of waste in building construction projects." *Proc., 3rd Annual Conf. of the Int. Group for Lean Construction*, Albuquerque, N.M.

Sheehan, S. E., and Gordon, I. (1998). "A comparison of statistical methods for meta-analysis." *Tech. Rep. No. 2*, Statistical Consulting Centre, Univ. of Melbourne, Melbourne, Australia.

Stevens, A. J. (1987). "Housebuilding productivity in the UK—results of case studies." *Proc., 5th CIB W65 Int. Symp. on the Organisation and Management of Construction: Managing Construction Worldwide*, Vol. 2, London, 697–708.

Thomas, J. C. (1998). "Review of: Hunt, How science takes stock: The story of meta-analysis (Russell Sage Foundation, 1997)." *Pers. Psychol.*, 51(2), 476–479.

Thomas, H. R. (1991). "Labor productivity and work sampling: the bottom line." *J. Constr. Eng. Manage.*, 117(3), 423–444.

Thomas, H. R., Guevara, J. M., and Gustenhoven, C. T. (1984). "Improving productivity estimates by work sampling." *J. Constr. Eng. Manage.*, 110(2), 178–188.

Thomas, H. R., and Napolitan, C. L. (1995). "Quantitative effects of construction changes on labor productivity." *J. Constr. Eng. Manage.*, 121(3), 290–296.

Thomas, H. R., Horman, M. J., Minchin, R. E., Jr., and Chen, D. (2003). "Improving labor flow reliability for better productivity as a lean construction principle." *J. Constr. Eng. Manage.*, 129(3), 251–261.

Thomas, H. R., and Završki, I. (1999). "Theoretical model for international benchmarking of labor productivity." *Rep. No. 9913*, Pennsylvania Transportation Institute, University Park, Pa.

Wolf, F. M. (1986). *Meta-analysis: quantitative methods for research synthesis*, Sage Publications, Beverly Hills, Calif.

Womack, J. P., and Jones, D. T. (1996). *Lean thinking: Banish waste and create wealth in your corporation*, Simon & Schuster, New York.

J. Constr. Eng. Manage., 2005, 131(1): 52-61