

Benchmarking Productivity Indicators for Electrical/Mechanical Projects

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Abstract: Labor-intensive industries such as the electrical and mechanical trades are considered high risk due to the high percentage of labor costs. Because of this high risk, it is important for contractors in these industries to closely track labor costs on projects and compare these costs to industry benchmarks. In this paper, benchmark indicators for these industries are established on the basis of actual project data. These benchmarks include the relationship between the percent complete or percent time and cumulative work hours or cost, project size and duration, project size and average man power, project size and peak man power, and average versus peak man power. These relationships were developed using regression analysis. Man power loading charts and the related S-curves were developed from actual project data. The man power loading charts and the related S-curves are useful for resource planning and for tracking progress on a construction project. They can be used to show the cause-and-effect relationship between projects impacted by outside factors and normal labor productivity.

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Introduction

Electrical and mechanical constructions are considered high-risk industries due to low profit margins (3–4%) and a high labor component (40–60% of the electrical/mechanical cost) (Hanna et al. 1999a,b; Robert 2000). Due to the high cost of labor and low profit margins, labor cost control is a very important function for profitability in these industries.

To control labor costs on a project, some cost control measures must be established, and important parameters must be benchmarked for well-executed projects. Well-executed projects can be defined using quantitative measures such as project duration and peak man power, which are both functions of project size. The definition of well-executed projects encompasses both design and construction stages. Historic characteristics of well-executed projects can be used for benchmark indicators to predict problems in the early stage of current projects.

Literature Review

The National Electrical Contractors Association (NECA) report “Normal project duration in electrical construction” (NECA

1984) presents tools for estimating project duration based upon the work hours utilized (project size). Its described purpose is “to assist electrical contractors in estimating, project planning, project management, and cost control.” Relationships between project size and duration are presented in graphs and tables for seven different facility types. The seven types of facilities are these—office, commercial, school, hospital, government, institutional, and industrial buildings. The sample size for each of these varies from 14 to 52 projects. The main problem with this NECA document is that these data do not fit with recent construction, because the model was developed using early 1980s data. The current study presented in this paper indicates that contractors execute their work faster than is reflected in the NECA study.

Average and peak man power can be predicted based upon the project size as well. NECA’s “Electrical construction peak workforce report” (NECA 1987) uses 120 projects to predict the peak number of workers from the actual work hours for seven different types of electrical projects. The seven types of projects are these—office, school, commercial, institutional, government, hospitals, and industrial projects. Predicted, average, and peak man power are used later in this paper to define the following ratios: estimated peak to actual peak man power, estimated average to actual average man power, and peak to average man power.

Problem Statement and Definitions

The purpose of this paper is twofold. First, data are presented that will serve as a benchmark for both the electrical and the mechanical industries in the areas of man power loading, S-curve, project size, and project duration measures. Second, it is shown how the contractor can use these data to determine cost control criteria for a particular project. S-curves show the relationship between the percent complete or percent time and cumulative work hours or cost. An additional analysis was completed to investigate the relationships between project size and duration, project size and average man power, project size and peak man power, and aver-

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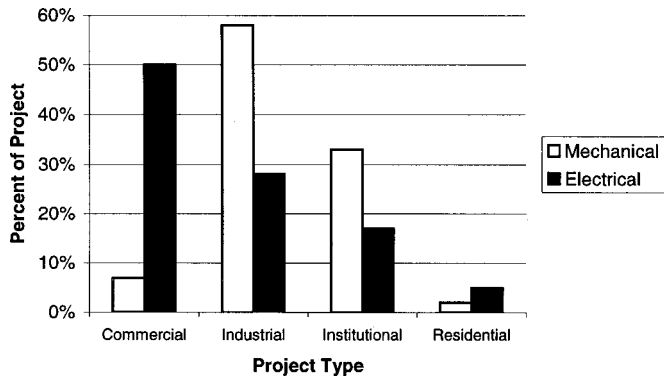


Fig. 1. Types of projects in data set

age man power and peak man power. These factors are components of the man power loading chart and are considered characteristics of well-executed projects.

Project Labor Hours versus Project Cost

Analysis of all projects' data was performed in terms of labor work hours. Labor work hours were used to define all benchmarking indicators, including man power loading, S-curve, project size, and average and peak labor hours. Using labor hours instead of cost allows one to combine projects from many different geographic locations into a single database. Classification in terms of labor hours eliminates biases that occur when data are classified in terms of cost, because of the use of different pay scales in different geographic locations. In addition, using labor hours instead of total cost is more appropriate because some projects contain a high material component that can add noise to the database.

Research Methodology

In this study, a data collection sheet was developed and distributed to numerous electrical and mechanical contractors through-

Table 1. Incremental Values Percent Complete for Industry and Research S-Curves

Percent time	NECA	Miller	Allen	Electrical	Mechanical
0	0.00	0.00	0.00	0.00	0.00
10	3.00	2.25	1.76	2.77	1.00
20	6.50	9.00	6.72	9.32	9.00
30	13.00	20.25	11.88	21.32	18.00
40	21.00	35.00	26.24	32.80	31.00
50	34.00	50.00	40.80	41.63	45.00
60	50.00	65.00	56.80	57.09	60.00
70	64.00	79.75	72.80	70.59	71.00
80	80.00	91.00	87.84	82.66	86.00
90	93.00	97.75	97.12	93.17	96.00
100	100.00	100.00	100.00	100.00	100.00

out the United States. The data collection sheet consisted of two sections—(1) company-specific data; and (2) project-specific data. Fifty-nine projects were reported on. Twenty-eight mechanical contractors responded, and 31 electrical contractors replied. When the questionnaires had been completed, projects were reviewed and telephone interviews were performed to verify the data submitted. The data collection sheet was intended to collect the following specific data:

- Contract budgeted labor hours at the notice to proceed for the electrical or mechanical part of the project. The term “contract budgeted labor hours” is defined as the total estimated labor hours that the contractor used to allocate labor resources. Labor hours include all field personnel and field supervision for the project;
- Daily or weekly labor consumption report;
- Actual project duration at completion in calendar weeks;
- Peak man power of electrical or mechanical workers used for the projects;
- Average number of electrical or mechanical workers used for the projects; and
- Project type (industrial, commercial, and so on).

Data Characteristics

A total of 59 project data were received from 28 mechanical projects and 31 electrical projects. Data were collected from con-

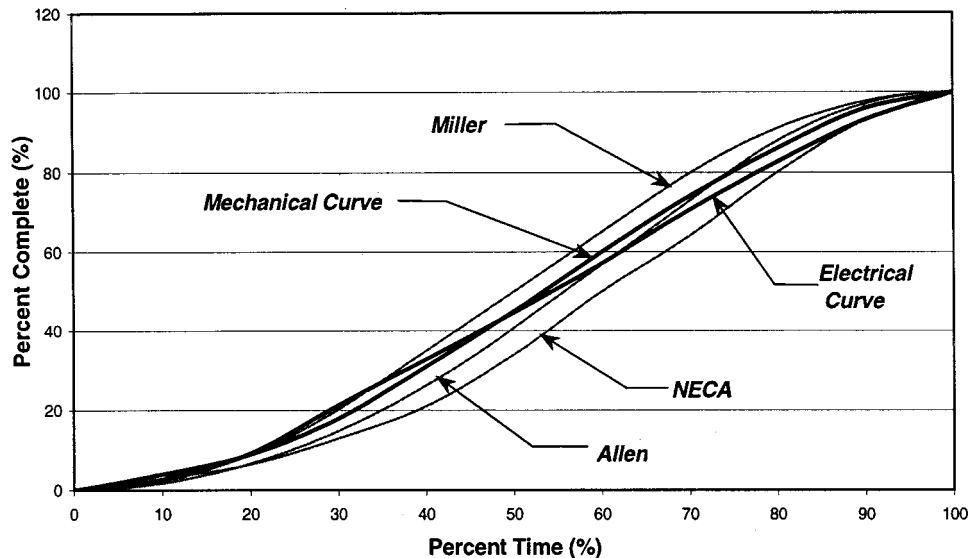


Fig. 2. Mechanical and electrical S-curves compared to those in existing literature

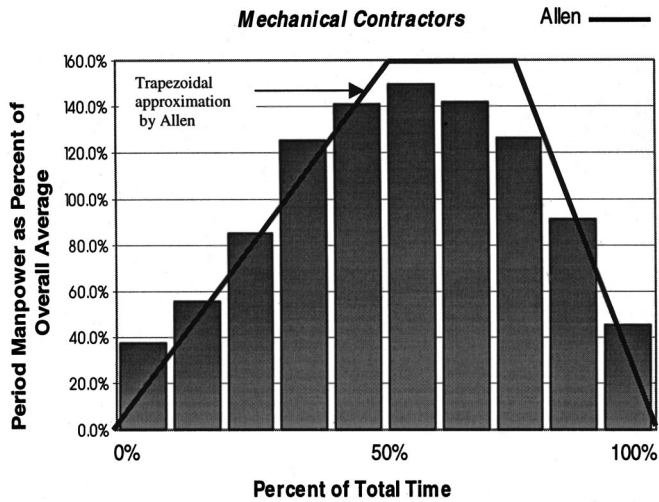


Fig. 3. Man power loading chart corresponding to average S-curve for mechanical projects

tractors in 19 states, with the majority from the Great Lakes region. The majority of the projects were smaller than 50,000 work hours (approximately 80%). There were no projects greater than 100,000 work hours. The research also was limited to projects of at least 2,000 work hours. The average mechanical project size was 32,200 work hours and the average electrical project size was 38,500 work hours. The types of projects are shown in Fig. 1. For the mechanical projects, industrial and institutional projects make up the largest portion of the data set. However, commercial projects comprise the largest portion of the electrical project data set.

Data Analysis

The data were analyzed by regression analysis, which quantified the relationships between project size and duration, project size and average man power, project size and peak man power, and peak man power and average man power. The regression analysis was performed using the statistical software package Minitab.

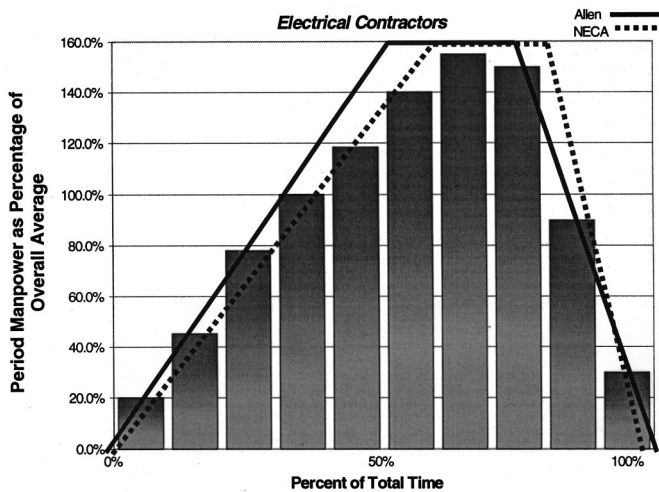


Fig. 4. Man power loading chart corresponding to average S-curve for electrical projects

Table 2. Comparison of Control Points in S-Curve Analysis

S-curves	Peak	50% Time	75% Time
Mechanical	150% of average	45% Labor	80% Labor
Electrical	155% of average	41% Labor	76% Labor
Allen	160% of average	40% Labor	80% Labor

Productivity Indicators and Characteristics of Well-Executed Projects

S-Curves

Fig. 2 shows the average S-curves for both mechanical and electrical projects. The average S-curves were developed by averaging the percent complete from the mechanical projects and the electrical projects at intervals of 10% time. A numeric representation of Fig. 2 is shown in Table 1.

As shown in Fig. 2, the average S-curves from the current research compare favorably to the S-curves developed from the NECA standard man power loading chart and the human-power loading proposed by Allen (Wideman 1994). In Fig. 2, the S-curve from the NECA study is approximately 7% behind the mechanical projects and the Allen curve. Wideman reported that this was due to the increased time required for start-up on electrical projects. However, this trend is not consistent with the electrical S-curve from the current research shown in Fig. 2. These cumulative resource-loading curves can be used to develop a loading chart for a new project or to compare planned and actual resource-loading curves on projects where a planned curve was never developed.

The man power loading curve is another means of representing the relationship between work hours and time or percent complete. Figs. 3 and 4 compare the man power loading charts from the current study to the resource-loading envelope developed by Allen (Wideman 1994). Fig. 4 also shows the NECA man power loading chart as a dotted line. The man power charts, reported by NECA, Allen, and this study, are similar; however, the peak from the current study is only 150% of the overall average labor for mechanical projects and 155% of the overall average labor for electrical projects. Table 2 shows a comparison of the control points established by Allen and the control points in the average S-curves from this research. The analysis presented later in this paper shows that the peak man power varies, depending upon the size of the project. The mechanical projects used to develop the S-curve and the man power charts in Figs. 2 and 3 have an average man power of 15 mechanical tradespersons; the median is 11 mechanical tradespersons. The electrical projects used to develop Figs. 2 and 4 have an average man power of 16 electrical tradespersons, and the median is 13 electrical tradespersons.

Rate of Man Power Consumption

Figs. 3 and 4 show important characteristics related to the rate of labor hour consumption. Well-executed electrical and mechanical projects consume approximately 40% of the total labor hours between 0 and 50% of their project duration. An additional 40% of

Table 3. Summary Statistics for Normal Project Duration Equations

Equation	Sample size	R ² (%)
Mechanical [Eq. (1)]	28	77.1
Electrical [Eq. (2)]	31	42.0

Table 4. Comparison of Research Data to NECA's Normal Project Duration (NECA 1984)

Project size (work hours)	Estimated project duration (weeks)				
	Mechanical		Electrical	NECA	
	ALL OTHERS	INDUSTRIAL	ALL PROJECTS	ALL PROJECTS	INDUSTRIAL
4,000	47	16	26	30	21
6,000	53	19	29	38	26
8,000	59	21	32	45	31
10,000	63	22	34	52	36
12,000	67	23	36	58	40
14,000	70	25	37	63	43
16,000	73	26	39	68	46
18,000	76	27	40	73	49
20,000	79	28	42	78	52
22,000	81	29	43	82	55
24,000	84	29	44	86	58
26,000	86	30	45	90	61
28,000	88	31	46	94	64
30,000	90	32	47	98	67
40,000	99	35	51	114	77
50,000	107	37	54	130	87
60,000	113	40	57	146	97
70,000	119	42	60	160	107
80,000	124	44	62	173	116
90,000	129	45	65	185	124
100,000	134	47	67	195	132

labor hours is consumed in the short period of time between 50 and 75% of the project duration. The final 25% of the project time consumes only 20% of the total labor hours. This rate of man power consumption indicates that project stakeholders should pay more attention to the project period between 50 and 70% of project completion.

Project Size and Duration

The prior NECA study was repeated for both the mechanical and the electrical industries on the basis of the 28 mechanical and 31 electrical projects. Mechanical data do not show a statistically significant difference between each project type. However, the

electrical data show two different groups. One is an “industrial” group and the other is an “all others” group. The industrial group includes industrial service facilities, manufacturing, the power plant, and wastewater treatment plant construction. The all others term includes commercial, institutional, and residential construction. Linear regression methods were used to create the models. The equations to estimate duration based upon project size (work hours) are as follows:

$$\begin{aligned} \text{Mechanical: } \log(\text{duration}) = & 0.491 + 0.327 \log(\text{project size}) \\ & - 0.454 \text{ industrial} \end{aligned} \quad (1)$$

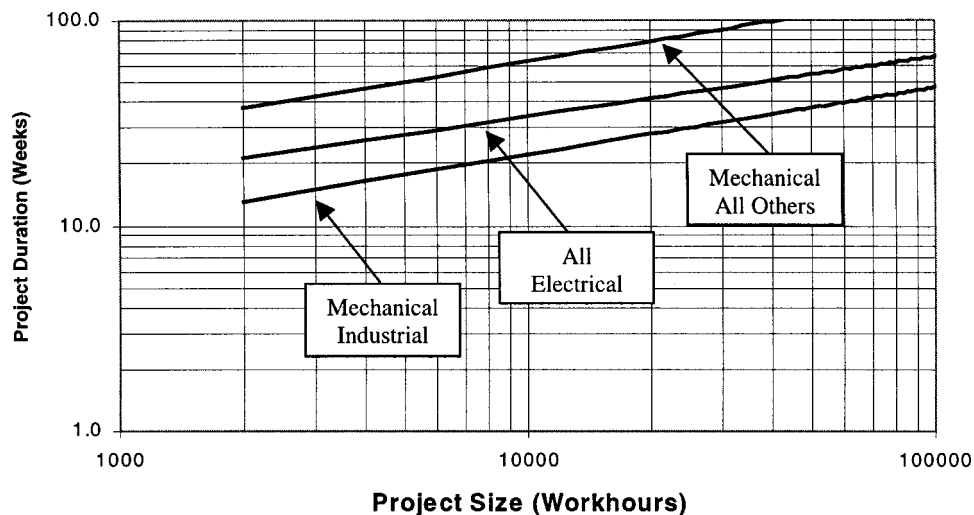


Fig. 5. Duration versus project size for mechanical and electrical projects

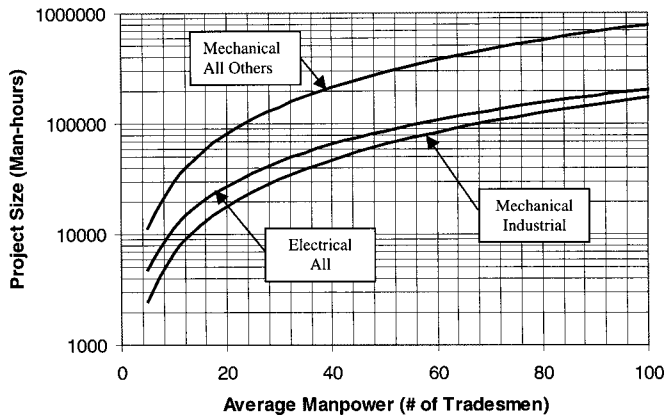


Fig. 6. Average number of tradespersons based upon project size

$$\text{Electrical: } \log(\text{duration}) = 0.359 + 0.293 \log(\text{project size}) \quad (2)$$

Log transformations were taken on “duration” and “project size” variables. The industrial variable in Eq. (1) is an indicator variable that takes the value of 1 for industrial projects and 0 for all other projects. The summary statistics are shown in Table 3. Fig. 5 shows a graphical representation of Eqs. (1) and (2). The project size is on the horizontal axis and the project duration is on the vertical axis. For example, on a mechanical project, a 10,000 work-hour job would take approximately 22 weeks for an industrial project and roughly 62 weeks for other project types.

The NECA study does not report the equation for the lines or the corresponding summary statistics. However, it is possible to compare the values in the tables from the electrical study. Table 4 shows the estimated duration based upon varying project sizes for both the mechanical and the electrical equations, and the prior NECA values for industrial projects and the overall average for all project types. The mechanical projects, other than industrial projects, are somewhere between the NECA average for all projects and the NECA industrial projects. Industrial-group projects in mechanical construction have much shorter project durations than the same size (work hours) of other types of projects. The electrical data (current study) also show lower values than prior NECA data. This is due to the changes in technology and other factors between 1983, when NECA reported its study, and 1998/1999, for the current study.

Average and Peak Man Power

The average and peak man power can be predicted based upon project size. NECA’s “Electrical construction peak workforce report” (NECA 1987) uses 120 projects to predict the peak number of workers. There is no study on the average man power.

Average Man Power

Fig. 6 shows the relationship between average man power and project size based upon Eqs. (3) and (4). The project size is in work hours. The industrial variable is 1 for industrial-group

Table 5. Summary of Statistics for Average Man Power Equations

Equation	Sample size	R ² (%)
Mechanical [Eq. (3)]	28	85.6
Electrical [Eq. (4)]	31	64.0

Table 6. Summary of Statistics for Peak Man Power Equations

Equation	Sample size	R ² (%)
Mechanical [Eq. (5)]	28	85.6
Electrical [Eq. (6)]	31	64.0

projects and 0 for all other project types. There was no statistically significant difference between the industrial type of projects and all other types of projects for electrical construction. The equations for the relationship between project size and average man power are as follows:

$$\begin{aligned} \text{Mechanical: } \log(\text{project size}) &= 3.07 + 1.41 \log(\text{average number of tradespersons}) \\ &\quad - 0.653 \text{ Industrial} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{Electrical: } \log(\text{project size}) &= 2.81 + 1.25 \log(\text{average number of tradespersons}) \end{aligned} \quad (4)$$

The summary statistics for the model [Eqs. (3) and (4)] are shown in Table 5. A 10,000 work-hour electrical project would have an average of nine workers. Similarly, a 10,000 work-hour mechanical project would have an average of 13 workers for an industrial-type project but five workers for other types (commercial, institutional, etc.) of projects.

Peak Man Power

The relationship between peak man power and project size was developed in the same manner as that between average man power and project size, as outlined in the previous section. Eqs. (5) and (6) are the models for the mechanical and electrical projects, respectively. The summary statistics for the models are shown in Table 6.

$$\begin{aligned} \text{Mechanical: } \log(\text{project size}) &= 2.75 + 1.27 * \log(\text{peak number of tradespersons}) \\ &\quad - 0.472 * \text{industrial} \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Electrical: } \log(\text{project size}) &= 2.40 + 1.31 * \log(\text{peak number of tradespersons}) \end{aligned} \quad (6)$$

Fig. 7 shows graphically the relationship between project size

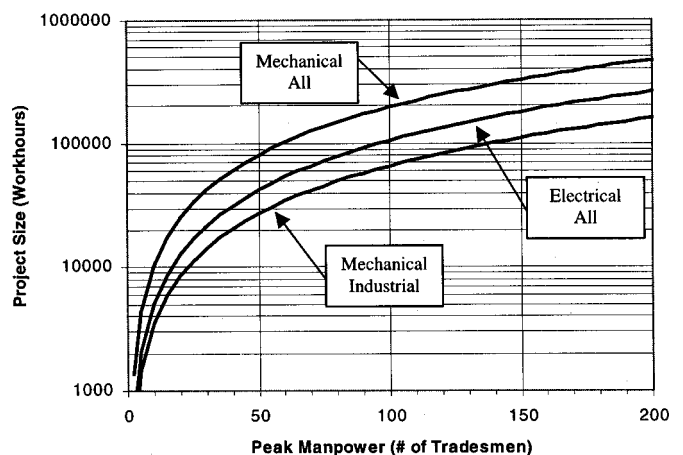


Fig. 7. Peak number of tradespersons based upon project size

Table 7. Comparison of Mechanical and Electrical Peak Number of Tradespersons to NECA's "Project Peak Workforce Report" (NECA 1987)

Project size (work hours)	Peak number of tradespersons				
	Mechanical		Electrical	NECA	
	ALL OTHERS	INDUSTRIAL	ALL PROJECTS	ALL PROJECTS	INDUSTRIAL
4,000	5	11	8	6	10
6,000	6	15	11	7	12
8,000	8	19	14	8	13
10,000	10	23	17	9	14
16,000	14	33	24	12	18
20,000	17	39	28	14	22
30,000	23	54	39	19	28
40,000	29	68	48	24	35
50,000	34	81	57	29	41
60,000	40	93	65	34	48
70,000	45	105	74	39	55
80,000	50	117	81	44	61
90,000	54	128	89	49	67
100,000	59	139	97	54	73

and peak man power. On a mechanical project, the peak number of workers on a 10,000 work-hour industrial-type project would be approximately 23, and on other projects of the same size, the peak number of workers would be 10. For an electrical project, a peak workforce of 17 would be expected on a 10,000 work-hour job.

The peak labor values from NECA's "Electrical construction peak workforce report" are similar to the peak labor values calculated for electrical projects presented in this paper. A comparison between the two is shown in Table 7. The mechanical-industrial projects have a much higher peak number of laborers than the electrical-industrial projects from the NECA report. The electrical model from the current study is closer to the data for the NECA-industrial projects.

Peak Man Power versus Average Man Power

A relationship also exists between the peak man power and the average man power. This is shown for both industries in Eqs. (7) and (8). The summary statistics for the models are shown in Table 8. The high R^2 values show that the relationship between peak and average man power is very strong. Fig. 8 graphically shows the models (equations) for the mechanical and electrical industries.

Mechanical: $\log(\text{peak number of tradespersons})$

$$= 0.292 + 1.07 * \log(\text{average number of tradespersons}) - 0.138 * \text{industrial} \quad (7)$$

Electrical: $\log(\text{peak number of tradespersons})$

$$= 0.313 + 0.958 * \log(\text{average number of tradespersons}) \quad (8)$$

Table 8. Summary of Statistics for Peak versus Average Man Power Equations

Equation	Sample size	R^2 (%)
Mechanical [Eq. (7)]	28	94.7
Electrical [Eq. (8)]	31	94.4

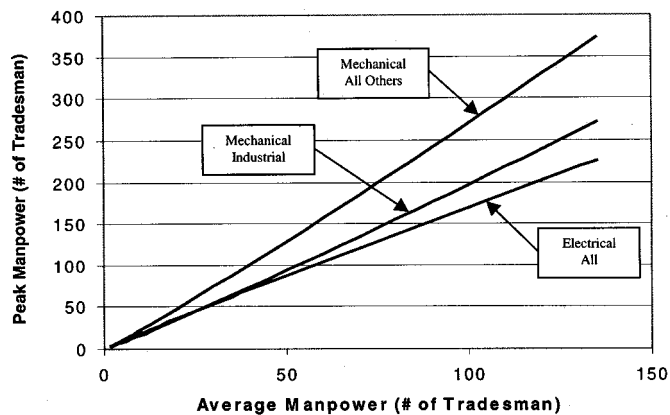


Fig. 8. Relationship between peak and average man power

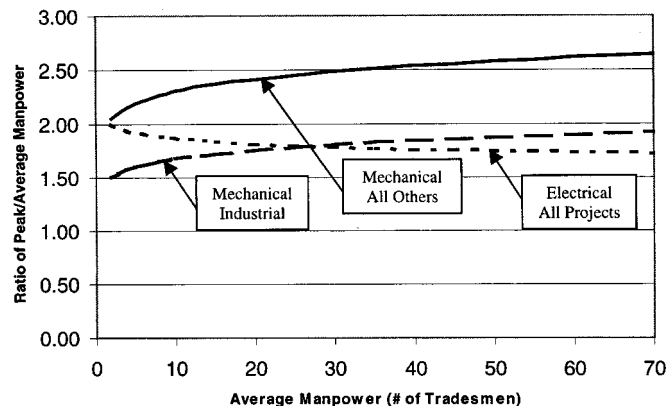


Fig. 9. Peak to average man power ratio

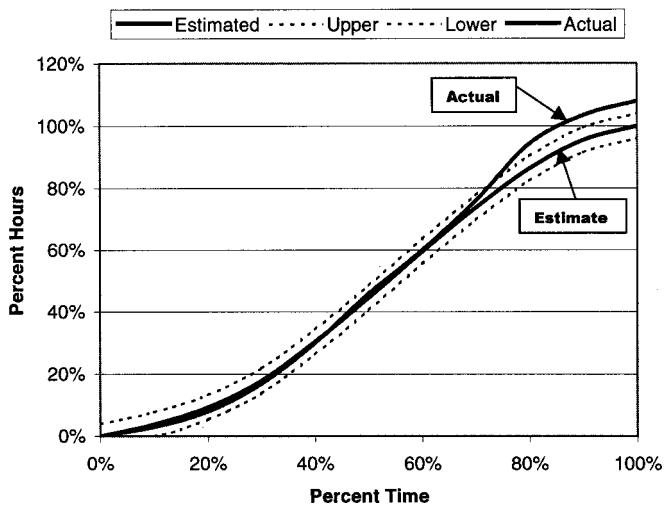


Fig. 10. Example of actual S-curve tracked against estimated S-curve with control limits

In creating man power loading charts, Allen suggested that the maximum man power is 160% of the average man power requirement (Wideman 1994). Based upon the relationships in Eqs. (7) and (8), the maximum (peak) man power varies, depending on the average man power. These ratio relationships are shown in Fig. 9.

Recommendations and Usage

These man power loading charts and the related S-curves are useful for resource planning and for tracking progress on a construction project; they can also be used to provide early warning signs for contractors and owners that the project deviates from the planned benchmark. It is recommended that contractors develop their own planned curves for each project.

In addition, contractors could use the same methodology discussed above to create standard curves for each project type (industrial, commercial, institutional, etc.), based upon their actual loading charts. A confidence interval or range could be developed around the estimated curves that would signify whether or not a project was beginning to have trouble. For instance, if, on the basis of actual project data, it were found that a normal, unimpacted project stayed within $\pm 4\%$ of the estimated curve, a control chart could be developed for each project. The actual project data could then be tracked against the estimated curve and the control chart. If the actual curve left the control limits, the project

would likely experience a loss of productivity. An example is shown in Fig. 10. After the project was 70% complete, the contractor would know that the actual hours were not within the control range of the estimated hours, and proactive measures could be taken to decrease the potential cumulative impact to the project. If the deviation were linked to a cause such as project acceleration, weather, or change orders, the chart could serve as supporting evidence in a loss-of-productivity claim. The chart might also show that the progress is behind schedule, and that it is necessary to use overtime, shiftwork, overstaffing, or any other acceleration technique to put the project back on schedule. Since this report was developed from projects varying in size from 2,000 to 100,000 work hours, it is recommended that the usage of these benchmark data be limited to this range of projects.

Summary and Conclusion

Several important benchmarking indicators have been presented for labor-intensive projects. These indicators are average man power required, peak man power, ratio between average and peak man power, and man power loading curves and their corresponding S-curves. A set of curves and tables was developed that shows the relationship between project size and duration, between project size and average man power, between project size and peak man power, and between average man power and peak man power. Where applicable, these curves were compared to similar curves from the existing literature.

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