ECONOMICS OF TIME MANAGEMENT: CASE STUDY AT NB POWER

By: Marc J. Demers, Joyendu Bhadury, and Mohammed A. Rahim

Demers, Marc J., Joyendu Bhadury, and Mohammed A. Rahim. Economics of Time Management: A Case Study at NBPower. *ASCE Journal of Management in Engineering*. Vol. 13, No. 2, pp 57-62, (March/April 1997).

Abstract:
This paper describes a project undertaken at the New Brunswick Power Corporation (NB Power) the utility corporation of the Canadian province, in a cost-cutting effort through the use of improved time management. The focus of the project was to investigate if the time estimates in use at the corporation for work completion were accurate. We begin with a description of how the data was gathered from two sets of time measurement and was validated—the first set represents the current times in use at NB Power while the second set represents estimates obtained from experts. This is followed by a discussion of the methodology. Finally, this paper summarizes the conclusions and recommendations that are made to serve as the basis for improvement of performance and quality measurement.

Article:

INTRODUCTION

The New Brunswick Power Corporation (NB Power) is an organization whose purpose is "to provide for the continuous supply of energy adequate for the needs and future development of the Province and to promote economy and efficiency in the generation, distribution, supply, sale and use of power" *(Electric Power Act*, 1973). NB Power has serviced the province of New Brunswick for more than 75 years. In doing so, the corporation is continuously reviewing methods to reduce costs. One such review, the "time" allotments for work performed on NB Power distribution lines, was recently reexamined. This review is the focus of the present paper.

Increasing scheduling efficiency, effective resource allocation, and adherence to a budget are important goals to NB Power. Another important goal is the quality of service. Quality has both an external and internal focus. While the external focus is on consistently meeting customer expectations, the internal focus is the improvement of material, machine, and labor efficiencies, and doing it right the first time (Rosier and Sink 1990).

At NB Power, one of the best potential sources of increased efficiency is the proper allocation of resources. If allocated properly, immense cost savings can be realized. On the other hand, large amounts of money can be lost if resources are inappropriately distributed. For example, a work crew that is given four hours to do a two-hour job is a prime example of time mismanagement. On a larger scale, dollars can be lost on a capital job through the needless hiring of extra contractors. If 500 hours are forecast to complete a job when in fact only 400 are required, the cost of the additional contractors is unnecessary. This emphasizes the need to properly measure the factors that can affect cost. Accurate time measurement of various activities ensures better measurement of crew productivity.

Accurate estimation also plays a crucial role in quality and productivity measurement efforts, both at NB Power and elsewhere. However, performance and quality measurement must be validated, as in this project. Properly designed measurement and evaluation systems ensure that we are constantly improving performance.

This paper is a description of the project that was undertaken to determine if the time allowed for work completion was accurate. It is organized as follows. The next section gives an illustration of the basic terms used and the third section details the techniques used to evaluate the problem. The fourth section displays the recommendations and conclusions, and is followed by Appendix I, which details the output from the tests conducted in this study.

BASIC TERMINOLOGY

Engineering Units

Each weekday, work crews at NB Power are assigned jobs that involve the maintenance and construction of

TABLE 1. Distribution Line Upgrade (Time Allotment)

Engineering unit (1)	Description (2)	Time (h) (3)
FT-40-4-F	Pole, F.T. 40FT CL4 fair	0.85
41-3	Ground (butt) number 4 solid copper	0.146
35-52	Pole numbering	0.1
7-1-2	ptp 1 phase number 2 (0–15)	0.17
C1	Tree trimming-main line span	0.96
T8	Transfer second or neut per	0.28
T23-1/4	Transfer 1/4 in. guy	0.19
D1-35	Retire 35 ft pole	0.39
Total	—	3.10

distribution lines. Each job consists of many work units or stages that must be completed in order for the job to be done properly. These work units are described as engineering units (EUs). Each EU has a time-frame allotment in which the work must be completed. Table 1 provides an example of EUs required for a distribution line upgrade (the times shown are averages of several observations, calculated to an accuracy of the second decimal point). As shown in the first column, a code number is assigned to each EU. This particular job requires the execution of eight EUs before the work can be completed. By adding the times of the eight EUs, the result would be the time frame in which the job itself must be completed. Therefore, the total time it takes to perform a distribution line upgrade is 3.1031 h. (Note: the times recorded in this table have been altered proportionately to avoid revealing actual figures).

Each workday at NB Power, the work planner plans and coordinates the work activity for each crew for the following workday(s). The work planner must ensure that each crew receives enough work for the entire day. If an insufficient amount of work is assigned, idle time is the result that leads to increased costs. This indicates the importance of accurate EU times.

In 1986, representatives from the Standards Committee at NB Power refined EUs based on knowledge and experience. In the same year, external consultants also conducted a "time and motion" study to determine the accuracy of EUs. The necessary refinements were made to rectify any inaccuracies. No changes have been made since that time.

Over the years, concerns grew that the times allotted for EUs were inaccurate since jobs were being completed quicker or slower than estimated. If the current times are too high, then job costs (in terms of resources—labor and vehicles) would be incorrectly forecasted. More dollars would be budgeted for the work than was actually required. Conversely, if the current times are too low, job costs will be underestimated, which again leads to inaccurate budgeting. NB Power had to determine if these times were inaccurate. If so, the necessary steps would be taken to remedy the situation.

Obtaining Time Estimates for Engineering Units

We now describe in detail how the time estimates of the various EUs were obtained for this study. First, management at NB Power decided that a second detailed "time and motion" study was too time-consuming and costly to execute. Hence, three employees at NB Power with extensive expertise in EUs and experience in field operations were chosen to provide realistic time estimates for this analysis.

First, all EUs in NB Power (a total of 1,846) were classified into nine distinct groups based on their functionalities. Table 2 illustrates the name and description of each group.

Next, a sample of 300 EUs was selected for the team of experts. To ensure an accurate representation, samples were chosen from each group based on their frequency of use in the field. In other words, the more frequently performed EUs were selected for the purpose of this study. Table 3 displays the sample size of each group. The column labeled "Total" shows the total number of EUs within each group.

Having chosen the sample EUs, the team of experts

TABLE 2. Engineering Unit Groups

Name (1)	Description (2)
Anchor/guy/ground	Anchors and guys are the hardware required to counteract the force created on poles from overhead conductors (on angle and dead-end structures.) Grounds are wires that connect the neutral conductor with the ground at the butt of the pole.
Apparatus	Devices installed on pole structures or on service entrances at homes (i.e., capacitors, lights, lightning arrestor, and meters).
Frame	The hardware installed on poles to support primary and secondary conductors.
Pole	Structure that supports all apparatus, hardware, and conductors on the distribution lines.
Primary	High-voltage conductors that transport power on distribution lines.
Riser	Hardware and cables along the sides of poles that make up the transition from underground to overhead facilities.
Secondary	Low conductor that supplies service voltage to customers.
Switch	High-voltage switches that enable sectionalizing of portions of the distribution system or feed changes (i.e., cutouts and oil reclosers). Switches are the operating points on distribution lines.
Transformer	Device that steps the voltage from the supply level down to a usable service voltage level for customers.

TABLE 3. Sample Size of Engineering Unit Groups

Group (1)	Observations (2)	Total (3)
Anchor/guy/ground	24	98
Apparatus	21	192
Frame	53	350
Pole	9	96
Primary	40	153
Riser	18	92
Secondary	40	148
Switch	22	443
Transformer	33	274
[Total]	[260]	[1,846]

was asked to estimate the times taken for each of them. Since most of the activities associated with EUs are both equipment and labor-intensive, and take place outdoors, the time taken to finish them can widely fluctuate, depending on factors such as weather, availability of equipment and personnel, and so on. For this purpose wherever possible, each expert was asked to provide three different time estimates for every EU. These estimates were optimistic time (activity time if everything proceeds in an ideal manner); most probable time (most likely activity time under routine conditions); and pessimistic time (activity time if delays are encountered). Note that due to the complexity of some EUs, the analysts were unable to provide all the three estimates for a few units. Once this was done, a fourth expert, who served in a supervisory capacity of the team of three experts at NB Power, was chosen. This fourth expert further reviewed the estimates and eliminated from the sample those EUs whose times differed in large proportion from one expert to the other. By eliminating these extreme estimates, it was hoped that the remaining sample of 260 EUs (Table 3) would be more accurate.

Next, we resorted to the theory of project management (Anderson et al. 1991; Kerzner 1995) to obtain the final estimates. Based on the standard assumption that the uncertainty in EU times can be described by a beta probability distribution, it is well known [see Anderson et al. (1991); Kerzner (1995)] that the expected time for each activity is best estimated by the following equation:

$$t = (a + 4m + b)/6 \qquad (1)$$

where t = expected time of an activity; a = optimistic time of an activity; m = most probable time of an activity; and b = pessimistic time of an activity.

Table 4 is an illustration of an expert's estimated times for the "riser" group. All times are in hours. Thus the expected time of each EU was calculated for each of the three experts. Finally, the three expected times for each EU were averaged to arrive at the final expert time es timate for that EU. It is this final time estimate that was used for the purpose of this analysis.

TABLE 4. Expert Activity Times

Engineering unit (1)	Optimistic time (2)	Normal time (3)	Pessimistic time (4)	Average time (5)
D23	0.67	1	1.33	1
37-49-2	0.33	0.5	0.67	0.5
D22	0.5	0.67	1	0.7
37-50-4/0	0.33	0.5	0.67	0.5
37-46	0.33	0.5	0.67	0.5
37-50-500	0.5	0.83	1	0.8
37-26-750	1	1.5	2	1.5
37-26-2/0	0.67	1	1.5	1.03
37-24-500	0.67	1	1.5	1.03
37-55-500	2	3	4	3
37-55-750	2	3	4	3
37-47-2/0	0.33	0.5	0.67	0.5
19U-21-2	0.83	1.17	1.5	1.17
T10	1	1.17	1.5	1.2
T11	1.5	2	2.5	2
37-24-2	0.67	1	1.5	1.03
19U-19-1/0	0.83	1.17	1.5	1.17
37-22-2X3/0	0.67	1	1.5	1.03

METHODOLOGY

We begin with a brief overview of the methodology used in this paper. For a more detailed description of the mathematical details of the individual tests, the interested reader is referred to Keller et al. (1994). At issue here in this problem is the comparison of two sets of times, namely the current times in use at NB Power and the expert times. The methodology of choice for this purpose is to use a hypothesis test from statistics that compares two populations. In addition, the two populations in this case (the two sets of times to be compared) have a natural relationship in that each member of one set (say, the time for any particular activity according to the NB Power estimate) has a corresponding member in the other (the time estimate for the same activity according to the expert time estimates). Therefore, the design required to compare these times was the matched pairs experimental design [see Keller et al. (1994)]. Further, the exact statistical procedure that ought to be used depends in whether the population difference in question (i.e., the distribution of the differences between the two different time estimates) is distributed as a normal curve or not. If so, then the hypothesis test used should be the matched pairs t-test (Keller et al. 1994). In case the population is not normally distributed, we have to resort to nonparametric tests—the appropriate ones to use here would be the Sign Test (Keller et al. 1994) and Wilcoxon Rank Sum Test for Matched Pairs (Keller et al. 1994). Hence the first step in performing these tests is to determine the groups for which the population differences are normally distributed. Table 5 provides an example of how the differences were calculated. The current times were subtracted from the expert times to obtain the differences.

A histogram was plotted for each of the nine groups. The results indicated that the "frame" and "anchor/guy/ ground" groups were normally distributed. Fig. 1 reveals the "frame" histogram, which has a normal distribution due to its symmetrical bell-shaped curve. As mentioned before, for those groups whose differences were normal, the Matched Pairs t-test was applied.

The remaining seven groups (apparatus, pole, primary, riser, secondary, switch, and transformer) contained non-

TABLE 5. Mean Difference

Engineering unit (1)	Expert average (2)	Current times (3)	Mean difference (4)
EU15-240-	0.75	0.5666	0.183
EU21-49-100	0.97	1.133	−0.161
EUD14	0.67	1.36	−0.694
EUT16	0.93	1.7	−0.774
EU21-51P-	4.01	4.25	−0.236
EUSD-500-	1.50	1.133	0.367
EU19-30-3/8	0.25	0.1	0.151
EU19-185	1.30	4.25	−2.947
EU19-167-3	2.00	1.275	0.725

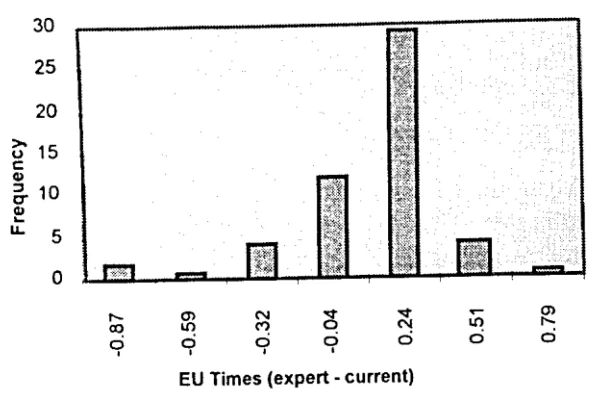

FIG. 1. Frame Group Histogram

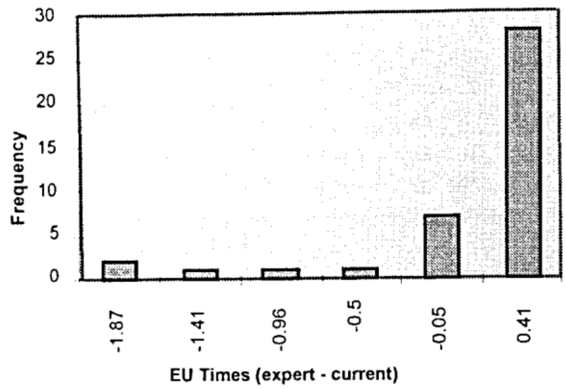

FIG. 2. Secondary Group Histogram

normal distributions. For example, Fig. 2 illustrates the "secondary" group histogram that is skewed to the left, which indicates a non-normal distribution. Nonparametric techniques were required for groups that were non-normal. The Wilcoxon Signed Rank Sum Test and the Sign Test were used in this instance.

The Matched Pairs t-test (Keller et al. 1994) was applied to the "anchor/guy/ground" and "frame" groups as the distribution was normal (Keller et al. 1994). For the rest of the seven groups, both the Sign Test and the Wilcoxon Rank Sum Test for matched pairs were used. The essential philosophy behind all of these tests can be summarized as follows. In all of them, the aim is to check which one of the following two hypotheses about the data is correct: (l) the null hypothesis, which states that the two population locations are the same (i.e., on the average, the expert time estimates equal the current time estimates); and (2) the alternative hypothesis, which states that the two population locations are not the same (i.e., expert times estimates are different from the current time estimates). In other words, if the null hypothesis is true, then it can be concluded that the current times in use by the crews at NB Power are accurate. However, if the test results are in favor of the alternative hypothesis, then it can be asserted that the current times in use are not accurate, and hence are in need for revision. To determine which one of the two hypotheses is true (within a margin of statistical error), the tests compute indicators called test statistics from the data, which are then compared against critical values (that are decided primarily by the margin of statistical error that is deemed acceptable for the problem). The margin of error that is deemed acceptable is given by the significance level of the test, which is denoted by a; in keeping with standard practice, this was set at 5% for our study. Another indicator of the possibility of an erroneous decision is the P-value, which indicates if there was ample/little evidence to support the alternative hypothesis; that was also calculated.

In both these cases, if it was proved that the two time estimates were different, then a second test was performed to check which of these sets of estimates is larger/smaller. A copy of the test results is given in Appendix I.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results shown in Appendix I, the following conclusions were made.

As is evident from the test results, the current time estimates for the "riser' group are excessively high. On further investigation, it was reasoned that this was due to the following reason. The "time and motion" study of 1986 did not include the "riser" group in its tests as the group size was deemed as being two small back then. This has probably resulted in the estimates being out-dated, thus requiring changes at the present time.

The data also indicates that the current times for EUs in the "switch" group are too low. This increase in times can be attributed to added safety precautions work crews have adopted when performing EUs in this group (which decreases productivity).

The remaining seven groups tested showed no difference between current times and the expert average. Status quo would be maintained.

On the basis of these, the following recommendations were made to NB Power. First, the expert times should replace the current times for the "riser" and "switch" groups. Since the sample was representative, the expert times should be allotted accordingly to the other EUs that it represented. Second, although we are fairly certain that the results of this study are accurate, it is recommended that as the next step beyond this project, our results should be validated by conducting study that gathers actual times. It was also recommended that if resources are limited, this should at least be done for the two groups that showed a discrepancy between expert and current time estimates, namely the "riser" and "switch" groups.

Extensions of this project could be pursued in the future. One avenue would be to assess the costs of over and underestimating the times of EUs. The cost of collecting this information can also be calculated. In addition, an investigation may be pursued into an optimization model that allows us to choose the optimal set of activities on which to focus in order to minimize total costs.

ACKNOWLEDGMENTS
This work was supported by a grant from the Natural Sciences and Engineering Research Council of Canada. This support is gratefully acknowledged. The writers also wish to acknowledge the helpful comments and suggestions of Charles Hanson at NB Power.

APPENDIX I. OUTPUT TESTS

Anchor/Guy/Ground and Frame Groups

The test statistic does not fall into the rejection region for both cases; therefore, the null hypothesis that the expert and current times are the same is true. In addition, the magnitude of the P-value ensures that there is little evidence to support the alternative hypothesis. The times need not be adjusted for these groups (see Table 6).

TABLE 6. Anchor/Guy/Ground and Frame Groups

Parameter (1)	Anchor/guy/ground (2)	Frame (3)
Observations	24	53
Degrees of freedom	23	52
Test statistic (t)	1.56	−0.43
Rejection region	$\|t\| > 2.069$	$\|t\| > 2.007$
P-value (two-tail)	0.132	0.666
Conclusion	Do not reject H_o	Do not reject H_o
$\bar{x}_1$	0.505	0.699
$\bar{x}_2$	0.414	0.718
Confidence interval	(−0.03, 0.214)	(−0.107, 0.069)

Apparatus Group

Both tests arrive at the same result. The null hypothesis is to be accepted, as seen in Table 7.

Pole Group

The sample size of the pole group was not large enough to use the sign test. There are no restrictions on sample size for the Wilcoxon signed rank sum test, which shows that the null hypothesis should be accepted (see Table 8).

Riser Group

Section 1 illustrates that both tests concluded with the rejection of the null hypothesis. Section 2 exhibits that the current times are too high. These times would have to be decreased to reflect the results shown in Table 9.

Primary and Secondary Groups

As shown in Table 10, the sign test and Wilcoxon signed rank sum test were applied. The results clearly

TABLE 7. Apparatus Group

Sign Test (1)	Wilcoxon Signed Rank Sum (2)
Number of positive differences: 9	n: 21
Number of zero differences: 0	$T+$: 91
n: 21	$T-$: 140
Test statistic (z): −0.655	Test statistic: $T = 91$
Rejection region: $\|z\| > 1.96$	Rejection region: $T \leq 59$
Conclusion: accept H_o	Conclusion: accept H_o
P-value: 0.5124	
Confidence interval: (−.36, 0.09)	

TABLE 8. Pole Group

Wilcoxon Signed Rank Sum (1)
n: 9
$T+$: 19
$T-$: 26
Test statistic: $T = 19$
Rejection region: $T \leq 6$
Conclusion: accept H_o
Confidence interval: (−0.17, 0.1)

TABLE 9. Riser Group

Section 1		Section 2	
Sign Test: riser (1)	Wilcoxon: riser (2)	Sign Test: riser (3)	Wilcoxon: riser (4)
Number of positive differences: 4 Number of negative differences: 0 $n = 18$ Test statistic (z): -2.36 Rejection region: $\|z\| > 1.96$ Conclusion: reject H_O P-value = 0.0182 Confidence interval: $(-1.46, -0.08)$	n: 18 $T+$: 32 $T-$: 139 Test statistic: $T = 32$ Rejection region: $T \leq 40$ Conclusion: reject H_O	H_O: $p = 0.5$ H_A: $p < 0.5$ Test statistic (z): -2.36 Rejection region: $z < -1.645$ Conclusion: reject H_O P-value: 0.0091	H_O: $A = B$ H_A: $A < B$ Test statistic: $T = 32$ Rejection region: $T \leq 47$ Conclusion: reject H_O

TABLE 10. Primary and Secondary Groups

Sign Test			Wilcoxon Signed Rank Sum Test		
Parameter (1)	Primary Group (2)	Secondary Group (3)	Parameter (4)	Primary Group (5)	Secondary Group (6)
Number of positive differences	25	25	n	40	39
Number of zero differences	0	1	$T+$	469	426
n	40	39	$T-$	351	354
Test statistic (z)	1.58	1.76	Test statistic	$T = 351$	$T = 354$
Rejection region	$\|z\| > 1.96$	$\|z\| > 1.96$	Rejection region	$T \leq 264$	$T \leq 250$
P-value	0.1142	0.0784			
Conclusion	Accept H_O	Accept H_O	Conclusion	Accept H_O	Accept H_O
Confidence interval	$(-0.10, 0.16)$	$[-0.34, 0.05)$			

TABLE 11. Switch Group

Section 1		Section 2	
Sign Test (1)	Wilcoxon (2)	Sign Test (3)	Wilcoxon (4)
Number of $+ve$ difference: 16 Number of zero difference: 0 n: 22 Test statistic (z): 2.13 Rejection region: $\|z\| > 1.96$ Conclusion: reject H_O Confidence interval: $(-0.03, 0.38)$ P-value: 0.0332	n: 22 $T+$: 182 $T-$: 71 Test statistic: $T = 71$ Rejection region: $T \leq 66$ Conclusion: accept H_O	H_O: $p = 0.5$ H_A: $p > 0.5$ Test statistic (z): 2.13 Rejection region: $z > -1.645$ Conclusion: reject H_O P-value: 0.0166	H_O: $A = B$ H_A: $A > B$ Test statistic: $T = 71$ Rejection region: $T \leq 75$ Conclusion: reject H_O

TABLE 12. Transformer Group

Sign Test (1)	Wilcoxon Signed Rank Sum (2)
Number of positive differences: 17 Number of zero differences: 0 n: 33 Test statistic (z): 0.17 Rejection region: $\|z\| > 1.96$ Conclusion: accept H_O P-value: 0.865 Confidence interval: $(-0.60, 0.02)$	n: 33 $T+$: 214.5 $T-$: 346.5 Test statistic: $T = 214.5$ Rejection region: $T \leq 171$ Conclusion: accept H_O

dictate that the null hypothesis is to be accepted. In other words, the two time estimates are similar.

Switch Group

Section 1 discloses that the null hypothesis should be accepted; therefore, the current times are accurate in this instance. However, the alternative hypothesis in section 2 tests to see if the expert times are greater than the current times (one-tailed test). The results indicate that this is the case. The current times for the switch group would have to be increased accordingly (see Table 11).

Transformer Group

Table 12 shows the results of the sign test and Wilcoxon signed rank sum test that were applied. The results indicate that the null hypothesis is true; i.e., the two sets of time estimates in this group are similar.

APPENDIX II. REFERENCES

Anderson, D. R., Sweeney, D. J., and Williams, T. A. (1991). "Project management." *An introduction to management science.* West Publishing Co., St. Paul, Minn.
Electric Power Act. (1973). Chapter E-5, New Brunswick, Canada. Keller, G., Warrack, B., and Bartel, H. (1994). *Statistics for management and economics.* Duxbury Press, Belmont, Calif.
Kerzner, H. E. (1995). *Project management.* Van Norstrand Reinhold, New York, N.Y.
Rossier, P. E., and Sink, S. D. (1990). "What's ahead for productivity and improvement?" *I.E.-Mag.*, 25-31.