Process Reengineering for Increased Manufacturing Efficiency (PRIME) Program Evaluation

prepared for

Northeast Utilities (CL&P, WMECO) & The Energy Conservation Management Board

ers

energy & resource solutions

13 Railroad Square, Suite 504
Haverhill, Massachusetts 01832
(978) 521-2550
Fax: (978) 521-4588
www.ers-inc.com

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executive summary

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1.1 INTRODUCTION

This report presents the findings and recommendations resulting from an evaluation of Northeast Utilities' (NU) Process Reengineering for Increased Manufacturing Efficiency (PRIME) program administered by NU's Connecticut Light and Power (CL&P) and Western Massachusetts Electric Company (WMECO). The NU PRIME program sponsors Lean Manufacturing events at eligible facilities in the CL&P and WMECO territories. The goal of each three- to four-day event is to improve productivity while decreasing energy use per unit produced. Through proper implementation of Lean Manufacturing techniques, utility customers are able to increase their manufacturing productivity with little additional electricity use, as compared to pre-event use.

Energy & Resources Solutions (ERS) was selected to conduct the evaluation. ERS worked closely with the NU representatives to achieve the primary objects of the evaluation as stated on Page 2 of the RFP, which were:

1. To verify through site visits that the actions taken by customers to improve their productivity have indeed taken place and that increased production has resulted.
2. To assess the merits of the method the Company uses to calculate the costs and benefits of the program, i.e., the electric savings.
3. To quantify the non-electric benefits resulting from each customer's participation.

Several other tasks were outlined in the RFP for completion within deliverables, and are discussed in Section 1.3.

1.2 SUMMARY OF FINDINGS AND RECOMMENDATIONS

A thorough literature search on Lean Manufacturing techniques as related to energy efficiency, combined with a comprehensive review of project documentation files, and five facility site visits provide the basis for our conclusion that the current algorithm employed to calculate energy savings (kWh) may misestimate the savings attributable to the PRIME program. Savings may be overestimated mainly due to input values of annual electricity use and production gains. With correct inputs, we believe the algorithm actually underestimates annual electricity savings, while overestimating lifetime savings. To some extent, lifetime savings overestimations can be attributed to the assumption of a 10-year measure life, which is very likely too high.

We evaluated the algorithm and assumption values based on data obtained from on-site evaluations of five PRIME events. This data sample is possibly non-representative and not statistically significant. However, the data does provide a starting point with which to examine the existing algorithm and assumption values. The dramatic difference in some assumption values suggests that revised values could provide more accurate savings estimates. Therefore, we are recommending several changes to the algorithm and the assumption values. These recommendations should be accepted with caution, and used only until refined values can be derived from a representative, statistically significant data set are determined.

Based on the results of our research and site evaluations, we also suggest several non-algorithmic recommendations for improving the PRIME program. Recommendations include: methods for more accurate assessments of electricity usage before, and energy savings after, a Lean Manufacturing event; strategies for targeting the types of companies most likely to experience significant increases in productivity and energy efficiency as a result of implementing Lean techniques; and guidelines for promoting use of the Lean Manufacturing productivity improvements that will result in the greatest energy savings.

Finally, we found that none of the PRIME projects evaluated had a positive benefit-to-cost ratio. The complete findings and recommendations are presented in the remaining four sections of this evaluation report and summarized below (1.2.1 to 1.2.4).

1.2.1 Review of Lean Manufacturing and Energy Efficiency

Section 2, Lean Manufacturing and Energy Efficiency, contains a review of Lean Manufacturing techniques and productivity improvement methods. Included in this section are an overview of industrial energy use and a detailed discussion of the relationship between Lean Manufacturing and energy efficiency. The concepts and engineering methods outlined in this section provide the theoretical framework for evaluation of the existing NU savings algorithm (see Section 4). Detailed descriptions of the calculations employed in this section are provided in Appendix I.

ERS conducted a literature search and an informal survey of relevant publications on Lean Manufacturing and productivity improvement, its effect on energy use, and quantification approaches. Unfortunately, the relationship between productivity improvements and energy efficiency benefits has been minimally addressed in existing literature. Therefore, this report represents a unique contribution to the body of literature related to the energy efficiency impact of Lean Manufacturing techniques.

Lean Manufacturing is an umbrella term that includes many specific types of productivity improvement techniques. Energy savings associated with the implementation of Lean Manufacturing techniques most commonly result from waste reduction and decreased production hours. However, different Lean techniques have variable effects on energy consumption within a manufacturing facility.

The overall effect that Lean techniques will have on energy efficiency is dependent upon the type of equipment impacted by productivity improvement measures. Therefore, in order to determine the energy consumption effects of Lean Manufacturing techniques, it is important to identify and classify the types of equipment impacted by Lean Manufacturing techniques. Equipment can be grouped into five categories – one for office equipment and four representing manufacturing equipment, referred to in the report as Types A through D.

The five types of equipment are:

1. Office equipment
2. Manufacturing equipment with energy use independent of production hours and production quantity (Type A)
3. Manufacturing equipment with energy use dependent on production quantity (Type B)
4. Manufacturing equipment with energy use dependent on production hours (Type C)
5. Manufacturing equipment with energy use dependent on production hours and quantity (Type D)

To determine the energy savings that result from a Lean event all relevant equipment must first be grouped according to the five categories listed above. Then pre-event, non-Lean productivity increase, and post-event energy use are calculated as described in Section 2. Energy savings (kWh) due to the implementation of Lean techniques can be quantified as the difference between ERS estimated post-event energy use and the estimated energy use of a non-Lean productivity increase of the same magnitude. The energy that would be required for non-Lean productivity increases is an instructive metric, which we have used to quantify the efficiency impact of the PRIME program. A comparison between ERS estimated post-event energy use and the estimated energy use of a non-Lean productivity increase provides the basis for calculating the incremental energy savings that result from a Lean Manufacturing event. Electrical demand (kW) savings may also be claimed if excess hourly production capacity results from post-event implementation of Lean Manufacturing techniques.

1.2.2 PRIME PROGRAM PROJECT DOCUMENTATION REVIEW

Section 3, ***Project Documentation Review***, contains a review of 20 PRIME project document files supplied by CL&P and WMECO. Project reviews include: industry sector summaries; descriptions of the Lean techniques employed; an assessment of the claimed savings and algorithm inputs; a summary account of completeness and adequacy for each project file; and recommended project documentation changes.

Based on a documentation review of 20 projects in the CL&P and WMECO service territories, we provide several summary points and recommendations for the PRIME program. The PRIME program serves a range of industries. However, projects are concentrated in Fabricated Metal Product Manufacturing plants (NAICS 332, SIC 34). The

Lean techniques most frequently employed in these projects were 5S, Visuals/Standardized Work, and Quick Changeover. The most common productivity improvements were reduced changeover, reduced cycle times, and reduced inventory. Please refer to Section 2 for a complete list of Lean Manufacturing terms and definitions.

Upon examination of the Benefit/Cost Ratio (BCR) and claimed savings calculation inputs for each project, we found, in many cases, that the input estimations were either incorrect or poorly justified. Annual electricity use inputs frequently did not match actual values, which significantly skewed the savings calculations. There were apparently many reasons for the miscalculation including summing two accounts when only one applied, summing one meter instead of two, and counting 13 months instead of 12. Furthermore, the percent of affected product/sales estimate often was not justified, nor were the production rates. Inconsistencies were not the result of data entry errors; in most cases the claimed savings entered into the NU tracking system matched the savings documented in the project files.

On the basis of this review, it does not appear that the current project file documentation adequately captures project descriptions and details. Therefore, it should be improved. In section 3, we recommend a number of changes to the project documentation. Recommendations include: improved project descriptions; inclusion of a document content sheet; stronger justification for percent affected production; production values and sample size; customer electricity billing history; and addition of NAICS/SIC code.

1.2.3 Savings Methodology Assessment and Recommendations

Section 4*, *Savings Methodology Analysis and Recommendations, is a review and evaluation of the existing NU savings algorithm. In this section we recommend modifications to the existing savings algorithm and assumption values. Estimated results of the ERS-recommended algorithm are compared to data generated using the existing NU algorithm.

Table 1-1 presents savings estimates of the NU algorithm compared with ERS calculated savings. We found that the existing savings algorithm regularly and significantly overestimated energy savings compared to ERS calculated results, both on an annual and lifetime basis (when using the Lean consultant-provided algorithm inputs). Overestimation of annual savings can be attributed primarily to inaccurate input variables, such as annual electricity use and production gains.

Table 1-1: Reported versus ERS estimated Annual Savings

Site	Reported Savings from NU Algorithm	ERS Estimated Savings	Difference	Reported Savings % of ERS Est. Savings
A - Event 1	20,904	2,205	18,699	948%
A - Event 2	36,582	9,369	27,213	390%
B	11,598	48,483	-36,884	24%
C	*885,620*	*0*	*885,620*	*NA*
D	1,191,124	21,787	1,169,337	5467%
E	20,786	6,927	13,859	300%
Average				**1426%**
Total	**1,280,994**	**88,771**	**1,192,224**	**1443%**

*Site C had no production improvement and is not included in the Total sums

Table 1-2 depicts the significantly improved results that can be obtained simply by using accurate input variables with the existing algorithm. Given accurate input variables, the existing algorithm underestimated ERS estimated savings by about half in several instances.

Table 1-2: Adjusted versus ERS Estimated Annual Savings

Site	Adjusted Savings from NU Algorithm	ERS Estimated Savings	Difference	Reported Savings % of ERS Est. Savings
A - Event 1	3,091	2,205	886	140%
A - Event 2	9,499	9,369	130	101%
B	19,710	48,483	-28,772	41%
C	*433,220*	*0*	*433,220*	*NA*
D	13,292	21,787	-8,495	61%
E	2,095	6,927	-4,832	30%
Total	**47,687**	**88,771**	**-41,083**	**54%**

*Site C had no production improvement and is not included in the Total sums

Overestimation of lifetime savings is due mainly to the assumption of a 10-year measure life. Furthermore, we believe the existing NU algorithm assumptions were inaccurate, and could result in misestimating of energy savings.

In order to obtain more accurate and representative energy savings estimates, we recommend the following changes to the existing NU energy savings algorithm and assumption values:

- ❑ Decrease the assumed measure life from 10 to 5 years. Multiple factors such as employee turnover, procedural regression, market influence, and business turnover warrant a decreased measure life (See Section 4.2.4).
- ❑ To accommodate energy savings variability among Lean productivity improvement techniques, choose the most appropriate savings algorithm for each project: (1) for general productivity increases; (2) for rework/scrap reduction improvements; and

(3) for reduced setup times during non-production hours. These three distinct classes of Lean productivity improvement techniques save energy in different ways. Therefore, selection of the correct algorithm will increase the accuracy of energy savings estimates. (See Section 4.3.1).

- ❑ Revise the 5% (no savings) component to 65%. Office Type A and Type B equipment, accounting for 65% of total energy use, are similar in that from the 'Non-Lean Productivity Increase' to Post-Event scenario they have no associated energy savings. Additionally, revise the 10% (production-hour dependent) component to 20%. Type C equipment accounts for 20% of total energy use and electricity savings are calculated the same as 'Non-manufacturing' savings were calculated in the existing NU algorithm. Finally, revise the 85% (production-quantity dependent) component to 15%. Electricity savings for Type D equipment are calculated similarly to how the "Manufacturing' savings were calculated in the existing NU algorithm, except with a variable percentage savings factor applied to all production units. (See Section 4.2.4 and Section 2.7.1).
- ❑ Replace the constant 6% savings factor currently applied to incremental production with a variable savings factor applied to all production. This factor should be based on reasonable assumptions of equipment cycle times and idle power draw (See Section 4.2.4).
- ❑ Claim demand savings where appropriate by integrating demand savings calculations into the algorithm. Demand savings can be claimed when existing plant operating hours are 24 hours per day, seven days a week (See Section 4.3.1).
- ❑ Provide an option to calculate labor savings within the savings spreadsheet. Labor savings can be calculated simply from avoided production hours (See Section 4.3.1).

These algorithm assumption changes will enhance the predictive accuracy of the PRIME program savings estimates. An in-depth discussion of the algorithm recommendations can be found in Section 4 of this report.

Table 1-3 shows annual energy savings estimated using the recommended algorithm compared with ERS estimated savings. ERS has independently created an analytical spreadsheet tool to help develop the recommendations and assess the results from this modified approach. If formalized for use in the program, this analytical tool would standardize calculations and provide a simple method for using the recommended algorithms in future PRIME programs.

Table 1-3: Recommended Algorithm versus ERS Estimated Annual Savings

Site	Savings from Recommended Algorithm	ERS Estimated Savings	Difference	Reported Savings % of ERS Est. Savings
A - Event 1	0	2,205	-2,205	0%
A - Event 2	17,300	9,369	7,931	185%
B	35,896	48,483	-12,587	74%
C	*0*	*0*	*0*	*NA*
D	24,207	21,787	2,420	111%
E	3,815	6,927	-3,112	55%
Average				**85%**
Total	**81,218**	**88,771**	**-7,553**	**91%**

*Site C had no production improvement and is not included in the Total sums

Table 1-4 presents the energy intensity of the pre-event, non-Lean productivity increase, and post-event scenarios in terms of annual production and annual energy savings. The incremental energy savings (kWh) resulting from a Lean Manufacturing event are calculated by comparing ERS estimated post-event energy use with the estimated energy use of a non-Lean productivity increase. Annual energy savings can be calculated based on per unit production energy intensities for each scenario (see Section 2 for calculation details). Note that energy intensity decreases from the pre-event to the non-Lean productivity increase scenario, and decreases even further from the non-Lean productivity increase to the post-event scenario.

Table 1-4: ERS Estimated Energy Intensities and Energy Savings

Site	Energy Intensity (kWh/unit)			Annual Production (units)	Energy Savings (kWh/yr)
	Pre-event	Non-Lean	Post-event		
A - Event 1	55.9	50.4	49.4	2,284	2,205
A - Event 2	0.0022	0.0017	0.0016	75,322,000	9,369
B	0.0734	0.0733	0.0727	79,088,659	48,483
D	0.0993	0.0990	0.0986	59,714,660	21,787
E	3.135	3.130	3.118	593,194	6,927
Total/Ave.					**88,771**

*Energy Savings (kWh/year) = (Non Lean kWh/unit – Post-event kWh/unit) x units/year

Table 1-5 depicts the lifetime savings, cost per kWh (i.e. benefit-cost-ratio), and program screening calculated using our recommended algorithm and adjusted measure life. The cost per kWh shown here is based only on electricity savings; it does not account for labor or other non-electric benefit (NEB) savings. We found that none of the events passed the BCR screen.

Table 1-5: ERS estimated Lifetime Savings, BCR and Program Screening

Site	Events	Total Event Cost	Lifetime Savings (kWh)	Cost ($/kWh)	Passes Screen
A - Event 1	1	$4,800	11,026	$0.435	No
A - Event 2	1	$4,800	46,844	$0.102	No
B	2	$9,600	242,414	$0.040	No
C	*1*	*$6,000*	*0*	*NA*	No
D	2	$6,000	108,935	$0.055	No
E	1	$12,000	34,634	$0.346	No
Total/Ave.	**8**	**$43,200**	**443,854**	**$0.196**	

1.2.4 General Findings and Recommendations for the PRIME Program

Section 5, ***PRIME Program Evaluation Findings and Recommendations***, presents the general findings and recommendations of this evaluation. In addition to the findings and recommendations presented above, our research and five site evaluations yielded several other suggestions for a more effective and successful PRIME program:

- ❑ Verify annual electricity use with facility employees before calculating savings. Annual electricity use is frequently miscalculated from billing records obtained from NU. These records are sometimes printed out in a confusing way that has contributed to the miscalculation of annual electricity use. We have found that most facilities maintain accurate, clear records of electricity use. Thus, we recommend that the Lean consultant obtain annual electrical energy (kWh) and demand (kW) from the site employees during the PRIME event.
- ❑ Calculate electricity savings using confirmed production gains obtained at least three months after the PRIME event. Currently, electricity savings are typically based on expected production gains calculated at the same time as the PRIME event. This more reflects an increase in maximum production capacity than real production gains. Because the Lean consultant contacts the facility for a three-month follow up as a matter of program protocol already, estimating productivity improvement at this point would yield a much more accurate value. Appendix L provides a template for information to gather at this point
- ❑ Target companies with a stable and/or increasing product demand. Market influences on production often negatively influence the gains from the PRIME sponsored Lean events. During many of the site evaluations, we found that production gains were lower than expected which was almost always due to market factors.
- ❑ Lower prioritize "job shop" type facilities. Job shops produce a large variety of products, and production requirements typically change from day to day. The frequency of product changes leads to decreased persistence of increased production and thus energy efficiency gains.

- Promote those types of Lean Manufacturing productivity improvements that result in energy savings. Through the evaluation process we identified a number of PRIME sponsored projects whose effect on plant production levels and manufacturing equipment was uncertain. We recommend that PRIME sponsored events utilize Lean techniques that significantly impact electricity use, such as:
  - reducing changeover time;
  - reducing downtime;
  - reducing setup time;
  - decreasing cycle time;
  - increasing throughput; and
  - reducing rework/scrap.

  Projects geared towards inventory reduction should be given lower priority, because inventory reduction typically does not yield increased production or electricity savings. The five sites we evaluated participated in a total of eight PRIME sponsored Lean events, two of which were targeted towards inventory reduction.
- Promote 5S, TPM, Visuals and Standardized Work projects that increase the operating efficiency of equipment. While Lean events will not change equipment efficiency, they can improve how the equipment is operated, often resulting in a direct decrease in electricity use. These low-cost/no-cost improvements typically rely on the integration of best practices into the company culture. This is exactly what TPM, Visuals, and Standardized Work are geared towards. In addition, 5S projects often improve equipment condition, resulting in increased operating efficiency. These types of projects may yield more measurable and consistent electricity savings.
- Qualitative site surveys suggest low spillover and free-ridership rates. Two of five sites surveyed indicated that spillover events had taken place as a result of PRIME sponsored events. Two of five sites surveyed indicated that they would have conducted the events without utility incentives, and are thus 'free riders'. Table 1-6 below summarizes the qualitative findings from our survey, further detailed in Appendix J. Note that these findings are from a small, statistically insignificant sample and should not be used for reporting purposes.

Table 1-6: Spillover and Free Ridership Summary

Site	Spillover	Free Ridership
A-1	No	No
A-2	No	No
B	Yes	No
C	No	No
D	No	Yes
E	Yes (Nevada)	Yes

- Hedge preliminary production increase estimates with site personnel estimates. Event estimates of production gains are often high, in the range of 10% to 30%. We found that realized production gains are typically much lower, under 5%. The evaluation team suggested that the facility employees should be asked before the PRIME event what they thought a realistic production increase would be. ERS agrees that this question would be helpful, in the sense that production increase estimates can be tempered. However, we do recommend that final savings should be based on production increased as derived from actual data.
- Require beneficiaries of PRIME incentives to participate in a program evaluation, if asked. We found that it was difficult to schedule on-site assessments of some PRIME participants. This difficulty could be repeated for impact evaluations. Thus, we recommend that PRIME participants agree to host on-site evaluations if required.

1.3 Evaluation Personnel & Deliverables

Mr. Gary Epstein and Mr. Mark D'Antonio served as project and technical advisors on the PRIME Program Evaluation project for ERS. Mr. John Seryak served as the day-to-day project manager and lead engineer for ERS, coordinating site visits and communication with the NU representatives and non-utility parties, hereafter referred to as the evaluation team. Mr. Yogesh Patil and Ms. Deborah Swarts of ERS also contributed to this evaluation as project engineers.

ERS worked closely with NU employees associated with the PRIME Program. Mr. Earle Taylor of NU served as the evaluation team leader. Mr. David Bebrin of CL&P assisted with consultation on the NU algorithm. Mr. James Motta of CL&P assisted in providing project documentation for PRIME events in CL&P territory and Mr. Carl Santoro of WMECO assisted in providing project documentation for PRIME events in WMECO territory. ERS would like to express our appreciation to all involved for their efforts in facilitating this evaluation and providing invaluable guidance and information for this project.

Evaluation project meetings included a kick-off meeting on August 16, 2005, including the evaluation team, and a conference call with Mr. Taylor and Mr. Bebrin on December 13, 2005. An evaluation team project review was meeting was held at CL&P's New Britain offices on March 1, 2006.

In the course of the evaluation, we reviewed 20 PRIME documentation files, looked closely at five of these 20 projects, conducted five in-depth site visits, and evaluated the NU savings algorithm used to estimate electricity savings. Descriptions of each evaluation deliverable are provided below.

The following five deliverables were required and have been completed as part of the PRIME program evaluation conducted by ERS:

1. Evaluation Workplan – Provided the scope of work, presented methodologies for implementation, and provided a general road map for the project. The full Evaluation Workplan is included as Appendix M.

2. Project Documentation Review – 20 project document files supplied by CL&P and WMECO were reviewed. The important characteristics of each project, including industry sector and Lean technique, were summarized. The availability of essential information (e.g. input annual electricity, percent of affected goods, and production rates) within each project file was assessed. The final Project Documentation Review document is included in this evaluation report as Section 3.

3. On-Site Measurement and Verification (M & V) Survey Forms – A survey form was created to guide the data collection process during site visits and ensure consistent information gathering at each of the five sites evaluated. Appendix J of this report contains the completed M&V Surveys for each site. The objectives of the On-Site M&V were to:

    - ❑ Verify affected production lines, line operating hours and pre and post-Event production rates.
    - ❑ Identify if and when productivity improvements were removed or are no longer in effect.
    - ❑ Determine the spill-over effect
    - ❑ Determine the free-rider effect
    - ❑ Derive an estimate of facility energy use broken down into appropriate components
    - ❑ Quantify the NEBs.

4. Site Evaluation Reports for PRIME projects – Five site visits were conducted to evaluate the implementation of PRIME recommendations, the associated production gains, and the energy savings. Site visit activities included: discussions with the Lean event participants, a tour of the facility, inventory of electricity-using equipment impacted by post-event Lean Manufacturing practices, and deployment of measurement equipment to log energy use when appropriate. Data collected during site visits were used to perform detailed calculations of productivity improvements and associated electricity savings. Site Evaluation Reports are submitted as Appendices A through F. In order to ensure confidentiality, these reports do not identify the customer by name or account number.

5. PRIME Program Evaluation Report – This document (sections 1 through 5 and appendices) represents the PRIME Program Evaluation Report, which provides a complete summary of all activities, findings, and conclusions of the ERS evaluation.