

Pollution Prevention and Lean Manufacturing

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ABSTRACT

The Colorado State University Industrial Assessment Center (CSU IAC) provides technical assistance to small and mid-size manufacturing plants in the Rocky Mountain Region. By performing assessments at these industrial facilities, the CSU IAC promotes energy conservation, pollution prevention, and productivity improvement. During the four-year period beginning October 1, 1996, the CSU IAC performed 99 industrial assessments that generated a total of 467 assessment recommendations (ARs) with pollution prevention benefits. Such benefits include reduced waste materials and reduced generation of polluting emissions. The guiding principle in lean manufacturing is elimination of non-value-added activities through continuous process improvement. Waste reduction is thus a central issue, where waste can be any activity that consumes resources but creates no value for customers. The following six categories are identified for the 467 pollution prevention recommendations: install energy-efficient replacement equipment; improve compressor system efficiency; turn off, turn down, or idle equipment when not required; improve heating and cooling system efficiencies; recycle waste materials; and develop conservative material usage practices. The first four of these categories entail reducing polluting emissions from power plants. Recycling reduces outputs of wastes and associated costs. Conserving raw materials reduces consumption of raw materials and associated costs. Implementation of the 467 recommendations can produce the following benefits: reduce electric energy usage by 46,220 MMBtu/yr, reduce CO₂ emissions from power plants by 29,565,000 lb/yr, reduce SO₂ emissions from power plants by 97,600 lb/yr, reduce NO_x emissions from power plants by 94,870 lb/yr, reduce gas energy usage by 50,670 MMBtu/yr, reduce nonhazardous solid waste by 15,011,000 lb/yr, reduce hazardous solid waste by 168,950 lb/yr, reduce nonhazardous liquid waste by 167,180 gal/yr, reduce hazardous liquid waste by 7,903,500 gal/yr, reduce wastewater by 30,289,000 gal/yr, reduce solvent air emissions by 63,100 lb/yr, and generate cost savings of \$2,361,000/yr. These results demonstrate that elimination of excess energy usage and reduction of wastes can enhance lean manufacturing.

INTRODUCTION

The Colorado State University Industrial Assessment Center (CSU IAC) performs industrial assessments for small and mid-size manufacturing plants in Colorado, Nebraska, New Mexico, Wyoming, and Utah. The program is sponsored by the U.S. Department of Energy through the Office of Industrial Technologies. Previously, we reported results demonstrating that the industrial assessments generate benefits in terms of energy conservation, pollution prevention, and productivity improvement¹⁻⁵. During

the 48-month period beginning October 1, 1996, CSU IAC personnel performed 99 industrial assessments that generated 467 assessment recommendations (ARs) with pollution prevention benefits. The results reported herein demonstrate that elimination of excess energy usage and reduction of process wastes can enhance lean manufacturing.

LEAN MANUFACTURING

Lean manufacturing emphasizes less waste, greater efficiency, and continuous improvement. It focuses on minimizing costs, maximizing customer options, fast delivery, and high quality products and services⁶. Proponents of lean manufacturing have identified about eight major types of wastes⁷. These include overproduction, waiting for the next process step, unnecessary transport of materials, overprocessing of parts, inventories more than minimum amounts, unnecessary movement by employees, production of defective parts, and underutilization of human resources. More broadly, waste can be defined as any activity that does not add value to the product or service. The guiding principle in lean manufacturing is elimination of non-value-added activities through continuous improvement efforts. In general, generation of waste consumes resources but creates no value for customers. Waste reduction is thus a central issue and can include elimination of excess usage of utilities and materials. Greenwood points out that, “There is a strong relationship between lean manufacturing and reducing the size of a company’s environmental footprint⁸.”

ASSESSMENT PROTOCOL

The primary objectives of the CSU IAC program are as follows: (1) Provide technical assistance to small and mid-size manufacturers by recommending improvements that can save money and conserve materials and energy, and (2) provide opportunities for CSU engineering students to acquire practical industrial experience. Assessment recommendations (ARs) are offered in the areas of energy conservation, pollution prevention, and productivity improvement. Commonly encountered energy conservation ARs include energy efficient lighting, improved compressed air systems, energy efficient replacement motors, and improved utilization of heating and cooling systems. Commonly encountered pollution prevention ARs include conserving raw materials, reducing generation of nonhazardous and hazardous solid and liquid wastes, reducing solvent air emissions, and recycling materials. Details concerning identification and analysis of ARs are given in the IAC training manual⁹.

Tasks

Each CSU IAC assessment includes the following sequence of tasks:

- Select manufacturing plant and schedule visit.
- Acquire pre-assessment data.
- Select team and visit plant.
- Identify ARs.
- Evaluate ARs.

- Prepare and submit assessment report.
- Conduct implementation survey.

The following criteria are employed to select manufacturing plants for CSU IAC industrial assessments:

- SIC code 2000-3999.
- Gross annual sales do not exceed \$75 million.
- No more than 500 employees at the plant site.
- Annual utility bills \$75,000 to \$1.75 million.
- No in-house professional staff to perform the assessment.

The industrial assessment is provided at no out-of-pocket cost to the plant. Plant personnel have no obligation to act on any of the CSU IAC recommendations. The CSU IAC is one of the 15 western IACs managed by University City Science Center. The 15 eastern IACs are managed by Rutgers University.

Plant Visit

A team of CSU IAC faculty members and students visits the manufacturing plant for one or more full workdays. The visit includes a guided tour of production facilities and waste-generating operations. The guide for the plant tour is often either the plant manager or the facilities manager. CSU IAC personnel obtain data for the most recent 12 months concerning utilities, wastes, and raw materials. CSU IAC personnel observe production operations and interview plant personnel. A brainstorming session is conducted to identify potential ARs and the data needed for analysis of the ARs in terms of engineering and economic criteria. The plant visit concludes with a wrap-up session with plant personnel.

Assessment Report

The primary purposes of the assessment report are to document and convey the ARs to the plant manager. The ARs recommend implementation of specific, cost-effective practices in the areas of energy conservation, pollution prevention, and productivity improvement. ARs are based upon analysis of data pertaining to plant operations. The assessment report is normally sent to the plant manager within 60 days after the plant visit. The report summarizes pertinent utility, equipment, waste, and cost data. Energy conservation and pollution prevention practices already in place are noted. A process flow diagram is prepared. Monthly electric, gas, water, sewer, and waste management costs are quantified for the 12-month period immediately prior to the date of the plant visit. The report then recommends implementing specific practices to reduce costs, conserve resources, and improve productivity. The technical and economic analyses that support each recommendation are given, including relevant data, assumptions, and equations. Six to twelve months after the plant visit, CSU IAC personnel contact the plant manager to obtain information concerning implementation of each AR.

RESULTS

In order to demonstrate that pollution prevention activities enhance lean manufacturing, all 467 pollution prevention ARs from the 99 manufacturing plants are sorted into the six categories given in Table 1. For each category, the most common ARs are given, with the associated pollutants reduced (pollution prevention benefits) and the non-value-added items reduced (lean manufacturing benefits).

Table 1. AR category information.

AR Category	ARs Included	Pollutants Reduced	Non-Value-Added Items Reduced
-Install Energy Efficient Replacement Equipment	-Install Energy Efficient Lamps and Ballasts as Existing Lamps Burn Out -Install Energy Efficient Replacement Motors -Replace Standard V-Belts and Drives -Replace Electric Hot Water Heaters with Gas-Fired Units -Replace Electric Ovens with Gas-Fired Units	-CO2 Emissions (Electrical) -SO2 Emissions -NOx Emissions	-Electrical Energy Consumption -Electrical Energy and Demand Charges
-Improve Compressor System Efficiency	-Reduce Compressed Air Leaks -Reduce Compressor Pressure -Use Outside Air for Compressor Intake -Install a Low Pressure Blower or Pumps for Tank Agitation -Replace Pneumatic Equipment with Electrically-Powered Equipment -Install a Smaller Compressor	-CO2 Emissions (Electrical) -SO2 Emissions -NOx Emissions	-Electrical Energy Consumption -Electrical Energy and Demand Charges
-Turn Off, Turn Down, or Idle Equipment When Not Required	-Install Occupancy Sensors -Install Setback Timers -Install Variable Frequency Drives (VFDs) -Turn-off Equipment During Nonproduction Hours -Delamp Over Lit Facility Areas -Increase Utilization of Existing Passive Lighting -Reset Thermostats in Offices	-CO2 Emissions (Electrical) -SO2 Emissions -NOx Emissions -CO2 Emissions (Natural Gas)	-Electrical Energy Consumption -Electrical Energy and Demand Charges -Gas Energy Consumption -Gas Energy Charges
-Improve Heating and Cooling System Efficiencies	-Recover Waste Heat from Machinery -Insulate Pipes -Insulate Dock Doors and Walls -Install Strip Doors -Adjust Boiler Air to Fuel Ratio -Duct Warm Air to Boiler Air Intake -Install Destratification Fans	-CO2 Emissions (Electrical) -SO2 Emissions -NOx Emissions -CO2 Emissions (Natural Gas)	-Electrical Energy Consumption -Electrical Energy and Demand Charges -Gas Energy Consumption -Gas Energy Charges

Table 1 (Continued). AR category information.

AR Category	ARs Included	Pollutants Reduced	Non-Value-Added Items Reduced
-Recycle Waste Materials	-Install a Sludge Drying System -Install a Solvent Recovery Unit -Install a Water Evaporator -Install an Oil Burner -Recycle Metal Scrap -Recycle Wood Pallets -Recycle Used Fluorescent Lamps and Replace with Low Mercury Lamps	-Nonhazardous Solid Waste -Hazardous Solid Waste -Nonhazardous Liquid Waste -Hazardous Liquid Waste -Wastewater	-Disposal Charges
-Develop Conservative Material Usage Practices	-Replace Conventional Paint Guns with HVLP Alternatives -Install an Enclosed Paint Gun Washer -Install a Cooling Tower to Reduce Water Usage -Replace Washing and Cleaning Solvents -Reduce Scrap Generation -Establish a Cutting Fluid Management Program	-Nonhazardous Solid Waste -Hazardous Solid Waste -Nonhazardous Liquid Waste -Hazardous Liquid Waste -Wastewater -Solvent Air Emissions	-Raw Material Usage -Raw Material Costs -Water Usage -Water Purchasing Costs -Disposal Charges -Defect and Scrap Generation

The first four categories are associated with energy conservation and resulting reduced emissions from electric power generating stations. Accordingly, the pollutant emissions reduced are CO₂, SO₂, and NO_x. Excess generation of these pollutants does not add value to the manufactured products. Cost savings are associated with reduced expenditures for electric usage, reduced demand charges, and reduced expenditures for gas usage.

The fifth category consists of on-site and off-site recycling of waste materials. Examples of on-site recycling include installation of a solvent recovery unit and use of waste oil in a burner for space heating. Examples of off-site recycling include selling scrap metal and manufacturing mulch from scrap wooden pallets. Cost savings are associated with reduced expenditures for waste disposal.

The sixth category includes practices that conserve raw materials. Examples include purchasing paint guns with higher transfer efficiencies and reducing scrap from cutting operations. Such measures can reduce expenditures for raw materials and waste disposal.

Table 2 quantifies both total and average annual cost savings for the various AR categories.

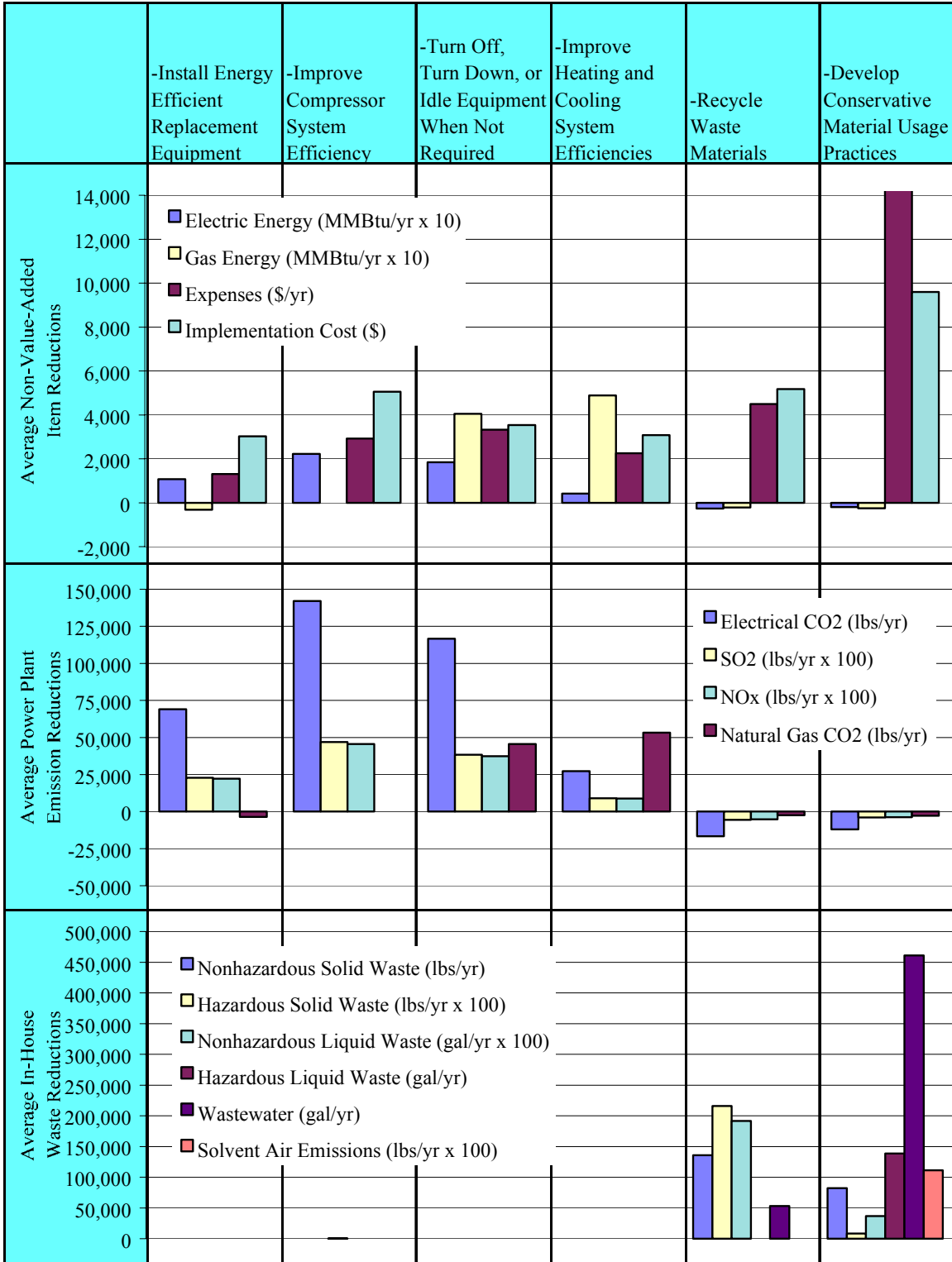
Table 2. Annual savings for AR categories.

AR Category	Total Cost Savings, <i>per year</i>	Number of ARs	Average Cost Savings, <i>per year</i>
-Install Energy Efficient Replacement Equipment	\$129,500	99	\$1,310
-Improve Compressor System Efficiency	\$313,100	107	\$2,930
-Turn Off, Turn Down, or Idle Equipment When Not Required	\$223,400	67	\$3,330
-Improve Heating and Cooling System Efficiencies	\$137,600	61	\$2,260
-Recycle Waste Materials	\$342,200	76	\$4,500
-Develop Conservative Material Usage Practices	\$1,215,200	57	\$21,320

On a total annual cost savings basis, the leading AR categories are conserving raw materials, recycling waste materials, and improving compressed air system performance. On an average annual cost savings basis, the leading AR categories are conserving raw materials, recycling waste materials, and switching off equipment not in use.

Figure 1 provides a graphical representation of data averages for the six AR categories.

Figure 1: Pollution prevention and lean manufacturing benefits



In terms of reducing power plant emissions, the leading AR categories are improving compressor system efficiency and switching off equipment not required. The major

emission reduction is for CO₂. Recycling and more conservative use of materials can require electricity and thus increase power plant emissions. Replacement of electric industrial appliances with gas appliances can reduce power plant emissions and energy costs. On a volumetric basis, the reduction in wastewater discharged is the leading measure associated with more conservative use of materials.

Implementation of the 467 pollution prevention ARs can provide the following total benefits: reduce electric energy usage by 46,220 MMBtu/yr, reduce CO₂ emissions from power plants by 29,565,000 lb/yr, reduce SO₂ emissions from power plants by 97,600 lb/yr, reduce NO_x emissions from power plants by 94,870 lb/yr, reduce gas energy usage by 50,670 MMBtu/yr, reduce natural-gas-generated CO₂ emissions by 5,611,000 lb/yr, reduce nonhazardous solid waste by 15,011,000 lb/yr, reduce hazardous solid waste by 168,950 lb/yr, reduce hazardous liquid waste by 7,903,500 gal/yr, reduce wastewater by 30,289,000 gal/yr, reduce solvent air emissions by 63,100 lb/yr, and generate cost savings of \$2,361,000/yr. Implementation costs for these practices total \$2,206,100, so the payback period is 0.9 years. Follow-up surveys indicate that 48% of the ARs for which the status is known have been implemented.

CASE STUDY

An IAC assessment team visited a manufacturer of flock transfers in February of 2000. During the site visit and the work that followed, nine recommendations were identified and found to enhance lean manufacturing by pollution prevention. Eight of the ARs either have been implemented or are planned for implementation.

The plant operated an old electric batch oven that was used to dry out temporary adhesives that had been applied to the flock transfers during the flocking process. It was recommended that this old electric batch oven be replaced with a new indirect-fired natural gas oven. The total electrical energy savings were 1,028 MMBtu/yr, corresponding to a reduction of 663,100 lbs/yr in CO₂ emissions, 2,193 lbs/yr in SO₂ emissions, and 2,126 lbs/yr in NO_x emissions. The total natural gas energy increase was 1,284 MMBtu/yr, corresponding to an increase of 145,100 lbs/yr in CO₂ emissions. While reducing the production of polluting emissions, this recommendation also reduced non-value-added utility costs by \$10,420 per year and had an implementation cost of only \$26,000. This recommendation is one that falls into the “install energy efficient replacement equipment” category.

Another AR falling into this category was a recommendation to install energy efficient lamps and ballasts as replacements to the existing lamps as they burned out. After two years of incremental implementation, the total annual cost savings were \$150/yr and the total electrical energy savings were 83 MMBtu/yr, corresponding to a reduction of 53,700 lbs/yr in CO₂ emissions, 178 lbs/yr in SO₂ emissions, and 172 lbs/yr in NO_x emissions.

The IAC team also recommended that this plant improve its compressor system efficiency by repairing leaking compressed air lines. The total electrical energy savings were 38 MMBtu/yr, corresponding to a reduction of 24,400 lbs/yr in CO₂ emissions, 81

lbs/yr in SO₂ emissions, and 78 lbs/yr in NO_x emissions. Implementation of this recommendation would reduce non-value-added utility costs by \$200 per year and would cost only \$410 to implement.

Three opportunities to turn off or turn down equipment when not required were found at this plant. First, it was recommended that the warehouse lighting be reduced since the measured light levels were above the Illuminating Engineering Society (IES) standards by more than 15 footcandles. It was also recommended that lighting occupancy sensors be installed in areas of the facility where lights may be turned off sporadically throughout the day, such as the locker rooms and restrooms. Finally, it was recommended that the thermostats in the plant offices be reset at night and over weekends during both the heating and cooling seasons to reduce the overall energy usage in the facility. Implementation of all three of these recommendations could provide a total electrical energy savings of 155 MMBtu/yr and a total natural gas energy savings of 136 MMBtu/yr, corresponding to a reduction of 100,100 lbs/yr in electrical CO₂ emissions, 331 lbs/yr in SO₂ emissions, 321 lbs/yr in NO_x emissions, and 15,400 lbs/yr in natural gas CO₂ emissions. Implementation of these recommendations would reduce non-value-added utility costs by \$2,270 per year and would cost only \$3,370 to implement.

The IAC team also recommended that this plant improve its heating and cooling system efficiencies by reusing exhaust in the flock room. The flock room is the location of the plant where the flock fibers are electrostatically transferred to the substrate material. This room requires tightly controlled psychometric conditions. Conditioned outside air was continuously brought into the flock room and then exhausted back outside, a process that consumed a considerable amount of energy. Reusing some of the exhaust air was found to yield a total electrical energy savings of 17 MMBtu/yr and a total natural gas energy savings of 255 MMBtu/yr, corresponding to a reduction of 11,000 lbs/yr in electrical CO₂ emissions, 36 lbs/yr in SO₂ emissions, 35 lbs/yr in NO_x emissions, and 28,800 lbs/yr in natural gas CO₂ emissions. Implementation of this recommendation would reduce non-value-added utility costs by \$1,500 per year and would cost only \$1,900 to implement.

The installation of an additional silver recovery stage for added silver recovery was another recommendation given to this plant. The additional stage would bring the pH and silver concentrations of the effluent mixture of fixer, developer, and washwater to acceptable wastewater levels as determined by the EPA and state regulations. Savings resulted from the elimination of \$800 of disposal costs per year since 270 gal/yr of nonhazardous liquid waste effluent could be disposed of as regular wastewater. This recommendation is one that falls into the “recycle waste materials” category.

A final AR given to this plant involving pollution prevention and lean manufacturing was a recommendation to repair a leaking hot water supply line. The total water savings were 36,700 gal/yr. Since the water was heated, the total natural gas energy savings were 8 MMBtu/yr, corresponding to a reduction of 900 lbs/yr in CO₂ emissions. Implementation of this recommendation would reduce non-value-added utility and water purchasing costs by \$190 per year and would cost only \$300 to implement. Since this recommendation

involves conserving water, this AR is one that falls into the “develop conservative material usage practices” category.

CONCLUSIONS

The results demonstrate that pollution prevention and lean manufacturing go hand in hand. Waste reduction is a central issue in lean manufacturing. The results reported herein demonstrate that pollution prevention practices can reduce polluting emissions and thereby reduce expenditures for non-value-added activities. The results show that recycling and reduction of manufacturing wastes can also enhance lean manufacturing. In terms of ARs that can produce the largest average costs savings, the leading ARs are more conservative use of materials, recycling, and switching off equipment not required. With an overall average payback period of approximately 0.9 years and an implementation rate of 48%, it is clear that the industrial assessments can contribute to lean manufacturing.

An additional benefit of the CSU IAC program is that CSU students obtain practical industrial experience. Such experience complements traditional classroom and laboratory instruction and provides potential advantages for students seeking industrial employment following graduation.

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