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# Prevention through Design (PtD): Combining Risk Assessment, Productivity and Sustainability


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## Introduction

Prevention through Design (PtD) addresses occupational safety and health needs in the design and redesign processes to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, equipment, and the service sector. One of the goals is to educate designers, engineers, machinery and equipment manufacturers, environmental, health and safety (EHS) professionals, business leaders, and workers to understand and implement PtD methods and apply this knowledge and skills to the design and re-design of new and existing facilities, processes, equipment, tools, and organization of work.

One of the many challenges EHS professionals are facing is developing skills to convince management to maximize the effectiveness of the safety program and consequently increase productivity. EHS professionals have to help management transform safety into an accepted business value for the organization. In order to be successful, the EHS students and professionals have to learn to use the PtD principles and incorporate them into standard business practices. A major hurdle to the adoption of PtD is the perception that the PtD cost/benefit ratio is unfavorable. EHS professionals should recognize business cost drivers and justify PtD design expenditures in the early product development stage. Therefore, the authors developed a PtD model that incorporates risk assessment, hierarchy of controls, productivity, financial analysis and future state projections. To demonstrate the applicability of the model; the authors selected a case study that was suitable for practical demonstration and for use as an educational module. A Value-added project for refuse trucks improvements is presented. In the model PtD principles were combined with risk assessment tools, productivity evaluation and sustainability. This case study demonstrates how EHS professionals can play a significant role in the development of new business plans and implementation of Lean Six Sigma practices, designed to minimize injuries and improve productivity.

## History of PtD

Prevention through design is not a new concept and as with many worthwhile endeavors has roots in the work of several previous individuals and organizations (Manuele, 2007, ANSI/SIHA, 2005). The work of Edward Demming via his total quality management process certainly provided foundational underpinnings for PtD (Manuele, 2008, Deming, 1982). Deming gives credit to others for the TQM process and thus the circle continues to turn and involve many participants. ASSE published a position paper on Designing for Safety, in the 1990s (1994). NIOSH gave the PtD movement a boast via a variety of meeting and publications, starting in the 1990s. In late 2010, NIOSH released its PtD plan (2010). ASSE and AIHA has also provided significant support for PtD. ASSE is the Secretariat for the recently published ANZI PtD standard.

PtD has been gaining momentum for the past several years as evidenced by the inclusion of PtD in current occupational safety and health textbooks (Blunt, Zey, Greife, Rose, 2011). The authors believe this trend will continue for the foreseeable future. This idea is also supported by recent publications (Manuele, 2008, Manuele, ND).

## Project Description

Trash collection requires significant amount of repetitive movements. Musculoskeletal Disorders (MSD's) including lower back, and Carpal Tunnel Syndrome (CTS) injuries were recognized as a main concern for business continuity and sustainability of the company. Human Resources (HR) reported difficulties in hiring new employees and the organization had experienced a high turnover rate. In today's global economy the management had to take the necessary steps to reduce ergonomic injuries and improve productivity. This study demonstrated potential savings an organization can realize from PtD implementation. The purchase of new refuse trucks had to be justified. The organization formed a safety and risk management team and prepared a business case for the investment. The team had to identify priorities and developed a project model. PtD was identified as a key component of the project. The main requirement was that the new refuse trucks were to be designed in a way to eliminate or minimize ergonomics injuries. Our recommendation was to utilize PtD, Lean and Six Sigma tools to perform current state of the art risk assessment and develop intervention priorities. PtD and Failure Mode and Effects Analysis (FMEA) tools may also be used to develop future state projections for reduced risk. Productivity gains may be evaluated utilizing common LEAN tools. Project Cycle Efficiency (PCE) could be calculated for current state productivity and future state projections. Value Stream Mapping (VSM) was used to evaluate current state vs. future state process.

A new tool for business investment analysis was developed for the project. Different solutions were evaluated and prioritized. The Excel-based tool helped EHS professionals involved in the project and the team to compare total annual incidence cost before the improvements/intervention; total annual incidences cost after the improvements/intervention, and calculate incident benefit and cost savings. The EHS professionals next calculated the Return on Safety, Health and Environmental Investments (ROSHEI) by simply adding net savings, new revenue (generated from increased productivity), and other benefits (maintenance, fuel savings, insurance, etc). Net Present Value (NPV) and the payback period for the safety investment were also calculated. Return on investment (ROI) was calculated next and is displayed as a numerical value as well as percentage. Internal Rate of Return (IRR) is another business term and is usually considered a simplified alternative to NPV. The tool calculates and displays IRR as a percentage. Based on our experience, we found that business managers would prefer to see comparisons of different proposals rather than a single solution. Therefore, a worksheet to compare four different proposals was developed. NPV's for the different proposals are compared and displayed as a numerical value, while IRR's and ROI's for all proposals/solutions are displayed as a percentage. To satisfy the new expectations and gain support for EHS improvements, the team had to complete a cost – benefit analysis for mitigating potential hazards.

Business analysis revealed a payback period of a little more than four years. IRR was only 12%. The management of the organization requested non-financial benefits to be included in the model for complete evaluation. The organization requested assistance from a team of UCM students to evaluate the existing truck emissions and compare them to the new trucks emissions. The new trucks run on Compressed Natural Gas (CNG) and the existing trucks use diesel fuel. Particulate matter (PM 2.5 and PM 10), $NO_2$, $SO_2$, $O_3$, and CO levels were evaluated. In addition, VOC's levels were also compared.

The management was not fully convinced based on the safety aspects alone. Therefore, gains in productivity and non financial benefits had to be included. "Projecting a green image" and reduced air pollutants emissions played a substantial part in the decision making process.

## Methods

A new decision making model was developed to improve the refuse collection process. This research identified potential areas for EHS professional involvement in the decision making process. The authors developed a new PtD model that incorporates risk assessment, hierarchy of controls, productivity, financial analysis and future state projections. The model follows Define, Measure, Analyze, Improve, and Control (DMAIC) logic. Separate tools were developed for each phase. For instance, Delphi, brainstorming and Preliminary Hazard Analysis may be used in the "Define" phase. Modified Bow Tie, Risk Assessment matrix, and Failure Mode Effect Analysis (FMEA) may be used in the "Measure" phase. (Popov, 2011).

The FMEA tool was used to prioritize the hazards and modify the procedure to demonstrate and quantify the risk reduction after the proposed EHS intervention. Several other tools were used during this evaluation, such as VSM, PCE and Pareto 80/20 analysis. Next, adjustments were made and the improvements were evaluated utilizing Lean Six Sigma tools.

Air pollutants levels were evaluated for the current diesel trucks and were compared to the new CNG trucks. The emissions were evaluated utilizing direct reading instruments.

To demonstrate the applicability of the newly developed PtD model, the authors present the following case study. Due to confidentiality agreements, the team members and company name can't be shared.

## Case Study

The refuse collection companies that still use manual trash collection technique usually have very high musculoskeletal disorders (MSD) injury rate. That results in high turnover rate, high absenteeism rate and significant financial losses for the company. Therefore, a value added business plan for replacement of old refuse trucks with new automated trucks had to be developed. EHS professionals may be hired to coordinate and manage the process to convince various levels of management, that such significant investment is justified.

Ergonomics risk assessment was completed utilizing PtD and Six Sigma tools. High priority areas for improvements had to be evaluated first. The study included initial cost-benefit analysis. Gross Cost Savings from Environmental, Health, and Safety (EHS) interventions were calculated. NPV, Payback Period, simple ROI and IRR calculations from EHS interventions were included in the study. A worksheet to compare proposals and interventions benefits was developed.

The main purpose of the project was to demonstrate the benefits of automated refuse collection trucks vs. conventional refuse collection trucks that are currently in use (Figure 1).

**Figure. 1. Refuse collection trucks**

Conventional refuse collection trucks

Automated refuse collection trucks

To understand the process and develop possible intervention plan, simple digital images were used. However, the authors had to develop a comprehensive management plan that would lead to complete analysis of the process and convince the management of the benefits of investing in new trucks. The team members observed the process and recorded the time required for each step. The steps are presented below.

Step 1. Position the truck.

Step 2. Lift two polyethylene bags.

Step 3. Dump the bags.

Step 4. Repeat steps 2 and 3 lifting and dumping two more bags. Four poly bags are allowed per household.

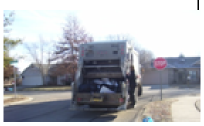
Step 5. Compress the trash.

Step 6. Refuse collector steps on the side platform (step) and holds on to the handle.


Step 7. Drive to the next house.

The first task was to perform Failure Mode and Effects Analysis. The process of potential injuries analysis was evaluated. After several meetings with risk managers and accounting professionals, a worksheet with automated calculations options was developed. Risk Priority Number (RPN) was also included in the worksheet. Please see the worksheet below.

## Figure 2. FMEA and RPN worksheet

| FMEA & RPN WORKSHEET | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Part or Process Name | Trash Pick up | Suppliers & Plants Affected | | | | Prepared By | | | | | | | | | | |
| Design/ Mfg Responsibility | | Model Date | | | | FMEA Date | | | | | Go to ROI | | | | | |
| Other Areas Involved | | Engineering Chang | | | | | | | | | | | | | | |
| Process Operation, Function or Purpose | Potential Failure Mode | Potential Effect(s) of Failure | SEV | Potential Cause(s) of Failure | OCC | Current Controls Evaluatio | DET | S x O | RPN | Recommended Action(s) | Area/Individual Responsible & Completion | Action Results Actions | SEV 2 | OCC 2 | DET 2 | RPN 2 |
| Trash pick up  | Back injur | Back | 4 | Rep. motion | 3 | None | 3 | 12 | 36 | Automate  | Management | Reduced Exposure | 3 | 1 | 1 | 3 |
| Lift bags  | Back injury and elbows | Back and elbows | 4 | Rep. motion | 2 | None | 3 | 8 | 24 | Automate  | Management | Reduced Exposure | 3 | 1 | 1 | 3 |
| Fall/slip probability  | Fall/slip injuries | Legs/arms | 4 | Fall | 1 | None | 3 | 4 | 12 | Eliminate (1 operator) | Management | Eliminated Exposure | 3 | 1 | 1 | 3 |

FMEA analysis shows high potential for back and shoulder injuries. Risk Priority Number was the highest for trash bags pick. In addition to the injuries, MSD's resulted in $ 49,822 workers compensation cost per year. The financial expenses were clearly communicated to the risk manager. The next task was to collect data and compare the Return on Investment (cost-benefit) analysis (Figure 3).

## Figure 3. ROI worksheet

**Return on Investment (ROI)**

| Current State | Annual Cost Items: | | | Line Item Description | Future State | Annual Cost Items: | | | Line Item Description |
|---|---|---|---|---|---|---|---|---|---|
| | 16 | | 1 | Number of employees - Refuse Collector I | | 10 | | 1 | Number of employees - Refuse Collector I |
| | Cost ($) | | | | | Cost ($) | | | |
| 1 | $49,822.06 | $49,822.06 | 2 | Workers Compensation cost | 1 | $12,455.00 | $12,455.00 | 2 | Workers Compensation cost |
| 16 | $34,595.00 | $553,520.00 | 3 | Annual cost Refuse Collector I salary | 10 | $34,595.00 | $345,950.00 | 3 | Annual cost Refuse Collector I salary |
| 16 | $10,378.50 | $166,056.00 | 4 | Annual cost Refuse Collector I benefits (30% salary | 10 | $10,378.50 | $103,785.00 | 4 | Annual cost Refuse Collector I benefits (30% salary) |
| 1 | $280,686.00 | $280,686.00 | 5 | Trucks maintenance | 1 | $0.00 | $0.00 | 5 | Trucks maintenance |
| 1 | $181,546.00 | $181,546.00 | 6 | Fuel | 1 | $132,528.00 | $132,528.00 | 6 | Fuel |
| | | $40,000.00 | 7 | Accident investigation/Admin time? | | | $10,000.00 | 7 | Accident investigation/Admin time? |
| | | $50,000.00 | 8 | Insurance? | | | $35,000.00 | 8 | Insurance? |
| | | | 9 | EMR? | | | | 9 | EMR? |
| | | | 10 | Turn over rate | | | | 10 | Turn over rate |
| | | | 11 | HR Cost to hire new employees | | | | 11 | HR Cost to hire new employees |
| | | | 12 | Other | | | | 12 | Other |
| | | | 13 | Other | | | | 13 | Other |
| | | | 14 | Other | | | | 14 | Other |
| | | | 15 | Other | | | | 15 | Other |
| | | | 16 | Other | | | | 16 | Other |
| | | | 17 | Other | | | | 17 | Other |
| | | | 18 | Other | | | | 18 | Other |
| | | | 19 | Other | | | | 19 | Other |
| | | | 20 | Other | | | | 20 | Other |
| | | | 21 | Other | | | | 21 | Other |
| Total: | $557,027.56 | $1,321,630.06 | | | Total: | $189,956.50 | $639,718.00 | | |

Go to NPV

$$ROI = \frac{P_b - P_c}{P_c}$$

Simple ROI = -0.51596 or -51.60%

Simple annual benefit $681,912.06

The worksheet was developed specifically for this project. However, it could be used for other projects as well. The form is a comprehensive analysis of different categories and the financial impact of each category. Some of the categories are easily quantifiable. For instance, workers compensation cost was obtained from the accounting department. Annual salaries and benefits were also obtained from the accounting department. Fuel and maintenance cost was obtained from the maintenance department. Experience Modification Rating (EMR) measures worker compensation claims. Maintained exclusively by the insurance industry, EMR is the objective measurement of each employer's claims experience. The published manual rate for each state is multiplied by the employer's EMR to determine the premium rate paid by the employer. An EMR below 1.00 indicates that the employer will pay premiums below the manual rate. The company was approaching an EMR of 1.00 and it was vitally important to lower the rate to avoid increased insurance premiums. Due to confidentiality concerns, EMR impact was not disclosed and could not be included in the calculations. Cost to hire new employees was not disclosed by the client. Therefore, it was not included in the calculations.

The financial analysis shows that the project is not beneficial after the first year. Therefore, more detailed financial analysis was requested. Three and five year's NPV was calculated (Figure 4).

### Figure 4. NPV calculations

Net Present Value (NPV)

$$\sum_{t=0}^{n} A_t (1+i)^{-t}$$

***$A_t$ represents the annual net discounted cash flow of program or intervention**

***i*** **represents the designated discount rate**

**$(1+i)^{-t}$ is called the 'Discount Factor' - DF**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_{t0}$ = | -2,800,000 | $A_{t1}$ = | 681,912 | $A_{t2}$ = | 681,912 | $A_{t3}$ = | 681,912 | $A_{t4}$ = | 681,912 | $A_{t5}$ = | 681,912 |
| $i$ = | 0.04 | | | | | | | | | | |

| | |
|---|---|
| For t=3, NPV = | -907632 |
| For t=5, NPV = | 235751.1 |

**If the discount factor is given instead of discount rate use the following:**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_{t0}$ = | -2,800,000 | $A_{t1}$ = | 681,912 | $A_{t2}$ = | 681,912 | $A_{t3}$ = | 681,912 | $A_{t4}$ = | 681,912 | $A_{t5}$ = | 681,912 |
| $DF_0$ = | 0.4 | $DF_1$ = | 0.9259 | $DF_2$ = | 0.8573 | $DF_3$ = | 0.7938 | $DF_4$ = | 0.735 | $DF_5$ = | 0.6806 |

| | |
|---|---|
| For t=3, NPV = | 637287.2 |
| For t=5, NPV = | 1602602 |

*These calculations will differ slightly from above due to rounding of the discount factor.

The analysis clearly shows that NPV is negative after three years, but after five years we can expect some benefits. Therefore, the Pay Back period had to be calculated precisely (Figure 5).

**Figure 5. Payback period calculations**

Payback Period

$$\sum_{t=0}^{p} A_{t,x} \geq 0$$

*$A_{t,x}$ represents the annual net cash flow of a program or intervention. The simple payback period does not consider the value of time; the cash flow entries are not discounted. The discounted payback period uses cash flow entries which have been discounted.

| | | | | | | |
|---|---|---|---|---|---|---|
| $t$ = | 0 | 1 | 2 | 3 | 4 | 5 |
| $A_t$ = | -2,800,000 | 681912 | 681912 | 681912 | 681912 | 681912 |
| Comulative Net Cash Flow = | -2800000 | -2118088 | -1436176 | -754264 | -72352 | 609560 |
| Payback Date = | | | | | | 4.106102 |

Next, complete financial analysis was requested by the client. Following two meetings with various levels of the company management, a worksheet was developed to calculate and capture financial benefits of the project. Typical business tools and statistics were used to develop the worksheet (Figure 6).

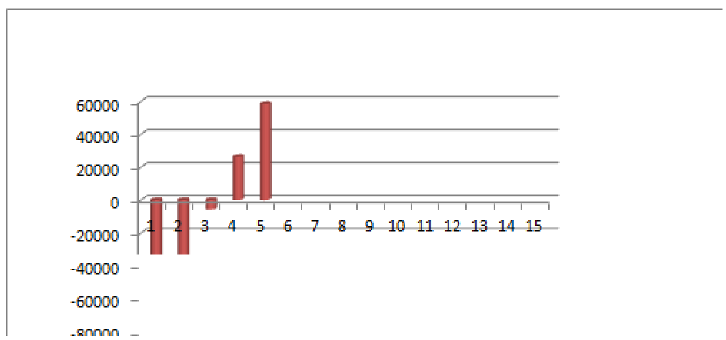
**Figure 6. Financial analysis**

| Interest Rate | | | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 |
|---|---|---|---|---|---|---|---|---|---|
| | Cost | | | | | | | | |
| 7% | | New Trucks | 2,800,000 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Other | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Other | | 0 | 0 | 0 | 0 | 0 | |
| | Total Costs to Implement | | 2800000 | 0 | 0 | 0 | 0 | | |

| | | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 |
|---|---|---|---|---|---|---|---|---|
| Benefits | | | | | | | | |
| | Benefits | | 681,912 | 681,912 | 681,912 | 681,912 | 681,912 | 681,912 |
| | | | | | | | | |
| | | | | | | | | |
| Total Benefits | | 0 | 681912 | 681912 | 681912 | 681912 | 681912 | 681912 |

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 |
|---|---|---|---|---|---|---|---|
| Net Savings | $ (2,800,000) | $ 681,912 | $ 681,912 | $ 681,912 | $ 681,912 | $ 681,912 | $ 681,912 |
| Cumulative Net Gain | $ (2,800,000) | $ (2,118,088) | $ (1,436,176) | $ (754,264) | $ (72,352) | $ 609,560 | $ 1,291,472 |

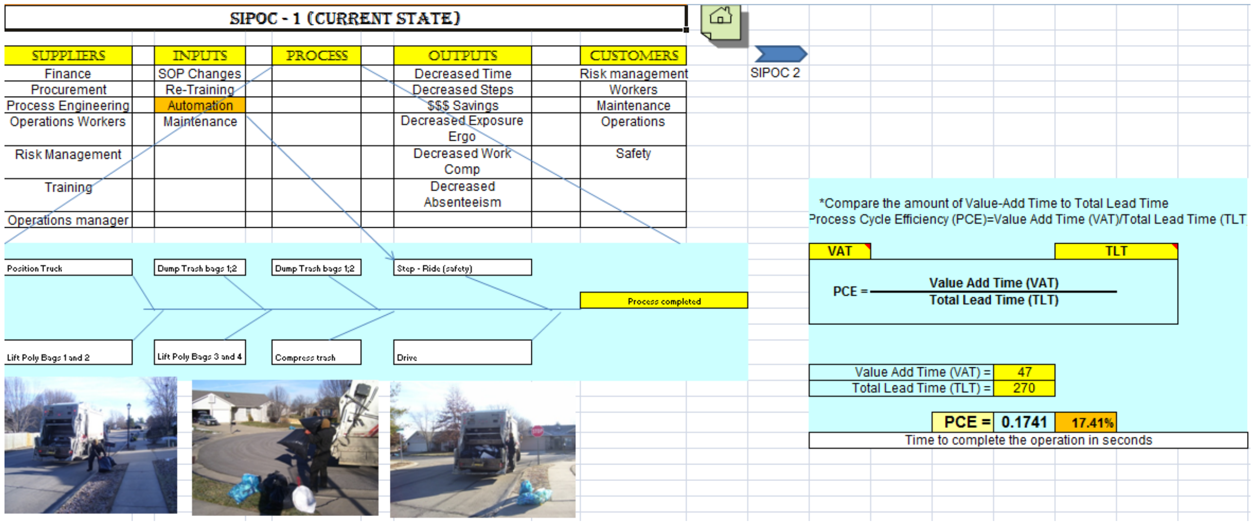
| | | |
|---|---|---|
| PV(costs) = | $2,629,108 | |
| PV(savings)= | $3,099,667 | |
| NPV= | $470,559 | |
| Payback= | | 4.106101667 |
| ROI (net) = | 18% | |
| IRR = | 12% | |




An interest rate of 7% was requested by the client. This is not a realistic interest rate at the moment. However, conservative estimates were required for this project. The worksheet and the built in formulas allow for interest rate adjustments. The worksheet also includes IRR calculations. The IRR is a rate of return used in capital budgeting to measure and compare the profitability of investments. The IRR calculated to 12%. For some companies IRR below 12% is not acceptable.

The payback period of 4.1 years was still not acceptable for the business managers. In order to capture other benefits and convince the management, a new LEAN Six Sigma tool had to be developed and the authors had to observe and measure productivity efficiency. Current state Project Cycle Efficiency (PCE) was evaluated and compared to future state PCE. A combination of Six Sigma “Suppliers, inputs, process, outputs, customers” (SIPOC) and LEAN Value Stream Mapping tools were utilized to present the benefits of the project (Figure 7).

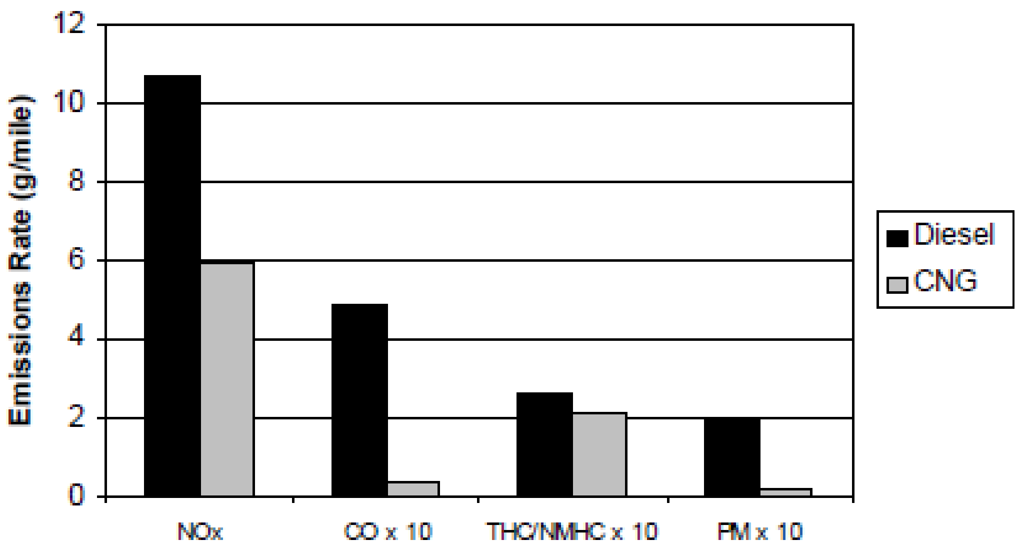
**Figure 7. Current state SIPOC and PCE**




A typical fish bone diagram was used to present VSM. It is easy to understand and a relatively simple tool to use.

However, it was noticed that the project may have non-financial benefits as well. A concern existed for emissions from the garbage trucks.  Therefore, two students measured the emissions from the diesel trucks. Another company that already implemented automated Compressed Natural Gas (CNG) trucks was kind enough to let us sample the CNG emissions. Diesel emissions were higher in all categories for the older type truck, that we were able to measure. Figure 8 provides the airborne data and comparisons for both types of trucks.

**Figure 8. Air pollution – Sustainability**

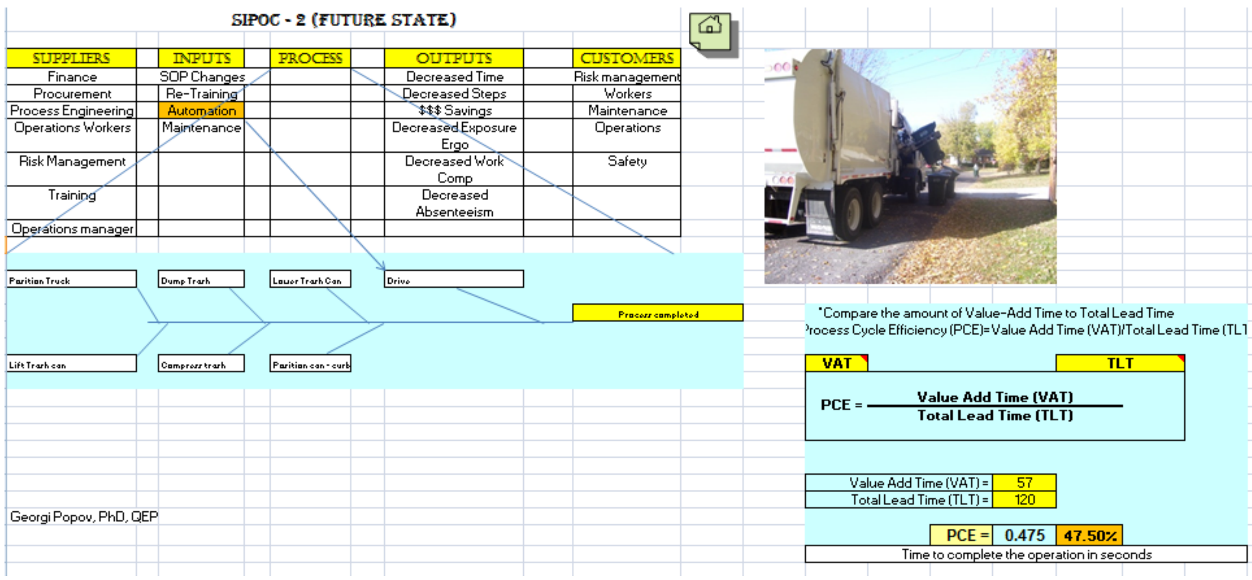


## Results

Process improvements were evaluated utilizing Lean Six Sigma tools and modified risk assessment methodologies. The same SIPOC and PCE worksheet was used to evaluate future state improvements and process efficiency.

Future state SIPOC and PCE worksheets are presented in Figure 9~~.~~

**Figure 9. Future state SIPOC**




Utilization of PtD, FMEA and Risk Assessment processes and the implementation of a new model are estimated to significantly reduce the ergonomics injuries and reduce the probability of fall hazards. PCE was improved from 17.41% to 47.50% due to the implementation of Lean practices. Possible EHS involvement in the process was evaluated. Based on the comparison calculations, PCE increased from 17.41% to 47.5%.

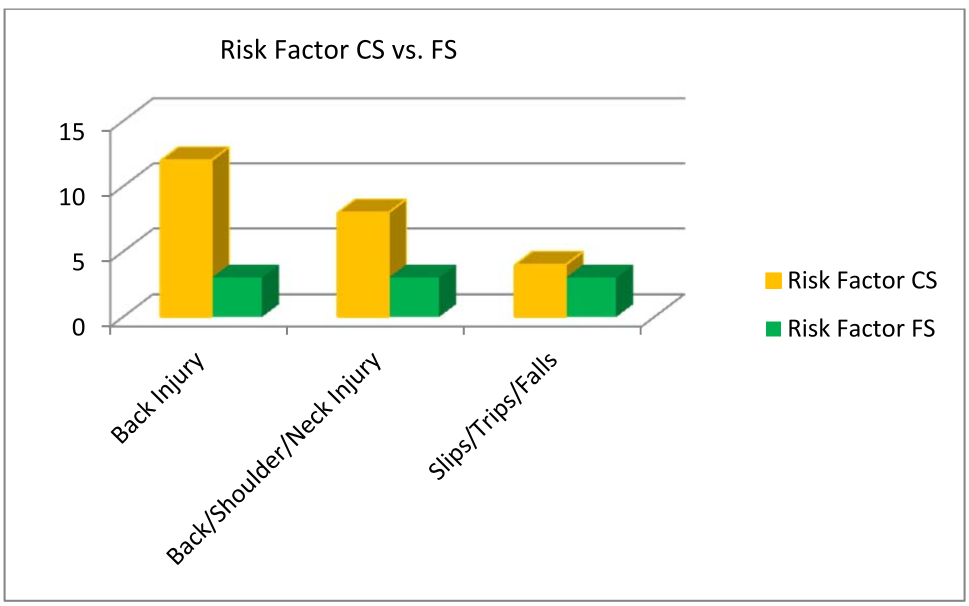
Additionally, Residual Risk Reduction (R3$^{TM}$) was calculated. EHS improvements resulted in 62.50% risk reduction. (R3$^{TM}$ evaluation tool). Figure 10 presents current state vs. future state risk factor comparison.

**Figure 10. Current state vs. future state risk factor comparison.**

| Residual Risk Reduction (R3™) | | | |
|---|---|---|---|
| | Hazards | Risk Factor CS | Risk Factor FS |
| | Back Injury | 12 | 3 |
| | Back/Shoulder/Neck Injury | 8 | 3 |
| | Slips/Trips/Falls | 4 | 3 |
| | Total | 24 | 9 |
| | | | |
| | % Reduction | 0.375 | 37.50% |
| | **R3** | 0.625 | 62.50% |
| R3=(RF CS-RF FS)/RF CS*100 % | | | 62.5 |

Figure 11 visualizes risk factor reduction and comparison of current state risk assessment vs. estimated future state risk factors.

**Figure 11. Risk Factor Reduction and Comparison**




Color codes could be used to present estimated risk reduction. The authors opted to use a PtD (5x5) composite of the matrix that include numerical values for probability and severity levels and their combinations are expressed as numerical risk scorings (ANSI/ASSE, 2011)~~.~~ As suggested in the standard, numerical values of 15 or higher suggests very high risk, therefore the color code is red. Numerical values of 10 to 14 suggest high risk and are highlighted in orange.

Moderate risk is from 6 – 9 and highlighted in yellow and low risk is under 1 to 5 and it is highlighted in green. The suggested EHS project is estimated to reduce all high and moderate risk ratings to low risk. Therefore, the chart visualizes significant risk reduction in all evaluated categories.

## Conclusions

EHS professionals could play a significant role in the development of new business plans and implementation of Lean Six Sigma practices designed to minimize injuries, improve productivity and reduce waste time. PCE for this process was improved significantly and was made safer due to input from the EHS professional and involvement of a team of students. The project led to a decision by management to buy new safer refuse trucks, which presents opportunities to reduce injuries, reduce emissions and improve productivity.

It was concluded that Risk Management, LEAN Six Sigma tools and financial analysis could be used successfully to develop and present business case for Environmental, Health, and Safety interventions.

Lessons Learned

EHS professionals have to develop management skills and diversify their knowledge to overcome difficulties during such projects. After the initial analysis, it became clear that significant investment projects can't not be easily justified based on risk assessment alone. Future leaders in the safety profession will have to develop statistical skills and demonstrate knowledge in financial management. In order to defend such projects, EHS professionals have to be familiar with variety of risk management techniques, LEAN Six Sigma tools and financial management principles. Being an expert in ergonomics is not enough to complete successful complex projects. Complex projects require multi-disciplinary knowledge and cross-disciplines management skills. Safety leaders have to become familiar with different organizational structures and the variety of stakeholders interests to complete such projects. EHS professionals have to be prepared to deal with various levels of the organizational management and demonstrate competencies.

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