Virtual Welding Systems at BCIT

Date: November 25, 2011

Company
British Columbia Institute of Technology
3700 Willingdon Avenue
Burnaby, BC

BCIT Directed Studies
Operations Management

Anna Le Good

Tara Chandra

Client
Alex Hebert, Energy Supervisor
Andrea Linsky, Energy Specialist
David Helman, Chief Welding Instructor

BCIT Project Coordinator/Advisor
Richard Vurdela

Executive Summary

A team of BCIT Business Operations Management students (hereafter referred to as the Team) were engaged by Alex Hebert, Andrea Linsky, and David Helman to investigate the feasibility of integrating a Virtual Welding System (VWS) into the welding program at BCIT. The purpose of the study was to determine if the integration of a VWS could reduce the environmental impact and carbon emissions in the Sustainability Precinct at BCIT, meet the requirements of the stakeholders, and be a valuable teaching tool.

The following steps were taken in conducting a feasibility study:

- The stakeholders were identified, analyzed and interviewed by the Team.
- User requirements were gathered and ranked from several interviews and analyzed.
- A cost-benefit analysis of integrating a VWS was conducted.
- Product analysis and recommendation was completed.

It was found that integrating a VWS into the welding program at BCIT will not significantly reduce the energy consumption of the Sustainability Precinct. Consequently, there will be little savings in carbon offset charges to BCIT or a reduction of energy consumption.

The findings in this study lead to the conclusion that the purchase of eight Virtual Welding Systems to support full integration into the welding program is not feasible. None of the investigated systems meet the requirement of a payback period of 5 years or less as stipulated by the Revolving Fund and the capacity of the current welding facility does not meet the space requirements of eight systems.

Although the purchase of eight systems is not feasible at this time, the integration of one system to be used as a remedial tool and for marketing and promotion is feasible. The system that best matches the requirements and features as determined by the users is DIGINEXT's CS Wave.

Additional information should be investigated and gathered prior to the decision of purchasing any of the investigated systems. The decision to integrate a VWS at BCIT will be enhanced with further investigation in the following areas:

- Future ventilation system and the additional energy savings associated with it
- Greater utilization of the VWS through deeper integration into the curriculum
- Verify assumption that one system would be used the equivalent of one welder
- Given the above, comprehensive assessment of the available virtual welding systems to refine machine comparison

Once these areas have been investigated fully, the decision to incorporate a VWS at BCIT can better be determined.

Acknowledgements

We would like to recognize the following people for their contribution to this study:

Alex Hebert

Energy and Sustainability Manager, BCIT

Andrea Linsky

Energy Specialist, BCIT

Chandra Stalker

Operations Administrator, BCIT School of Construction and the Environment

Claude Choquet

President and Founder 123 Certification Inc.

David Helman

Chief Instructor of Welding BCIT School of Construction and the Environment

Donna Marshall

Barry Hamel

Ken Mui

Lincoln Electric

Ken Pearce

Account Executive Western Canada, CWB Group

Laurent Da Dalto

Product Manager DIGINEXT

Merv Kube

Welding Instructor, PIAB

Mike Bednarz

Instructor, Operations Management, BCIT School of Business

Richard Fowler

Purchaser, BCIT

Richard Ranftl

Program Head, Business Operations Management, BCIT School of Business

Richard Vurdela

Project Advisor BCIT School of Business

Rod Walters

Welding Instructor, BCIT School of Construction and the Environment

Scott Stanley

Sales Representative Lincoln Electric

Tamara Pongracz

Chief Instructor of Trades Discovery, BCIT School of Construction and the Environment

Table of Contents

List of Tables

List of Appendices

Introduction

Purpose

The purpose of this study is to determine if a Virtual Welding System (VWS) can provide a significant decrease in waste, environmental resources, and cost to the welding program, meet the requirements of all stakeholders, and improve quality of teaching.

Project Goals

Decrease the Carbon Offsets at BCIT

In 2008, BC's provincial government passed the Greenhouse Gas Reduction Targets Act, Bill 44. This act established a target for all public-sector organizations, including BCIT, to be carbon-neutral by 2010. This means that starting in 2010, for every ton of CO_2 emitted, BCIT was charged $25 (per ton). The total bill for 2010 was $280,000.

BCIT's School of Construction and Energy has created a Sustainability Precinct with the intention of reducing energy and materials consumption on a portion of the Burnaby Campus by 90%, while maintaining current service levels.

The integration of a VWS is seen as a project that could positively affect the efforts of the Sustainability Precinct.

Supplement the Existing Curriculum

In BCIT's 2009-2014 Strategic Plan's Strategic Initiative 1 (Education and Research), an objective of BCIT is to "advance the BCIT learning experience through excellent instruction, the innovative and appropriate use of educational technologies, the provision of modern learning spaces and access to a virtual BCIT that provides a gateway to many institute services online". Determining the impact and effects of the integration of a VWS into BCIT's welding curriculum is important in aligning with that strategic objective.

Establishing how or if a VWS could supplement the existing curriculum and provide an innovative and appropriate use of educational technology is pertinent in determining the feasibility of such a decision.

Decrease Costs

Use of a VWS suggests significant reduction in energy savings by reducing the use of regular welding machines. Furthermore, there may be a significant reduction in the consumption of materials used by welding students, and thus a significant savings on materials purchased by the Welding Department. Not only would it reduce materials spending for the department, but it would also reduce the amount of waste produced.

A primary study conducted by BCIT of the current energy consumption of current machines and the costs of materials used by the welding department would be needed to determine the actual amount of savings possible and whether it is significant enough to consider purchasing a VWS.

Marketing

The use of virtual technologies in training environments has increased due to several industries' demand and interest. To remain competitive as a training facility, it would be optimal for BCIT to be on the cutting edge of technology in the welding program.

The demand for quality welding training in B.C. has already increased and will continue to increase due to the announcement of the $8 billion federal shipbuilding contract.

Current users of VWSs in Canadian training institutions are using the systems as promotional and marketing tools. Potential students interested in trades have the opportunity to try out welding without having to step foot in the shop. As with supplementing the existing curriculum, the integration of a VWS has the potential of further aligning BCIT's welding school with the 2009-2014 Strategic Plan's Strategic Initiative 1. Objective 8 states "…Remain at the forefront of technological change and the state-of-practice through our programming and applied research."

Scope

This study was limited to collecting and analyzing the data needed to determine the feasibility of introducing a Virtual Welding System to the Welding Program in BCIT's School of Construction and the Environment. Three key areas of focus were identified for the study: user requirements, cost benefit analysis, and brand selection.

Assumptions

Certain assumptions were made throughout the project in lieu of unavailable information. In each instance an educated assumption was made based on relevant information attained from interviewing stakeholders. The following are the assumptions made:

- materials consumption throughout the year is constant
- amount of students is constant throughout the year
- the welding department's share of the recycling of scrap metal is 15%, according to Dave Helman and Ron Rollins, Chief Instructor of Steel Trades.
- energy use by each student is approximately consistent

Methodology

The steps taken to determine the feasibility of integrating a virtual welding system (VWS) at BCIT were:

- Identification of stakeholders
- Interviews with stakeholders
- Identification and verification of user requirements
- Gathering of cost data
- Analysis of cost data and the benefits associated with purchasing a VWS
- Identification of available VWSs
- Research of available VWSs
- Analysis and comparison of available VWSs

Stakeholder Identification

Stakeholders affected by this study were identified through Stakeholder Analysis. The first step in conducting a stakeholder analysis is to brainstorm who those affected by this study might be.

Potential stakeholders were identified as:

- anyone who will operate the system
- anyone who will benefit from the integration of a VWS
- anyone involved with the purchasing process
- organizations who regulate the welding training curriculum, the testing, and the certification of students
- anyone opposed to the integration of a VWS
- organizations responsible for any additional systems required to interface with a VWS.

A list of the people who fit the above criteria was compiled and placed into a grid (as exampled below) based on influence and importance.

Importance to Stakeholder

Influence of Stakeholder	Unknown	Little	Somewhat	Significant
Significant				
Somewhat				
Little				
Unknown				

Table 1 - Example of Stakeholder Analysis Influence/Importance Grid

Stakeholder Interviews

Members from each of the identified stakeholder groups were interviewed to obtain information on the following:

- user requirements of a VWS
- materials spending and consumption
- personal experience using a VWS
- VWS primary information not advertised

Identification and Verification of User Requirements

User requirements were identified using the following methods:

- Interviews conducted through emails, telephone, and face to face
- A live trial/demonstration of VRTEX™360
- Surveys and Questionnaires

Once the user requirements were identified and compiled, major stakeholders were asked to verify the requirements using Kano Analysis.

	LIKE	NORMAL	DON'T CARE	DON'T LIKE
LIKE		Delighter	Delighter	Satisfier
NORMAL				Dissatisfier
DON'T CARE				Dissatisfier
DON'T LIKE				

Table 2 - Example of Kano Analysis Table

Kano Analysis separates user requirements into four categories - Dissatisfiers, Satisfiers, Delighters, and Indifferent. The requirements are placed into the four categories by asking:

- How would you feel if the requirement was satisfied?
- How would you feel if the requirement was not satisfied?

To ensure consistency, stakeholders were asked to respond to the above questions with only one of the four possible responses listed below.

- I'd like it
- It is normal (or expected) that way
- I don't care
- I wouldn't like it

Based on the stakeholders' responses to the above questions, the user requirements were placed into a chart as exampled below. If a requirement fell into one of the grey areas (the 'Indifferent' category), it was not included in the final list of requirements.

Research of Available Virtual Welding Systems

Secondary research, through each company's website, was conducted. Information was obtained on product features, benefits and capabilities for all three VWSs. After the secondary research was complete, a list of remaining unanswered questions was compiled and interviews with representatives from each of the companies were conducted.

A trial of the VRTEX™360 virtual welding system was conducted on November 2, 2011. A small amount of instructors and students had a chance to try the system. Those that tried the machine were asked for their feedback and comments in face-to-face interviews. The system was later demonstrated at the BCIT Big Info Night and prospective students were given an opportunity to try the system. Their comments and feedback were compiled in an online survey. For the results of the interviews and surveys, see Appendices B and C.

Gathering Cost Data

Materials consumed by the School of Welding are identified and categorized as:

- Steel
- Consumables
- Gas

Gathering cost data for each consumable was obtained through the following methods:

- Interviewing BCIT purchasing department
- Contacting vendors; invoices for materials were collected for the period of April 2011 – October 2011.
- Interviewing instructors in the BCIT Welding Department

Investigation and Calculation of Materials Savings

In order to accurately prepare a cost benefit analysis, it had to be determined which materials were used by each of the three levels of welding, Level C, B, and A.

Each category of consumables is separated into the following groups

- Those used by only Level C welders
- Those used by all Levels

Scenario 1 – Full Integration into Curriculum – 8 Systems

A sensitivity analysis using three life cycle costing cases (base, pessimistic, and optimistic) were done for each of the three different virtual welding systems using the consumption of materials used by only Level C welders. Each case is based on purchasing eight virtual welding machines to be used by Level C students. A usage rate to apply to material consumption is calculated with the following equation.

$$Usage\ Rate = \frac{X\ amount\ of\ weeks}{total\ amount\ of\ weeks}$$

For all three cases, the following usage rates were applied to determine the effect on material savings.

	Base	Pessimistic	Optimistic
Amount of weeks used in curriculum	2	1	4.2
Total weeks in curriculum	28	28	28
Usage Rate	**7%**	**3.6%**	**15%**

Table 3 - Usage Rates of Scenario 1

Scenario 2 – Remedial Use Only and Marketing – 1 System

A sensitivity analysis using a life cycle costing case was done for each of the three different virtual welding systems using the consumption of materials used by only Level C welders. The case is based on purchasing one virtual welding system to be used by Level C students as a remedial tool. A usage rate to apply to material consumption is calculated with the following equation.

$$Usage\ Rate = \frac{X\ amount\ of\ systems}{total\ amount\ of\ systems}$$

The usage rate used to calculate material savings was based on the assumption that one VWS will replace the use of one real welder. For this case, the following usage rate was applied to determine the effect on material savings.

	Base
Amount of machines used in curriculum	1
Total machines in curriculum	16
Usage Rate	**6.25%**

Table 4 - Usage Rate for Scenario 2

Analysis and Comparison of Virtual Welding System to User Requirements

Each of the virtual welding systems was compared by common criteria pertaining to cost and systems capabilities. A Quality Functional Deployment (QFD) chart was chosen as the best method in comparing system features to user requirements. A QFD is designed to aid planners' focus on characteristics of a new or existing product from the viewpoint of stakeholders. This is done by translating user requirements into technical design requirements. Each characteristic is prioritized while setting targets for the product(s).

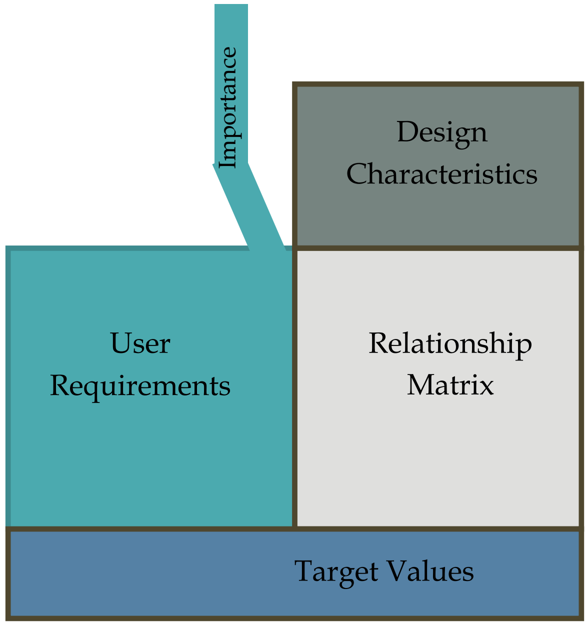


Table 5 - Quality Functional Deployment Chart

The benefits of utilizing a QFD are that it:

- Promotes better understanding of customer demands;
- Promotes better understand of design interactions;
- Involves users in the design/selection process;
- Provides documentation of the design/selection process.

The use of a QFD chart also ensures that the focus remains primarily on customer (or user) satisfaction.

Investigation and Calculation of Electricity Savings

To calculate energy consumption of the current welding machines, Dent Smart Loggers (a tool to measure on and off times of electrical machines) were placed on 3 of the welders (Lincoln Electric PowerWave 355M) for 22 days.

Dent Smart Logger Number	Placed on Welding Machine Number	Date of Attachment	Date Removed
2	FCAW #7	October 11, 2011	November 4, 2011
3	SMAW #9	October 11, 2011	November 4, 2011
4	FCAW #5	October 11, 2011	November 4, 2011

Table 6 - Dent Smart Logger Placement Information

To confirm energy usage logged by the Dent Smart Loggers was realistic, Dave Helman was interviewed to obtain an estimate of the actual amount of time a welder is occupied by a student and the percentage of time that was spent at high output. Each welder is available for use 10 hours a day and the percentage of time at high output is 35%.

To calculate average energy costs of the current welding machines and the available virtual welding systems, the voltage and amperage for high draw and phantom load of each system was collected. These figures were then used to calculate kilowatts. Once the on-time was known, the total hours were multiplied by the kilowatts to determine total kilowatt hours. The electricity rate was then applied to total kilowatt hours.

Analysis

Analysis of Stakeholders

Major stakeholders of the project are identified in the following groups:

- Existing students of the BCIT Welding Program
- Future students of the BCIT Welding Program
- Instructors of the BCIT Welding Program
- Trades Discovery Program at BCIT
- Piping Industry Apprenticeship Board (PIAB)
- CWB Group
- BCIT Sustainability and Energy
- BCIT Supply Chain Management
- BCIT Purchasing Department

From these groupings and the Stakeholder Analysis Influence/Importance grid, the following individuals were identified as the key stakeholders:

- David Helman
- Welding Instructors
- Alex Hebert
- Andrea Linksy
- Richard Vurdela
- Welding Students

Analysis of User Requirements

Prior to the Kano analysis, user requirements were collected from multiple stakeholders and grouped into the following categories:

- Usability
- Visual Accuracy
- Realistic
- Covers Curriculum
- Energy and Materials Savings

Within these groupings are a number of requirements. These requirements were ranked by the use of Kano Analysis. From this analysis, the most important requirements of a virtual welding system are:

- Simple and easy to use
- Convenient to service and fix
- Puddle Graphics

- Accurate depth perception
- Student and instructor can visually inspect a completed weld
- Length of weld between 6 – 8" long to ensure proper positioning throughout the entire weld
- Ability to perform successful welds in a variety of joints
- Ability to perform successful welds in a variety of positions
- Ability to perform successful welds in SMAW and GMAW
- Reliable and transparent way to track material and energy savings
- Consumes less material

The ranking of each requirement was determined by Dave Helman, Alex Hebert, and Andrea Linksy.

To view the results of the complete Kano analysis of this study, refer to Appendix D.

Using a Quality Functional Deployment (QFD) chart, user requirements were compared to system features (from secondary research). For each user requirement, features of a virtual welding system that addressed that need were put into the chart. A rating was then assigned based on how well that particular feature addressed the need.

These relationships were then reviewed by Dave Helman on relevancy and accuracy. Modifications were made based on his review. Refer to Appendix E for the complete results.

Based on these relationships, the top 10 most important features required in a virtual welding system and there weightings are profiled in the table below. To view the complete results, refer to Appendix F.

Feature	Weighting of Importance
Advanced and realistic graphics	163
Realistic accessories	69
Different weld joint configurations	65
Graphics are in high definition	62
Multi-positioning	60
Built-in curriculum	53
Teacher training on full usage	53
Warranty and local servicing	50
Record keeping of material savings	48
Welding surface is at least 6-8"	48

Table 7 - Top 10 Features of a VWS

Analysis of Electricity Usage

The results from the Dent Smart Loggers are as follows:

Dent Smart Logger Number	Placed on Welding Machine Number	On-time (hours)
2	FCAW #7	9.2
3	SMAW #9	2.0
4	FCAW #5	n/a

Table 8 - Dent Smart Logger On-Time Chart

Dent Smart Logger #4 had an error and did not record any electricity usage. The data received from the loggers was analyzed with Alex Hebert.

The variance in the on-time hours of Dent Smart Logger 2 and 3 (as shown in the above table) is significant and given the estimates by Dave Helman, it was decided that the higher on-time of 9.2 hours is a more accurate representation. The on-time of 9.2 hours was used in analyzing electricity usage.

Using the information provided by Lincoln Electric (as shown in Appendix G), an estimate of energy consumption was calculated using the following formulas.

$$Total\ kilowatts = \frac{voltage\ x\ amps}{1000}$$

$$Time\ used = \frac{on\ time\ hours}{logged\ weekdays * hrs\ per\ day} * weekdays\ per\ year * work\ hrs\ per\ day$$

$$Total\ kilowatt\ hours\ in\ 1\ year = \ total\ kilowatts\ x\ time\ used$$

Analyses using the Dent Smart loggers' on-time of 9.2 hours (5.3% of the total available time) and one using the 35% usage rate estimated by Dave Helman were conducted and then compared.

The total kilowatt hours in one year was calculated for both high draw and phantom draw. Each figure was then multiplied by $0.068 (price/kWh) and added together. The total cost was multiplied by 16 students, yielding a yearly cost range of between $3,481.92 and $16,942.20.

The following chart outlines the results from both analyses:

	Energy cost estimate using 5.3%	Energy cost estimate using 35% Usage
High Draw kWh/yr.	2314	14,963
Phantom Draw kWh/yr.	887	609
Cost/Machine/Year	$217.62	$1,058.89
Total Cost of 16 Students	$3,481.92	$16,942.20

Table 9 - Analysis of Total Electricity Consumption

Based on the same usage, each of the investigated virtual welding systems would consume a considerably less amount of electricity. The averages of the three investigated systems yielded an average yearly cost range of between $119.17 and $1,232.98. To see the full analyses of each system, refer to Appendices G and H.

	VRTEX™360		arc+		CS Wave	
Energy Cost Estimate Using a Rate of	5.3%	35%	5.3%	35%	5.3%	35%
High Draw kWh/yr.	62	403	130	840	170	1101
Phantom Draw kWh/yr.	47	33	47	33	47	33
Cost/Machine/Year	$7.45	$29.58	$12.05	$59.33	$14.79	$77.06
Total Cost of 16 Students	$119.17	$473.28	$192.77	$949.28	$236.63	$1,232.98

Table 10 – Analysis of Total Electricity Consumption of Investigated VWSs

Analysis of Energy Savings

The total costs of electricity for each of the investigated systems were analyzed using the same methods as with the current welding machines. The results from these analyses were then used to calculate the estimated energy savings that would accompany the integration of a VWS. By taking the low and high values in the range of costs for the current welding machines and subtracting the low and high values in the range of electricity costs to run all of the investigated VWS, the amount of electricity costs that would be saved were realized.

Scenario 1 – Full Integration into Curriculum – 8 Systems

The following outlines energy savings of the base case (7%) for each machine with usage of 5.3% of the available time (the low end of the range).

	PowerWave355M	VRTEX™360	arc+™	CS Wave
Total Cost	$3,481.92	$119.17	$192.77	$236.63
Usage Rate	7%	7%	7%	7%
Total Cost with Usage Applied	$243.73	$8.34	$13.49	$16.56
Savings/Year	0	$235.39	$230.24	$227.17

Table 11 - Low Range of Electricity Savings in Scenario 1

The following table outlines energy savings for each machine with usage of 35% of the available time (the high end of the range).

	PowerWave355M	VRTEX™360	arc+™	CS Wave
Total Cost	$16,942.20	$473.28	$949.28	$1,232.98
Usage Rate	7%	7%	7%	7%
Total Cost with Usage Applied	$1,185.95	$33.13	$66.45	$86.31
Savings/Year	$0	$1,152.82	$1,119.50	$1,099.64

Table 12 - High Range of Electricity Savings in Scenario 1

By integrating eight VWSs into the current welding curriculum, the average electricity cost savings would be between $230 and $1,124.

Scenario 2 – Remedial Use Only and Marketing – 1 System

The following table outlines the energy savings from the use of one system with an assumed usage of 5.3% of the available time (the low end of the range).

	PowerWave355M	VRTEX™360	arc+™	CS Wave
Total Cost	$3,481.92	$119.17	$192.77	$236.63
Usage Rate	6.25%	6.25%	6.25%	6.25%
Total Cost with Usage Applied	$217.62	$7.45	$12.05	$14.79
Savings/Year	$0	$210.17	$205.57	$202.83

Table 13 - Low Range of Electricity Savings in Scenario 2

The following table outlines energy savings from the use of one system with an assumed usage of 35% of the available time (the high end of the range).

	PowerWave355M	VRTEX™360	arc+™	CS Wave
Total Cost	$16,942.20	$473.28	$949.28	$1,232.98
Usage Rate	6.25%	6.25%	6.25%	6.25%
Total Cost with Usage Applied	$1,058.89	$29.58	$59.33	$77.06
Savings/Year	$0	$1,029.31	$999.56	$981.83

Table 14 - High Range of Electricity Savings in Scenario 2

By integrating one VWS into the current welding curriculum, the average electricity cost savings would be between $11.43 and $52.32.

Analysis of Materials Costs

In analyzing material usage by level C, a usage factor based on percentage of hours welding was calculated. The results are shown in the following table.

	Hours Spent in Training/ Student	Time spent Welding (%)	# of Students Enrolled (2010)	Total Hours of Welding/ Year	% of Total Hours Welding
Level A	240	0.95	30	6840	4%
Level B	480	0.95	63	28728	18%
Level C	840	0.95	152	127680	78%
Total	1560	0.95	245	163248	100%

Table 15 - Calculations of Level C Usage Rate

The total hours welding per year for each level was compared with the total hours welding for all levels. It was determined that the percentage of total materials consumed by level C is 78%. This rate was then rounded up to 80% to allow for a certain margin of error in the calculation.

The majority of cost data for each of the identified materials groups was collected from invoices supplied by vendors dated April 2011 through October 2011. Consumption was assumed to remain constant, as confirmed by David Helman. Total spending figures were then multiplied by two to give an approximation for one year for the department. Department figures included materials used by all levels of students; materials used by Level C were identified and isolated. Some of these materials are also used by other levels; therefore, the usage factor of 80% (as calculated above) was applied to this figure and then rounded to a conservative number. The chart below outlines a conservative figure for Level C consumption which is hereafter used in the analysis.

	Department Wide	Items Identified as used by Level C	Level C with 80% Usage Rate	TOTAL	Conservative Figure
Steel	$204,979.57	$115,175.33	$92,140.27	$90,563.36	$90,000.00
Steel Recycling	($1,971.14)		($1,576.91)		
Consumables	$ 59,998.67	$40,166.34	$32,133.07	$37,279.63	$37,000.00
Welding Rod Recycling	($166.80)		($133.44)		
Extra Consumables	$10,000*	$6,600*	$5,280		
Gas	$108,000.00	$108,000.00	$86,400.00		$86,000.00

Table 16 – Summary of costs obtained during this study

*Figure estimated by Dave Helman

Analysis of Materials Savings

In the analysis of materials savings, it was important to investigate different usage scenarios to provide a range of savings within these scenarios.

Scenario 1 – Full Integration into Curriculum – 8 Systems

Three cases were identified: Base (most likely to occur), Pessimistic (lowest usage), and Optimistic (highest usage). The usage cases were based on how much time was estimated to be spent on a VWS, which is based on the percentage of time a level C student is assumed to replace the use of a welding machine with time spent on a VWS.

The estimates made are:

Base: 2 weeks

Pessimistic: 1 week

Optimistic: 4.2 weeks

Given these estimates, a usage rate for each case was calculated.

Base Case: $Usage\ rate\ of\ time = \frac{2\ weeks}{28\ weeks}\ x\ 100\% = 7\%$

Pessimistic Case: $Usage\ rate\ of\ time = \frac{1\ week}{28\ weeks}\ x\ 100\% = 3.6\%$

Optimistic Case: $Usage\ rate\ of\ time = \frac{4.2\ weeks}{28\ weeks}\ x\ 100\% = 15\%$

The following table exhibits the estimated materials savings based on the calculations above.

	Conservative Figure	Pessimistic Case	Base Case	Optimistic Case
Steel	$90,000	$3,240	$6,300	$13,500
Consumables	$37,000	$1,332	$2,590	$5,550
Gas	$86,000	$3,096	$6,020	$12,900
Total	$213,000	$7,668	$14,910	$31,950

Table 17 – Material savings used for LCC analysis of Scenario 1

Scenario 2 – Remedial Use Only and Marketing – 1 System

The usage rate used to calculate material savings was based on the assumption that one VWS will replace the use of one real welder. For this case, the following usage rate was applied to determine the effect on material savings.

$$Usage\ Rate = \frac{1\ system}{16\ systems} x\ 100\% = 6.25\%$$

The following table exhibits the estimated materials savings based on the calculations above.

	Conservative Figure	Usage Rate 6.25%
Steel	$90,000	$5,625
Consumables	$37,000	$2,313
Gas	$86,000	$5,375
Total	$213,000	$13,313

Table 18 - Material savings used for LCC analysis of Scenario 2

Analysis of Life Cycle Costing

The results from the analysis of material and electricity savings, as well as the capital costs and operation and maintenance costs of each investigated VWSs, were used in conducting Life Cycle Cost Analysis for each investigated VWS. The lower end of the range of electricity savings was used to build a conservative analysis.

Scenario 1 – Full Integration into Curriculum – 8 Systems

To be able to fully integrate a virtual welding system into the curriculum, eight virtual welding systems would be needed (rotating two groups of eight students).

The following table outlines the figures used.

	VRTEX™360	arc+™	CS Wave
Capital Cost of 8 systems	$425,200	$682,000	$416,265
Operation and Maintenance Costs	$72,000	$48,000	0
Base Case Savings per year	$15,145	$15,140	$15,137
Pessimistic Case Savings per year	$7,789	$7,786	$7,785
Optimistic Case Savings per year	$32,454	$32,443	$32,437

Table 19 – Costs and Savings Used in LCC Analysis for Scenario 1

The results of the base case analysis for each of the systems are as follows.

	VRTEX™360	Arc+™	CS Wave
VWS Units	8	8	8
Annual Software Updates	Yes	Yes	No
Usage Rate	7%	7%	7%
Total Life Cycle Net Present Value	($1,198,620)	($1,130,824)	($153,222)
Simple payback	28.1 years	45 years	23.8 years
Internal Rate of Return	n/a*	n/a*	-4%
Lifetime	15 years	15 years	15 years

Table 20 - LCC Base Case Analysis for Scenario 1

** IRR could not be calculated*

The results of the pessimistic case analysis for each of the systems are as follows.

	VRTEX™360	Arc+™	CS Wave
VWS Units	8	8	8
Annual Software Updates	Yes	Yes	No
Usage Rate	3.6%	3.6%	3.6%
Total Life Cycle Net Present Value	($1,299,054)	($1,229,165)	($253,591)
Simple payback	54.6 years	87.6 years	46.9 years
Internal Rate of Return	n/a*	n/a*	-10%
Lifetime	15 years	15 years	15 years

Table 21 - LCC Pessimistic Case Analysis for Scenario 1

** IRR could not be calculated*

The results of the optimistic case analysis for each of the systems are as follows.

	VRTEX™360	Arc+™	CS Wave
VWS Units	8	8	8
Annual Software Updates	No	No	No
Usage Rate	15%	15%	15%
Total Life Cycle Net Present Value	$17,891	($239,087)	$82,942
Simple payback	13.1 years	21 years	11.1 years
Internal Rate of Return	4%	-2%	6%
Lifetime	15 years	15 years	15 years

Table 22 - LCC Optimistic Case Analysis for Scenario 1

For the complete LCC analyses, refer to Appendix I or click here.

Scenario 2 – Remedial Use Only and Marketing – 1 System

For use as a remedial tool in the curriculum, one virtual welding system would be needed.

The figures used to conduct a Life Cycle Cost Analysis based on one machine are exhibited in the following table:

	VRTEX™360	arc+™	CS Wave
Capital Cost	$53,150	$85,000	$61,850
Operation and Maintenance Cost	$9,000	$6,000	0
Savings per year	$13,523	$13,518	$13,515

Table 23 - Costs and Savings Used in LCC Analysis for Scenario 2

The following table outlines the results of the LCC base cases.

	VRTEX™360	Arc+™	CS Wave
VWS Units	1	1	1
Annual Software Updates	Yes	Yes	No
Usage Rate	6.25%	6.25%	6.25%
Total Life Cycle Net Present Value	$8,947	$17,864	$129,703
Simple payback	3.9 years	6.3 years	4.1 years
Internal Rate of Return	5%	6%	26%
Lifetime	15 years	15 years	15 years

Table 24 - LCC Analysis for Scenario 2

Findings

User Requirements

The results from the QFD chart found that a virtual welding system does possess features and benefits that address the needs of system users. The CS Wave is the best alternative out of the three investigated VWSs. The CS Wave scores totaled 6862, compared to that of VRTEX™360 at 5234 and arc+™ at 4996. It is the machine that best encompasses the features needed to satisfy the requirements of the stakeholders. The CS Wave is also recommended by Ken Pearce from the Canadian Welding Bureau (CWB) as being far superior as a teaching tool and in graphics and technology.

Scenario 1 – Full Integration into Curriculum – 8 Systems

Electricity

The VRTEX™360 has a lower wattage than the other virtual welding systems. It has the highest energy savings; however, because the variance in savings is between $5 to $8 dollars, the savings is not significant enough to conclude that the VRTEX™360 is the best alternative.

The table below compares the minimum and maximum energy savings of each virtual welder; the exact energy savings is somewhere between the two figures. The data obtained from the Dent Smart Loggers resulted in the lower figure; the higher figure resulted from the estimated usage from Dave Helman.

	VRTEX™360	arc+™	CS Wave
Minimum Energy Savings	$235.39	$230.24	$227.17
Maximum Energy Savings	$1,152.82	$1,119.50	$1,099.64

Table 25 - Range of Energy Savings for Scenario 1

A variety of factors will influence how large the energy savings will be, including the length of time students actually spend welding. Actual time welding could be impacted by student absences, skill level, course level, and personal dedication to the task.

Materials

Each of the virtual welding machines will reduce materials consumption by $14,910 per year. This does not offset the cost of software upgrades for eight systems. However, these savings will have a positive impact on the reduction of global emissions and energy used in the production and disposal of these materials.

	All Virtual Welding Systems
Steel	$6,300
Consumables	$2,590
Gas	$6,020
Total	$14,910

Table 26 - Exhibit of Material Savings for Scenario 1

The savings could in fact be more, as some beginner students typically consume much higher amounts of materials than the average student.

Cost Benefit Analysis

Through the analysis of Life Cycle Costing (LCC), it was found that each of the investigated VWSs have negative NPVs, and simple paybacks of well beyond the maximum time allowed, as stipulated in the requirements of the Revolving Fund. The internal rate of return for the VRTEX™360 and arc+™ could not even be calculated for the base cases.

	VRTEX™360	arc+™	CS Wave
Total Life Cycle Net Present Value	**($1,198,620)**	**($1,130,824)**	**($153,222)**
Simple payback	**28.1 years**	**45 years**	**23.8 years**
Internal Rate of Return	*	*	**-4%**

Table 27 - Cost Benefit Analysis for Scenario 1

At this time, eight virtual welding machines will not be of any financial benefit to the welding department.

Scenario 2 – Remedial Use Only and Marketing – 1 System

Electricity

The VRTEX™360 has a lower wattage than the other virtual welding systems. It has the highest energy savings; however, because the variance in savings is between $5 to $8 dollars, the savings is not significant enough to conclude that the VRTEX™360 is the best alternative.

The table below compares the minimum and maximum energy savings of each virtual welder; the exact energy savings is somewhere between the two figures. The data obtained from the Dent Smart Loggers resulted in the lower figure; the higher figure resulted from the estimated usage from Dave Helman.

	VRTEX™360	arc+™	CS Wave
Minimum Energy Savings	$210.17	$205.57	$202.83
Maximum Energy Savings	$1,029.31	$999.56	$981.83

Table 28 - Range of Energy Savings for Scenario 2

A variety of factors will influence how large the energy savings will be, including the length of time students actually spend welding. Actual time welding could be impacted by how many students utilize the VWS as a remedial tool.

Materials

Each of the virtual welding machines will reduce materials consumption by $13,313 per year. This will offset the annual software upgrade fees of the VRTEX™360 and the arc+™. The CS Wave does not have any annual software upgrade fees. In addition, these savings will have a positive impact on the reduction of global emissions and energy used in the production and disposal of these materials.

	All Virtual Welders
Steel	$5,625
Consumables	$2,313
Gas	$5,375
Total	$13,313

Table 29 - Exhibit of Material Savings for Scenario 2

Cost Benefit Analysis

The life cycle cost analysis of one VWS produced results that would comply with the Revolving Fund requirements.

	VRTEX™360	arc+™	CS Wave
Total Life Cycle Net Present Value	**$8,947**	**$17,864**	**$129,703**
Simple payback	**3.9 years**	**6.3 years**	**4.1 years**
Internal Rate of Return	**5%**	**6%**	**26%**

Table 30 - Cost Benefit Analysis for Scenario 2

Through the analysis of Life Cycle Costing (LCC), it was found that each of the investigated VWSs have positive NPVs. Both the VRTEX™360 and CS Wave have a simple payback within the maximum time stipulated by the Revolving Fund. While each system of has a positive internal rate return (IRR), the CS Wave has an IRR at least 20% higher than that of the other two systems.

Recommendation

Scenario 1 – Full Integration into Curriculum – 8 Systems

It is recommended that integrating eight VWSs into the current curriculum should not be considered any further at this point. Based on the findings, and capacity constraints outlined late in the study by Dave Helman, it was determined that integrating eight systems would not significantly reduce the environmental impact and carbon emissions in the Sustainability Precinct at BCIT, nor be of any financial benefit to the welding department. If integration into the curriculum can be significantly increased to 8 weeks of the 28 week Level C program, this scenario may be feasible.

Scenario 2 – Remedial Use Only and Marketing – 1 System

Based on the usage by current users of the investigated virtual welding systems, it is recommended that purchasing one VWS be considered. Although the purchase of one VWS would not have the capacity to be fully integrated into the curriculum as originally intended, it could be used as a remedial tool for students struggling with certain processes. It would also be of benefit to the marketing and promotion of the welding program at BCIT.

The energy and material savings that will be realized by the integration of one VWS to be used as a remedial tool will provide a positive project cash flow. This may allow more room in the current welding budget for improvements and capacity upgrades.

The life cycle cost analysis produced results that would comply with the Revolving Fund requirements. The following table outlines the results of the LCC base cases.

	VRTEX™360	Arc+™	CS Wave
Total Life Cycle Net Present Value	$8,947	$17,864	$129,703
Simple payback	3.9 years	6.3 years	4.1 years
Internal Rate of Return	5%	6%	26%

Table 31 - Comparison of Life Cycle Net Present Value Findings of 1 System

From the above analysis, it would be a sound decision to purchase one VWS to use as a remedial tool and as a marketing and promotional tool for the welding department.

Used as a remedial tool, it is possible for use throughout all levels; C, B, and A. The amount of students that may benefit from using a VWS as a remedial tool throughout the year in all levels should be further investigated, as this information is not currently available. From that investigation, an accurate amount of savings and percentage of time used by a VWS can be placed into a Life Cycle Cost Analysis.

Optimal VWS

The virtual welding system that should be considered for integration is the CS Wave. The CS Wave is the best alternative financially with the highest NPV, shortest payback, and highest IRR. It also possesses the highest amount of features that address the requirements of the users. BCIT would be the first Canadian user of the CS Wave, presenting a variety of marketing and promotional options. For more details on the CS Wave, refer to Appendices J, K, L, and M.

Additional Recommendations

Further Investigation of Virtual Welding Systems

The trial of Lincoln Electric's VRTEX™360 highlighted concerns and perceived deficiencies. A decision against the purchase of any VWS based on this extremely brief trial and exposure to only this system would not be sufficiently thorough or reliable. It is recommended that other systems are explored and lengthier trials of all the available systems are arranged.

A welding instructor from within BCIT's faculty could be sent to CWB in Milton, ON to investigate the CS Wave. This may aid in achieving a better understanding of the different approach to virtual welding that the CS Wave takes and may provide the other instructors with trusted and honest feedback of the systems.

Contacting more users of virtual welding systems would also help with gaining a better idea of how these systems are currently being used. The white papers suggest all of the systems are valuable tools in the development of a successful and capable welder. Unbiased feedback from current users, especially those in post-secondary institutions, will help provide an objective and realistic picture of the utility of a particular virtual welding system in practice.

Conclusion

The technology of virtual welding systems is still fairly new, and until further developments have been made in the industry and the capital and software upgrading costs reduce, it will not be feasible to purchase the number of units necessary for full integration into the curriculum at BCIT. Virtual Reality is however, a growing interest in the welding industry and it would be beneficial for BCIT to be an early adopter in available technological advances of the welding industry. Purchasing one CS Wave system will lower the consumption of materials and electricity consumed by the welding process. If used as a remedial tool, it will allow struggling students to progress faster through areas they have difficulty with.

Although the impact on reducing the energy consumption in the Sustainability Precinct is relatively insignificant, the savings in material consumption from implementing a VWS would reduce global carbon emission impact and global energy consumption. For example, the energy involved in producing a ton of steel plates is 17.37 GJ/tonne. The amount of CO_2 emitted in producing steel plates is 0.919 tonnes/tonne. This would result in BCIT reducing global carbon emissions by 2.74 tonnes of CO_2 and global energy consumption by 51.74 GJ (based on Level C students 7% usage rate). Figures are taken from Appendix XX. If paired with a new ventilation system, this project will further reduce this impact and may result in an increase of savings in carbon offsets at BCIT.

With the recent announcement of the $8 billion federal shipbuilding contract being awarded to Seaspan Marine Corp. in Vancouver, the need for high quality training of trades people, welders in particular, is already on the rise. BCIT is already one of the first choices amongst people wanting to gain their welding certification. The integration of a VWS has the potential to increase the demand and attract even more people to the welding program.

References

(n.d.). Retrieved November 7, 2011, from DIGINEXT CS WAVE: http://www.vlearn.com/welding/downloads/cswaveflyer_eng.pdf

Steelmaking Commodity Prices. (2011, November 5). Retrieved November 11, 2011, from Steelonthenet.com Strength in steel: http://www.steelonthenet.com/commodity_prices.html

The carbon footprint of steel. (2011). Retrieved November 11, 2011, from TATA Steel: http://www.tatasteelconstruction.com/en/sustainability/carbon_and_steel/

ARC+® Welding simulator . (n.d.). Retrieved September 28, 2011, from 123arc.com: http://www.123arc.com/en/ARCpluspresentation.htm

BENEFITS. (n.d.). Retrieved November 6, 2011, from DIGINEXT CS WAVE: http://www.vlearn.com/welding/index.php/en/approach/benefits

Blast Furnace Route Steelmaking Costs 2011. (n.d.). Retrieved November 11, 2011, from Steelonthenet.com: http://www.steelonthenet.com/cost-bof.html

Boyce, M. (2011, November 9). Instructor, Welding, BCIT. (A. Le Good, Interviewer)

British Columbia Institute of Technology. (n.d.). *Strategic Plan 2009-2014.* Retrieved November 22, 2011, from British Columbia Institute of Technology Web site: http://www.bcit.ca/files/about/pdf/stratplan.pdf

CASE STUDIES. (n.d.). Retrieved November 7, 2011, from DIGINEXT CS WAVE: http://www.vlearn.com/welding/index.php/en/support/casestudies

Choquet, C. (2011, October 12, 21, 28). Research on ARC+. (D. He, Interviewer)

DALTO, L. D., & BENUS, F. (2011, July 15 - 16). *The Use and Benefits of Virtual Reality Tools for the Welding Training.* (Laurent DA DALTO, Ferenc BENUS, Performer) IIW International Conference (63rd) Theater, Istanbul.

Fitzpatrick, E. (2011, November 2). Research Analyst, Institutional Planning and Analysis Office, BCIT. (A. Le Good, Interviewer)

Flynn, M. (2011, November 2). Instructor, Welding, BCIT. (A. Le Good, Interviewer)

Fowler, R. (2011, October 5). Senior Buyer, Purchasing Department, BCIT. (T. Chandra, & A. Le Good, Interviewers)

Helman, D. (2011, October 28). Chief Welding Instructor, BCIT. (A. Le Good, Interviewer)

Jordan, D. (2011, October 12). Research on Vertex 360. (D. He, Interviewer)

Kube, M. (2011, October 5). Instructor, A Level Welder, Level II Inspector, Piping Industry Apprenticeship Board. (A. Le Good, Interviewer)

Laufman, G. (2011, November 2). Instructor, Welding, BCIT. (A. Le Good, Interviewer)

Lincoln Electric's Virtual Welding System Helps Put New Welders on Solid Career Track. (n.d.). Retrieved November 9, 2011, from Lincoln Electric: http://www.lincolnelectric.com/en-us/support/application-stories/pages/pitt-community-college.aspx

Ottney, R. S. (2011, August 30). *CTC students learn welding in virtual reality*. Retrieved November 9, 2011, from Portsmouth Daily Times: http://portsmouth-dailytimes.com/view/full_story/15259420/article-CTC-students-learn-welding-in-virtual-reality?instance=home_news_lead

OUR DIFFERENCE. (n.d.). Retrieved November 7, 2011, from DIGINEXT CS WAVE: http://www.vlearn.com/welding/index.php/en/support/casestudies

Pearce, K. (2011, November 4). Manager Corporate Sales, CWB Group. (A. Le Good, Interviewer)

Pongracz, T. (2011, October 5). Chief Instructor, Trades Discovery, BCIT. (A. Le Good, Interviewer)

Sanghera, R. (2011, September 28). Manager, Supply Management, BCIT. (T. Chandra, Interviewer)

Superior Adds Virtual Welder to Welding Training Center Curriculum. (n.d.). Retrieved November 9, 2011, from Heavy Equipment Guide: http://heg.baumpub.com/news/1531/superior-adds-virtual-welder-to-welding-training-center-curriculum

VERTEX 360. (n.d.). Retrieved September 15, 2011, from Lincoln Electric: http://www.lincolnelectric.com/assets/en_US/products/literature/mc0998.pdf

VRTEX® Virtual Reality Arc Welding Trainer . (n.d.). Retrieved October 10, 2011, from Lincoln Electric: http://www.lincolnelectric.com/en-us/equipment/training-equipment/Pages/vrtex360.aspx

Walters, R. (2011, October 5). Welding Instructor, BCIT. (A. Le Good, Interviewer)

Wiggins, F. (2010, October 12). *Welding goes virtual at Fort Lee*. Retrieved November 9, 2011, from progress-index.com: http://progress-index.com/news/military/welding-goes-virtual-at-fort-lee-1.1047179#ixzz1buruENoO

Appendices

Appendix A – Terms of Reference

Version 1.7

Subject of the study

To investigate whether or not integrating a Virtual Welding System into the BCIT welding curriculum meets all user requirements and provides a strong cost benefit to BCIT School of Construction.

Name and Address of Organization

BCIT Energy and Sustainability
3700 Willingdon Avenue
Building NE3 Room 111
Burnaby, BC

Client

Alex Hebert
Energy and Sustainability Manager
Alexandre_Hebert@bcit.ca
604-451-7011

Andrea Linsky
Energy Specialist
Andrea_Linsky@bcit.ca
604-453-4060

David Helman
Chief Welding Instructor
David_Helman@bcit.ca
604-456-8082

Investigators

Anna Le Good and Tara Chandra
bcit.vws@gmail.com

Faculty Advisor

Richard Vurdela
Richard_vurdela@bcit.ca

Purpose

The purpose of this study is to:

- determine if a Virtual Welding system can meet the requirements and be of benefit to all stakeholders
- determine if a Virtual Welding System will improve quality of teaching
- provide a better understanding of whether there will be a significant decrease in waste, environmental resources, and cost by integrating a Virtual Welding System into the welding program.

Scope

This investigation is limited to collecting and analyzing data needed to determine the feasibility of introducing a Virtual Welding System to the Welding Program in BCIT's School of Construction. Three key areas have been identified for study: user requirements, cost benefit analysis, and brand selection.

The investigators will:

- interview all stakeholders in order to gather user requirements and from it will develop a criteria of evaluation
- collect data on materials cost, material waste, and energy usage to provide a cost benefit analysis
- research three Virtual Welding Systems- VRTEX™360, Arc+, and CS Wave; match them against criteria of evaluation and provide a recommendation

Deliverables

A formal written report issued on November 23, 2011. This will include:

- Observations and analysis of the current costs and cost benefit
- Comprehensive summary of interviews of all stakeholders
- User Requirements
- Criteria of Evaluation of Alternative
- Research summary of alternatives
- Recommendations

An oral presentation to present findings and recommendations to stakeholders will take place on November 30, 2011.

Symptoms

The following symptoms have been identified:

- BCIT spent $280,000 last year on carbon offsets in response to Bill 44 which mandated all public-sector organizations to be carbon neutral by 2010.
- There is potential for physical harm to unskilled students during learning welding techniques
- The materials used in the welding program are contributing to greenhouse gas emitted at BCIT

Actions

The project team's intended action steps to determine user requirements, cost benefit analysis and brand selection are outlined below:

User Requirements

- Identify and interview key stakeholders to determine their system requirements
- Facilitate a trial of a Virtual Welding System
- Summarize findings from interviews
- Compare requirements from each stakeholder to determine a common set of criteria
- Establish a Criteria of Evaluation from which to measure feasibility

Cost Benefit Analysis

- Identify and interview suppliers and purchasers of welding materials/consumables
- Gather and analyze costs of materials and wastage
- Conduct activity sampling to generate an educated assumption of energy usage
- Prepare a cost benefit analysis of a Virtual Welding System

Brand Selection

- Preliminary research on three possible alternatives; Arc +™, VRTEX™ 360, and CS WAVE
- Evaluate each alternative according to Criteria of Evaluation
- Recommend a system based on preliminary research

Criteria of Evaluation

Identification of user requirements during   the project will be used to finalize the Criteria of Evaluation. The anticipated criteria to evaluate the alternatives are:

- Cost
- Life Cycle Costing
- Meets users requirements
- Quality of teaching
- Waste Reduction
- Savings on energy and greenhouse gas emissions
- Value

Customers

Our study will have a direct impact on the following people:

- David Helman, Chief Welding Instructor
- BCIT Welding Faculty
- BCIT Welding Students
- Alexandre Hebert, BCIT Energy and Sustainability Manager
- Andrea Linsky, BCIT Energy Specialist

Stakeholders

The stakeholders of this project include:

- Richard Vurdela, Project Advisor, BCIT
- BCIT Business Operations Management Program
- David Dunn, Associate Dean, School of Construction
- Ken Mui, Lincoln Electric Representative
- Future welding students
- Palvinder Moses, Finance, School of Construction
- Barry Gildersleve, Welding Instructor, BCIT
- Rand Sanghera, Manager, Supply Management, BCIT
- Cindy MacIntosh, Waste Management, School of Construction
- Ron Mastromonaco, BC Hydro

Constraints

Possible factors/limitations that may affect the project are:

- Maximum of twelve weeks, with Wednesday as a designated day for the study
- Curriculum must comply with ITA's regulations
- Scheduling interviews within investigators timetable

Assumptions

These are the assumptions given the information provided:

- Information needed will be provided in a timely manner
- Student team will have access to all the necessary information and facts
- There are only two possible Virtual Welding systems to consider

Risks

The potential risks to be faced by the investigators and how they will be mitigated are:

- Some cost data may not be available or precisely quantifiable and will be determined with educated assumptions when possible
- Electricity and environmental impact may be difficult or unavailable to quantify and will be determined with educated assumptions when possible
- Some interviewees may not have the time or be willing to participate in interviewing; investigators will find alternate interviewees who may provide the necessary information

Success Measures

Upon completion of this study, we will measure our success based upon the following:

- A complete, clear, and concise report on the requirements needed to be fulfilled in order to proceed further in the integration of a virtual welding system at BCIT
- Provided a sound recommendation that satisfies all user requirements
- David Helman, Alex Hebert, and Andrea Linsky will be able to proceed seamlessly with the project
- A clear picture of the costs and benefits associated with the study
- All team members will have learned and improved upon the areas they indicated at the beginning of the project.

Benefits

The benefits of this study will be

- a comprehensive list of stakeholder requirements and how they were measured
- a clearer understanding of the environmental, cost, and educational impact of a Virtual Welding System at BCIT
- a better awareness of the Sustainability Precinct at BCIT and how a Virtual Welding System may contribute to the objectives of the precinct.

Appendix B – Interview Summaries

The following are summaries of the interviews conducted throughout this study. Stakeholders' requirements of a Virtual Welding System were obtained through analyzing and comparing interview information.

Tamara Pongracz

Chief Instructor, Trades Discovery Program, BCIT
Interview on October 5, 2011

Tamara has never used any virtual welding system. Students in the Trades Discovery Program are exposed to welding for 5 days. Out of 140 students in the discovery program, 3 or 4 go on to welding training. Most students go into Steel Fabrication and Boilermaking. Trades Discovery instructors encourage students to go into other trades and have welding as a supplement to their certifications. As the students in the discovery program only have 5 days to weld, she does not feel like a virtual welding system would be used for her students. From the secondary research she has done herself, she thinks this may be a useful tool for "green" welders and that there will be savings in terms of cost and environmental impact.

Merv Kube

Instructor, A Level Welder, Level II Inspector, Piping Industry Apprenticeship Board (PIAB)
Interview on October 5, 2011

Merv Kube had a brief trial of Lincoln Electric's VRTEX™360 last spring. He had about 20 students try it out as well. After the trial, they decided against purchasing the machine for the following reasons:

- Little connection or transferability from the virtual welding machine to the actual welding training
- Has potential, but the imagery needs to be developed much more for it to be considered again
- High cost
- Students were bored after 5 – 10 minutes
- Some of the 20 students selected to try the machine were extremely resistant and did not try it
- Still in the very early stages
- Experienced welders and instructors scored lower than inexperienced welders

He noted that this system may be useful if the students using the machine have zero experience with welding. He was also surprised to hear that students who had used the VRTEX system in their training had a higher pass rate than ones who had not (according to Physical and

Cognitive Effects of Virtual Reality Integrated Training study done by students at Iowa State University).

Rod Walters

Instructor, Welding, BCIT
Interview on October 5, 2011

Rod is an instructor at BCIT and has been teaching for over 20 years. He has never tried a virtual welding system before. Rod was asked what he thought students have the most trouble with when learning how to weld. The following is his response.

- Adapting to the welding environment (constricted vision, sparks, smoke, etc.)
- Fine motor skills
- Hand-eye coordination

He said the difficulties of teaching welding are that students can get frustrated and don't want any help.

Rod would be open to using a Virtual Welding System provided he gets an opportunity to try out the system for an acceptable amount of time prior to purchase.

George Laufman

Instructor, Welding, BCIT
Interview on November 2, 2011

George is an instructor at BCIT and has been teaching for 5 years. He teaches level C students and has some concerns regarding the current program. In the classroom time, he shows students a video of actual welding procedures. There are currently only old VHS tapes to show this and the quality is not very good. He would like to see the use of innovating and exciting technology integrated into the curriculum.

He got to try Lincoln Electric's VRTEX™360 briefly on Wednesday, November 2, 2011. He thinks this machine will help to break up the monotony of the current curriculum and possibly replace the VHS tapes students are shown in their classroom time.

Ken Pearce

Manager Corporate Sales, CWB Group
Interview on November 4, 2011

Ken was contacted after finding out from Rod Walters and Dave Helman that CWB had a Virtual Welding System in their possession. Ken attended BCIT from 1980-1991, taking Welding, Sheet Metal, and Business. Ken has had extensive training on both the CS Wave and the VRTEX™360.

Ken likes the idea of virtual welding systems for the following reasons:

- He is a private pilot and has used simulators for many hours in his instrument training
- Removing distractions in the initial phase of learning and training is beneficial, allowing the student to concentrate on the basic and pertinent skills.

In Ken's opinion, the most important aspects that should be included in any welding training in order to produce a capable and job-ready welder are:

- Health and safety
- Theoretical understanding of basic metallurgy and the reaction of metal in the weld zone
- Understand the importance of weld procedures and how to read them
- Know how to read drawings and understand weld symbols
- Basic visual inspection techniques
- Ability to operate oxy fuel or other cutting systems
- Ability to perform successful welds in a variety of joints, positions, and processes
- Prove competency in a nationally recognized weld test.

Ken feels that welders struggle the most with patience in their welding training. Some don't have enough discipline to stick to it and practice, practice, practice. They want to be perfect the first time around.

CWB brought in the CS Wave to their Milton, Ontario office late 2009 in response to industry interest. Ken has had extensive training on both the CS Wave and the VRTEX™360. Ken prefers the CS Wave over the VRTEX™360 for the following reasons:

- The CS Wave has had more extensive research and development.
- The CS Wave has comprehensive training programs and curriculum built into the system.
- The VRTEX™360's helmet is very delicate and if broken or damaged, the system is rendered useless.
- The VRTEX™360 is very game like and he doesn't see any educational value in that.
- With the CS Wave, you experience the feeling of the electrode and can manipulate the puddle.
- The CS Wave's welding gun and electrode holder are much more realistic.

Ken thinks Virtual Welding Systems provide an excellent way to start the learning process of welding.

David Helman

Chief Welding Instructor, BCIT
Interview on October 28, 2011 and throughout the entire study

1. What concerns do you have (if any) about using a Virtual Welding System (VWS)?

    - It won't be advanced enough
    - It won't fit into the curriculum
    - It won't be accepted as an educational tool

2. What do you think will mitigate your concerns?

    - If using the equipment is natural and realistic
    - If it is easily implemented and has minimal training time for the instructors to use
    - If all the instructors are willing to use it

3. Do you think a VWS will aide or interrupt welding training? If so, please explain.

Aid	**Interrupt**
- In the initial stick welding (SMAW) training, students will be less frustrated and the system will provide immediate feed back	- Instructors will have to find time to schedule students on the machine at various times
- Reduction of consumption of electrodes	

4. What are the top five requirements you have of a Virtual Welding System?

    - Reduce consumption of materials
    - Provide feedback to students
    - Proves practical and theory of welding
    - Helps correct frustrated students so they aren't making the same mistake
    - Easily fits into curriculum, preferably all levels of welding
    - Easily adaptable for instructors to use in training
    - Shows benefit to student and instructor

5. What are the most important aspects of welding training in producing a capable welder?

- Knowledge of the fundamentals of welding
- Development of a skill set by work experience and/or training experience in a practical environment

6. What are the most difficult things about teaching welding?

   - Hand-eye coordination
   - Good balance
   - Re-iterating how to weld over and over
   - Students want to move on, but don't have the skills to do so
   - Little bit of ego; already think they are good

7. What do welders in training have the most trouble with?

   - Developing an initial skill (watching the puddle, adjusting the amperage)
   - Hand-eye coordination
   - Understanding theory
   - Control and manipulation of the electrode

Rand Sanghera

Manager, Supply Management, BCIT
Interview Date: September 28 2011

Rand Sanghera is the manager of the purchasing department at BCIT. As he was working on a similar project to quantify materials consumption for BCIT welding department, Rand was interested in scheduling an interview. Rand was unable to provide any information on types or costs of materials purchased by the department.

The following information was provided:

- All departments within the School of Construction order under one account; if invoices were available, it would be a challenge to determine which materials were used by the welding department
- At the beginning of the year, vendors are given an open purchase order; only when BCIT reaches a spending cap is an invoice issued
- Vendors would not release any information to unauthorized parties
- Invoices for the previous year were not available

Rand was eager to help with the project and suggested contacting Palvinder Moses, Operations Manager to help obtain the information as he would do the same.

Richard Fowler

Senior Buyer, Purchasing Department, BCIT
Rand Sanghera
Manager, Supply Management, BCIT
Interview Date: October 5 2011

Richard Fowler is senior buyer at BCIT and places orders for BCIT welding department. He joined in on a follow up interview with Rand Sanghera.

Richard provided the following information on their order processing:

- The welding department makes an order requisition, gives it to the purchasing department who generates a purchase order and gives to the vendor
- Once an order is placed, the purchase order number is erased, thus he is unable to pull a report
- Requisitions are returned for storage to the Welding Department

Richard suggests meeting with Barry Gildersleve, previous Chief Instructor of the Welding Department. If he has last years' requisitions, Richard will use them to get invoices from vendors. Rand left a message with Palvinder for permission to proceed with the plan.

Richard thinks it will be possible to obtain invoices for steal, rods, and other consumables. Gas consumption specific to the welding department cannot be quantified and will have to be estimated based on educated guess by Barry.

VRTEX360 TRIAL AT BCIT

Interview date: November 2 2011

A VRTEX360 virtual welding machine was brought to the welding school for demonstration. Instructors and students had the opportunity to try the machine; those who were willing were interviewed for their opinions on the VRTEX360.

Student 1

One student said he felt a sense of floating, where he didn't feel the pressure of the machine as he does in real life. He said he would rather weld without the helmet, as he could not see his arm (in real welding there is more view through a helmet).

Student 2

One student remarked that he could not see his hands through the helmet and the virtual welder was unable to simulate a spark. When asked by Scott, Lincoln Representative, if he would have liked to use it during the first week of training, he responded with "maybe".

Mark Flynn, Teacher

Mark found the machine to have poor depth perception as he was having trouble seeing how far away his hand was from the coupon he was welding.

Appendix C – Big Info Night Survey Results

Response Started:	Response Modified:
Wednesday, November 2, 2011 5:41:06 PM	Wednesday, November 2, 2011 5:45:45 PM

1. Do you have any experience with welding?

No Response

2. How interested are you in taking the welding Program

No Response

3. What did you like about using the Virtual Welding System?

I found that it was nice to see the immediate feedback. No need to cut the weld or make joints

4. What didn't you like about using the Virtual Welding System?

there was no tactile feel of the gun and wire feeding

5. How accurately do you think welding on the Virtual System mimics how you weld in real life?

Accurate

6. How would you feel if a Virtual Welding System was a part of the training you received in your program?

I would like it

7. Would you have had an easier time learning to weld if initial training were done in a Virtual Welder?

No

8. What are the top five requirements you have of a Virtual Welding System?

immediate feedback

good tactile feel with weight of gun

visual accuracy

Response Started:	Response Modified:
Wednesday, November 2, 2011 6:23:33 PM	Wednesday, November 2, 2011 6:24:39 PM

1. Do you have any experience with welding?

No Response

2. How interested are you in taking the welding Program

No Response

3. What did you like about using the Virtual Welding System?

Its good

4. What didn't you like about using the Virtual Welding System?

Don't get a sense of a real welding environment

5. How accurately do you think welding on the Virtual System mimics how you weld in real life?

Accurate

6. How would you feel if a Virtual Welding System was a part of the training you received in your program?

I wouldn't care

7. Would you have had an easier time learning to weld if initial training were done in a Virtual Welder?

No

8. What are the top five requirements you have of a Virtual Welding System?

No Response

Response Started:	**Response Modified:**
Wednesday, November 2, 2011 6:35:57 PM	Wednesday, November 2, 2011 6:39:59 PM

1. Do you have any experience with welding?

No

2. How interested are you in taking the welding Program

Maybe

3. What did you like about using the Virtual Welding System?

that its virtual, the realism of it

4. What didn't you like about using the Virtual Welding System?

Having a hard time with the screen, doesn't give you same visual cues

5. How accurately do you think welding on the Virtual System mimics how you weld in real life?

No Response

6. How would you feel if a Virtual Welding System was a part of the training you received in your program?

I would like it

7. Would you have had an easier time learning to weld if initial training were done in a Virtual Welder?

Yes

8. What are the top five requirements you have of a Virtual Welding System?

No Response

Response Started:	**Response Modified:**
Wednesday, November 2, 2011 7:14:15 PM	Wednesday, November 2, 2011 7:16:19 PM

1. Have you ever welded before?

Yes

2. What did you like best about using the Virtual Welding System?

No wastage of metal. You can try again without using another piece

3. What didn't you like about using the Virtual Welding system?

Very touchy

4. What factors will influence your decision whether or not to choose welding as your area of study?

Length of time of the program and income after

5. How interested are you in taking the welding program?

Maybe

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

Yes

Response Started:	Response Modified:
Wednesday, November 2, 2011 7:00:52 PM	Wednesday, November 2, 2011 7:04:35 PM

1. Have you ever welded before?

No

2. What did you like best about using the Virtual Welding System?

Good for practice and hand steadiness

3. What didn't you like about using the Virtual Welding system?

Adjusting was difficult, seeing with helmet, doesn't give you real life environment (eg. smoke)

4. What factors will influence your decision whether or not to choose welding as your area of study?

No Response

5. How interested are you in taking the welding program?

Interested

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

Yes

Response Started:	Response Modified:
Wednesday, November 2, 2011 6:02:24 PM	Wednesday, November 2, 2011 6:03:33 PM

1. Have you ever welded before?

Yes

2. What did you like best about using the Virtual Welding System?

it's amazing

3. What didn't you like about using the Virtual Welding system?

just need more practice

4. What factors will influence your decision whether or not to choose welding as your area of study?

No Response

5. How interested are you in taking the welding program?

Not Interested

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

No

Response Started:	Response Modified:
Wednesday, November 2, 2011 5:59:07 PM	Wednesday, November 2, 2011 6:00:45 PM

1. Have you ever welded before?

No

2. What did you like best about using the Virtual Welding System?

didn't have to waste materials,

3. What didn't you like about using the Virtual Welding system?

not too much

4. What factors will influence your decision whether or not to choose welding as your area of study?

knows for sure want metal fabrication

5. How interested are you in taking the welding program?

Very interested

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

Yes

Response Started:	Response Modified:
Wednesday, November 2, 2011 5:50:08 PM	Wednesday, November 2, 2011 5:51:50 PM

1. Have you ever welded before?

No

2. What did you like best about using the Virtual Welding System?

No Response

3. What didn't you like about using the Virtual Welding system?

No Response

4. What factors will influence your decision whether or not to choose welding as your area of study?

No Response

5. How interested are you in taking the welding program?

Maybe

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

Yes

Response Started:	Response Modified:
Wednesday, November 2, 2011 5:24:23 PM	Wednesday, November 2, 2011 5:26:44 PM

1. Have you ever welded before?

No

2. What did you like best about using the Virtual Welding System?

closest you can get to actual welding without having to use real materials

3. What didn't you like about using the Virtual Welding system?

little disorientating

4. What factors will influence your decision whether or not to choose welding as your area of study?

already decided to go into welding

5. How interested are you in taking the welding program?

Very interested

6. If you could initially learn to weld using a Virtual Welding System, would you be more inclined to choose welding as your program choice?

No

Appendix D – Kano Analysis

Kano Analysis is a tool for weighting user requirements; each requirement is rated on scale to determine which are most important to the users. The top rating requirements are used to determining which alternative best suites stakeholder needs.

To view the Kano Analysis, click here.

Appendix E – QFD Matrix – Requirements Vs. Features

Machine features are matched to each user requirement and then weighted as to how well they meet the user requirement.

To view the full Matrix, click here.

Appendix F – QFD Matrix – Features Vs. Systems

Row #	Max Relationship Value in Row	Weight / Importance	Column # / **Quality Characteristics** (a.k.a. "Functional Requirements") / **Demanded Quality** (a.k.a. "Customer Requirements")	VRTEX™360 (1)	ARC+™ (2)	CS WAVE (3)
1	3	27	Low electricity usage	3		3
2	9	45	Tracking of student progress	9	3	9
3	9	50	No consumption of materials	9	9	9
4	3	30	Provides realistic and accurate welding sounds	3	3	3
5	9	45	Includes SMAW	9	9	9
6	9	27	Includes GTAW		9	9
7	9	45	Includes GMAW	9	9	9
8	9	27	Includes FCAW	9	9	
9	9	60	Multi-positioning	9	9	9
10	3	50	Warranty and local servicing	3	1	1
11	9	53	Built-in curriculum	3	1	9
12	9	53	Teacher training on full usage			9
13	3	20	Adaptable; easy to move	1	3	3
14	3	65	Different weld joint configurations	3	3	1
15	3	163	Advanced and realistic graphics	1	3	3
16	3	45	Partial or total immersion Virtual Reality System	3	3	3
17	9	48	Record keeping of material savings	9		
18	1	0	Recyclable	1	1	1
19	1	33	Produces welding sparks	1	1	
20	0	30	Produces heat similar to welding			
21	1	27	Produces welding smoke	1	1	
22	3	27	Used in other training schools	3	?	3
23	9	27	Used in reputable companies	9	1	9
24	9	42	Built-in training schedule	3	1	9
25	0	3	Includes weld symbols to comprehend in training			
26	9	48	Welding surface is at least 6 - 8"	3	9	9
27	0	45	Payback period of 5 years or less			
28	3	48	Large screen to view weld on	1	3	3
29	3	62	Graphics are in high definition	3	3	3
30	9	69	Realistic Accessories	1	3	9
31	9	45	Length of weld between 6 - 8"	9	9	9
			Max Relationship Value in Column	9	9	9
			Weight/Importance	5235	4996	6862

Appendix G – Electricity Calculations for 35% Usage Rate

		Amps	Volts	Kilowatts	Time (hrs)	kWh / year	Price / kWh	Cost / Machine / Year	16 students	7% Usage Rate	3.6% Usage Rate	15% Usage Rate
PowerWave 355M	Full Draw	450	38	17.1	875	14962.5	$ 0.068	$ 1,017.45				
	Phantom	5	75	0.375	1625	609.4	$ 0.068	$ 41.44				
	Total							**$ 1,058.89**	**$ 16,942.20**	**$ 1,185.95**	**$609.92**	**$2,541.33**
arc+	Full Draw	8	120	0.96	875	840	$ 0.068	$ 57.12				
	Phantom			0.02	1625	32.5	$ 0.068	$ 2.21				
	Total							**$ 59.33**	**$ 949.28**	**$ 66.45**	**$ 34.17**	**$ 142.39**
CS Wave	Full Draw	7-5	220	1.258	875	1100.75	$ 0.068	$ 74.85				
	Phantom			0.02	1625	32.5	$ 0.068	$ 2.21				
	Total							**$ 77.06**	**$ 1,232.98**	**$ 86.31**	**$ 44.39**	**$ 184.95**
VRTEX 360	Full Draw	4-2	115-230	0.46	875	402.5	$ 0.068	$ 27.37				
	Phantom			0.02	1625	32.5	$ 0.068	$ 2.21				
	Total							**$ 29.58**	**$ 473.28**	**$ 33.13**	**$ 17.04**	**$ 70.99**

ASSUMPTIONS:

Machine is on for 10 hrs a day

Each student is given a machine for their entire program

Actual welding time (high draw) estimated at 35% of that time

Phantom load of a computer estimated at 20 watts per day

TO VIEW THE FULL IMAGE, CLICK HERE

Appendix H – Electricity Calculations for 5.3% Usage Rate

		Amps	Volts	Kilowatts	Time (hrs)	kWh / year	Price / kWh	Cost / Machine / Year	16 students	7% Usage Rate	3.6% Usage Rate	15% Usage Rate
PowerWave 355M	Full Draw	450	38	17.1	135.29	2313.5	$ 0.068	$ 157.32				
	Phantom	5	75	0.375	2364.71	886.8	$ 0.068	$ 60.30				
	Total					3200.3		**$ 217.62**	**$ 3,481.92**	**$243.73**	**$ 125.35**	**$ 522.29**
arc+	Full Draw	8	120	0.96	135.29	129.9	$ 0.068	$ 8.83				
	Phantom			0.02	2364.71	47.3	$ 0.068	$ 3.22				
	Total					177.2		**$ 12.05**	**$ 192.77**	**$ 13.49**	**$ 6.94**	**$ 28.92**
CS Wave	Full Draw	7-5	220	1.258	135.29	170.2	$ 0.068	$ 11.57				
	Phantom			0.02	2364.71	47.3	$ 0.068	$ 3.22				
	Total					217.5		**$ 14.79**	**$ 236.63**	**$ 16.56**	**$ 8.52**	**$ 35.50**
VRTEX 360	Full Draw	4-2	115-230	0.46	135.29	62.2	$ 0.068	$ 4.23				
	Phantom			0.02	2364.71	47.3	$ 0.068	$ 3.22				
	Total					109.5		**$ 7.45**	**$ 119.17**	**$ 8.34**	**$ 4.29**	**$ 17.88**

ASSUMPTIONS:
Welder is on for 10 hrs a day
Each student is given a machine for their entire program
Actual welding time (high draw) 9.2 out of 170 hours, as per SMART Dent Loggers
We are not entirely sure that this machine was being used for 170 hours of the time
Phantom load of a computer estimated at 20 watts per day

TO VIEW THE FULL IMAGE, CLICK HERE

Appendix I – Life Cycle Cost Analysis Cases

VRTEX™360 Base, Pessimistic, and Optimistic Cases

The LCC Cases for the VRTEX™360 can be found by clicking here.

arc+™ Base, Pessimistic, and Optimistic Cases

The LCC Cases for the arc+™ can be found by clicking here.

CS Wave Base, Pessimistic, and Optimistic Cases

The LCC Cases for the CS Wave can be found by clicking here.

Appendix J - Virtual Welding Systems

The following are summaries on the available virtual welding systems that were looked at in this study.

Lincoln Electric's VRTEX™ 360

Description

The VRTEX™360 is a virtual reality arc welding trainer. This computer based training system is an educational tool designed to allow students to practice their welding technique in a simulated environment. It promotes the efficient transfer of welding skills to the welding booth while reducing material waste associated with traditional welding training. The combination of realistic puddle simulation and arc welding sound tied to the welder's movement provides a realistic and exciting, hands-on training experience.

Figure XX Image of VRTEX™ 360

123 Certification Inc.'s arc+™

Description

arc+™ is user friendly and High-Tech thanks to:

- Motion tracking technology at the state of the art of spatial metrology
- Metallurgy processing with most recent research in CFD, thermodynamics and heat transmission
- 3D image rendering with state of the art computer language and platform

The goal of arc+™ is not to replace the traditional learning methods, but rather to come as a complement, especially as regards to the beginners. Moreover, arc+™ allows you to optimize the welders' performances as well as the quality of the training while diminishing your training costs.

Figure XXX Image of arc+™

DIGINEXT's CS Wave

Description

The CS WAVE virtual welding trainer is available in 2 versions: a workbench for the permanent running and a mobile version for on-site training. The machine is provided with control centre software to monitor the trainee's progress from the trainer's workstation. Most welding processes and positions are addressed.

Figure XXX Image of the CS WAVE workbench and Lite model

Processes Available

CS Wave focuses on the three main techniques widely used in the welding manual work:

- GMAW – simulated with a real torch and MAG cable to recreate realistic welding motion constraints
- SMAW – simulated by handling the electrode gun, but the electrode itself is virtual and will appear in 3D view. The electrode is burning while you are welding and requires a very precise and smooth motion.
- GTAW – as in reality, the CS WAVE enables students to work the coordination of both hands and the complex techniques of feeding the welding pool.

Positions Available

The workbench screen is motorized to move vertically and horizontally to represent all the welding positions. The automated motion of the screen can be personalized according to each individual user's height and the trainer's specifications.

The mobile Lite model's screen automatically detects a vertical or horizontal position depending on the exercise to practice.

Appendix K – Features and Benefits of All VWS

Lincoln Electric VRTEX™360

Features	Benefits
Software Upgrade package available	New product features and other enhancements, software patches, upgrades and support, advanced notification of seminars, classes, and educational materials First Pass Welding Curriculum Upgrades
24/7 Phone Support, online Support FAQ's	
Warranty and Replacement Programs	
Instructor mode with key required	Lincoln Electric Welding School defaults can be used to train students the way Lincoln does in their welding school or instructors can customize their own system. Fine tune student experience through modification of preferred welding technique, weld procedures and tolerances. Modify these parameters to match how you teach welding.
Instructor Cam	The Instructor Cam can be used while the student is welding or used for visual inspection after the weld has been completed. Welds can be visually inspected for porosity, undercut and proper bead placement
Weldometer™	Allows instructors to track material and cost savings, verify cost savings and track student arc time
First Pass™ Welding Curriculum	Helps instructors integrate VR Welding into traditional welding training. Gives recommendations on amount of time spent in the VR welding lab versus traditional booth time, welding lessons and supporting resources and curriculum.
Performance scoring system	Each weld is scored based on how accurately the student performs the welding technique set by the instructor. Areas of potential discontinuities and visual indications can be seen in virtual weld

Features	**Benefits**
Graphs students' welding technique and color codes results	Student results are compared to correct welding technique selected by the instructor. Parameters include: - Position in the joint - Contact Tip to Work Distance (CTWD) / Arc Length - Work Angle - Travel Angle - Travel Speed
Simulates multiple welding processes: **SMAW** **E6010 (Fleetweld® 5P+)** **E7018 (Excalibur® 7018)** **GMAW** **Short Arc [.035 in. (0.9 mm) SuperArc® L-56]** **Axial Spray [.045 in. (1.1mm) SuperArc® L-56]** **Pulse [.045 in. (1.1 mm) SuperArc® L-56]** **STT® [.045 in. (1.1 mm) SuperArc® L-56]** **FCAW** **Gas-shielded [.045 in. (1.1 mm) UltraCore® 71A85]** **Self-Shielded [5/64 in. (2.0 mm) Innershield® NR-232]**	
Multiple joint configurations: **Flat Plate, Tee Joint, 6 inch Diameter Schedule 40 Pipe, 2 inch Diameter XXS Pipe, and Groove Joint**	
Multiple Positioning: **Weld table can be moved to away Position** **Left, right and center Weld Arm positions** **90, 45 and 0 degree arm position**	Simulates real life welding applications and allows for 2G, 5G and 6G pipe welding.
ProFlo™ Puddle Modeling Technology	Creates realistic puddle modeling, simulates sparks, slag, grinding and weld cooling. Virtual weld discontinuities appear in the weld when improper welding techniques used

Features	**Benefits**
Magnatron™ technology	The haptic feedback adds realism to the simulation and allows for simulation of processes that require touching the electrode to the base metal such as when using stick electrodes that require a drag technique and when making the root pass in pipe. Accurate positional data results in scores that help students improve their technique and translates to real welding lab success
VR Stinger	Retracts at the same rate a real stick electrode would melt off to simulate melting or a real electrode
VR Stand	Allows the virtual welding coupon to be placed in multiple positions with or without the adjustable table
Helmet; 3D stereo eye pieces and sound	
Virtual Welding Gun	Student can practice GMAW and FCAW welding techniques
Optional Graphic overlays	Gives students real time welding technique feedback
Changeable settings on welding machine interface	Learn welding machine set up; Process Selection, Wire Feed Speed/ Amperage, Voltage, Polarity, Gas Selection and Flow Rate. Learn welding actions; trim wire, get a new electrode, quench metal, and remove slag.
Save student reports on USB	Student can keep track and monitor progress

Features	Benefits
Eduwelding+®	Learning of psychomotor skills Basic knowledge acquisition Training activities with arc+™® simulator
Weld diagnostics with evaluation and comments	
3D radiographic of the weld bead	
Weld defects identifications	
Weld Beads Replay including complete image reconstitution and dynamic display of welding parameters	
Welding datasheets generated while tests are carried out	
eCertify the welding parameter tests to industry code requirements	
Variety of weld defects taken into account: **Lack of Penetration, Lack of Fusion, Porosity, Internal and External Undercuts, Excessive Convexity, Excessive Concavity, Solid Inclusion Cold lap, Cracks.**	
Processes **Semi-automatic welding process : GMAW, MCAW, FCAW** **Manual : GTAW, SMAW**	

Features	**Benefits**
Pedagogy **-Fine Motor skill Welding Parameter Breakdown and Reconstruction: Welding Speed, Motion Straightness, Work and Travel Angles, Arc Length** **-Weld Defects Localization** **-On time virtual Assistant** **-Training Level (Beginner, Intermediate and Expert)** **-Weld Replay** **-Virtual Class Management**	
Special Effects **Realistic Sounds according to Metal Transfer mode** **Fumes and metal projections** **Weld pool with electrical arc**	Realistic welding environment
On time Welding Diagnostic **Electrical adjustment Evaluation** **Manual Dexterity Evaluation** **Weld Quality Evaluation (visual inspection and internal defects)**	
Multilingual teaching: English and French	
Multiple models: Private network, internet-ready, standalone	Adaptable to specific needs
15” touch screen	
Adjustable platform	
Motion tracking technology	
Portable and easy to set up	

Features	Benefits
Universal adapters for real welding handles	
More than 100 welding procedures, with up to 25 exercises	
Multi Positioning; Flat, Horizontal, Vertical	
Multi Joints; Butt, Bevel-Groove, V Groove	

DIGINEXT's CS Wave

Features	Benefits
Multi Processes: GMAW, SMAW, GTAW	
GMAW simulated with real torch and MAG cable	Recreates realistic welding motion constraints
Control Center	Trainees can be monitored and supervised and their progress analyzed during a training course. Application can be installed on any computer inside or outside the training centre Collects all the virtual training information in real-time through the network. Trainer can easily access student's results at any time and in real-time. Trainer can instantly track, interpret and compare the results of each student Automated alerts can be set-up by the trainer based on some critical student behavior
Adjustable workbench	Each user can adjust to fit his or her height
178 exercises in 3 processes	Under ISO or ASME codes
Screen height can vary from 840 mm to 1520 mm	Adjustable to the required welding position and rotates from a vertical to horizontal position
Four parameters of hand motion; speed, trajectory, distance, and orientation	The student practices on those parameters combining them together until a perfect hand motion with the 4 simultaneous parameters is achieved
Result graphs	Tracks students' progress and can be used to discuss with students their areas needing improvement
One central server managing several work benches using an internet connection	Windows software that can run on any computer and can be distant or locally installed
Mobile TFT screen	Automatically positions to users height and exercise to perform

Features	**Benefits**
Embedded PC with an Ethernet Port	
Training Manager	Has a server in charge of the communication between all CS WAVE elements and provides security and storage procedures to ensure data integrity It is the trainer’s main tool, allowing follow up and update of the training progressions and also a tool for the trainees to consult and analyze their results.
CS Wave portable option	A lite version that can be carried; ideal for marketing The portative unit can be installed in the same network architecture as the workbench and can communicate with the same central server
Customize training stages	Adapt the training course to the individual learner’s needs
Each user has specific access rights	Depending if you are a trainee, a trainer, a training manager or a system manager, you will have specific tools to access and update information. The system also provide an automated

Appendix L – VWS Comparison Table

	Initial Purchase Price	Software Upgrade Price	Set-up Fee	Warranty	Maintenance Costs	Repair	Disposal of Machine	Life Span
VRTEX™360	$51,150 per machine; volume discounts are available.	Optional software upgrade per year, at $9,000 per year. The software upgrade is optional for additional welding training and technical improvements. If the software upgrade hasn't been bought during the first year, all the previous software upgrades will be required to purchase in order to upgrade any software in the following years.	Free	3 year limited Warranty	No maintenance cost for the VRTEX™360 machines.	Lincoln tech come in and repairs for free; may be a fee if replacing expensive parts. If there's a defect or it's beyond the limit of repair by tech, ship the machine back to Lincoln for a replacement or repair. Lincoln will cover the shipping cost and the customer will usually get the machine back in 1-3 weeks.* *Estimated time. It depends on customer's location and the machine's condition.	Two types of materials from the machine are recyclable- steel and plastic. The monitor and main case of the machine can be recycled in the same way as a normal computer.	Average life 10 yrs.; durability or lifespan of the machine depends on how and where it is being used. If well-treated in a clean environment, it will last between 10 to 20 years.

	Initial Purchase Price	Software Upgrade Price	Set-up Fee	Warranty	Maintenance Costs	Repair	Disposal of Machine	Life Span
arc+™	Estimated at $82,000 per machine. License cost per student of $250	Software upgrades are included with maintenance costs; two software versions released per year, specific software to debug released whenever required. Customers can easily upgrade the arc+™ simulator by downloading a new software version through a Web connection.	Free	12 months	No maintenance cost for the arc+™ machine for the first year. Software upgrades are free but physical configuration of the machine will cost $6,000 per year after the first year of purchase.	Software problem: customer can easily reconfigure online; For hardware problem: ship back to the company facility to reconfigure and repair. First year will be covered; customer pays* for the shipping and repairing afterwards. The time for repairing and receiving the machine back usually takes up to *3 weeks.	123 Certification has no plan on buying back the arc+™ machine after end of amortization. They suggest recycling the machine as a normal personal computer.	Average life 10 yrs.; durability or lifespan of the machine depends on how and where it is being used. If well-treated in a clean environment, it will last between 10 to 20 years.

	Initial Purchase Price	Software Upgrade Price	Set-up Fee	Warranty	Maintenance Costs	Repair	Disposal of Machine	Life Span
CS WAVE	$47,000 per machine *excluding shipment and customs	All software is provided with a lifetime license; any upgrades in the first year are included in warranty; prices for upgrades vary	3000 €; includes installation, 4-5 days training of up to six users, transportation and accommodation of CS Wave Representative.	1 year warranty including any upgrades	DIGINEXT will train BCIT IT technicians to do maintenance on the CS Wave	DIGINEXT will train BCIT IT technicians to do repairs on the CS Wave	Recycle like normal PC. An authorized networking partner might buy back the machine based on the machine's condition	Average life 10 yrs.; durability or lifespan of the machine depends on how and where it is being used. If well-treated in a clean environment, it will last between 10 to 20 years.

Appendix M – Current Customers of Virtual Welding Systems

VRTEX™ 360

The VRTEX™ 360 has a wide range of customers including welding shops, educational institutes, and correctional institutes in the United States. In Canada, it hasn't yet been widely implemented. There are a few post-secondary institutes in Western Canada currently using the machines as marketing tools to attract new students. Other users include:

Superior Industries

Superior Industries (manufacturer of conveyor systems and components) purchased a new VRTEX™ 360for its welding training center on August 9, 2011. Superior's welders are using it to practice their techniques in a simulated environment. The virtual machine does not replace Superior's existing weld theory courses or time in the lab, but it is a practical tool to develop and promote the welder's muscle memory. The goal for Superior to use the virtual machine is to promote the efficient transfer of welding skills to the booth, while reducing material waste associated with traditional training.

The Scioto County Career Technical Center

The Scioto County Career Technical Center in Lucasville is using the VRTEX™ 360to teach its students the basics of welding. The machine's instant feedback system gives the students a score, motivating the students to compete for the highest score. However, the machine will not make the students become skilled welders and it will only get the training process started. The center is more focused on the core benefit from the machine, which is the cost savings on material (steel, electrodes, etc.) usage in the actual welding process and energy (mainly electricity) usage.

Pitt Community College

Pitt Community College in Eastern North Carolina is using the VRTEX™ 360for recruiting new welders, especially high school graduates and younger students. The eco-friendly and score-tracking virtual machine has attracted other colleges and young students interested in the welding trade.

Fort Lee Military Training Post

At Fort Lee, the military training post is using the VRTEX™ 360to train its soldiers by using a 1-16 instructor-to-student ratio for each machine. Before going into the welding bays and handling a real welding torch, soldiers learn to use the virtual welder. After the soldiers learn the muscle memory of welding, they progress to the real welding equipment in actual welding bays. The military post highly appreciates the cost savings and real time feedback benefits by using the VRTEX™ 360.

arc+™

In the past 30 months, 123 Certification Inc. has sold 25 units in many different countries, including the USA, France, Australia, Germany, Kazakhstan, China, UAE, India, and also in Canada. The machine has been mainly used for educational and training purposes among welding shops, welding institutes, and construction companies. The arc+™ has not yet been placed in any British Columbian training centers. The company is looking for partners and training centers at this moment for a training center pilot project in B.C. to implement a laboratory (welding training centre).

*Information of customers (name, address, email, etc.) is confidential and access is restricted by 123 Certification Inc.

CS Wave

DIGINEXT has customers for CS Wave all around the world. The current customers range from secondary schools in France and large companies around the globe. They are primarily using the machine for training and promotional purposes. For instance, Caterpillar is using the machine for internal promotion and in house training, AFPA Cherbourg is using it for professional training, and Canadian Welding Bureau (CWB) has one for display and educational research purposes, but does not use it for actual training purposes.

Caterpillar France

Caterpillar France installed CS Wave in their plant. They have approximately 130 new welders to train each year. The training period for each welder is 3 weeks. Every 2 years, the welders must be recertified. Traditionally, this process was a full day session.

The training manager decided to update the training program to integrate CS Wave. New hires are obligated to spend some time on the CS Wave system before proceeding with the internal qualification. If the results from the CS Wave are not sufficient, the candidate is rejected before even entering formal qualification testing. With the integration of CS Wave, the initial training process has been reduced from 3 weeks to 2 weeks and the recertification process from a full day to half a day.

At the end of the first year of implementation of CS Wave, Caterpillar France observed a 30,000€ savings of raw material and 25,000€ in salary costs.

Appendix N – User Requirements (Grouped)

Usability

Used in reputable institutions or facilities
Simple and easy to use
Convenient to service and fix

Visual Accuracy

Puddle graphics
Accurate depth perception
Student and instructor can visually inspect a completed weld

Realistic

Real welding environment (sparks, heat, smoke)
Welding gun/stinger weighted the same as real gun/stinger
Length of weld longer than 8" to ensure proper positioning throughout the entire weld
Length of weld between 6 – 8" long to ensure proper positioning throughout the entire weld

Covers Curriculum

Ability to perform successful welds in a variety of joints
Ability to perform successful welds in a variety of positions
Ability to perform successful welds in SMAW and GMAW
Ability to perform successful welds in other processes
Ability to perform a variety of other welding processes (oxy fuel or other cutting systems)
Provides valuable feedback
Accurate based on theory of welding (basic metallurgy and the reaction of metal in the weld zone) and welding procedures

Energy and Material Savings

Energy savings
Reliable and transparent way to track material and energy savings
Consumes less material
Return on investment

Appendix O – Steelmaking Raw Material and Input Costs

Year / Month	Thermal Coal $/tonne	Coking Coal $/ton	Iron Ore C/dmtu	Natural Gas $/000m³	Steel Scrap $/tonne	Electric C/kWh
2011 / 1	141.9	169.3	179.6	330.8	420	6.73
2011 / 2	137.5	169.3	187.2	329.0	457	6.72
2011 / 3	135.1	169.3	169.4	328.3	461	6.59
2011 / 4	131.3	n/a	179.3	361.1	454	6.58
2011 / 5	127.6	n/a	177.1	360.7	430	6.76
2011 / 6	127.8	n/a	170.9	360.0	435	7.21

Typically, it takes 1.5 tonnes of iron ore and about 450 kg of coke to produce a tonne of pig iron, the raw iron that comes out of a blast furnace. Some of the coke can be replaced by injecting pulverised coal into the blast furnace.

Appendix P – Blast Furnace Route Steelmaking Costs 2011

Conversion costs for BOF steelmaking

Integrated steelmaking - crude steel cost model						
Item $/unit	**Factor**	**Unit**	**Unit cost**	**Fixed**	**Variable**	**Total**
Iron ore	1.435	t	124		177.94	177.94
Iron ore transport	1.435	t	20		28.7	28.7
Coking coal	0.519	t	200		103.80	103.80
Coking coal transport	0.519	t	19.5		10.12	10.12
Steel scrap	0.162	t	330		53.46	53.46
Scrap delivery	0.162	t	5		0.81	0.81
Oxygen	83	m 3	0.085		7.06	7.06
Ferroalloys	0.014	t	1650		23.10	23.10
Fluxes	0.59	t	45		26.55	26.55
Refractories	0.011	t	650		7.15	7.15
Other costs	1		14.25	3.56	10.69	14.25
By-product credits					-21.6	-21.6
Thermal energy, net	-2.67	GJ	12.50		-33.38	-33.38
Electricity	0.122	MWh	100	1.83	10.37	12.2
Labour	0.48	Man hr.	37	4.44	13.32	17.76
Depreciation				48.00		48.00
Interest				58.00		58.00
Total				**115.83**	**418.09**	**533.92**

Appendix Q – The Carbon Footprint of Steel

	Plate	Sections	Tubes	Hot Dip Galvanized (generally)
CO_2 (t/t)	0.919	0.76	0.857	1.35
Energy (GJ/t)	17.37	13.12	15.42	21.63

Carbon and energy impacts of steel construction products in the UK*

* The data provided has been generated based on worldsteel data collection and methodology for calculation the LCI for steel products. It is based on the worldsteel Life Cycle Inventory Methodology Report 1999/2000, and data collected and published in 2002. To accurately establish the environmental impact of steel manufacturing, the World Steel Association uses the 'system expansion' method of life-cycle assessment.

Steel is manufactured predominantly using two methods. Both methods of production require a significant input of scrap steel. The primary route uses 13.8% scrap, with emissions of 1.987 tonnes of CO_2/tonne of steel. The secondary route uses 105% scrap steel, with emissions of 0.357 tonnes CO_2/tonne. From these basic figures it is possible to calculate the tonnage of CO_2 that is saved for each tonne of scrap steel that is recycled.

CO_2 saved = (1.987-0.357)/(1.05-0.138) = 1.787 t CO_2 / t.

We can now calculate the CO_2 emissions associated with the production of a tonne of steel, independently of the production route. Using two scenarios demonstrates that the CO_2 emissions for steel are the same irrespective of the proportions of primary and secondary sourced steel assumed.

- Scenario A – assume the market sources 50% of its steel from primary production and 50% from secondary production.
- Scenario B – assume the market sources 100% of its steel from secondary production.

In both scenarios, the same end-of-life recycling rate is used. In this case, the value that has been demonstrated by research for steel sections in the UK is 99%.

	Scenario A	Scenario B
Average amount of scrap in the steel is	(105+13.8)/2 = 59.4%	105%
Average CO_2 /t	1.987x0.5 +0.357x0.5 = 1.172 t/ t	0.357 t/t
Net scrap produced through product life-cycle	99%-59.4% = 39.6%	99%-105% = -6%(some is lost)
CO_2 emissions /t	1.172- (0.396x1.787) =**0.464** t/t	0.357 -(-0.06x1.787) =**0.464** t/t

Scenarios for proportions of primary and secondary sourced steel

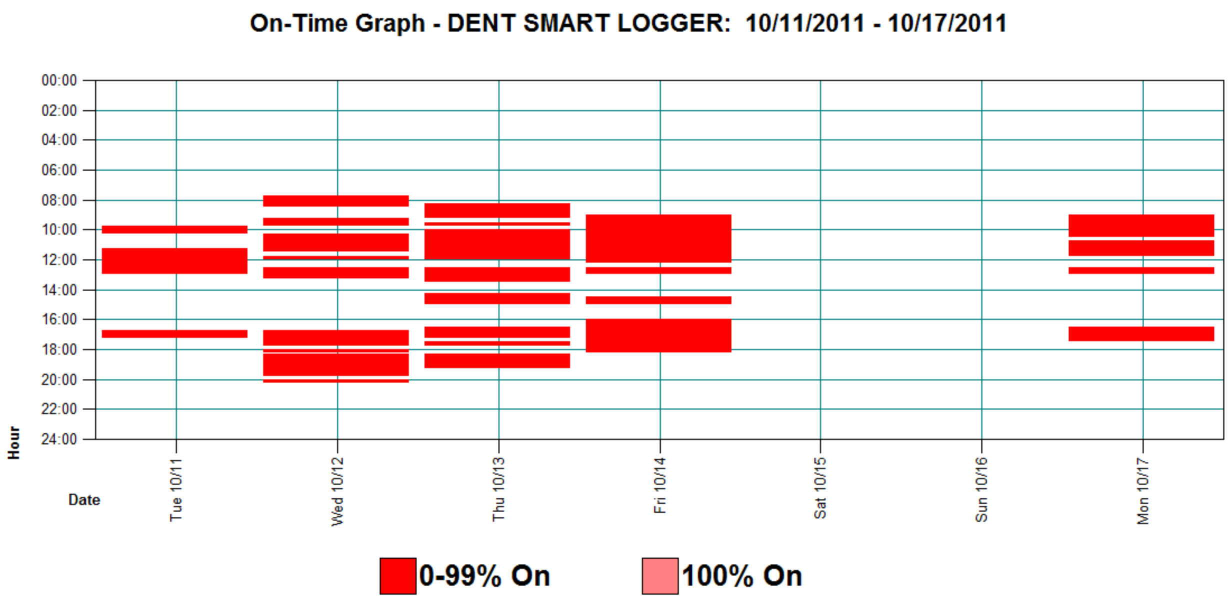
The results in Table XX demonstrate that the impact of steel manufacture is identical regardless of the level of recycled content. These results relate specifically to the production of steel slab for further processing into steel sections.

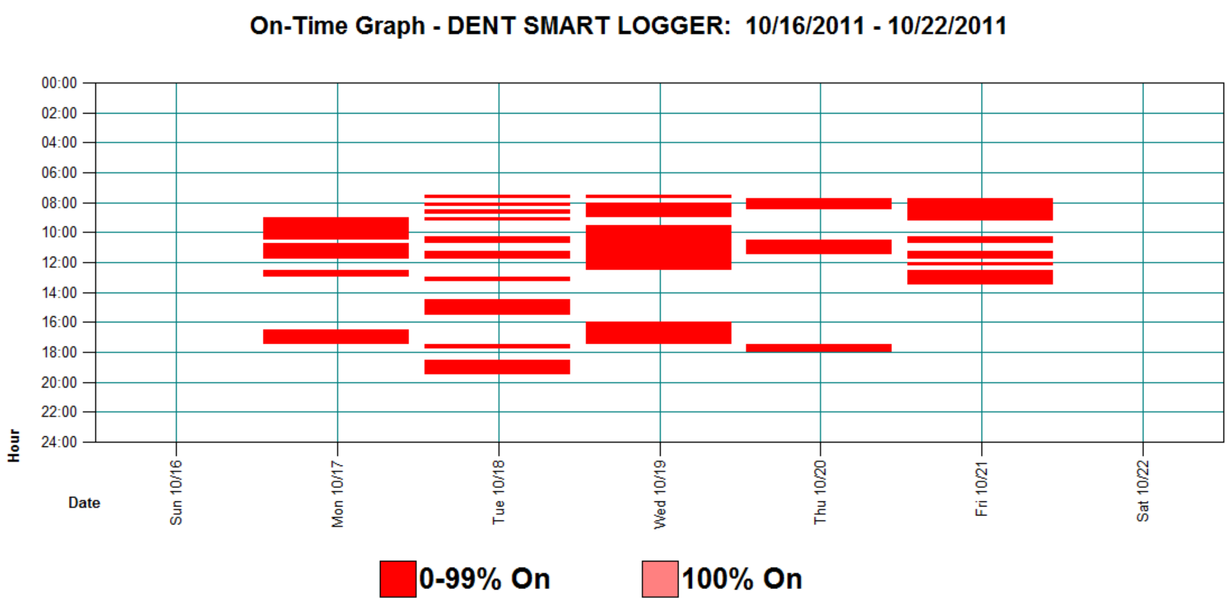
Appendix R – Dent Smart Logger Summaries and On-Time Graphs

Summary for Logger 2 - Removed November 2, 2011

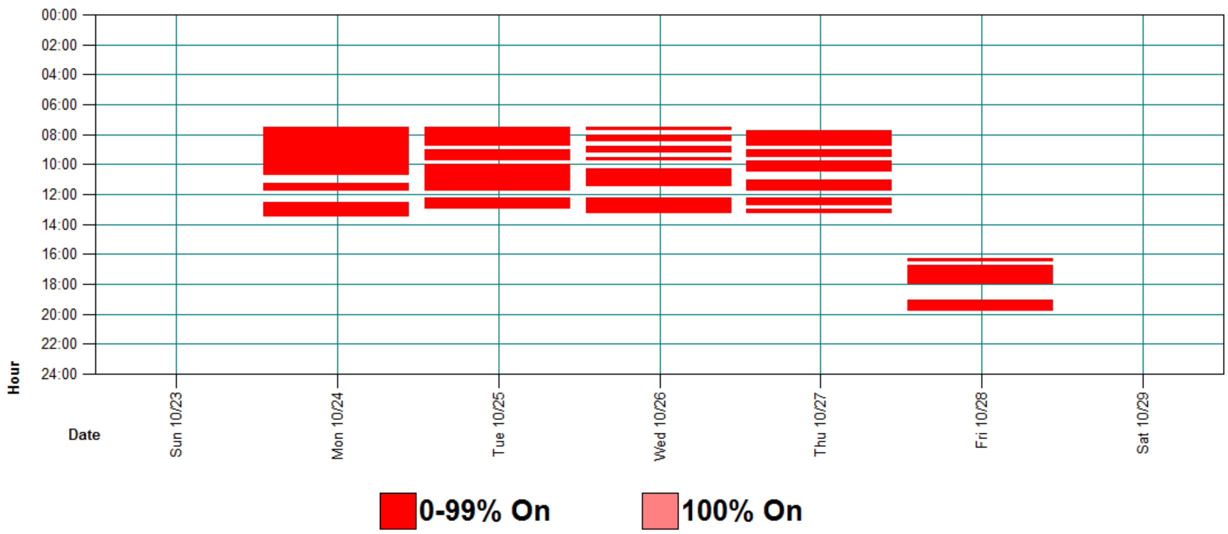
Data File Name:	Logger 2 Nov 4 2011.log	
Logger Serial Number:	ML10070023	
Description:	DENT SMART LOGGER	
Logger Reset:	10/11/2011	9:12:23 AM
Elapsed Time Since Reset:	578.97	hrs
On-Time Since Reset:	9.20	hrs
Percent On Since Reset:	1.59%	
Connected Load:	No Load Define	
Energy Cost:	Unknown	
Data Starts:	10/11/2011	9:12:23 AM
Data Ends:	11/4/2011	12:10:54 PM
Data Elapsed Time:	578.98	hrs
Estimated Annual Hours O	140	hrs
Number of Turn Ons:	3216	
Percent On:	1.59	%
Data On-Time:	9.22	hrs
Average On-Time:	0.00	hrs
Longest On-Time:	0.07	hrs
Shortest On-Time:	< 0.01	hrs
Number of Turn Offs:	3217	
Percent Off:	98.41	%
Data Off-Time:	569.75	hrs
Average Off-Time:	0.18	hrs
Longest Off-Time:	66.44	hrs
Shortest Off-Time:	< 0.01	hrs

On-Time Graph for Logger 2 - Removed November 2, 2011

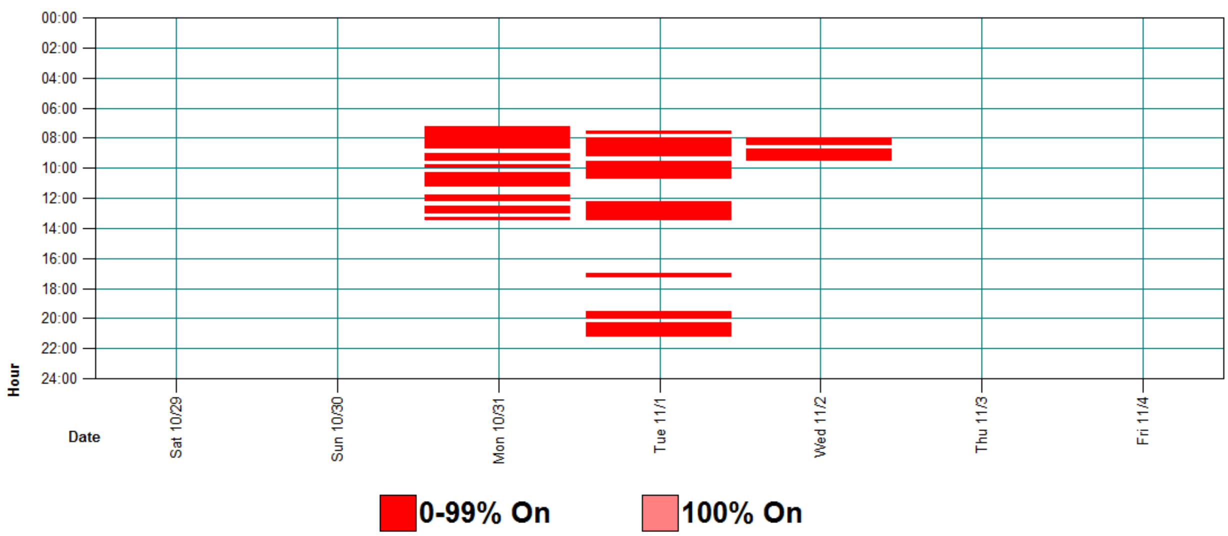




On-Time Graph - DENT SMART LOGGER: 10/23/2011 - 10/29/2011



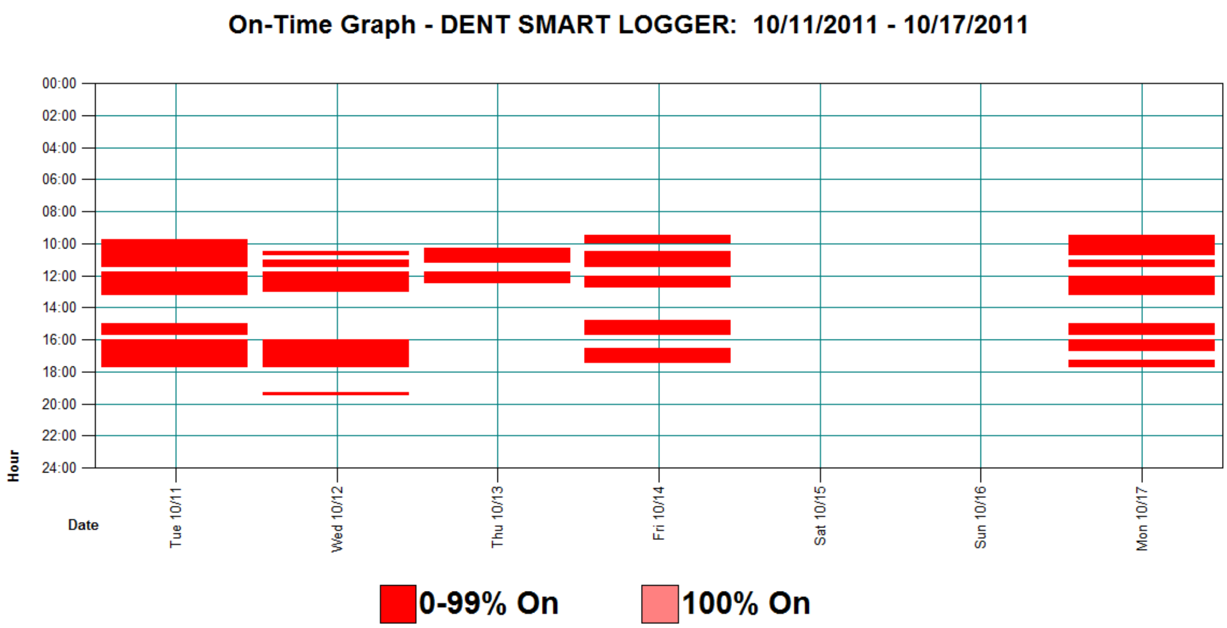
On-Time Graph - DENT SMART LOGGER: 10/29/2011 - 11/4/2011

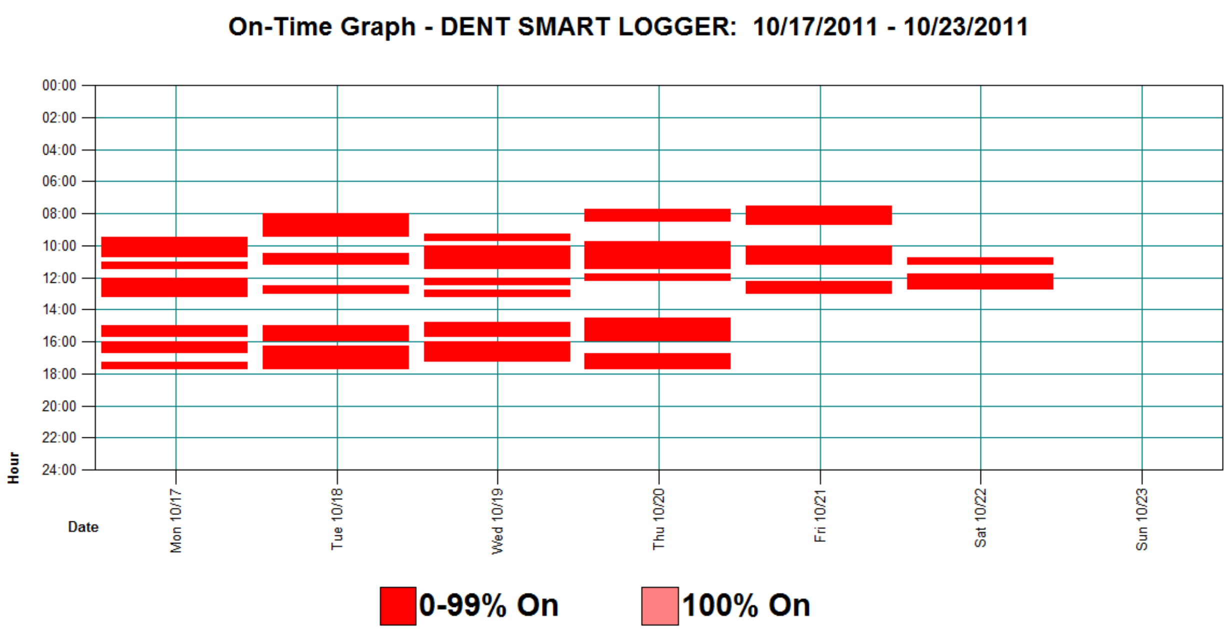


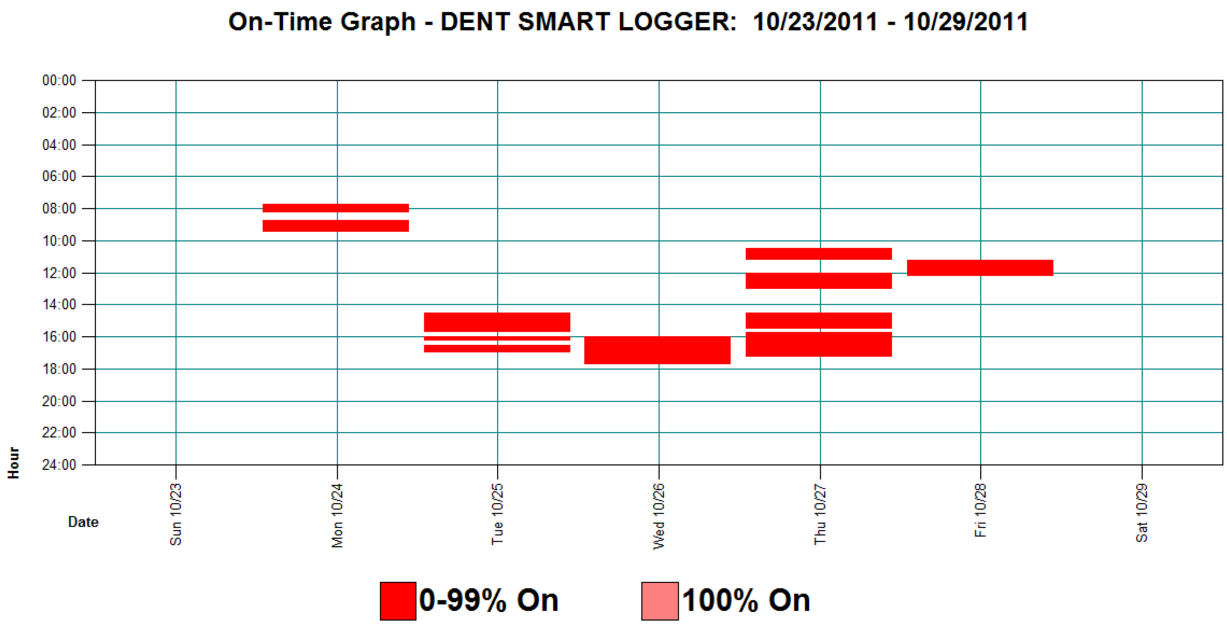
Summary for Logger 3 - Removed November 2, 2011

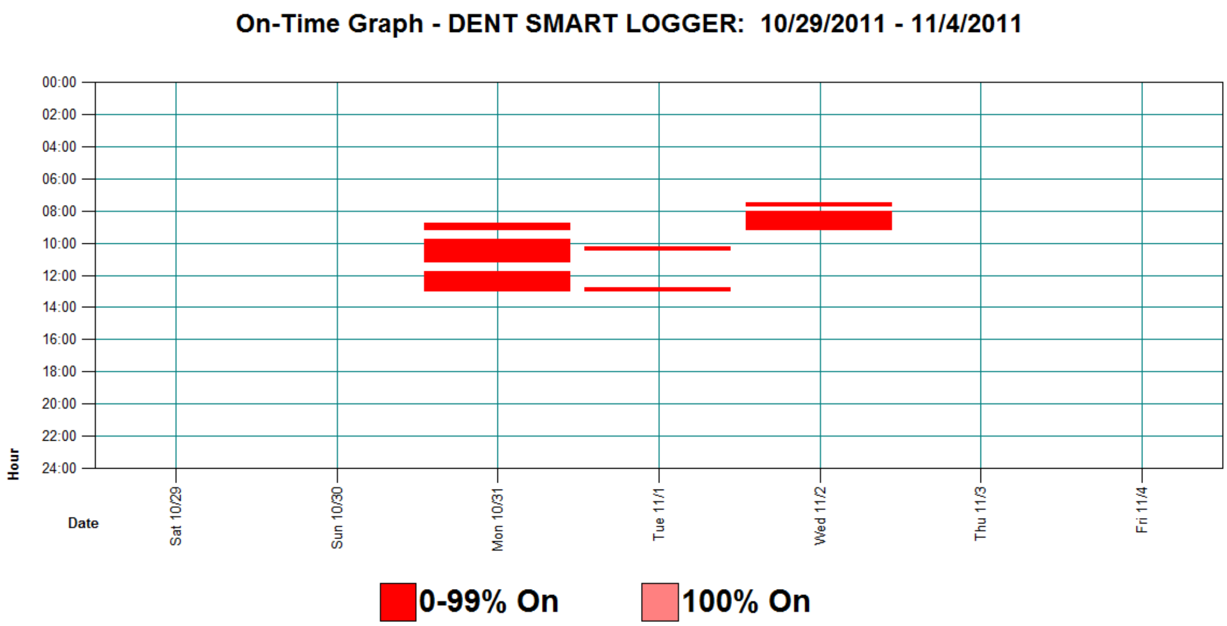
Data File Name:	Logger 3 Nov 4 2011.log	
Logger Serial Number:	ML10070019	
Description:	DENT SMART LOGGER	
Logger Reset:	10/11/2011	9:10:53 AM
Elapsed Time Since Reset:	578.92	hrs
On-Time Since Reset:	2.00	hrs
Percent On Since Reset:	0.35%	
Connected Load:	No Load Define	
Energy Cost:	Unknown	
Data Starts:	10/11/2011	9:10:53 AM
Data Ends:	11/4/2011	12:06:31 PM
Data Elapsed Time:	578.93	hrs
Estimated Annual Hours O	32	hrs
Number of Turn Ons:	1572	
Percent On:	0.36	%
Data On-Time:	2.10	hrs
Average On-Time:	0.00	hrs
Longest On-Time:	0.04	hrs
Shortest On-Time:	< 0.01	hrs
Number of Turn Offs:	1573	
Percent Off:	99.64	%
Data Off-Time:	576.83	hrs
Average Off-Time:	0.37	hrs
Longest Off-Time:	68.73	hrs
Shortest Off-Time:	< 0.01	hrs

On-Time Graph for Logger 3 – Removed November 2, 2011






On-Time Graph - DENT SMART LOGGER: 10/23/2011 - 10/29/2011
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00
Hour
Date
Sun 10/23
Mon 10/24
Tue 10/25
Wed 10/26
Thu 10/27
Fri 10/28
Sat 10/29
0-99% On
100% On


On-Time Graph - DENT SMART LOGGER: 10/29/2011 - 11/4/2011
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00
Hour
Date
Sat 10/29
Sun 10/30
Mon 10/31
Tue 11/1
Wed 11/2
Thu 11/3
Fri 11/4
0-99% On
100% On

Appendix S – Welding Program Details

	# of Students / Year (Based on 2010 enrolment)	Days in Training / Student	Hours / Day in Training / Student	Welding Practices Covered
A-Level	30	Approx. 40*	6.5	P11 Shielded Metal Arc Welding P12 Gas Tungsten Arc Weld RK8 Welding Metallurgy RK9 Blueprint Reading
B-Level	63	Up to 80*	6.5	P7 Shielded Metal Arc Welding P8 Gas Metal Arc Welding P9 Flux Core Arc Welding P10 Gas Tungsten Arc Welding RK4 Welding Qual Control / Inspection RK5 Welding Code Standards / Specs RK6 Blueprint Reading RK7 Welding Metallurgy
C-Level	152	140	6.5	P1 Introduction and Safety P2 Oxyfuel Gas Cutting P3 Oxyacetylene Welding P4 Shielded Metal Arc Welding P5 Air Carbon Arc Cutting P6 Gas Metal Arc / Flux Core Arc Welding RK1 Material Handling RK2 Blueprint Reading RK3 Metallurgy
TOTAL	245			

* Depends on modules required

To view the full document, click here.

Appendix T – Consumables Purchased from Barry Hamel (April – October 2011)

To view the Consumables Purchased from Barry Hamel, click here.

Appendix U – Consumables Identified as Used by Level C

To view the Consumables Identified as Used by Level C, click here.

Appendix V – Total Steel Consumption (April – October 2011)

To view the Total Steel Consumption, click here.

Appendix W – Steel Identified as Consumed by Level C

Order Date	Request Date	Order Number	P.O. #	Item No.	Quantity (each)	Quantity (lb.)	Description	Unit Price	Amount	HST	Total
4/13/2011	4/14/2011	73613118	P0060208	13858	40	19,602	.375 (3/8) HR PLT A36 Width 48" Length 96"	$305.31	$12,212.40	$1,465.49	$13,677.89
4/13/2011	4/14/2011	73613118	P0060208	13946	4	2,614	.500 (1/2) HR PLT A36 Width 48" Length 96"	$407.14	$1,628.56	$195.43	$1,823.99
5/3/2011	5/4/2011	73614560	P0060427	13946	6	3,921	.500 (1/2) HR PLT A36 Width 48" Length 96"	$407.14	$2,442.84	$293.14	$2,735.98
5/24/2011	5/25/2011	73616489	P0060754	13858	40	19,602	.375 (3/8) HR PLT A36 Width 48" Length 96"	$290.60	$11,624.00	$1,394.88	$13,018.88
7/11/2011	7/12/2011	73620816	P0061249	13858	20	9,801	.375 (3/8) HR PLT A36 Width 48" Length 96"	$290.60	$5,812.00	$697.44	$6,509.44
7/11/2011	7/12/2011	73620816	P0061249	13946	4	2,614	.500 (1/2) HR PLT A36 Width 48" Length 96"	$407.14	$1,628.56	$195.43	$1,823.99
8/12/2011	8/15/2011	73623739	P0061608	13858	30	14,702	.375 (3/8) HR PLT A36 Width 48" Length 96"	$290.60	$8,718.00	$1,046.16	$9,764.16
8/12/2011	8/15/2011	73623739	P0061608	13950	15	12,252	.500 (1/2) HR PLT A36 Width 48" Length 96"	$490.08	$7,351.20	$882.14	$8,233.34

TOTAL	$115,175
Assume Level C's share of steel consumption	0.80
Assume Level C Total Cost	**$92,140.27**

TO VIEW THE FULL SIZE IMAGE, CLICK HERE.

Appendix X – Subtotal of All Welding Expenditures (including Recycling)

	Total Cost / Year	Recycling Cost[5]	Total Cost For Level C
Steel[1]	$ 204,979.58	$ (1,971.14)	$ 90,563.36
Welding Consumables[2 3]	$ 59,999.67	$ (166.80)	$ 37,279.62
Gas[4]	$ 108,000.00	-	$ 86,400.00
TOTAL	**$ 372,979.25**	**$ (2,137.94)**	**$ 214,242.98**

[1] - Records were only for 6 months. Assumption was that consumption for the other 6 months was the same or very similar.

[2] - Consumption could increase in the next few years as the department will be growing due to Seaspan Marine's $8-billion contract for building coast guard and other non-navy ships

[3] - Welding Consumables for Total Cost for Level C was derived from the total usage rate per student and then applied to how many C level students there are.

[4] - Gas consumption is an estimate provided by David Helman, based on an average of the months of September 2011 and October 2011

[5] - Recycling Costs were derived from applying a 15% usage rate to the total amount received by the Steel Trades Department and Welding Department.

Appendix Y – Capital Costs

	PowerWave 355M	VRTEX360	CS Wave	Arc+™	
EQUIPMENT COSTS					
Machine	$ 4,325.00	$ 51,150.00	$ 47,000.00	$ 82,000.00	
Software (per annum)	$ -	$ 9,000.00	$ -	$ 6,000.00	
Licensing fee	$ -	$ -	$ -	$ 250.00	license per student
INSTALLATION	$ -	$ -	$ 4,150.00	$ -	
Shipping	$ -	$ -	$ 8,700.00		
MAINTENANCE	$ 500.00	$ -		$ -	

Appendix Z – Summary of Enrolment Numbers with Costs and Usage Rates

	Hours in training / student	Time spent welding (%)	Students enrolled	Total Hours Welding per year	% of Total Hours Welding
Level A	240	0.95	30	6840	4%
	6 per day / 5 days / Up to 8 weeks		12%		
Level B	480	0.95	63	28728	18%
	6 per day / 5 days / Up to 16 weeks		26%		
Level C	840	0.95	152	127680	78%
	6 per day / 5 days / 28 weeks		62%		
Total	1560	0.95	245	163248	100%

Cost of Expendables	Total per year	Total for Level C per year	Total per student	Total per hour
Steel	$204,979.60	$92,140.27	$836.65	$0.54
Recycling of Steel	$(1,971.14)	$(1,576.91)		
Consumables (electrodes, tips, grinding discs, etc.)	$69,998.66	$32,133.07	$285.71	$0.18
Recycling of Welding Rods	$(166.80)	$(133.44)		
Gas	$108,000.00	$86,400.00	$440.82	$0.28
Total	**$380,840.32**	**$208,962.98**	**$1,563.18**	**$1.00**

	Capital Cost	Lifespan (yrs.)
VRTEX™360	$51,150	15
arc+™	$82,000	15
CS Wave	$47,000	15
PowerWave 355M	$4,325	25

% of Time spent on Virtual Welder	Time in Hours per day	Time in total hours	Savings per hour	Savings per year
0.05	0.31	8,162	1.00	$8,179.02
0.07	0.40	11,427	1.00	$11,450.63
0.1	0.62	16,325	1.00	$16,358.04
0.15	0.93	24,487	1.00	$24,537.06
0.2	1.24	32,650	1.00	$32,716.08
0.25	1.54	40,812	1.00	$40,895.10
0.3	1.85	48,974	1.00	$49,074.12
0.35	2.16	57,137	1.00	$57,253.15
0.4	2.47	65,299	1.00	$65,432.17
0.45	2.78	73,462	1.00	$73,611.19

Appendix AA – Usage Rates with Possible Scenarios

Scenario	Details	Students	Time	Usage rate	Savings
1	Machine will be used by all students for their entire training at BCIT	100%	100%	100.00%	$380,840.32
2	Machine will be used by only level C students (152) for all of their training	62.04%	100%	62.04%	$129,642.34
3	Machine will be used by only level C students (152) for 50% of their training (14 weeks)	62.04%	50%	31.02%	$ 64,821.17
4	Machine will be used by only level C students (152) for 25% of their training (7 weeks)	62.04%	25%	15.51%	$ 32,410.59
5	Machine will be used by only level C students (152) for 10% of their training (2.8 weeks)	62.04%	10%	6.20%	$ 12,964.23
6	Machine will be used by only level C students (152) for 7% of their training (2 weeks)	62.04%	7%	4.34%	$ 9,074.96
7	Machine will be used by only level C students (152) for 3.6% of their training (1 week)	62.04%	3.60%	2.23%	$ 4,667.12

Total Expendables per year

$380,840.32

Total Level C Expendables per year

$208,962.98