Tools for Ergonomic Intervention: The Development and Analysis of a Cost Calculator

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ABSTRACT

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Tools for Ergonomic Intervention: The Development and Analysis of a Cost Calculator

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The purpose of this study was to determine if safety professionals can use an ergonomic intervention costing calculator, which integrates performance and quality data into the costing matrix, to increase communication and better of decision making for the company. The sample size included 9 participants, which included four safety managers, four EHS managers, and one HR generalist. Results showed that all participants found the calculator very useful, well integrated, and it increased communication across the company. The mean System Usability Score (SUS) score was 82, which is rated as a perfectly acceptable software for use. Recommendations from this study include adding some additional features to the calculator, increasing awareness and availability of the calculator, and conducting further analysis using larger sample sizes. Limitations in this study include small sample size and limited interventions that were tested.

DEDICATION

I would like to dedicate this work to;

My mother, Loretta, for all the things she has done for me that got me to this point in life,

My father, Clint, who shaped me into being the better man I am today,

My fiancée, Lacie, for putting up with me and my ever-changing goals and aspirations,

And finally, all the professors I have had, through undergrad and graduate school, that instilled upon me the desire to never stop learning and always be a better person than I was yesterday.

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CHAPTER 1: INTRODUCTION

According to the Bureau of Labor Statistics (BLS), in 2015, work related musculoskeletal disorders (WMSD) accounted for 31% of all nonfatal occupational injuries, most of which are recorded in private industry (BLS, 2016). The median number of days away from work per incident was over two weeks, meaning it can take someone almost 2 weeks to recover from a WMSD incident (BLS, 2016). These injuries can cost employees lost wages, health care expenses, pain, and quality of life (Riano-Casallas and Tompa, 2018). Employers may also see an impact through lost production, turnover, training, and sometimes even legal cost (Riano-Casallas and Tompa, 2018). According to the Liberty Mutual 2019 Safety Index (Liberty Mutual, 2019), nonfatal injuries have a direct cost of around 55.4 billion to employers.. The presence of financial burdens from WMSD's is not a secret, but placing a quantitative value that accurately, and precisely, represents the overall cost of a WMSD can be challenging.

Due to the case to case variation, it is very hard to put a cost to employers for WMSD injuries. The variable costing is a contributing factor that leads to upper management being reluctant to allocate funds to prevent the injuries. In the business world, it comes down to determining the return on investment, and trying to determine the return on improving ergonomics usually ends up being categorized as cost avoidance rather than an actual cost savings or a profitable intervention (Ip, Gober, and Rostykus, 2016). Ergonomists and safety professionals understand these costs and know the value of doing an ergonomic intervention, but it can be difficult to translate the risk into a financial metric to put (Kerr et al., 2008). Ergonomic interventions to decrease WMSD injuries have difficulty succeeding without supervisor and manager commitment and buy-in to see the job through (Hickey, 2017). If the benefits of ergonomic interventions could be transferred into the language of business, managers could clearly understand the difference between the cost they paid and the financial savings they saw through injury avoidance, improved productivity, and potential for new markets (Kerr et al., 2008). Therefore, a need exists for a tool that allows all managers within the business to collaborate on the same solution. Such individuals could benefit from a tool that could estimate the cost of an intervention, as well as the predicted cost savings through improvements in production, quality, and decrease in worker injuries, making it easier for the safety professional to put ergonomics into the language of business.

Tools exist today that help safety professional put a monetary value on their ergonomic intervention, but they are limited in the ability to offer a descriptive pre and post project report. OSHA provides an online calculator that is part of their Safety Pays Program that allows users to see the direct and indirect cost of a workplace injury (OSHA.gov). This calculator also allows the user to see the sales needed to cover the expenses of that injury. The Washington State Department of Labor and Industries provides many ergonomic tools online, one of which is the Washington State Ergonomics Cost Benefit Calculator that is provided by The Puget Sound Chapter of the Human Factors and Ergonomics Society (Goggins, Spielholz, & Nothstein, 2008). This calculator, according to The Puget Sound Chapter of the Human Factors and Ergonomics Society online website, is based on the review of 250 case studies (2012). The calculator allows a user to insert injuries that have occurred for the past three years, up to three different intervention options along with their estimation of how effective they will be, and then calculates the estimated cost benefits for the three options as well as the estimated payback periods. Additionally, Cornell University has created a ROI calculator that helps justify the cost of ergonomic intervention. It can be found online at Cornell University Ergonomics Web (CUErgo, 2008). This does not represent a complete list of ergonomic tools for assessment, but rather the free and readily available options found on the web that are commonly cited.

These tools mentioned use the cost (either actual or estimated) of the interventions and the noticed savings (either actual or estimated) from the intervention to give a post project return on investment. They all work well to define the injury costs to a company and the potential/realized cost savings after the intervention from lack of injuries but very few go more detailed into the cost savings from performance and quality improvements, nor do they clearly distinguish cost avoidance from cost savings. Ergonomic interventions impact more than just a reduction of injuries, as it has been shown the productivity increases and so does quality as a result (de Looze et al., 2010). Because of the impact that the interventions have in improving quality and productivity, these savings also should be included in the tool used by safety professionals to help convey the message to the whole business.

While these tools are predictive, the intention of the proposed research is to develop a tool that is both predictive and post-intervention capable. It would allow the user to compare the results and see the post intervention savings that are real savings based on quality, performance, and safety improvement, as well as some cost avoidance, and compare those to the predictive numbers to see how close they were. This calculator differs from what is already available because it is a central tool that pulls together the cost avoidance from injury reduction and actual cost savings from performance and quality improvements. A particular benefit of this tool is that it allows the user to change estimated factors based on the post-intervention success compared to the pre-intervention estimates. This has not been done in the intervention calculators currently available.

The proposed research seeks to bridge the gap between costing ergonomic interventions and the financial benefits seen by decreased injuries, increased productivity, and increased quality. There are two main objectives to this study:

1. Create a useable tool that allows users to input data related to cost to see predictive cost savings of an ergonomic intervention as well as post intervention results and compare the differences.
2. Determine usability and acceptance of the tool by working personnel.

Through the objectives mentioned above, the following research questions will be answered:

1. Does the integrative cost calculator utilize the needed metrics of ergonomic, productivity, and quality improvements into both a predictive and post analysis form?
2. Does the cost calculator make it easier to implement ergonomic improvements through easier decision-making capabilities from better cross-department communication?

3. Does the calculator improve decision-making capabilities from better project documentation?

CHAPTER 2: LITERATURE REVIEW

2.1 Work Related Musculoskeletal Disorders

2.1.1 What They Are

Work-related musculoskeletal disorders (WMSD's) are nonfatal injuries that can impact the joints, tendons, muscles, nervous system, sometimes the blood circulation within the body, and even bones (Ribeiro, Serranheira, and Loureiro, 2016). WMSD's can range from sudden onset to chronic disorders that result from repetitive actions at work (NIOSH, 2007). Risk factors for WMSD's include: repetitive tasks, awkward or standing posture for long periods of the day, heavy lifting, bending and twisting, sitting for long durations without an ergonomic chair, and/or a fast work pace (Asivandzadeh, Azami, and Jamalizadeh, 2018). According to the Centers for Disease Control and Prevention, WMSD injuries are more serious than the average nonfatal injury that occurs at work and incur high cost to the employers (CDC, 2018). WMSD's account for close to 130 million health care visits, which include going to the emergency room, having surgery in a hospital, and outpatient visits to a physician (CDC, 2018). They impact more than just physical body parts, as they have been shown to increase occupational stress and impact a person's psychosocial factors (Asivandzadeh et al., 2018).

2.1.2 Cost of WMSD's

WMSD's are a burden and cost employers somewhere between $45 and $54 billion dollars a year according to the Institute of Medicine (as cited by the CDC, 2018). The cost associated with WMSD's can be split into two categories: direct and indirect cost (Riaño and Tompa, 2018). The direct cost associated with WMSD's are the cost generated from workers' comp claims, legal fees, and resources to deal with the injuries or try to prevent them (Van Roijen et al., 1996). The indirect costs are all the costs that happen as a result of the injuries, such as: production loss, quality defects, training for new employees, overtime for employees to pick up the slack, and supervision (Oxenburgh and Marlow, 2005). According to the online OSHA Safety Pays Program, for small businesses the indirect cost of a WMSD is higher than the direct cost by about 110%, meaning that for every $1 spent on direct cost, $1.10 is spent on indirect cost. For larger businesses, the indirect cost of a WSMD can be more than double the cost incurred directly (Baldwin, 2004). Because the cost of WMSDs is very impactful to businesses, using ergonomic intervention within a company can have serious financial benefits (Beevis, 2003).

2.2 Ergonomics Intervention

2.2.1 Ergonomic Intervention Defined

Ergonomic intervention (EI) is a method for treatment of WMSD's by modifying the work environment, tools, long term education on prevention techniques, and worker behaviors (Jun-Gyu Kim, Chun, and Hong, 2013). Participatory interventions work well, where both management and worker groups within the organization work together to create a better, safer working environment (Tompa, Dolinschi, and Natale, 2012). The EI can be implemented at any stage within a company's life cycle, but it is easiest and least expensive to implement within the design phase early on, before production is in full swing (Dul and Neumann, 2008). EI can be replacing chairs for workers to correct posture problems, replacing tools that work for a job with tools that were made for the job to increase effectiveness of the work, or changing the position of a conveyor belt or storage location to prevent workers from reaching too far (Jun-Gyu Kim et al., 2013). Through EI employees can be retained and growth maximized, increasing the company's competitive advantage (Dul and Nuemann, 2009). Although cost savings should not be the goal of EI, it has been shown to produce economic benefits through the end results (Beevis, 2003).

2.2.2 Successful use of Ergonomic Intervention

A study conducted by Tompa et al. on EI, found that workers were extremely positive with their perception on the results and there was substantial reduction in first aid cases for all injury types, days away from work for both long term sick leaves and casual days, and cases of modified work (2012). Another study by Riano-Casallas and Tompa on large to medium companies in Columbia showed that after an intervention, costs averted were roughly $3,949,957 total from having a reduction in injuries over a two-year span, resulting in an average benefit to cost ratio being a 1.3 (2018). An EI conducted by de Looze *et al.* showed that by reducing the days of overtime required to make up lost time, the company was able to save $67,242 (converted from Euro to US dollar based on 2010 exchange rate) annually, with a payback period on investment of only 8 months (2010). Oxenburgh and Marlow had an EI study that showed after intervention, severity of injuries and total injury rates went down substantially, and they saw a decrease in turnover from 60% to 40%, allowing for a two-month payback period (Oxenburgh and Marlow, 2005).

The methods for EI have evolved rapidly since 1989, but it has always been inherently difficult to cost the intervention in terms of business language (Morse, Kros, and Nadler, 2009). Based on research, it is best to use all options to display the financial possibilities of an EI, such as: payback period, rate of return, possible process improvement, and possible quality improvements (Morse et al., 2008). An issue with costing EI is that many businesses only see it as cost avoidance, which is the potential to avoid paying the cost for an injury or incident that hasn't happened yet (Beevis, 2003). However, the cost should also be viewed as cost savings, which are the realized savings after an intervention from improved processes and reduction in quality issues, along with new opportunities (Bevis, 2003). For best manager buy-in, all costs associated with implementing the EI should be compared with modeled projected cost savings (and possibly true savings from previous EI's completed), as well as cost avoidance, to allow for proper decision making (Morse et al., 2009).

2.3 Process Improvement

2.3.1 Explaining Process Improvement

Process improvement (PI) is an always evolving methodology that focuses around the performance of people, processes, and company organizations, with the main goal of maximizing efficiency (Bornstein, 2001). Continuous improvement, which is a foundation pillar of lean manufacturing practices and involves identifying improvement opportunity and taking corrective actions regularly, is a common form of process improvement thanks to the introduction of the Toyota Production System (Desai, 2008). PI is evaluated in terms of Key Performance Indicators (KPI), which could be production rate, on time deliveries, downtime, or lead time, but these metrics are slightly different depending on the company being referenced (Jevgeni, Eduard, and Roman, 2014). Wong *et al.* (as cited in Ikuma, Nahmens, and James, 2011) states that PI should not just focus on increasing production speed because this can lead to WMSD's in workers who are not using ergonomic processes. In fact, many manufacturing problems that could benefit from process improvement are caused by unbearable working conditions or inadequate labor qualifications for the job (Jevgeni et al., 2014). Ergonomics should be seamlessly integrated into PI to facilitate the relationship between corporate managers and workers on the line and reduce the risk of injuries (Desai, 2008).

2.3.2 Ergonomic Process Improvement

Ergonomic interventions have been shown to improve the process performance. A study by Yeow and Sen was conducted on operators in a manual insertion process to see how using ergonomic intervention techniques improve the overall process (2006). The study concluded that after the EI, labor productivity went up 50.1% which equaled a yearly revenue increase of $4,233,736 for the company and a return on investment of 7300% (Yeow and Sen, 2006). Another similar study saw process improvements, but not on such a large scale, with reduction in cycle time by 6.1% and a productivity increase around 6.5% through the use of EI (Yeow and Sen, 2003). This same study calculated the average yearly revenue to increase by $717,600 and the cost to implement the EI was only $1100 (2003). A modular home construction company implemented an EI in hopes to improve the safety of their workers. As a result of this study, the company saw a decrease in labor hours needed by to complete the job by 55%, and workers experienced less fatigue from the decrease in walking and manual processes (Ikuma et al., 2011). A study conducted on EI of an appliance manufacturing facility saw an increase in productivity by 10-30% which equaled a cost savings of about $17 million over all improved production lines (Lee, 2005). These research studies indicate that process improvement potential is an important aspect to consider when planning an ergonomic intervention.

2.4 Quality Improvement

2.4.1 Understanding Quality Measurements

Quality, as defined in the 2011 edition of Future of Quality Study, is a term the represents a drive for excellence, or the joint venture of trying to achieve lower cost, better production, better durability, and highest customer satisfaction (Borawski, 2011, pg. 38-39). Quality is not free, and therefore there is the term cost of quality (COQ) that blankets all cost associated with achieving quality under one expression (Cermakova and Bris, 2017). Arabian et al. define COQ as a sum of all costs associated with conforming and non-conforming parts, where conforming is good quality and non-conforming is poor quality (2013). COQ is a general term that has different definitions depending on which expert is asked, but they lead to the same end. Gupta and Campbell define COQ as all cost incurred from quality, from both producing good quality and dealing with bad quality and can be split into four categories known as: appraisal, prevention, internal failures and external failures (1995). Campanella (as cited in Cermakova and Bris, 2017), combines failures into one category, leaving only three categories. Internal failure costs are all costs associated with a product failure, such as scrap, rework, and reinspection, before it reaches the customer (Gupta and Campbell, 1995). External failure costs, as the name implies, are costs associated with failed products reaching a customer, such a product replacement or warranty claims (Zimak, 2000). Prevention costs are all cost associated with being proactive and trying to minimize opportunity for quality issues, such as reviewing new product designs, training, and implementing process improvement (Gupta and Campbell, 1995). Appraisal costs are generated through calibrations and inspections of raw materials (Zimak, 2000). Some COQ metrics used to measure how well a company is doing include, but are not limited to, defects seen per one million opportunities (less opportunities for smaller companies), number of customer complaints per month, or return on quality (ROQ) which is the increase of profits seen divided by the cost of the quality improvement program implemented (Arabian et al., 2013). Balancing all of these costs is not an easy task for those in charge of the COQ; prevention actions. Implementing an ergonomic intervention for process improvement has the most potential because it eliminates the core causes of defects, rather than just dealing with the easily identifiable issues (Gupta and Campbell, 1995).

2.4.2 Ergonomics for Quality Improvement

Quality and EI both benefit from using small teams composed of employees to drive the improvement initiative, and therefore can be integrated together easily (Drury, 2000). Both the ISO16949 and QS-9000, standards that drive quality initiatives, have sections that outline the evaluation of ergonomics for process improvement (Lee, 2005). Poor ergonomics within a production facility can lead to quality losses that the end customer then ends up paying for through higher product cost (Falck, Örtengren, and

Högberg, 2009). The Yeow and Sen studies mentioned earlier also saw substantial quality improvements from EI. In one study, there was a decrease in quality defects by 29.6% in the factory setting and when going to a customer's site for assembly, there was a reduction of defects by 11.4%. These reductions in defects saved the company $956,136 per year (2006). In another study, defects at customer sites decreased by a combined 5.2% which saved the company %574,560 a year (2003). Eklund (as cited in Yeow and Sen, 2006) saw a 50% reduction in quality issues after the implementation of EI. Yeow and Sen (2003) have conducted even more studies into EI for quality improvement where one company saw a reduction in defects by approximately 52% and another by approximately 32%. Falck et al. documented that about 80% of the ergonomic problems in a car manufacturing facility were identified as quality problems (2009). Drury analyzed a study and concluded that 53% of variance in error rates was a resultant of ergonomic variable and went on to state that assembly quality is directly impacted by ergonomics in the process (2000). Such studies document a clear relationship between quality errors and poor ergonomic programs (Falck et al., 2009).

2.5 Integration of Improvement Opportunities

Ergonomics, process improvement, and quality improvement are sometimes viewed as independent of each other, with the closest relationship being PI and quality, but integrating these independent programs can be beneficial (Drury, 2000). Previous studies (Yeow and Sen, 2003 and 2006) demonstrate that EI impacted both the PI and quality of a company, showing integration is inherently happening. Both PI and quality improvement strategies require identifying a gap in the current state and ideal state. EI can be the tool to integrate such factors (Bornstein, 2001). Ergonomic projects are typically viewed by management as separate costs that compete with funds for other improvement projects (Ip et al., 2016). That is why Ip et al. have suggested that when calculating ROI for an ergonomics project, the cost benefits should include the process and quality improvements in addition to the cost avoidance of injury prevention (2016). They continue on to support ergonomics as a tool to reduce or remove WMSD's from the workplace in order to reduce injury and improve quality and the process (2016). Management's support of ergonomic improvements can lead to a great safety culture (Schwerha, Boudinot, & Loree, 2017).

2.6 Safety Culture

Lack of management support has been shown to be one of the leading barriers for ergonomics (Straub, 2018b). However, these barriers prevent companies from getting accurate measurements of ergonomic projects that are necessary to show the possible benefits the company could see from them (Rostykus and Mallon, 2017). Supervisors can effectively bridge the gap between employees and management, leading the safety performance movement to a better overall safety culture (Hickey, 2017). Safety culture, as defined by Cox S. and Cox T. (as cited in Soares, 2012), is an organizational atmosphere where all employees share attitudes and beliefs towards safety. Measuring metrics needed to show why ergonomics can be the solution to a company's injury challenges is a major problem and that is why having a strong safety culture within a business is so important (Straub, 2018a). Studies have shown that incorporating a strong safety culture will lead to beliefs in ergonomic importance, which can drive quality and

PI from EI (Rozlina et al., 2012). Once the culture has embraced ergonomics, it has been shown that costs are no longer seen as a barrier for EI (Straub, 2018b). Not only does a great safety culture lead to better buy in for EI, it also leads to safer work practices by employees that result in less injuries overall (Soares, 2012).

2.7 The Intervention Calculator

The purpose of this study was to develop a calculator that could document the ergonomic intervention by demonstrating an integrated approach to the improvement of ergonomics, productivity, and quality. Companies can enter their own cost data for injuries and illness, or estimate their cost from data collected from previous studies. Then, they can predict what they feel their performance and quality improvements may be from the intervention. The calculator details the projected savings from PI and quality, as well as the cost avoided yearly by reducing the injury rate and cost incurred from the intervention. After the intervention, companies can enter in their realized savings to see how their actual results compare. This calculator, pulling together all cost and savings into one central tool, serves to help bridge the gap between management and employees, potentially creating a better safety culture in the business.

CHAPTER 3: METHODOLOGY

The methodology of this research was split into three tasks. The first task was to create the calculator that was tested in the field. This calculator was the foundation for the study. The second part was to do field evaluations. The experts in the field shared their opinions on the calculator and tested the calculator. The last part of the methodology was to develop the methods for analysis of the data. Field study results were analyzed to answer the following research questions:

1. Does the integrative cost calculator utilize the needed metrics of ergonomic, productivity, and quality improvements into both a predictive and post analysis form?
2. Does the cost calculator make it easier to implement ergonomic improvements through easier decision-making capabilities from better cross-department communication?
3. Does the calculator improve decision-making capabilities from better project documentation?

3.1 Developing the Calculator

The first step in this study was to create the calculator. The calculator varies from previous research in three ways: 1) it is not independently pre-intervention estimation or post-intervention calculations that just focus on the cost of ergonomic related injuries, 2) the calculator integrates productivity and quality improvement data into the ergonomic intervention costing metrics, and 3) the data are all transparent, allowing the users to change any metrics to better reflect their system. The calculator has other differences from available options today, but it was built upon the foundation of the three main differences.

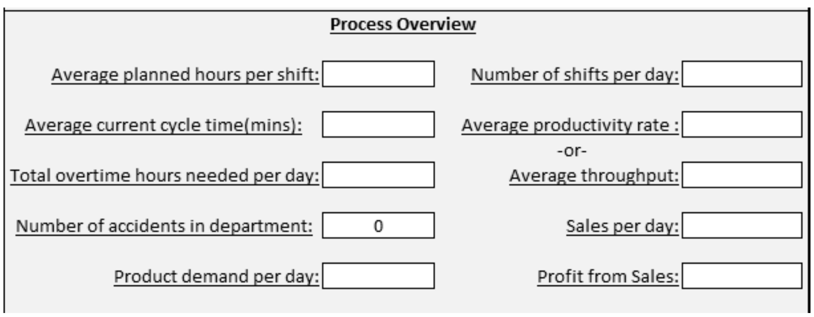
The first step in creation was to assemble a database of cost estimation for injuries to employees. Companies should have a log of their own incurred cost from injuries, but estimated data was provided as an option for companies who have struggled to maintain records. This estimated data for the calculator came from free resources available to the public, such as the Washington State Ergonomics Cost Benefit Calculator that is provided by The Puget Sound Chapter of the Human Factors and Ergonomics Society (Goggins, Spielholz, & Nothstein, 2008) and the Washington State Department of Labor and Industries SHARP program's summary of 2015 WMSD cost by industry. The summary of costs from each resource can be found in Appendix A and Figure 1 below shows where the estimated data are used. These data were limited in quantity,

Estimates relating to type and quantity of injuries **Do not use if direct cost are known, as they will be more accurate**				
Types	**Quantity**	**Direct Cost**	**Indirect cost Low**	**Indirect cost High**
Shoulder Strain	1	$ 10,178.52	$ -	$ -
Back Strain	1	$ 6,413.40	$ -	$ -
Epicondylitis (Tennis Elbow)	1	$ 8,003.54	$ -	$ -
Knee Strain	1	$ 7,526.73	$ -	$ -
None	0	$ -	$ -	$ -
None	0	$ -	$ -	$ -
None	0	$ -	$ -	$ -
None	0	$ -	$ -	$ -
None	0	$ -	$ -	$ -
None	0	$ -	$ -	$ -

Figure 1: Injury Estimation

as insurance companies were not readily willing to give out the data without being a paying customer. The data were averaged out into one cost per WMSD type based on the average across all industry data provided by the resources mentioned. This provides a baseline to estimate potential cost avoidance when no other data are present.

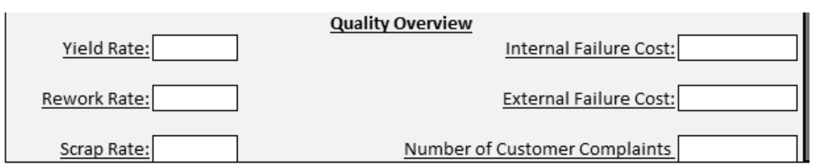
The next step was to formulate the metrics impacted and understand all costs that would be associated with an ergonomic intervention. For this, meta-analysis was conducted while researching the different ergonomic intervention studies for the reoccurring metrics used for reporting the success of the project. Figures 2, 3, and 4 below show the metrics and how they were integrated into the calculator. Expert



Process Overview

Average planned hours per shift:
Number of shifts per day:
Average current cycle time(mins):
Average productivity rate :
-or-
Total overtime hours needed per day:
Average throughput:
Number of accidents in department: 0
Sales per day:
Product demand per day:
Profit from Sales:

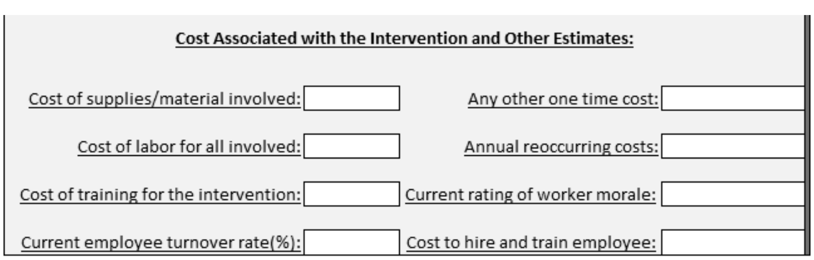
Figure 2: Performance Metrics



Quality Overview

Yield Rate:
Internal Failure Cost:
Rework Rate:
External Failure Cost:
Scrap Rate:
Number of Customer Complaints

Figure 3: Quality Metrics

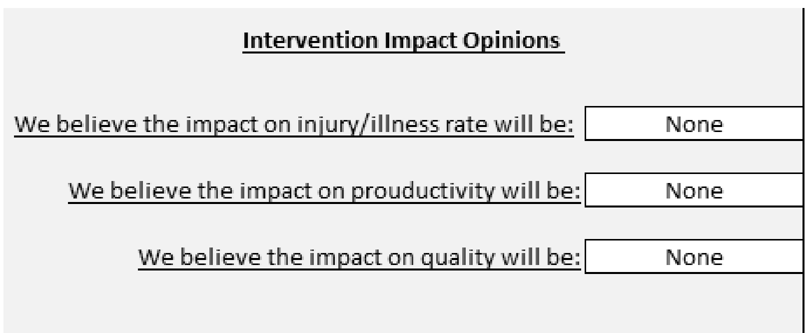


Cost Associated with the Intervention and Other Estimates:

Cost of supplies/material involved:
Any other one time cost:
Cost of labor for all involved:
Annual reoccurring costs:
Cost of training for the intervention:
Current rating of worker morale:
Current employee turnover rate(%):
Cost to hire and train employee:

Figure 4: Intervention Cost

opinions were then used to predict the outcomes of each intervention. A three-part question was put in place, Figure 5 below, that asks the expert how much they anticipate the project improving the injuries, performance, and quality. The estimating percentages then multiply the current metrics to give projected value. These estimated percentages were taken from the Washington State Department of Labor and Industries studies over 250 cases. The average highs and lows were taken to represent the correlating options in



Intervention Impact Opinions

We believe the impact on injury/illness rate will be: None

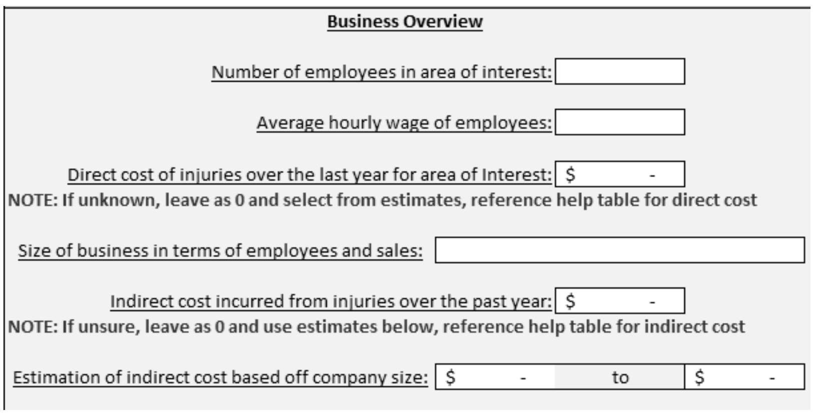
We believe the impact on prouductivity will be: None

We believe the impact on quality will be: None

Figure 5: Expert Opinion Input

this calculator, and a median value was used to represent the median options. A barrier for this calculator is making sure the figures needed by the calculator to see results are already collected, and a delay isn't required for data collection. There were many resources used in this stage, and a detailed list of sources and data used from each source can be found in Appendix B.

A section was added to the calculator to gather a baseline of how much employees earn, and how many employees are present in the department of interest. This section is also where the manager will enter their cost data if they have it readily available. A drop-down option was implemented to select the size of the company. This was an important feature to add because research shows that the company size determines the multiplying factor of indirect cost experienced from an injury (Baldwin, 2004 & OSHA.gov). Figure 6 shows this section of the calculator that is used to gather the basic employee information.



Business Overview

Number of employees in area of interest:

Average hourly wage of employees:

Direct cost of injuries over the last year for area of Interest: $ -

NOTE: If unknown, leave as 0 and select from estimates, reference help table for direct cost

Size of business in terms of employees and sales:

Indirect cost incurred from injuries over the past year: $ -

NOTE: If unsure, leave as 0 and use estimates below, reference help table for indirect cost

Estimation of indirect cost based off company size: $ - to $ -

Figure 6: Company Information

The final step in creating the calculator was to put all metrics and data into a useable presentation format . On the pre intervention tabs, costs for the intervention are clearly defined, and injury reduction savings, both direct and indirect, are identified as cost avoidance savings. The cost avoidance classification is used because management has viewed injury reduction as cost avoidance since they do not spend the money, rather than saving the money. Furthermore, potential savings from estimated process improvement and quality improvement are identified to let management see ‘real’ potential savings after the intervention. Figure 7 below displays the pre-intervention

Projected WMSD cost after interventions	
Direct Cost of WMSD's:	$ -
Indirect Cost of WMSD's:	$ -
Total Cost of WMSD's:	$ -
Projected Process Improvement after Intervention	
Projected Cycle Time after Intervention:	#VALUE!
Projected Productivity Rate:	#VALUE!
Projected Daily Throughput	#VALUE!
Projected Efficiency:	#DIV/0!
Projected OT still needed:	#DIV/0!
Projected Quality Improvements after Intervention	
Projected Yield Rate:	0.00
Projected Rework Rate:	0.00
Projected Scrap Rate:	0.00
Projected Customer Complaints:	0

Projected Cost Avoided	
Direct Cost from WMSD's avoided:	$ -
Indirect Cost from WMSD's avoided:	$ -
Total Cost from WMSD's avoided:	$ -
Projected Cost Savings	
Potential Cycle time improvement of (mins):	#VALUE!
Potential productivity improvement of(rate):	#VALUE!
Potential daily throughput increase of(units):	#VALUE!
Potential OT savings of:	#DIV/0!
Potential sales profit increase of:	#VALUE!
Potential internal failure savings of:	#DIV/0!
Potential external savings of:	#DIV/0!
Projected ROI	#DIV/0!
Projected payback period (months):	#VALUE!

Figure 7: Pre-Intervention Summary

summary tab. On the post intervention tab (Figure 8), management can see the actual savings the business experienced after a defined time period and compare to the estimated savings. The next tab is part of the defining features of this calculator, and that is the comparison tab (Figure 9 and 10). This tab allows management to benchmark the differences and then better predict how the next intervention can impact them by altering the metrics used in the calculator to better reflect their business. This calculator serves as a resource to pull together employees, supervisors, and management to better improve the ergonomic intervention decision making process.

Previous cost associated of WMSD	
Previous Direct Cost of WMSD's:	$ -
Previous Indirect Cost of WMSD's:	$ -
Previous Total Cost of WMSD's:	$ -
Previously Process Improvement	
Previous Cycle Time :	#VALUE!
Previous Productivity Rate:	#DIV/0!
Previous Takt Time (mins):	#DIV/0!
Previous Daily Throughput	#VALUE!
Previous Efficiency:	#DIV/0!
Previous OT needed:	0.00
Previously Quality	
Previous Yield Rate:	0.00
Previous Rework Rate:	0.00
Previous Scrap Rate:	0.00
Previous Customer Complaints:	0

Actual Cost Avoided	
Direct Cost from WMSD's avoided:	$ -
Indirect Cost from WMSD's avoided:	$ -
Total Cost from WMSD's avoided:	$ -
Actual Cost Savings	
Cycle time improvement of (mins):	#VALUE!
Productivity improvement of (rate):	#DIV/0!
Daily throughput increase of (units):	#VALUE!
OT savings of:	$ -
Sales profit increase of:	$ -
Internal failure savings of:	$ -
External savings of:	$ -
ROI	#DIV/0!
Payback period (months):	#DIV/0!

Figure 8: Post-Intervention Summary

Current cost associated of WMSD		Previously Projected WMSD cost		Differences
Direct Cost of WMSD's:	$ -	Direct Cost of WMSD's:	$ -	$ -
Indirect Cost of WMSD's:	$ -	Indirect Cost of WMSD's:	$ -	$ -
Total Cost of WMSD's:	$ -	Total Cost of WMSD's:	$ -	$ -
Current Process Metrics		**Previously Projected Process Improvement**		**Differences**
Current Cycle Time:	#VALUE!	Projected Cycle Time after Intervention:	#VALUE!	#VALUE!
Current Productivity Rate:	#DIV/0!	Projected Productivity Rate:	#VALUE!	#DIV/0!
Current Daily Throughput:	#VALUE!	Projected Daily Throughput	#VALUE!	#VALUE!
Current Efficiency:	#DIV/0!	Projected Efficiency:	#DIV/0!	#DIV/0!
OT Needed	0.00	Projected OT still needed:	#DIV/0!	#DIV/0!
Current Quality		**Previously Projected Quality Improvements**		**Differences**
Current Yield Rate:	0.00	Projected Yield Rate:	0	0.00
Current Rework Rate:	0.00	Projected Rework Rate:	0	0.00
Current Scrap rate:	0.00	Projected Scrap Rate:	0	0.00
Current Customer Complaints:	0	Projected Customer Complaints:	0	0.00

Figure 9: Post Comparison of Improvements

Actual Cost Avoided		Projected Cost Avoided		Differences
Direct Cost from WMSD's avoided:	$ -	Direct Cost from WMSD's avoided:	$ -	$ -
Indirect Cost from WMSD's avoided:	$ -	Indirect Cost from WMSD's avoided:	$ -	$ -
Total Cost from WMSD's avoided:	$ -	Total Cost from WMSD's avoided:	$ -	$ -
Actual Cost Savings		**Projected Cost Savings**		**Differences**
Cycle time improvement of:	#VALUE!	Projected Cycle time improvement of:	#VALUE!	#VALUE!
Productivity improvement of:	#DIV/0!	Projected productivity improvement of:	#VALUE!	#DIV/0!
Daily throughput increase of:	#VALUE!	Projected daily throughput increase of:	#VALUE!	#VALUE!
OT savings of:	0.00	Projected OT savings of:	#DIV/0!	#DIV/0!
Sales profit increase of:	$ -	Projected sales profit increase of:	#VALUE!	#VALUE!
Internal failure savings of:	$ -	Projected internal failure savings of:	#DIV/0!	#DIV/0!
External failure savings of:	$ -	Projected external failure savings of:	#DIV/0!	#DIV/0!
ROI	#DIV/0!	Projected ROI	#DIV/0!	#DIV/0!
Payback period (months):	#DIV/0!	Projected payback period (months):	#VALUE!	#VALUE!
Previous Cost of Employee Turnover		Current Cost of Employee Turnover		**Differences**
$ -		$ -		0.00

Figure 10: Post Comparison Savings

One of the most challenging aspects of this calculator was to ensure the usability of the system. The calculator was designed to minimize data entry. Users must enter text into less than 25 boxes per entry form, allowing them to select the other needed information from drop-down boxes. Auto calculated fields were used on the data entry forms to minimize some calculations that a user would have to do by hand. Color contrasting was used to direct the user's attentions to the empty boxes that need filled out. Color coding was used to help the user keep track of which data entry tab correlates with the respective summary page. All summary pages are auto populating and calculated based upon the data entry forms. All technical terms used on the form can be found in the terminology help table located on the data entry tabs or at the bottom of the summary tables. All reference data is located on the same table and clearly labeled to allow the user to know it cannot be deleted. Everything in the calculator is designed to flow from top to bottom and left to right.

To help users better understand what is required to use the calculator, documented instructions and a walk-through video were created. The paper instructions go through step by step on what should be entered into the calculator. Screen shots of the calculator were inserted and referenced accordingly to help people navigate along. The video walk through goes box by box, and tab by tab, to help users understand the inputs and how they are related. Further details are explained in the video about how the numbers impact the summary pages and what the various terms mean. The video was uploaded to YouTube and included as a link on the instruction handouts that were given to all participants (Ergo Labs, 2019).

3.2 Field Evaluation

In order for the methodology to answer the research question, the tool had to be tested in the field by safety professionals. A recruiting document and plan of study were sent to the Institutional Review Board for approval to conduct the study. After approval, the Central Ohio Chapter of ASSP posted the recruiting document online for all safety members to see. Nine safety professionals responded and gave informed consent to use the calculator to document an ergonomic intervention. Time was a constraint in asking them to create a new project to test, and therefore previously documented projects were used when available. The calculator was sent to those willing to test it, along with the detailed instruction document to get them started using it. The participants were asked to spend approximately three weeks testing the calculator to get a better feel for its functionalities. At the end of the third week, a phone call was scheduled to answer any questions/concerns they had, as well as administer the survey to them. Some participants responded to the survey by email only if they did not have any questions about the calculator. The survey consisted of a system usability survey that was customized to ask only questions related to the use of the calculator system but is scored the same. In addition to the system usability scale, there were additional questions to better understand their experience with what the calculator was presenting to them and how useful the provided materials were. These questions were scored on a Likert scale and can be found in Appendix C. At the conclusion of each interview, the data were charted in excel for comparison with all professionals interviewed, and the professionals were allowed to keep and utilize the calculator if they desired to.

3.3 Data Analysis

The final part of this study was to compile and analyze the results from the survey. The survey was broken into six parts to answer the three research questions, and allow for system usability testing, instructional/system feedback and correlation testing. A total of five questions were asked to answer research question one, helping researchers understand how the safety professionals felt about the metrics. Research questions two and three had two questions each on the survey that reflected the same format as the first five asked for research question one. Participants were asked two questions for the purpose of providing feedback on the instructions and overall system, with an additional open-ended comments section. The correlation section involved three questions on the survey. The system usability was comprised of a standard, 10 question form filled out after using the calculator. Overall, there were 24 questions asked with one open ended comment section to provide the data for this research.

3.3.1 System Usability

The system usability survey asked the user a series of questions regarding their experience navigating the calculator. It asked them to rate their level of agreement with the statement and these values were assessed based on the scoring of a system usability scale (SUS) (Thomas, 2015). The scoring of the SUS determined if the calculator was proficient enough to be used in industry to answer the research question. A score of 80 or higher indicates that the calculator was excellent and safety managers would recommend this program to others. A score between 52 and 80 indicates that the calculator is manageable but could be improved upon before safety managers are willing to recommend it to others. A score of 51 or less indicates that the calculator failed in regard to usability and it needs to be reconfigured before conducting another study using it. The calculator needed to be usable to ensure safety managers understood the inputs and results they were viewing.

3.3.2 Metric Verification

To answer the first research question in regard to having a calculator that integrates the three components well and displays them in a pre and post summary, questions needed to be asked to see if the calculator successfully integrated the metrics participants collect into a logical summary. All questions asked in this section were rated on a Likert scale, ranging from strongly agree (5) to strongly disagree (1). Participants had the ability to write in an explanation if they disagreed with any of the statements. The answers were charted in a bar graph showing the results to each question. The modes were compared, and the results must be above a three to be considered a yes to the first part of the research question. Responding with a three or below meant respondents either had no opinion on the statement or they disagreed with it. Responses of a four or a five meant respondents agreed or strongly agreed with the statement. Modes were used in comparison because it is not always clear when using Likert scales if the values in between whole numbers are equal (McLeod, 2019). The questions asked in regard to research question one can be found in Table 1 below.

Table 1: Establishing the Metrics

Questions Asked	**Purpose of Question**
The calculator used many of the metrics we already collect.	Research question 1: Does the integrative cost calculator utilize the needed metrics of ergonomic, productivity, and quality improvements into both a predictive and post analysis form?
The calculator had all the injury metrics I need to see to make a decision.	
The calculator had all of the performance metrics I would need to see for decision making.	
The calculator had all of the quality metrics I would need see for decision making.	
The calculator successfully demonstrates the predictive summary and post project results in an easy to understand chart for comparison.	

3.3.3 Improved Communication and Documentation

Similarly to the first research question, these questions were answered using questions rated on a Likert scale. The results were charted the same and compared using the same method of greater than three to be considered a yes. The questions asked can be found in Table 2 and 3 below.

Table 2: Better Communication

Questions Asked	Purpose of Question
Using this calculator could make it easier for decision making about ergonomic projects.	Research question 2: Does the cost calculator make it easier to implement ergonomic improvements through easier decision-making capabilities from better cross-department communication?
I felt I had better cross department communication for decision making because of all the data present in front of me using the calculator.	

Table 3: Improved Documentation

Questions Asked	Purpose of Question
I felt project documentation improved from using the calculator based on previous methods practiced.	Research question 3: Does the calculator improve decision-making capabilities from better project documentation?
Better project documentation helps lead to easier decision making from multiple departments involved.	

3.3.4 Instructional Feedback

Two questions were included on the survey asking participants if they watched the YouTube video and/or read the instruction sheet. The questions further asked the participants to express if they found them useful. These questions were used to better understand which should be included with the calculator as it moves out of testing. There was an additional open-ended comment section where participants were encouraged to suggest missing features or additional features that could improve the calculator.

3.3.5 Correlation Testing

This part of the survey used two fill-in questions regarding what software the companies had used in the past and if they collected the data. The third question was answered and scored using a Likert Scale. The questions can be found in Table 4. The intent of these questions was to be able to do correlation testing to see if there was a relationship between previous use and acceptance. However, the results of the survey did not allow for correlation testing to be conducted.

Table 4: Background of Use

Questions Asked	**Purpose of Question**
Do you already use a costing software? If yes, please briefly explain its parameter and functions	To conduct correlation testing on acceptance rating in relation to participants already using a previous software.
Do you regularly collect performance and quality metrics when assessing ergonomic projects? If yes, please list them.	Conduct correlation testing on acceptance based on if metrics are already collected.
How difficult would it be for you to collect the metrics needed on the calculator?	Conduct correlation testing to see if difficulty rating leads to decreased acceptance.

CHAPTER 4: RESULTS

4.1 Participant Information

For this study, nine participants agreed to test out the calculator and answer the survey. The sample included: four environmental health and safety managers, four safety managers, and one human resources generalist. Only two of the participants stated they actually tested a project with the calculator, while the other seven chose to use historical data that was available to them. Four participants chose to opt out of the requested phone call interview, suggesting they were too busy, and only emailed their results back because they had no questions about the calculator. Of the nine participants, two stated they were new to the job position, which was not asked, and were still learning how to manage their tasks.

4.2 System Usability Survey Results

The SUS survey questions were rated on a scale of one, being strongly disagree, to five, which means strongly agree. Scoring of the Likert scale used followed a system where each of the even numbered questions were subtracted from the value five, and each of the odd number questions had a value of one subtracted from their score. Then, the remaining values were added, and the total was multiplied by 2.5. The resulting number was the final score for the system usability, and it is out of 100 total points, but does not represent a percentage value. The resulting scores from this study ranged from 60 points to 100 points.

The SUS was evaluated on an overall average score system. All of the results from the SUS were put into Table 1. Table 1 shows the average, median, mode, min, max, and the standard deviation for each question. The overall average of SUS scores is what defined the usability. The final score of 82 is within the "perfectly acceptable" score range of 80.3-100, resulting in an A for the system's usability.

Table 5: Overall SUS Scores

Questions	Means	Median	Mode	Min	Max	St Dev
I think I would use this system frequently	4	4	3	3	5	0.87
I found this system unnecessarily complex	2	2	2	1	3	0.71
I thought the system was easy to use	4	4	4	4	5	0.50
I think that I would need the support of a technical person to be able to use this system	2	2	2	1	3	0.67
I found the various functions in this system were well integrated	4	4	5	2	5	1.12
I thought there was too much inconsistency in this system	2	1	1	1	4	1.09
I would imagine that most people would learn to use this system very quickly	4	3	3	3	5	0.87
I found the system very cumbersome to use	2	2	2	1	3	0.71
I felt very confident using the system	4	4	4	4	5	0.50
I needed to learn a lot of things before I could get going with this system.	2	2	1	1	4	1.22
SUS Score	82	82.5	72.5	60	100	12.73

4.3 Value of the Integrated Features

The first five questions on the survey were used to answer the first research question. The values were compared using the mode responses, because, as stated earlier, comparing averages cannot guarantee that values in between the whole numbers are equivalent (McLeod, 2019). As seen in Table 2, the mode response for all five questions is a four, which means participants agreed. The first statement had eight out of nine state they agreed, with one participant stating they disagreed. Statement two on the survey had one participant disagree, six agreed, and two strongly agreed with the statement. For statement number three, one participant disagreed, two were undecided, five agreed, and one strongly agreed. Statements four and five and similar responses: two participants answering undecided and seven agreeing with the statement. With the mode being greater than 3, this means participants agreed overall with the statements that the calculator utilized and integrated the metrics they wanted to see. This satisfies the first research question about having an integrative cost calculator that utilizes ergonomic, productivity, and quality improvements into both a predictive and post analysis form. The research shows the calculator integrated the three features into a summary form that professionals can use and understand.

Table 6: Responses for Metric Collection

Question	Means	Median	Mode	Min	Max	St Dev
The calculator used many of the metrics we already collect.	3.78	4.00	4.00	2.00	4.00	0.67
The calculator had all the injury metrics I need to see to make a decision.	4.00	4.00	4.00	2.00	5.00	0.87
The calculator had all of the performance metrics I would need to see for decision making.	3.67	4.00	4.00	2.00	5.00	0.87
The calculator had all of the quality metrics I would need see for decision making.	3.78	4.00	4.00	3.00	4.00	0.44
The calculator successfully demonstrates the predictive summary and post project results in an easy to understand chart for comparison.	3.78	4.00	4.00	3.00	4.00	0.44

4.4 Improved Communication Abilities

Questions six and seven were designed to answer research question two. This inquiry was to see if the calculator provided increased cross-department communication that improved decision-making abilities. The results from these questions can be seen in Table 3. These questions are scored on the same Likert Scale as mentioned before. Both questions have a mode value that is four, meaning participants agreed with the statement. Statement six had seven participants agree and two strongly agree. Statement seven had one undecided answer, six agrees, and two strongly agrees. One participant who works in HR stated that this calculator gave them the ability to communicate with safety and production because they could understand what they were collecting. Results indicated

Table 7: Cross-Department Communication

Question	Means	Median	Mode	Min	Max	St Dev
Using this calculator could make it easier for decision making about ergonomic projects.	4.22	4.00	4.00	4.00	5.00	0.44
I felt I had better cross department communication for decision making because of all the data present in front of me using the calculator.	4.11	4.00	4.00	3.00	5.00	0.60

that participants found the calculator successfully improved their ability to make decisions and communicate across their facility.

4.5 Documentation Improvement

The next two questions, eight and nine, provided the insight to answer the third research question. Using the same Likert Scale rating system, the responses can be seen in Table 8 below. Statement eight had two participants that answered undecided, six participants that agreed, and one that strongly agreed. Statement nine had five participants agree and four that strongly agreed. The mode for both questions was a 4, meaning they agreed. The mode responses show that participants felt their documentation abilities improved and it helped make easier decisions on projects. One participant noted that using the calculator helped highlight some missing information collection from their current documentation process. Another participant said that this calculator provided the documentation that upper management wanted to see; helping them justify the cost better than they previously were able to. The results validate research question three, and the calculator improved participants' documentation abilities that led to easier decision making.

Table 8: Documentation Responses

Question	Means	Median	Mode	Min	Max	St Dev
I felt project documentation improved from using the calculator based on previous methods practiced.	3.89	4.00	4.00	3.00	5.00	0.60
Better project documentation helps lead to easier decision making from multiple departments involved.	4.44	4.00	4.00	4.00	5.00	0.53

4.6 Previous Uses

Participants were asked if they have ever used a costing software before when trying to implement ergonomic projects. The results showed that 100% of them (9 out of 9) have never used any kind of costing software before. One respondent stated they used a paper version of an ROI worksheet, but never anything else. Eight out of nine respondents said it would be easy to collect the data needed to use the costing software, and the last respondent said it would be very easy. The lack of responses from professionals who have used software before led to an inability to correlate responses as planned, since there were no opposing views on the matter.

4.7 Instructional Feedback and Comments

Eight out of nine participants said they watched the instruction video and knew exactly how to use it, and the remaining participant said they only needed to read the directions to use it. In the interviews, it was stated that the instructional video was key to getting started and they recommend it be included when giving the calculator out in the future. The response rate for additional comments about the calculator was under 50%, as only four out of the nine wanted to provide additional open-ended remarks. Their comments can be seen in Table 9. The comments were mostly related to features that could be added to improve the information displayed, with only one comment being related to a missing desired feature. Overall, the participants were satisfied with all material provided to them and stated they would continue to use it moving forward.

Table 9: Calculator Comments

Job Role	**Comment**
HR Generalist	Include a tab that allows the table data to be displayed visually in graphs and charts.
EHS Manager	Include an input on the entry tabs for near misses and days away from work
Safety Manager	This calculator would go great with the BWC innovation grant program, allowing it to be the tool for cost justification that the BWC asks for.
Safety Manager	This calculator could benefit from getting updated insurance data that is relevant to the current year.

CHAPTER 5: CONCLUSION

The purpose of this research was to answer the three research questions of interest and develop a new, ergonomic invention costing tool. Although the sample size was small, all participants agreed the calculator satisfied the research goals. One participant who is in HR stated that the calculator helped them better communicate with the safety lead even though they had no prior experience costing an intervention. A metal manufacturing safety manager stated that this calculator helped them solve the communication barrier with upper management and was the missing link they needed. This barrier was crossed by using the calculator, which could help other companies who too often deal with the same communication barriers (Straub, 2018b). The research conducted on the calculator has concluded that safety professionals are willing to use this calculator but have not had access to things like it before.

This research uncovered that safety professionals do not readily have the ability to effectively cost an ergonomic intervention using an integrative tool. Participants stated they saw a lot of value in the calculator but have not used anything like it. It is possible that safety managers who already have a costing calculator saw no value in trying a new one, and therefore did not take the time to reach out and participate. The participants were asked to volunteer their time to test out the calculator. Their overall acceptance and enthusiasm to use the calculator shows a need for this technology to be readily available to safety professionals. This research further emphasizes the need to get free, readily available software to people who can use this to better their intervention costing, and in turn help the lives of the workers in need of ergonomic interventions.

Free software already exists today to help safety professionals calculate the cost of an injury and what they could save if they mitigate the injury (Osha.gov & Goggins, Spielholz, & Nothstein, 2008). However, this is the first free calculator to integrate performance and quality into the system, a characterization that was documented. Additionally, this calculator is designed to be used throughout the project cycle, and not just for a quote or retrospective view of results. The metrics on the calculator separate savings effectively into cost savings and cost avoidance, allowing management to see what they are actually going to save or money they may not have to spend. All participants stated they would continue to use this software and would recommend it to others at safety conventions. It is clear from the research that the calculator has successfully completed the goals of this research and is ready to be posted for all safety professionals to use.

CHAPTER 6: RECOMMENDATIONS FOR FUTURE WORK

Data collection for this research spanned over three months of collection. The recruiting documents were posted online and announced at multiple safety meetings. However, participation was still low. This research could benefit from a longer timeframe of data collection. Organizations who regularly work with professionals completing ergonomic interventions, such as the BWC, could be utilized to help increase awareness of the calculator. Allowing a year or more for data collection could encourage professionals to actual design and implement a project. Increasing participant compensation could have also increased the number of participants. Professionals in the field are often very busy and asking them to donate an hour or more of their time could be troublesome.

A few recommended features could be added to the calculator. The study estimated data could be updated from a paid insurance source. When creating the calculator, only free, historical data was available. Once the calculator gets more use, insurance companies may be more willing to release the estimated data. One user suggested seeing near misses and accident data in the same central hub. Further research could be conducted to integrate those metrics into the view without lowering the SUS score. Another user asked to see bar graphs and line charts to summarize the data better for management. A new tab could be added to the calculator just for pre and post summary graphs to turn the numbers into a more visually appealing source. Upon completion, testing would need to be carried out to validate the SUS score does not drop below 80.

Another recommendation is that a study could be carried out using only participants who have previously used software. This study would allow for a comparison of how this free software compares to others that professionals pay for. Then, the results could be correlated against those who never have used a software before to see if acceptance is higher. This would clarify if people are more accepting of this software when never using one before.

An additional recommended study could be conducted over the span of two years. The study could be structured so that the safety professionals use the calculator to get approval from management. Then, the intervention could be carried out and completed over the course of a year and the post intervention metrics are calculated. The purpose of this study would be to validate the accuracy of projections. The second year would be a follow up where the safety professional double checks the post data to see if anything has changed over the course of a year. This difference would be recorded in the results. The data would then allow for more accurate projections of estimates that are used in the calculator instead of only using historical data that is available.

Finally, the calculator could be integrated onto the Ohio University Safety website where professionals can go on and easily download the software as an integrative tool (Schwerha, Boudinot, & Loree, 2017). The accompanying instructions should also be uploaded with the calculator. This calculator can be used in conjunction with the Mod VSSM that is already available for download. The BWC could also be made aware of the calculator to direct people to the page for free download and use.

CHAPTER 7: LIMITATIONS

The limitations of this study include having a small sample size, limited questions asked, and limited time for the study. Additionally, participants were not compensated for their time due to the inability to meet everyone in person. This study only utilized nine participants and would have benefited from having a larger sample size. There is the possibility of a selection bias in participant recruitment for this study. Participants were not randomly selected, but rather reached out to the researchers on their own to participate. Participants who contacted the researchers could have been more informed on the costing process and more interested in the calculator as a result. It is speculated that there was a lack of participation because there was a lack of time to complete a full project. After completing the study and seeing the results, more questions should have been asked regarding why they do not cost safety projects or collect metrics. The questions asked them if they could collect the metrics, but they were never asked why they don't already collect them. Looking back at the data, there is a gap in the understanding as to why no one who participated has used costing software, or why they didn't seek a software to use before this one. There also was not enough time to do a full, large scale test of the calculator. Most participants had to use historical data because they did not have enough time to do a project. This study would have benefitted from running the course of at least a year.

Although the costing data for the WMSD injuries is accurate, it was inflated to represent the gap in time from collection to use today. A better representation of data would have been to partner with an insurance provider to help get their most up-to-date injury information. Insurance providers were not willing to do this without having a paid partnership. This would have improved the accuracy of cost estimating the projects, since no two companies are the same.

The surveys were not designed to investigate why professionals are not using costing software. There was a minor assumption that the professionals who would participate had some experience costing projects using similar data and methods. However, all participants had never used any type of costing calculator. This created a gap in the research as to why safety professionals are not regularly using these tools. The survey could have benefitted from asking participants why they haven't used costing software if they answered no to using it. This question could have helped fill that unplanned research gap that was uncovered.

REFERENCES

Arabian, T., Mehdi Jourabchi, S. M., Leman, Z., Ismail, M.Y. (2013). A research on the impact of cost of quality models and reporting system on managing cost of quality, 50-54. Retrieved from http://www.ipedr.com/vol59/011-ICEMM2013-P00017.pdf

Asivandzadeh, E., Azami, K. & Zeynab J. (2018). Work-related musculoskeletal disorders, occupational stress, and their associations with general health in working populations in various industries. *Journal of Human, Environment, and Health Promotion*, (4), 169. https://doi-org.proxy.library.ohio.edu/10.29252/jhehp.4.4.5

Baldwin, M. L. (2004). Reducing the costs of work-related musculoskeletal disorders: targeting strategies to chronic disability cases. *Journal of Electromyography and Kinesiology*, 14(1), 33–41. https://doi-org.proxy.library.ohio.edu/10.1016/j.jelekin.2003.09.013

Beevis, D. (2003). Ergonomics—Costs and benefits revisited. *Applied Ergonomics*, 34(5), 491–496. https://doi-org.proxy.library.ohio.edu/10.1016/S0003-6870(03)00068-1

Borawski, P. (2011). Looking to the future from the rearview mirror. *2011 Future of Quality Study*. 38-39, Retrieved from http://asq.org/2011/09/global-quality/emergence-2011-future-of-quality-study.pdf

Bornstein, T. (2001). Quality improvement and performance improvement: different means to the same end? *International Society for Performance Improvement*. Retrieved from http://v2020eresource.org/content/files/quality_improvement.pdf

Cermakova, M., & Bris, P. (2017). Managing the costs of quality in a czech manufacturing company. *Scientific Papers of the University of Pardubice. Series D, Faculty of Economics & Administration*, 25(41), 6–18. Retrieved from https://proxy.library.ohio.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=126926097&site=ehost-live&scope=site

CUErgo (2008). Retrieved from http://ergo.human.cornell.edu/CUROIEstimator.htm

de Looze, M. P., Vink, P., Koningsveld, E. A. P., Kuijt-Evers, L., & Van Rhijn, G. (J. W. . (n.d.). Cost-effectiveness of ergonomic interventions in production. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 20(4), 316–323. https://doi-org.proxy.library.ohio.edu/10.1002/hfm.20223

Desai, D. (2008). Using continuous improvement events in an ergo program. (cover story). *Professional Safety*, 53(7), 40–42. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=iih&AN=32968386&site=eds-live&scope=site

Drury, C. G. (2000). Human factors and quality: integration and new directions. *Human Factors & Ergonomics in Manufacturing*, 10(1), 45. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=edo&AN=13361322&site=eds-live&scope=site

Dul, J., & Neumann, W. P. (2009). Ergonomics contributions to company strategies. *Applied Ergonomics*, 40(4), 745–752. https://doi-org.proxy.library.ohio.edu/10.1016/j.apergo.2008.07.001

[Ergo Labs]. (2019, October 4). Ergo intervention costing calculator tutorial [Video File]. Retrieved from https://www.youtube.com/watch?v=mWplPFpmwcY&feature=youtu.be

Falck, A.-C., Ortengren, R., & Hogberg, D. (n.d.). The impact of poor assembly ergonomics on product quality: a cost-benefit analysis in car manufacturing. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 20(1), 24–41. https://doi-org.proxy.library.ohio.edu/10.1002/hfm.20172

Goggins, R. W., Spielholz, P., & Nothstein, G. L. (2008). Estimating the effectiveness of ergonomics interventions through case studies: Implications for predictive cost-benefit analysis. *Journal of Safety Research*, 39(3), 339–344. https://doi-org.proxy.library.ohio.edu/10.1016/j.jsr.2007.12.006

Gupta, Mahesh & S. Campbell, Vickie. (1995). Cost of quality. 36. 43-49. Retrieved from https://www.researchgate.net/publication/290791158_Cost_of_quality

Hickey, D. L. (2017). Supervisors as leading indicators of safety performance. *Professional Safety*, 62(4), 41–44. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=bth&AN=122516417&site=eds-live&scope=site

Ikuma, L. H., Nahmens, I., & James, J. (2011). Use of safety and lean integrated kaizen to improve performance in modular homebuilding. *Journal of Construction Engineering & Management*, 137(7), 551–560. https://doi-org.proxy.library.ohio.edu/10.1061/(ASCE)CO.1943-7862.0000330

Ip, W., Gober, J., & Rostykus, W. (2016). Ergonomics return on investment. *Professional Safety*, 61(4), 48–52. Retrieved from https://proxy.library.ohio.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=114346066&site=ehost-live&scope=site

Jevgeni, S., Eduard, S., & Roman, Z. (2015). Framework for continuous improvement of production processes and product throughput. *Procedia Engineering*, 100, 511–519. https://doi-org.proxy.library.ohio.edu/10.1016/j.proeng.2015.01.398

Jun-Gyu Kim, S. E., Jihyun Chun, & Junggi Hong. (2013). Ergonomic interventions as a treatment and preventative tool for work-related musculoskeletal disorders. *International Journal of Caring Sciences*, 6(3), 339–348. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=rzh&AN=103886166&site=eds-live&scope=site

Kerr, M. P., Knott, D. S., Moss, M. A., Clegg, C. W., & Horton, R. P. (2008). Assessing the value of human factors initiatives. *Applied Ergonomics*, 39(3), 305–315. https://doi-org.proxy.library.ohio.edu/10.1016/j.apergo.2007.10.003

Lee K. (2005). Ergonomics in total quality management: how can we sell ergonomics to management? *Ergonomics*, 48(5), 547–558. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=rzh&AN=106085793&site=eds-live&scope=site

McLeod, S. A. (2019). Likert scale. *Simply Psychology.* Retrieved from https://www.simplypsychology.org/likert-scale.html

Morse, M., Kros, J. F., & Nadler, S. S. (2009). A decision model for the analysis of ergonomic investments. *International Journal of Production Research*, 47(21), 6109–6128. https://doi-org.proxy.library.ohio.edu/10.1080/00207540802165809

M. S. Rozlina, M. S. Awaluddin, Z. Norhayati and S. H. S. A. Hamid. (2012). The mediating impact of ergonomics between existing safety culture and targeted safety culture amongst safety and health (SH) practitioners, *2012 IEEE International Conference on Industrial Engineering and Engineering Management,* Hong Kong, 2012, pp. 1297-1301. https://ieeexplore-ieee-org.proxy.library.ohio.edu/document/6837953?arnumber=6837953&SID=EBSCO:edseee

NIOSH (2007). Chapter: 10 review of research on the reduction of cumulative musculoskeletal injuries in mining safety and health research at NIOSH: reviews of research programs of the national institute for occupational safety and health (p. 120). *Washington, DC: The National Academic Press*. Retrieved from https://www.nap.edu/read/11850/chapter/10

Osha.gov/shpguidelines/safety-pays.html

Oxenburgh, M., & Marlow, P. (2005). The productivity assessment tool: computer-based cost benefit analysis model for the economic assessment of occupational health and safety interventions in the workplace. *Journal of Safety Research*, 36(3), 209–214. https://doi-org.proxy.library.ohio.edu/10.1016/j.jsr.2005.06.002

Riaño, C. M. I., & Tompa, E. (2018). Cost-benefit analysis of investment in occupational health and safety in colombian companies. *American Journal of Industrial Medicine*, 61(11), 893–900. https://doi-org.proxy.library.ohio.edu/10.1002/ajim.22911

Ribeiro, T., Serranheira, F., & Loureiro, H. (2017). Work related musculoskeletal disorders in primary health care nurses. *Applied Nursing Research*, 33, 72–77. https://doi-org.proxy.library.ohio.edu/10.1016/j.apnr.2016.09.003

Rostykus, W., & Mallon, J. (2017). Leading measures: preventing msds & driving ergonomic improvements. *Professional Safety*, 62(9), 37–42. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=bth&AN=125252330&site=eds-live&scope=site

Schwerha, D. J., Boudinot, A., and Loree, N. (2017). Integrating Safety with Process Improvement for Sustainable Manufacturing. Paper accepted as presentation for the 2017 IISE Annual Conference, Pgh, PA, May 21-23.

Soares, M. M., Jacobs, K., & Lallemand, C. (2012). Contributions of participatory ergonomics to the improvement of safety culture in an industrial context. *Work*, 41, 3284–3290. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=rzh&AN=104522829&site=eds-live&scope=site

SHARP Washington State Department of Labor and Industries Summaries. (2015). Retrieved from https://www.lni.wa.gov/safety/research/wmsd/

Straub, F. (2018a). Leading ergonomic indicators: their importance in the american workplace, part 1. *Professional Safety*, 63(10), 60–67. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=eih&AN=132120629&site=eds-live&scope=site

Straub, F. (2018b Leading ergonomic indicators: their importance in the american workplace, part 2. *Professional Safety*, 63(11), 44–48. Retrieved from https://search-ebscohost-com.proxy.library.ohio.edu/login.aspx?direct=true&db=bth&AN=132773658&site=eds-live&scope=site

Tompa, E., Dolinschi, R., & Natale, J. (2013). Economic evaluation of a participatory ergonomics intervention in a textile plant. *Applied Ergonomics*, 44(3), 480–487. https://doi-org.proxy.library.ohio.edu/10.1016/j.apergo.2012.10.019

U.S. Bureau of Labor Statistics. (2016). Retrieved June/July, 19, Retrieved from https://www.bls.gov/news.release/pdf/osh2.pdf

Van Roijen, L., Essink-bot, M., Koopmanschap, M., Bonsel, G., & Rutten, F. (1996). Labor and health status in economic evaluation of health care: the health and labor questionnaire. *International Journal of Technology Assessment in Health Care*, 12(3), 405-415. doi:10.1017/S0266462300009764

The Washington State Department of Labor and Industries Puget Sound Chapter of the Human Factors and Ergonomics Society. Retrieved from https://pshfes.org/cost-calculator

Thomas, N. (2015), How to use the system usability scale (SUS) to evaluate the usability of your website. *UsabilityGeek*. Retrieved from https://usabilitygeek.com/how-to-use-the-system-usability-scale-sus-to-evaluate-the-usability-of-your-website/

Workplace Safety Indices by Industry: Insights and Methodology. (2019). *Risk Control Services from Liberty Mutual* [PDF file]. Retrieved from https://business.libertymutualgroup.com/business-insurance/Documents/Services/DS200.pdf

Work-Related Musculoskeletal Disorders & Ergonomics | Workplace Health Strategies by Condition | Workplace Health Promotion | CDC. (2018). Retrieved June/July, 2019, from https://www.cdc.gov/workplacehealthpromotion/health-strategies/musculoskeletal-disorders/index.html

Yeow, P. H. P., & Nath Sen, R. (2003). Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. *International Journal of Industrial Ergonomics*, 32(3), 147–163. https://doi-org.proxy.library.ohio.edu/10.1016/S0169-8141(03)00051-9

Yeow, P. H. P., & Nath Sen, R. (2006). Productivity and quality improvements, revenue increment, and rejection cost reduction in the manual component insertion lines through the application of ergonomics. *International Journal of Industrial Ergonomics*, 36(4), 367–377. https://doi-org.proxy.library.ohio.edu/10.1016/j.ergon.2005.12.008

Zimak, G. (2000). Cost of quality (COQ): which collection system should be used? *ASQ's 54th Annual Quality Congress Proceedings.* 18-24. Retrieved from http://asq.org/learn-about-quality/cost-of-quality/overview/14434.pdf

APPENDIX A:

Sources for WMSD cost data		
WMSD	**Cost Average**	**Source**
Shoulder	$66,118.50	2015 SHARP Washington State Department of Labor and Industries Summaries
Elbow	$56,636.83	2015 SHARP Washington State Department of Labor and Industries Summaries
Hand/Wrist	$47,446.50	2015 SHARP Washington State Department of Labor and Industries Summaries
Back	$50,782.17	2015 SHARP Washington State Department of Labor and Industries Summaries
Knee	$45,422.17	2015 SHARP Washington State Department of Labor and Industries Summaries
Carpal Tunnel	$10,517	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Back strain	$5,461	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Sciatica	$21,286	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Neck strain	$16,011	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Shoulder strain	$8,667	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Rotator cuff injury	$15,010	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Elbow strain	$6,605	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Epicondylitis	$6,815	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Hand/wrist strain	$5,657	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Tendonitis	$6,632	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Bursitis	$7,877	The Puget Sound Chapter of the Human Factors and Ergonomics Society
Knee strain	$6,409	The Puget Sound Chapter of the Human Factors and Ergonomics Society
All other MSDs	$5,373	The Puget Sound Chapter of the Human Factors and Ergonomics Society

APPENDIX B:

Authors	Article Title	Referenced Material
Jevgeni, S., Eduard, S., & Roman, Z.	Framework for Continuous Improvement of Production Processes and Product Throughput	Key Performance Indicators
Gupta, Mahesh & S. Campbell, Vickie.	Cost of quality	Quality Metrics
Ip, W., Gober, J., & Rostykus, W.	Ergonomics Return on Investment	Quality, Performance, and Safety Metrics, Estimations on improvements
Riaño, C. M. I., & Tompa, E	Cost-benefit analysis of investment in occupational health and safety in Colombian companies	Direct and Indirect cost types and comparisons, Estimations of improvements
Cermakova, M., & Bris, P.	Managing the Costs of Quality in a Czech Manufacturing Company	Quality Cost Breakdowns
Gagne R.	What Does a Workplace Injury Cost	Direct vs Indirect cost
de Looze, M. P., Vink, P., Koningsveld, E. A. P., Kuijt-Evers, L., & Van Rhijn, G	Cost-Effectiveness of Ergonomic Interventions in Production	Estimations on Improvements

APPENDIX C:

Job Position Title:____________________________ Company type:________________

Usability of the Calculator

	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I think that I would like to use this system frequently.					
2. I found the system unnecessarily complex.					
3. I thought the system was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this system were well integrated.					
6. I thought there was too much inconsistency in this system.					
7. I would imagine that most people would learn to use this system very quickly.					
8. I found the system very cumbersome to use.					
9. I felt very confident using the system.					
10. I needed to learn a lot of things before I could get going with this system.					

Value of the Calculator

(This form will be administered and filled out by researcher while conducting interview)

1. **The calculator used many of the metrics we already collect.**

Strongly Agree Agree Undecided Disagree Strongly Disagree

2. **The calculator had all the injury metrics I need to see to make a decision.**

Strongly Agree Agree Undecided Disagree Strongly Disagree

If you disagree, please explain:____

3. **The calculator had all of the performance metrics I would need to see for decision making.**

Strongly Agree Agree Undecided Disagree Strongly Disagree

If you disagree, please explain:____

4. **The calculator had all of the quality metrics I would need see for decision making.**

Strongly Agree Agree Undecided Disagree Strongly Disagree

If you disagree, please explain:____

5. **The calculator successfully demonstrates the predictive summary and post project results in an easy to understand chart for comparison.**

Strongly Agree   Agree   Undecided   Disagree   Strongly Disagree

6. **Using this calculator could make it easier for decision making about ergonomic projects.**

Strongly Agree   Agree   Undecided   Disagree   Strongly Disagree

7. **I felt I had better cross department communication for decision making because of all the data present in front of me using the calculator.**

Strongly Agree   Agree   Undecided   Disagree   Strongly Disagree

If you disagree, please explain:____

8. **I felt project documentation improved from using the calculator based on previous methods practiced.**

Strongly Agree   Agree   Undecided   Disagree   Strongly Disagree

If you disagree, please explain:____

9. **Better project documentation helps lead to easier decision making from multiple departments involved.**

Strongly Agree Agree Undecided Disagree Strongly Disagree

10. **Do you already use a costing software? If yes, please briefly explain its parameters and functions**. ____

____

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11. **Do you regularly collect performance and quality metrics when assessing ergonomic projects? If yes, please list them:** ______________________________

____

____

12. **How difficult would it be for you to collect the metrics needed on the calculator?**

Very Easy Easy Unknown Difficult Very Difficult

13. **Did you watch the tutorial video? If so, did you find it helpful?**

____

____

14. **Did you read the walk-through instructions? If so, did you find it helpful?**

____

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Notes and Comments:____

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