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Apply & Evaluate a Health Cost Calculation Model for Ergonomic Interventions

A case study at Volvo Cars, Torslanda, Sweden

Master Thesis in Production Engineering

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Cover: Operators working in under-up position at the Tailgate in one of the assembly lines. *(Image reproduced with permission from Volvo Cars, Torslanda)*

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Abstract

The art of ergonomics has evolved over the years and the assembly operations at Volvo Cars are relatively more productive than ever. However, the risk of getting injured is still in the cards which paves the way for continuous improvements. The work related injuries occurring due to poor ergonomic conditions have been a major concern in today's industries as these injuries immensely affect the overall productivity and cost a lot of money. Volvo Cars is striving towards achieving a state-of-the-art of sound ergonomics that reduces the risk of occupational health injuries. However, at times the engineers and ergonomists fail to convince the management to implement the proposed interventions due to lack of cost-related arguments. Hence, it becomes absolutely necessary for these stakeholders to work on translating the proposed interventions into monetary terms. This could be made possible with an appropriate calculation tool that validates the above stakeholders' claim and identifies other hidden factors to assist them in obtaining funds for the intervention. This thesis work develops a health cost analysis tool for ergonomic interventions that involves scrutinizing the current health cost model and discussing the effects of adapting to different approaches, which help to identify the improvement potentials. The scope of this work is limited to analyzing the ergonomic conditions specific to the tailgate assembly at a Volvo Cars Plant in Sweden. With valuable inputs from interviews, a health cost tool has been created and validated to act as a decision support to the ergonomists and engineers in convincing the management. In addition, the authors further recommend to use this validated model as a skeleton for future studies at Volvo and incorporate the same across their other plants.

Keywords : Ergonomics, Economics, Health cost model, Presenteeism, Proactive, Reactive

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Contents

Abbreviations

H&S - Health and Safety

MSD - Musculo-Skeletal Disorder

MTM - Methods Time Management

PEWD - Production Ergonomics and Work Design
PSHFES - Puget Sound chapter of the Human Factors and Ergonomics Society

ROI - Return on Investment

R&D - Research and Development

SDA-M - System Decision Alternative - Manufacturing

SEK - Swedish Krona

TMU - Time Measurement Unit

VCT - Volvo Cars, Torslanda

VPDS - Volvo Product Development System

WMSD - Work related Musculo-Skeletal Disorder

Glossary

Balance - A series of workstations or a production line at Volvo

Calculation model - A configuration that affects the decisions in making an investment

Compilation - A logical formulation of factors into a model on a digital scale/platform

Comprehensive - Inclusion of all kinds of factors into the calculation model irrespective of their degree of impact

Factors - Parameters to be included in the calculation model that directly or indirectly affect the ergonomic investment

Ideal - A most suitable or appropriate condition that fits the situation at Volvo Cars

Intangible factors - Factors that affect the decision, but cannot be quantified in monetary terms. Examples include employee morale, safety, environmental effects etc.

Intervention - An act of making improvement changes to the current situation which will eventually result in increased quality, productivity and safety

Investments - Purchasing of materials or making changes to the existing equipment to increase productivity and ergonomic quality of the workstation/task

Knowledge base - Collection of a set of data or information essential for this thesis work from previous experiences and literature study

Model complexity - The complications in the model assessed in terms of time required to feed the inputs involved

Qualitative - A type of analysis that focuses on collecting information that is not numerical in nature. Mostly includes unstructured and semi-structured techniques

Quantitative - A type of analysis that involves conversion of available numerical data into usable statistics that supports the calculation model

ROI - A measure to determine the efficiency of an investment

Stakeholder - People who can affect or get affected by the outcome of this work

Station - Workplace where specific assembly operation or value adding work takes place

Static forces - Forces that affect a limited muscle group for a sustained period of time, allowing little or no rest and recovery, leading to discomfort

Under-up - Performing assembly operations with hands above the head and neck bent backwards

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1
Introduction

This chapter describes the background to the thesis followed by the problem description and the objective. Delimitations and the research questions will conclude the chapter.

1.1 Background

Work related injuries are one of the most costly health problems in today's automotive industries. To tackle this, many organizations aim to improve the design of workstations to reduce such risk of injuries by proposing an intervention. However, the engineers and the ergonomists often fail to convince the management and the stakeholders involved to implement the proposed interventions due to lack of use of cost related arguments. Hence, it becomes absolutely necessary for the ergonomists to work on translating the proposed interventions into monetary terms. In such cases, they will need a comprehensive calculation model to validate their claim and identify other hidden factors to assist them in obtaining funds for investments. Return on Investments (ROI) is one of the legitimate measures that evaluates the performance of business in economic terms. Such a calculation model that produces realistic numbers by addressing the effects of an intervention must be made use of either through proactive or reactive approach. The point of this thesis is to compile such a calculation model that supports the given scenario at Volvo Cars, Torslanda(VCT), Sweden.

1.2 Problem Description

In order to justify an intervention, the importance of ergonomics must be well motivated in economic terms using a valid cost calculation model. With such an attitude, most manufacturing industries emphasize mainly to reduce ergonomic costs related to productivity and quality loss and often fail to address the health cost aspect of it. The health costs are concerned with the ergonomic health related issues that arise from the work environment
A well conveyed cost model that includes the health costs of ergonomic deviations serves as a substantial support in motivating the managers to approve the investments. In order to address such a comprehensive model that measures the total costs, this thesis mainly focuses on addressing the health cost aspects and developing a tool to obtain the necessary calculations.

1.3 Objectives

The intention of the authors is to analyze the health costs related to the ergonomics of assembly operations in the automotive industries.

- Apply a methods engineering approach to assess the improvement potentials for the current health cost tool on ergonomic interventions at Volvo Cars .
- Compile the health cost analysis tool with return on investment (ROI) calculation that can serve as a decision support by providing cost justification to the management and other stakeholders.

1.4 Scope and Delimitations

The focus of our study is to unearth different health cost calculation models in the manufacturing industry in order to assess the benefits of carrying out ergonomic interventions. This serves as a decision support to match the expectations of the stakeholders involved in bringing about ergonomic changes in the assembly line or plant that enhances overall safety, productivity and quality.
The study is specifically targeted towards the ergonomic conditions in tailgate assembly of cars at Volvo Torslanda plant, Sweden. The health cost calculation model will not address its effects on productivity and quality. In addition, only the costs incurred by the organization are taken into consideration i.e. the insurance costs for employees are excluded. Also, the area of cognitive ergonomics such as mental stress and human reliability have been excluded from the study due to lack of proper documentation at VCT.

1.5 Needs and Wants

This section can be said to be an extension of the scope and delimitations explaining the product and project's needs and wants. Needs can be defined as well-defined necessities required to fulfill the objective of this thesis while on the other hand, wants are limited by imagination and can be said to be the best possible way to fulfill the stated objective [1]. The above definition is explained visually in figure 1.1. The proposed calculation model is considered as a product and its corresponding needs and wants are stated. Such a division of necessities can help the authors of this thesis to plan appropriately to have a steady thought process.

	Product (Calculation Model)	Project
Needs	• To address the effects of ergonomic initiatives in monetary and qualitative terms at Volvo Cars	• Use existing ROI calculation models as reference • Qualitative and quantitative data collection • Identify hidden factors that are necessary to be included in our calculation • Comparison of ROI models that fits best to the given case • To compile a digital calculation model tool
Wants	• To design an applicable model such that it is independent of the case	• To design a comprehensive calculation model

Figure 1.1: Needs and Wants of the health cost model and thesis project

1.6 Research questions

- How does the current health cost calculation model at VCT function?
- What factors are relevant in the health cost calculation model?
- What are the different approaches in literature that estimate ergonomics costs ?
- What changes to the model are expected by the stakeholders ?
- Does the created calculation model serve as a decision support to demonstrate the improvement impact of a task/workstation at VCT?

These set of questions will serve the contents of the Methods and Results section and further discussed.

2
Theory

This section provides the theoretical background to the procedures and techniques used in this thesis work.

2.1 Ergonomics

Ergonomics is an applied science where the working postures and traits of a person at a workplace are studied to design the environment and tools, giving prime importance to safety, quality and higher productivity. For the purposes of this thesis, ergonomics is a concept of creating an ideal work environment where physical stress is reduced. If a person has to adapt to a job that exceeds his/her physical abilities, he/she is more prone to get injured. In most of the cases, when injuries are prolonged, it leads to Work related Musculo-skeletal Disorders (WMSD). The sooner the employee reports the symptoms and have the injury risks attended to, the better the chance of avoiding WMSD. In order to address this, simple changes to the job or workstation must be made such that there is reduction in the symptoms to a level where it is no longer a threat. From this, ergonomics can now be defined as a methodical study to improve human-machine interaction so that everything works safely and efficiently. It is not only the information exchange between the two that matters, but also how the user interacts with the interface and how the interface influences the user [2]. This is where ergonomics comes into play. It is the responsibility of an industrial engineer to continuously improve such an interaction between the interface and the user. These engineers analyze the distinct ergonomic problems and study their impacts. The impacts of ergonomic solutions can be improved safety, reduced costs and improved productivity and quality [3].

2.1.1 Economics of Ergonomics

The economics of ergonomics is important from a managerial and technical standpoint [4]. There are a few studies that aim at the economic side of ergonomics. In the literature - "Good Ergonomics is Good Economics", Hendrick [5] has thrown light on several ergonomic projects that have canceled out the initial costs resulting in economic benefits. The necessity and importance of an assessment method to document the costs and savings have been stressed upon . With similar views, Tompa et al. has scrutinized such case studies by conducting a systematic review of workplace occupational health and safety (H&S) interventions with economic evaluations. Of all that exist, every case has a connection between ergonomics, musculo-skeletal injury

prevention and either quality, productivity or health related costs. This study concludes that it is worth undertaking such interventions on the basis of their economic terms as they are beneficial due to reduced number of injuries, which ultimately result in savings and productivity improvements [6]. Similar cases where small investments made towards the well-being of operators resulted in huge savings later for the same financial year. All resulted in shorter payback periods, reduction in injuries and increased productivity and quality [7], [8], [9].
Most often, the costs of ergonomic interventions are justified using a number of ways which are briefly explained in the following section.

2.2 Cost Justification Methods

Often costs become a barrier when ergonomic interventions demand a large investment. Hence, it becomes necessary to quantify the costs in a presentable manner using some kind of a cost calculator. Here are a number of cost justification methods that are often used to assess the economic side of ergonomics.

2.2.1 Benefit/Cost Ratio

Benefit cost ratio is a simple technique that evaluates an investment by comparing the economic benefits of a project and the costs required to implement it. Also known as benefit cost analysis, this tool serves as a concrete quantitative evidence to the qualitative arguments.

$Benefit\ cost\ ratio = \frac{Valueofbenefits}{Costofchanges}$

Generally if the benefit is higher than the cost of the project, it is said to be a sound investment. Of course VCT aims at a high benefit cost ratio but then again arises the problem of the exact definition and the values of benefits and costs limiting its usage.

2.2.2 Payback Period

Payback period refers to the time taken for the benefits of a solution to recover the costs of the investments. Mathematically it is represented as the ratio of costs per year and benefits per year.

$Payback\ period\ (years) = \frac{Costs\ per\ year}{Benefits\ per\ year}$

Usually, the payback period of an ergonomic intervention is within one year, but again this completely depends upon the type of intervention proposed.

2.2.3 Return on Investment (ROI)

This method is the most commonly used cost justification method of all as the calculations are straightforward. A typical ROI calculation compares the financial benefits of a proposed solution to its costs. Usually, ROI is expressed as a percentage.
Based on its simplicity and straightforwardness, the authors have chosen to use this method to justify the costs for the considered case in later chapters.

$$Return\ on\ Investment\ (\%) = \frac{Return\ to\ the\ company}{Investment\ of\ changes} * 100$$

2.2.4 Present Value

Assuming that the value of money changes every year, this cost justification method helps us to find the values of benefits and costs over the life of a project. Both the present value of the future investments (P/F) and the future value of the present investments (F/P) can be calculated provided the rate of interest is known. To calculate either the present worth (P/F,i,N) or future worth (F/P,i,N), tables are to be made use of which are available in every financial or engineering economy book [10].
This method in itself is a complex method as it involves a lot of variables.

2.2.5 Losses vs Goods Sold

This techniques provides a final monetary figure that a company must be willing to spend to implement an ergonomic solution. Knowing the profit margin for the business is a prerequisite to this method. Mathematically the ratio of the cost of losses due to bad ergonomics and the profit margin gives the volume of sales required to offset loss.

$$Sales\ volume\ to\ offset\ loss = \frac{Costs\ of\ losses}{Profit\ margin}$$

In order to utilize the full potential of such cost justification methods, companies must also start tracking expenses associated with health and not just productivity and quality issues.

2.3 Health cost Analysis

Until companies start realizing the importance of health related ergonomics, they will continue to find it hard to justify spending money to make interventions. VCT faces similar problems and fails to justify the investments due to lack of health related arguments to their cost models. A reason to this, as Hendrick [11] puts forward, is due to management's perception of ergonomic measures as costs rather than investments which is a theory supported by Falck's research [12]. Having explained the need of inclusion of a reliable health cost tool at VCT, this section briefly

explains some of the health cost models found during literature survey that can be of extreme help to prove its worthy inclusion. In order to support the process of economic justification of ergonomic projects, Riel and Imbeau [13] recommend developing a "comprehensive support system" that includes "a model of H&S costs, a safety information system, and a proper user interface all of which make the analysis efficient and effective ." From a broader perspective, developing such models can have two different approaches: Proactive or Reactive.
Regardless of numerous sources that state that ergonomically bad workplaces lead to injuries, companies have failed to implement changes in the early stages of production and end up implementing short term solutions. This is mainly due to ergonomic incompetence and lack of cooperation between various functions of the system [14]. In simple words, reactive ergonomics is implemented after a problem has occurred. Such an approach usually results in a poor product because it is too late to make physical changes at the start of production [12]. Even though a reactive approach is less advantageous, it can be said to be a process of strengthening the proactive process whilst assessing the next phase of the design system.

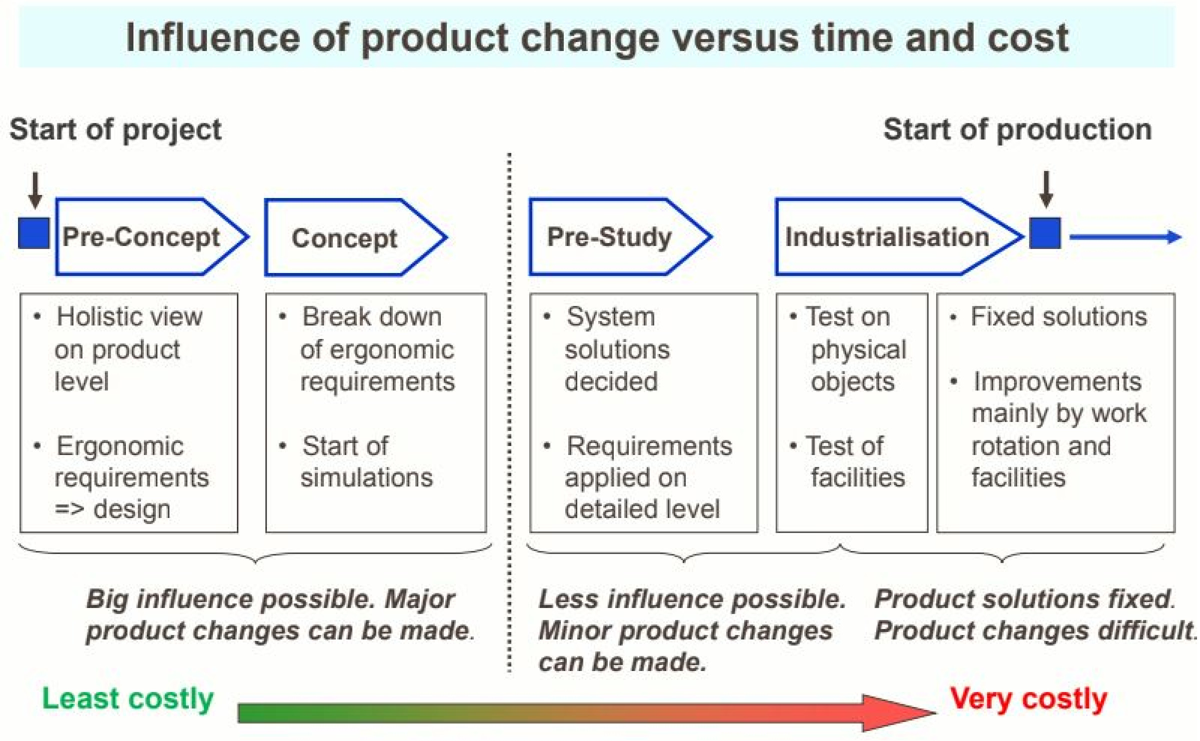


Figure 2.1: Influence of product change during the development process [15] *(Image produced with permission from A.-C Falck)*

On the other hand a proactive approach is where the importance of the effects of an ergonomic problem are realized beforehand i.e. in the concept phase. It is based on the assumption that a problem can be identified prior to its occurrence [2]. To better understand this theory that anticipates health, productivity and quality risks, it becomes important to establish the ergonomic initiatives in the early development stages as seen in the figure 2.1. It can be clearly seen that the changes made at the start of the project costs less and has the biggest influence on the final product solution. Such decisions are purely based on scientific research and experience based on previous projects. Nonetheless, exercising a proactive approach does not always lead to a positive result in the future which can be seen as a disadvantage [16]. This is mainly due to inadequate ergonomic competence and recognition of consequence of design by the engineers [17]. As a result of this, prediction of ergonomic risks through simulation of workplaces before their actual implementation have gained popularity [18], [19], [20]. In conclusion, of the two approaches, manufacturers must prioritize implementing ergonomic initiatives proactively as it not only provides safe and healthy workplaces for employees, but also facilitates increased levels of productivity [14].

Mostly the data required to calculate costs and savings are specific to a given facility and entirely depend on the quality of data available within the facility. A number of case studies are collected from ergonomics literature that provide concrete evidence as to how elimination of H&S risks result in many other advantages such as reduced costs, increased efficiency and productivity.

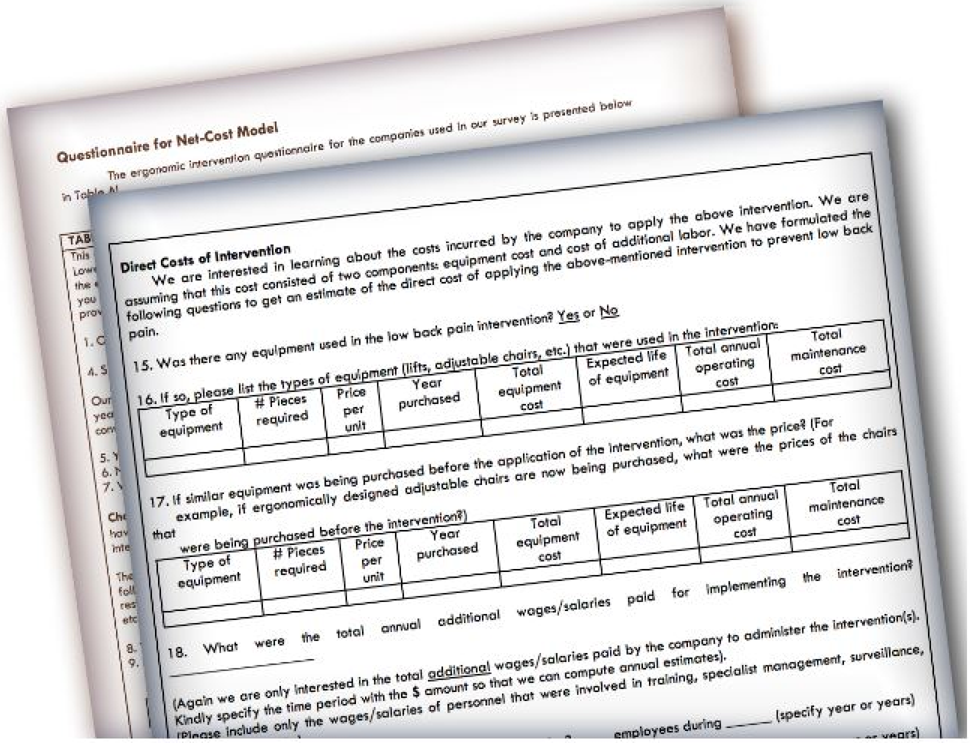
Over the past decades, many models that analyze the economic side of ergonomic interventions are developed and discussed. But, hardly any of them are used in practice except a few. This is either due to the complexity of the model or the time taken to collect the data [21]. Here are some of the models attempting to reduce the health costs of ergonomic issues either proactively or reactively. The approach of these models are used as ground rules in compiling a tool that fits the given case at VCT.

2.3.1 Calculate Sickness absence costs

The Swedish social insurance agency (Swedish- Försäkringskassan) is a government agency that manages social insurance in Sweden. This agency provides an online cost calculator that gives an estimate of how much a sick leave costs. Some of the rules (Day 1 of sickness - 0% of salary, Day 2-14 - 80% of salary) followed by VCT are similar to that of this agency. This calculator is available online [22]. This calculator is adapted to Swedish social security regulations and compensation rates. Such a comprehensive calculator has made it reliable to the authors to use it in this thesis.

2.3.2 Net cost model for workplace intervention

This model provides the net costs and gains calculated at company level for the proposed intervention targeted at decreasing health related costs due to bad ergonomic issues. The model focuses on the economic evaluation of the intervention to reduce work-related low back pain. The study also takes into account the avoided costs of lost work time and direct costs of the interventions (including equipment costs, additional wages, training costs and medical care costs). In addition, a sensitivity analysis on the result is conducted to validate the model by varying two of its critical variables. This model is available as a questionnaire based method in the appendix of the article [23] or as an online document [24].


Questionnaire for Net-Cost Model

The ergonomic intervention questionnaire for the companies used in our survey is presented below in Table A1

Direct Costs of Intervention

We are interested in learning about the costs incurred by the company to apply the above intervention. We are assuming that this cost consisted of two components: equipment cost and cost of additional labor. We have formulated the following questions to get an estimate of the direct cost of applying the above-mentioned intervention to prevent low back pain.

15. Was there any equipment used in the low back pain intervention? Yes or No

16. If so, please list the types of equipment (lifts, adjustable chairs, etc.) that were used in the intervention:

Type of equipment	# Pieces required	Price per unit	Year purchased	Total equipment cost	Expected life of equipment	Total annual operating cost	Total maintenance cost

17. If similar equipment was being purchased before the application of the intervention, what was the price? (For example, if ergonomically designed adjustable chairs are now being purchased, what were the prices of the chairs that were being purchased before the intervention?)

Type of equipment	# Pieces required	Price per unit	Year purchased	Total equipment cost	Expected life of equipment	Total annual operating cost	Total maintenance cost

18. What were the total annual additional wages/salaries paid for implementing the intervention? ______

(Again we are only interested in the total additional wages/salaries paid by the company to administer the intervention(s). Kindly specify the time period with the $ amount so that we can compute annual estimates).

(Please include only the wages/salaries of personnel that were involved in training, specialist management, surveillance,

employees during ____ (specify year or years)

Figure 2.2: Illustration of the Net cost model
(Image from Berlin and Adams [14] (CC-BY4.0))

2.3.3 Washington State ergonomics cost benefit calculator

In most of the cases, since the cost side of ergonomic implementation dominates over the benefits side, many organizations fail to realize the fact that it is easier to quantify the benefits of any ergonomic interventions after its implementation. To help such organizations that believe in such erroneous conclusions to better quantify the benefits of ergonomic interventions, Rick Goggins, a Labor and Industries ergonomist and a member of the Puget Sound Chapter of the human factors and Ergonomics Society (PSHFES), has developed a cost-benefit calculator. Calculations are based on a review of 250 case studies in which organizations reported the outcomes of ergonomics programs and individual solutions [25]. The groundwork of this calculator is based on the findings by Oxenburgh [26]. This calculator is so comprehensive that it can be applied for organization in various branches such as in woodworking, construction and metalworking enterprises by simply altering the calculator to its local specifications [27]. A screen shot of the online calculator is shown in the figure 2.3. This calculator is available as a spreadsheet with multiple sheets each for inputs, benefits and paybacks. It also includes a set of instructions as to how to use the calculator to its full potential. It is also intended to be used under a set of conditions such as: expectation of payback period to be less than a year, consideration of implementing multiple ergonomics solutions, a well thought through active ergonomics program and much more. With such absolute options, the calculator also includes options for effectiveness of the implemented solution such as time reduction of exposure, elimination exposure to hazard and reduction in injuries. It also estimates the effectiveness of the ergonomic solution on productivity.

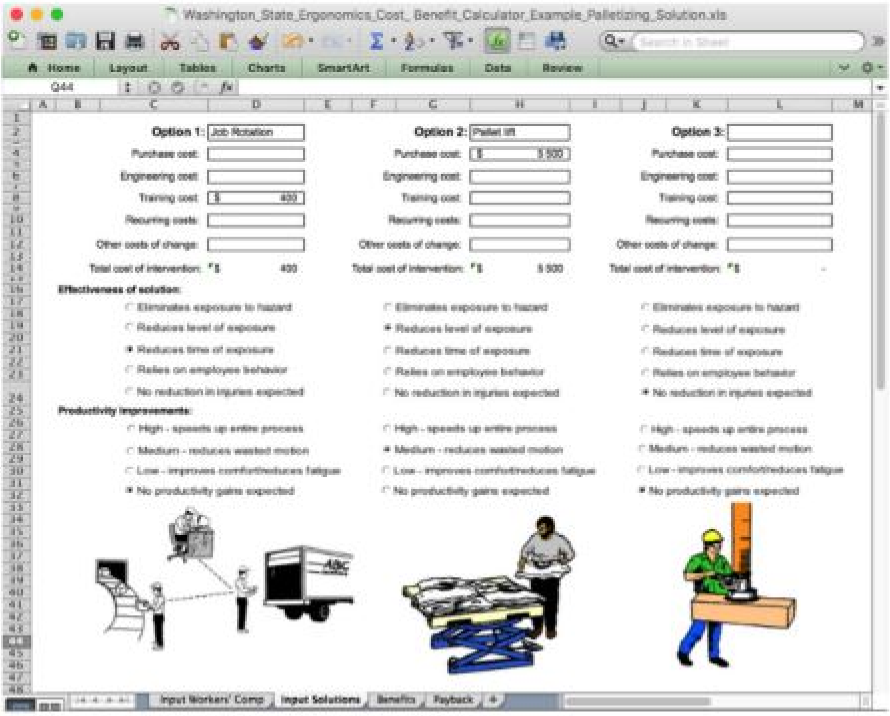


Figure 2.3: Illustration of the Washington State cost benefit calculator
(Image from Berlin and Adams [14] (CC-BY4.0))

2.3.4 Other cost models

Apart from the above literature that have a case specific model/tool to address the costs of health related ergonomic issues, there are a few that convey similar messages without the help of a calculation model. According to Shi [28], the results of a cost benefit analysis showed modest decrease in a specific health injury rate that resulted in significant improvement in the workplace culture. This literature also creates an awareness of how creating a health awareness program can support the reduction of employee health risks at any workplace .
Another model developed by Falck et al. [29] conveys a similar message that the costs of poor assembly related to assembly ergonomic conditions have benefited the engineers and stakeholders to design or redesign manual assembly solutions. Though this model is inclined towards the quality related ergonomic costs, it has a mention of the health related ergonomic issues (work related sick leave and rehabilitation) making it worth mentioning. It seems that compiling a wholesome health cost tool is no piece of cake. With similar views, De Looze et al. [30] talks about the complexity in analyzing the costs and benefits of ergonomic intervention due to requirement of large amount of data. This article also proposes a decision tool that addresses the relevant factors in the cost–benefit analysis of ergonomics in a step by step method

relating to health and productivity gains. Among the main costs related to health, personal costs and material costs were included. Addressing the ergonomic costs in such a way helps the stakeholders to support the investment decision .
In addition to this, M. Morse et al. [31] proposed a similar model that is helpful to a firm to comprehensively examine the cost/benefit trade offs of ergonomic investments. This model categorizes savings as a probability and predicts returns using the present value justification method in calculating the payback period for ergonomic investments . This is represented as a decision tree and serves as a decision support to the firm enabling it to monitor some of the uncertainties.

The way of implementation and the theory behind these health cost models are used by the authors of this thesis as a basis to narrow down the available knowledge and derive some of the commonly used cost functions.

2.4 Cost Factors

This section brings out the most common cost factors used in most of the health cost calculations explained above.

1. **Sick leave or Absenteeism** is the cost that the company has to pay to a sick employee when he/she is away from work mostly due to work related injuries. In Sweden, the social insurance agency pays the benefits except for the first two weeks of sick leaves which is paid by the employer [Discussion sessions].

2. **Personnel Turnover costs**
   (a) **Cost of an employee leaving** The company may incur replacement costs until a new employee is hired.
   (b) **Cost of hiring a new employee** The costs that the company incurs to recruit and hire a fitting person to the job.
   (c) **Training costs** A worker unfamiliar with the job will need to be trained and this costs money and time for the company. There are also costs associated with the person who conducts the training.
   (d) **Increased supervisory costs**

3. **Rehabilitation costs** Expenses incurred in restoring an individual so that he/she is fit to work without experiencing any discomfort due to previous injury.

Often, the H&S specialists, ergonomists and engineers do not have a clear picture of how to use the above cost factors effectively. This is of no surprise, since the involved stakeholders many a times fail to integrate the cost model into the company's information system. This makes it hard for the management to approve the investments due to lack of valid reasoning. Keeping this in mind, the next section explains the techniques required to achieve an ideal model. This helps the authors of this thesis to validate the proposed model which revolves around the company's information system.[32]

3 Methods

This chapter is about the methodology used and how the chosen techniques are implemented to improve the given case. This gives a clear idea of how each and every phase has been planned and executed to obtain the final results.

3.1 Methods Engineering

Methods engineering [2] is a recognized method that explains the design and analysis of a work system that includes workplace layout, plant layout, work environment and cost management. Having explained the need for a groundwork in previous sections, methods engineering serves as a decision support system that makes the model integrated and acceptable. This method can be used to overcome common problems such as low productivity, high costs, inefficient methods (repetitiveness, job rotation) and a need for new method. These problems fit like pieces of a puzzle in our considered case at VCT. Hence the objective is to optimize methods, reduce costs and to improve safety and information. Following such a method that facilitates increased productivity, reduced labor, reduced product cost and reduced cycle times enables the final output of the proposed health cost model to be more reliable and realistic [2].

3.2 Visualization & Description of Methodology

Figure 3.1 is a schematic representation of how the thesis work is developed in different stages. The elementary step in this work is to strengthen the roots towards the topic through a comprehensive literature study and some previous knowledge which forms the overall knowledge base. With such a strong foundation laid, it helps the authors to choose stakeholders wisely and categorize them into realization stakeholders and result stakeholders based on their involvement into this work. The next phase is to accumulate relevant data and figures from the company and other stakeholders. In addition, the data collection phase involves semi-structured interviews with all the stakeholders to gain different perspectives to this work. With such a huge pile of data, the data analysis phase is initated by processing and extracting some useful information from the literature study, related documents at VCT and the interviews conducted. In the next phase, conclusions are drawn by thorough analysis of data in accordance with the needs and wants of this work. The results are compiled into a cost model as per the objective and subjected to validation by

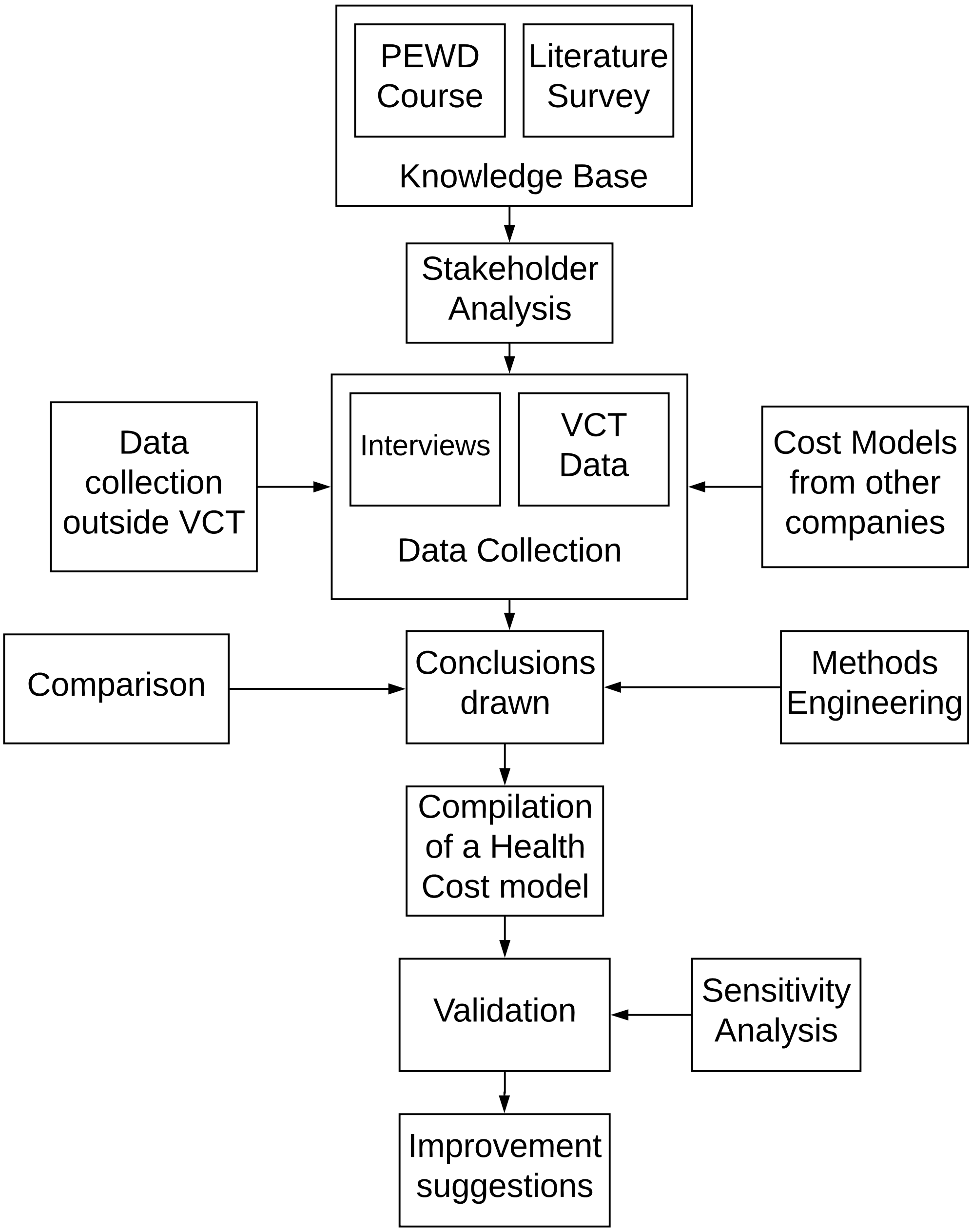


Figure 3.1: Visualization of Methodology

testifying the results through sensitivity analysis. Finally, a few suggestions are made for carrying out future studies on this topic. Each phase of this work has been explained in detail in the subsequent sections.

3.2.1 Structuring the knowledge base

The fundamental knowledge building for this work commences with a brief understanding of the problem outline of the thesis with some prior knowledge acquired during the Production ergonomics and work design (PEWD) course at Chalmers.

This Knowledge-building process is further intensified with literature findings on topics such as return on investment and various health cost analyses for assembly ergonomics. These findings provide a better picture on how the health related costs are incurred from poor ergonomic conditions at the work place and how are they calculated. Each health cost model is unique in the way of choosing factors for calculating the ergonomic costs and a few of the factors are quite common in most of these models. This sums up the knowledge gaining phase covering some important aspects of health cost analysis with a time span of over 3 weeks and provides a framework for the next step to choose our stakeholders appropriately. However, the literature study extended until the end of the data collection phase which will be discussed in further sections.

3.2.2 Stakeholder Analysis

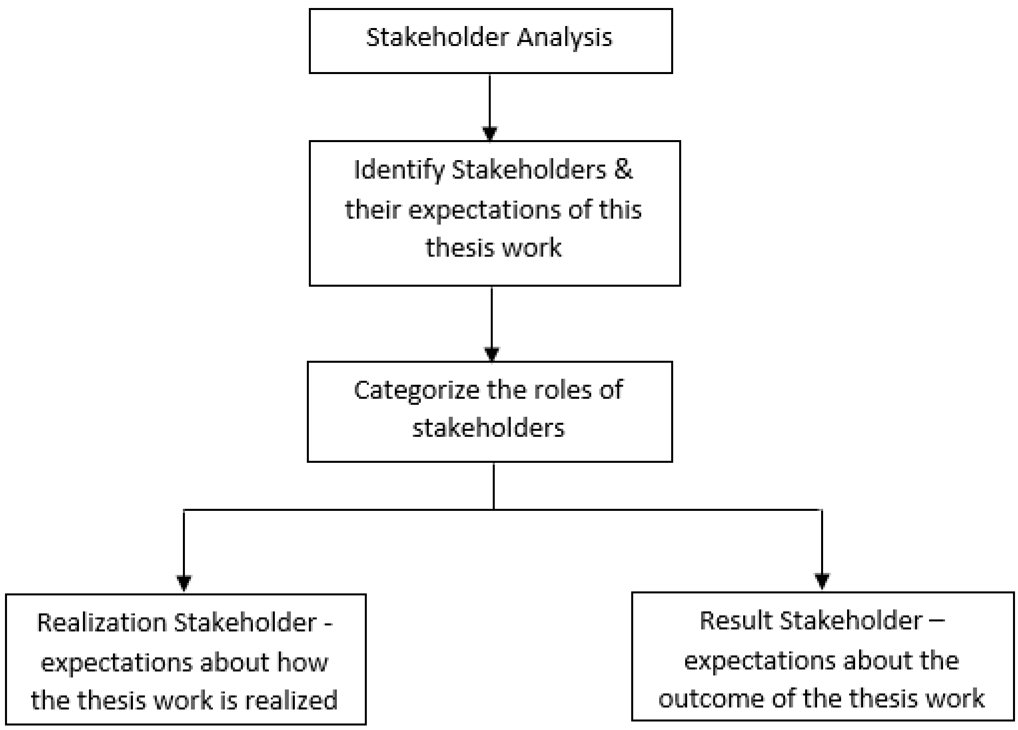


Figure 3.2: Stakeholder Analysis

According to Freeman, a stakeholder can be a group or an individual who can affect or is affected by the results of the projects objectives [33]. With a sound knowledge base set, the horizon of this topic is on a broader scale and indicates a sense of liability in narrowing down the scope and shaping the boundary. The timeline of this thesis work is broken down into different stages or phases in order to focus on identifying the potential stakeholders in every phase. Here, the roles of the identified stakeholders are analyzed briefly to categorize them as realization and result stakeholders. Realization stakeholders (academic supervisor and the authors themselves) are more concerned with the approach or technique incorporated in arriving at the results while the result stakeholders are more interested in the findings that emerge from the realization phase. Apart from them, a few experts from different backgrounds are chosen to be stakeholders for this work as suggested by the supervisors (company and academic) and other primary stakeholders. This gives justification and validation to the collected and presented data [34].

The following are the listed Primary stakeholders from different functions across the manufacturing engineering department, VCT who provide a collective perspective into this health cost analysis. These primary stakeholders are more concerned about the outcomes from this health cost analysis approach, also deemed as the result stakeholders.

Ergonomists - This thesis is focused on the issues resulting from poor ergonomic conditions in the assembly operations and resolving them. Also, the ergonomists are responsible for evaluating the ergonomic costs and validating them to get approval from top management for an intervention.
Core Manufacturing Engineers - Responsible in working with a simulation tool to identify the ergonomic deviations (under-up, bending, twisting etc.) and trying to eliminate them using ergonomic standards. Also, involved in calculating certain factors and delivering inputs to the health cost model.
System Engineers - Responsible with calculation of assembly forces, frequencies by conducting physical tests of every ergonomically deviating task and reporting the duration of these tasks and converting them into TMUs.
Managers - They are concerned about the estimation of the ergonomic and intervention costs and have a few expectations from the health cost tool.

The academic supervisor and the authors are considered as both realization and result stakeholders.

3.3 Current state analysis

Current state analysis refers to scrutinizing a scenario comprehensively in order to understand the present state and identify the potential risks or challenges and improvement opportunities involved in it. This stage is critical as it can help the organization in deciding to bring about a change by comprehensive understanding of its functions, stakeholders and processes. There are a few techniques for conducting a current state analysis and among the most common is interviews which is adapted to this work.

3.3.1 Data collection

Data collection is a systematic gathering of necessary information that can be carried out with two different approaches when involving humans, namely qualitative and quantitative approach [14]. The data collection phase is very important in strengthening the insights into the topic and structuring a framework for the findings.
The qualitative approach involves gathering information from stakeholders or other sources through discussion, interviews or by observation of the existing scenario. This approach covers a major portion of the timeline of this work, provides an overview of different concepts involved and the relationship that exists between them. The quality of data derived from this approach is limited to a Small group of people due to practical necessity to address the time consumption within our limited project time. The quantitative approach involves measuring or quantifying the relationship of the described concepts on a numerical scale. The quantitative method is supposedly reliable only in circumstances where the sample size is large and the selection is representative [14].

The data collection for this work incorporates mostly qualitative approach through a few rounds of interviews with the chosen stakeholders both from the Manufacturing Engineering and Health and Rehabilitation department at VCT. Also, this approach includes data acquisition from the discussion sessions where the related data/documents were obtained for this work since the authors weren't granted access to the Volvo data systems. The data derived from this approach is subjected to a quantitative study where the credibility of the factors are quantified and the results are analyzed before validating it.

3.3.1.1 Interviews

Interviews are carried out to see how different functions within the company perceive the selected case. According to Gillham [35], there are many ways of conducting a research interview . According to Denscombe [36], semi-structured interviews are an effective way to collect information in most cases i.e. the list of questions framed are open ended and the follow up questions come up based on the answers provided until a clear or satisfactory explanation is obtained. The interviewer does not have to follow a strict template and can stay adaptive. This kind of interview grants the author more flexibility in pursuing the right choice of questions since different interviews bring out different perspectives to the same topic which leads to risks of being more ambiguous and complex. The other methods such as formal structured interviews, unstructured interviews, ethnographic interviews etc are either vague, unbalanced or cause loss in data.

The set of questions vary with the different class of engineers, ergonomists etc. depending on the role they play in this health cost model. The set of questions framed for different stakeholders can be found in Appendix A. The outcomes of these interviews are discussed in the further chapters.

3.3.1.2 Discussion sessions

Discussion sessions set up an opportunity for sharing information or documents via mail or hard copy, which was essential for the timely progress of the thesis work as the authors lacked access to the Volvo systems. At times, they are held as a consequence of doubts that arose from analysis of the data retrieved from the interviews. These sessions turned out to be productive as a lot of clarifications were made by the stakeholders or supervisor on the current scenario and also discussing how to tackle the uncertainty conditions.

3.4 Summary

Having understood the methodology incorporated to identify stakeholders, collecting data and processing into information, the authors introduce the actual case scenario at Volvo Cars in a detailed manner in the next section.

4

Prerequisites at Volvo Cars

This chapter is an introduction to the considered case at Volvo Cars in Torslanda, Sweden. The contents of this chapter The presented information is specific to the VCT plant.

4.1 Case Description

Volvo Cars on a global scale, always strives hard to continuously improve the art of ergonomics of assembly operations. Currently, the ergonomics in the assembly plant is not up to their expectations mainly due to geometrical variations and not because of improper product design or process design [Discussion sessions]. This ergonomic condition is adding up to a lot of unnecessary costs. This in mind, the engineers and ergonomists at VCT have made a few ergonomic interventions in the past years to improve the workplace and reduce resulting costs. In recent times, the above stakeholders have failed to convince the management to invest in such interventions due to lack of convincing cost justifications. The ergonomic cost evaluations performed using the existing health calculation tool were perceived as unrealistic leaving the involved stakeholders and management unsatisfied. Hence, a need arises for a valid health cost evaluation technique in the form of a tool to initiate convincing justifications. Having explained the need of an ideal health cost tool, it becomes necessary to know how the information required to feed this tool flows within VCT.

4.2 Work instruction and information flow

Most of the ergonomic deviations during assembly at VCT are not concentrated at a single station but are distributed across all balances. This is mainly to distribute the work load and to avoid bottle neck situations [Discussion sessions]. Every proposed change that mitigates ergonomic deviations, results in reducing health issues and eventually affecting the final time of assembling the product. The work at each balance is distributed such that no worker operates in compromised positions (mainly under-up) for more than 30 minutes a day [Discussion sessions]. This norm is followed at VCT according to the Requirement specification for load ergonomics [37]. The core manufacturing engineers in collaboration with the research and development (R&D) engineers simulate the work and extract the working times for compromised position stressing more upon the red regions. The take that have been analyzed for bad ergonomics are classified as red when they are deemed too risky .

In other words, the jobs that influence very high and extremely high loads on the body fall under the red regions according to the ergonomics standard used at VCT [37]. These times are cross checked with the actual work in the plant by the ergonomists at the manufacturing engineering department, VCT. These verified times are then fed to the system engineers who evaluate the costs incurred by assessing the ergonomic risks. A detailed explanation of the information flow is explained in later sections. This entire process is sometimes used in the early stages and mostly in the concept stage which can be better understood through figure 2.1. VCT uses a proactive approach to have a fixed product solution from early stages [Discussion sessions].

This can also be explained with an overview of its hierarchy as shown in figure 4.1. To be specific, the System Decision Alternative - Manufacturing (SDA-M), a prerequisite of Volvo Product Development System (VPDS) is the most benefited. The purpose of SDA-M is quite similar to that of this project, aiming at proposing changes in a system that supports the decision process of selecting product system solutions. The results of this project are of prime consideration to the engineers of the core trim and final sector working under the manufacturing and logistics wing who are eventually answerable to the CEO of the company [Discussion sessions]. The findings of this thesis will contribute to the prerequisites of VPDS. VPDS is a cross functional logic used to develop vehicles in time with the right quality, mostly made use of in the concept and industrialization phase of the product.

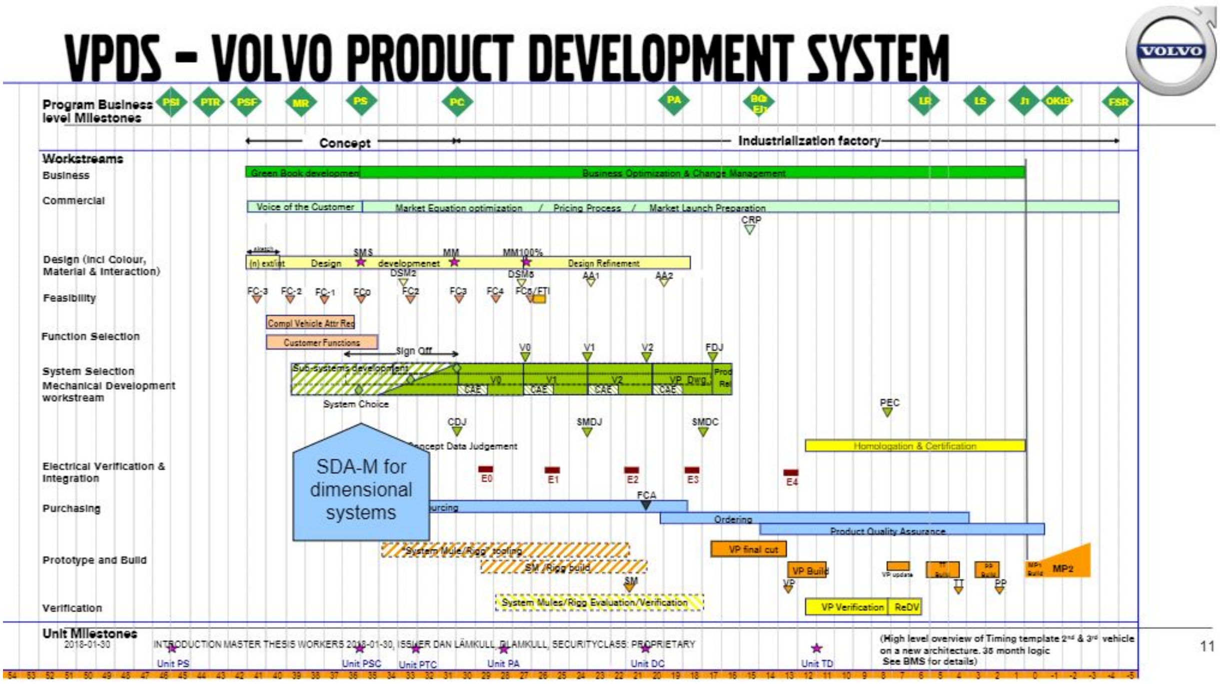


Figure 4.1: Information flow at VCT - VPDS
(Image produced with permission from Volvo Cars, Torslanda)

With such a brief background on how different functions across VCT affect the output of the health cost tool, the authors have decided to focus on a part of the final assembly that enumerates the effects of health related ergonomic costs.

4.3 Tailgate assembly

A tailgate is a hinged door at the rear of a car used during loading and unloading. Tailgate assembly is an integral part of the final assembly and mainly due to geometrical issues, there is a strategy within Volvo Cars to have the tailgate assembled on the car body during the whole way through the paint-shop and the assembly-shop. Due to this, a lot of under-up ergonomic deviations have increased leading to many health injuries that eventually costs money to the company. As this assembly is spread out in the whole assembly, the ergonomics at every balance/station is compromised making the operators prone to injuries. As a reason of which, the study is delimited to assess the health costs of the ergonomic deviations in the tailgate assembly as it gives an impression of pretty much covering the entire assembly [Discussion sessions].

4.3.1 Assembly complexity

Based on the verbal description of the workers who experience injuries, VCT has been recording sequence of events that lead to injuries for 5 consecutive years since 2013 [38]. The document is company-internal and therefore subject to confidentiality and only available internally at VCT. The authors of this thesis have decided to focus on the events that occurred in 2017 so as to have taken into account all changes implemented in the past years. Most of the injuries occurring at the tailgate assembly are mainly because of not following the Volvo standards. For example - ergonomic standards at VCT, state a maximum of 50N force to be experienced by an operator [37] but, in actual case, the operator experiences as much as 200N leading to injuries. Unorganized job rotations, repetitiveness, improper working design/-components are some of the other reasons that add to the injuries of the worker. [38]. These reasons for injuries are explained in detail in the results section.

To explain the assembly complexity in a bigger picture, there are two variants of tailgate available - plastic tailgate and metal tailgate. Most of the cars assembled at VCT use metal tailgates [Discussion sessions]. If plastic tailgates are used, it is easy to maintain the same color or shade for a longer period of time. This is not the case when it comes to using a metal tailgate. As a reason of which, maintaining uniformity in color of the tailgate with the rest of the car, tailgate has to be assembled on the car body during the whole way through the paint-shop and the assembly-shop. When in assembly stage the assemblage is carried out in 3 ways-fully open, semi open and closed. Under-up occurs when assembling in semi open and fully open ways. As mentioned earlier, the ergonomic deviations are mainly due to geometrical reasons. Discussions are continuously ongoing to have a separate tailgate pre-assembly to avoid most of these complexities [Discussion sessions].

4.3.2 Need of a health cost model

This section explains the need of a health cost tool in the phases of production so that the assembly complexities can be eliminated or reduced. As seen in figure 4.1, SDA-M is a phase where the project strategy is finalized in coordination with the concept phase. This includes the data of the variant of the car, number of cars and the reason for adopting such strategies. Once this has been established, the commencement of the next phase is triggered. The commodity engineers in correlation with the R&D, decide on the number of jobs to be worked on and discuss the additional changes to be made in the plant. The engineers also discuss on the need of new tools and setup required to implement a strategy. After having studied the pros and cons of the necessary resources required to propose an intervention, a list of the investments is generated. At this stage, it becomes necessary for the engineers to have an effective cost tool that helps them to justify these proposed investments [Discussion sessions]. With such an approach, VCT has a health cost tool that helps them serve as a validation to their investments. The tool is briefly discussed in the next section [39].

4.4 Health Cost Model

The current model at VCT has a proactive approach and is completely based on the assembly times measured through simulations using MTM-Sam analysis [Discussion sessions]. Methods time management (MTM-Sam) is a tool to document both working method and time frame. This tool is mainly used to emphasize good ergonomic stability. The final output of this model is the additional ergonomic cost per product due to poor ergonomics. VCT completely follows the concept of implementing changes in the early development stages and have managed to achieve fruitful results through it. The total value adding times are divided into exterior, interior and electrical assembly times as shown in Appendix B. VCT uses a predetermined motion time system and use time measurement units (TMU) instead of seconds to measure time [39].

$$1\, Time\ Measurement\ unit\ (TMU) = 0.00001\ hours\ or\ 0.036\ seconds \tag{4.1}$$

Using such smaller units allow accuracy in calculation by eliminating decimals. Once the total assembly times are calculated which is a sum of the value-adding and non value-adding times, it is divided by the TMU per station to get the number of stations that perform bad ergonomic work as shown in Appendix B.

$$\frac{Total\ Value\ adding\ time\ (TMU)}{TMU/station} = No.\ of\ Stations \tag{4.2}$$

After noticing that the total bad ergonomic exposure is between the range of 1-2 hours a day (assuming the duration of the each under-up operation is 40-60 seconds), a document (created by a former ergonomist at VCT) that approximately calculates the cost of such ergonomic exposures is made use of depending on the number of worsening factors (each factor that contributes to bad ergonomics is classified as a worsening factor) involved as shown in Appendix C. From the document - *Direct ergonomic costs for work from underneath*, an estimated amount of the total ergonomic costs is calculated as seen in Equation 4.3.

$$\begin{aligned} Static\ work/high\ precision &= X......(SEK/yr) \\ High\ force/Torque\ &= Y......(SEK/yr) \\ Heavy\ tools/Equipment &= Z......(SEK/yr) \\ Ergonomic\ costs/station &= (X+Y+Z)*No.\ of\ Operators......(SEK/yr) \end{aligned} \tag{4.3}$$

The multiplication of the outputs of equation 4.2 and equation 4.3 give the total ergonomic cost per year as seen in equation 4.4.

$$No.\ of\ Stations * Ergonomic\ costs = Total\ Ergonomic\ cost......(SEK/yr) \tag{4.4}$$

This total ergonomic cost per year is divided by the annual production of cars at VCT to get the ergonomic cost per car.

$$Total\ Ergonomic\ Cost\ /Annual\ production\ = Ergonomic\ cost\ ......(SEK/car) \tag{4.5}$$

The output of equation 4.5 is the final output of the existing model at VCT. The management's and the involved stakeholder's decision of approving a proposed intervention is entirely dependent on this number. A template of the existing model used at VCT is recreated for confidentiality reasons in Appendix B.

4.4.1 Consistencies and Discrepancies

The most explicit point in using the above model is that it has a proactive approach. The advantages of using such an approach are already explained in section 2.3. On the other hand proactive approach leads to calculations based on approximations. This has caused a noticeable difference in the numbers produced using this model and those happening in real time. This difference creates results that are unsatisfying to the management. In addition to this, the model does not calculate the number of worsening factors at each station and rather assumes every assembly to be affected by 3 worsening factors each time which is not the case in reality [Discussion sessions]. This assumption adds to the discrepancy of producing unacceptable numbers. Also, a few necessary indirect costs such as the costs of sick leaves/absenteeism, turnover costs and work related disorder costs are not included in the model. After scrutinizing data from several internal documents provided at VCT , the authors of this thesis concluded that VCT has an excellent product design but lack in systematically implementing the process design [38], [39]. This inconsistency is elaborated further in the Discussion section to study its effect on the final output of the model.
In summary, it can be said that inclusion of all the above points in a new model can lead to an ideal health cost tool which might convince the management to look at the same data with a different perspective.

5
Results

This chapter highlights the significant findings of this thesis work.

5.1 Literature findings

The literature study has provided major breakthroughs in this work and here are the most critical findings listed below:

5.1.1 Proactive and Reactive approach

In order to address the ergonomic concerns of manufacturing and assembly operations, it is essential to identify the ways to tackle it. Proactive and reactive are two such approaches that address the ergonomic conditions of the workplace at different stages of the development process. Firstly, the scope for implementation of ergonomic initiatives has to be planned out through different stages. From the literature survey, it is clear that a proactive approach is desired since the repercussion of ergonomic deviations can be foreseen in the conceptual stages and its effect can be mitigated by a great margin in the production phase [14]. Exercising simulation of the workplace is more preferable to validate the foreseen effects of ergonomic deviations in the early stages. On the other hand, a reactive approach is only responsive to the effects of ergonomic deviations which can afford only short term solutions to address the issue. This results in loss of productivity, quality of products and eventually costs a lot for the company.

5.1.2 Total ergonomic costs - Division of costs into direct and indirect

According to Jallon, R. et al. [41], "Occupational injury or disease can cause a significant disruption to the balance of the work environment. The repercussions of workplace accidents indicates a financial burden for the employers as they must catch up with the loss in productivity, a lowered profit, and reduced investment opportunities" . Apart from the common health cost functions mentioned in section 2.4, other major factors like productivity and quality are affected as a consequence of occupational injury. Figure 5.1 gives a clear picture of the composition of total ergonomics costs by dividing into direct and indirect cost. In this context, direct costs are the costs that the company must pay its employee as a compensation for a workplace injury occurred often termed as rehabilitation costs. Indirect costs are those costs that are hidden, hard to quantify and often neglected for the same reason. These costs are generated by factors such as downtime where the productivity drops down due to employee's work ability after an injury and the quality of work is compromised [41].

Figure 5.1: Total Ergonomic Costs
(Image from Berlin and Adams [14] (CC-BY4.0))

5.2 Interview Outcomes - Characteristics and Expectations of the current model

One of the main objectives of this thesis work is to assess the current health cost model and bring out the improvement potentials. Proceeding with the assessment, it is essential to understand the characteristics and the functioning of the model in the first place. An effective way to achieve this is to analyze the model by conducting interviews and hold discussions with the stakeholders to consider their thoughts and expectations about the new model. These thoughts and expectations are summarized below:

- Include the influence of factors like repetitiveness, static forces during assembling operations into the model
- Assess how job rotation takes place and the number of assembly operators involved in it
- Load Categorization should be done - categorize the costs for injuries based on the classification of load levels (relatively high, high, very high) as shown in figure 6.1

- Determine the number of operators involved in ergonomically deviating tasks and the percentage of them affected by injury
- Include the influence of factors such as height, age, gender, right handed or left handed in the model
- Categorize the injuries based on the body part affected and determine the frequency of each body part affected

5.3 Comparison of health cost models from different companies of the same industry

The literature found on different health cost models was more inclined towards return on investment calculation. Also, each model is distinct and mostly case specific i.e. these models do not demonstrate an overall aspect of health cost calculation and thereby a need arose for an extended literature study. The scope was tuned to look for health cost calculation models that are in practice in other manufacturing industries (preferably automotive) and study them to gain some insight of how the health costs are calculated. A comparison of different models can help the authors scrutinize the essential factors of a health cost model and how to measure them. In addition, to investigate how, the mentioned factors in the stakeholder interviews are calculated. The access to these models came from reliable sources [Discussion sessions] and the companies using these models are not disclosed for confidentiality reasons.

5.3.1 Model X

The model was developed by an US automaker and was practiced at Volvo. The model limits its concern by calculating only the health related costs, such as sick leave costs, worker's compensation etc. that occur as a consequence of occupational health injuries, and does not consider the costs pertaining to loss in productivity and quality. The calculations are based on an estimation of the disorder frequency by conducting ergonomic load analyses for the affected body parts and the nature of work. The load acting on the body is categorized based on standard load levels which are based on ergonomic standards and consequently the percentages of damage risk is estimated. These estimations purely rely on previous experiences or knowledge of the local conditions and statistics [Discussion sessions].

5.3.2 Model Y

The model is an internal document inspired by Arbetshälsoekonomiskt analysverktyg (Labor health economics analysis tool) [40]. This is a holistic model which widens its scope into calculating all cost factors mentioned in section 2.4 alongside the loss in productivity and quality of work that occur as a consequence of injuries. The model also provides insight on factors like efficiency and motivation of the group. Unlike Model X, this model is detailed and comparatively more accurate in calculating the factors that involve input of precise values from R&D, purchases, production etc. and less estimated values. This model makes use of the online calculation tool adapted by the Swedish social insurance agency to calculate the sick leave costs, explained in detail in section 2.3.1. In addition, the model also makes a comparison of the before and after investment values of all the factors to determine the total savings [40].

Factors		Existing Model	Model X	Model Y
1. Sick Leave/Absenteeism (Indirect cost)			✓	✓
2. Personnel Turnover			✓	✓
3. Work related disorder cost			✓	✓
4. Presenteeism				
5. Load Analysis (Direct cost)	Job rotation	No Data	No Data	No Data
	Load Characterization		✓	
	Static forces	No Data	No Data	No Data

Figure 5.2: Comparison of Models - Checklist

The checklist indicates all the necessary factors that will be included in the newly developed health cost model by making a legitimate comparison between the different health cost models from other companies which acts as a sense of validation in disguise. However, there are certain factors like presenteeism and ergonomic load analysis missing in these health cost models chosen for comparison.

5.4 Solution to potential problems

Now that the authors have scrutinized the current scenario with the processed data from literature and stakeholder interviews, it is time to come up with a solution to address the potential problems.

- From the current state analysis, the authors have realized that the proactive approach will not be suitable to accommodate the necessary factors mentioned in the interviews into the model. i.e. the simulation tool does not yield any data on the static forces, job rotation etc. Hence, the authors have chosen to adapt the reactive approach with the available data and utilize them into determining the desired factors in the health cost model

- The documented occupational diseases for the year 2017 have been analyzed pertaining to the tailgate assembly and the injuries are segregated according to the reason of occurrence as shown in figure 5.3

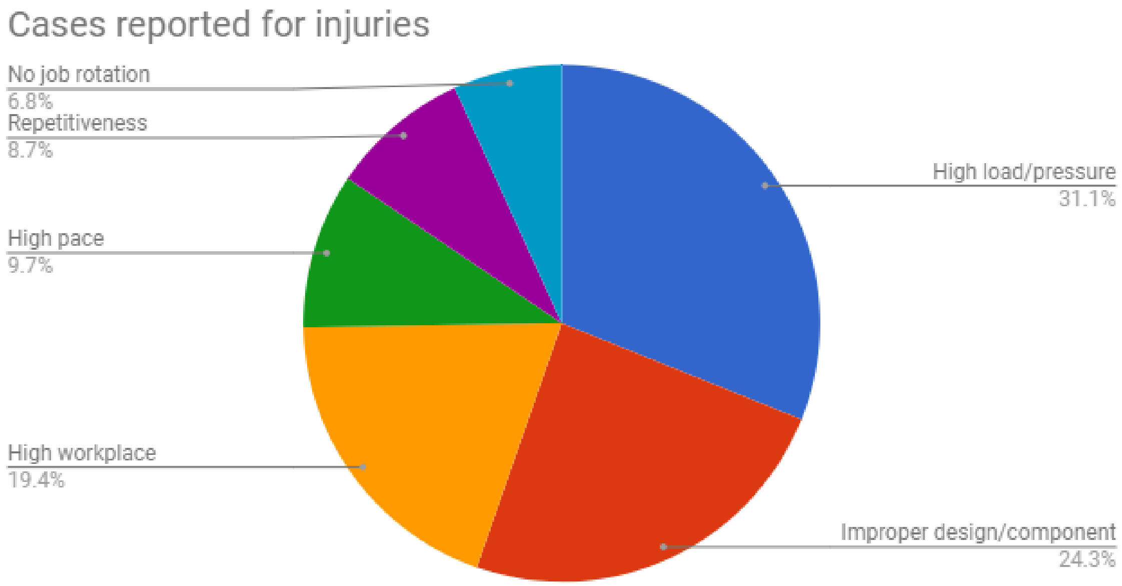


Figure 5.3: Reasons for Injury at Tailgate assembly

- The injuries are also categorized into affected body parts for men and women and also segregated by age groups as shown in Figure 5.4 and 5.5 respectively.

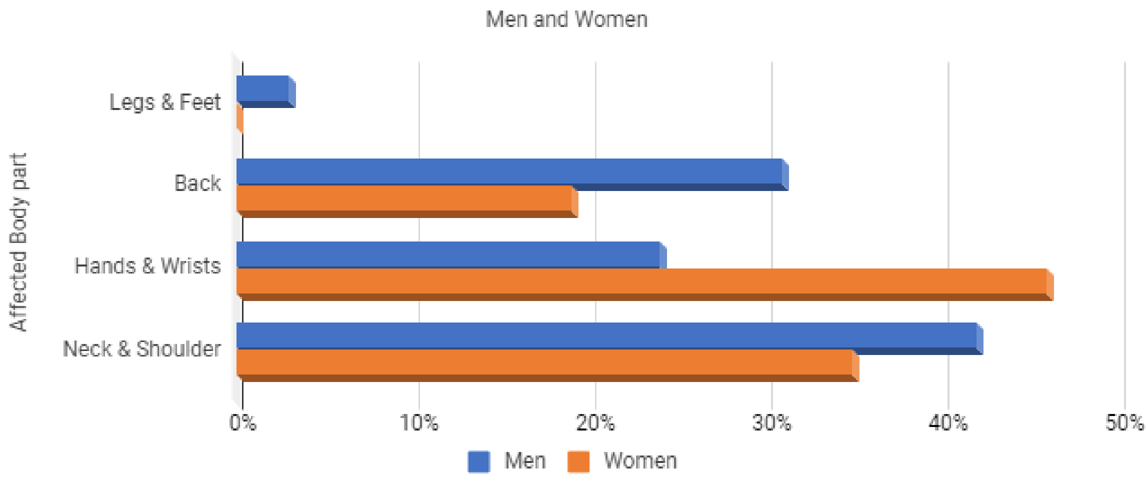


Figure 5.4: Body parts affected

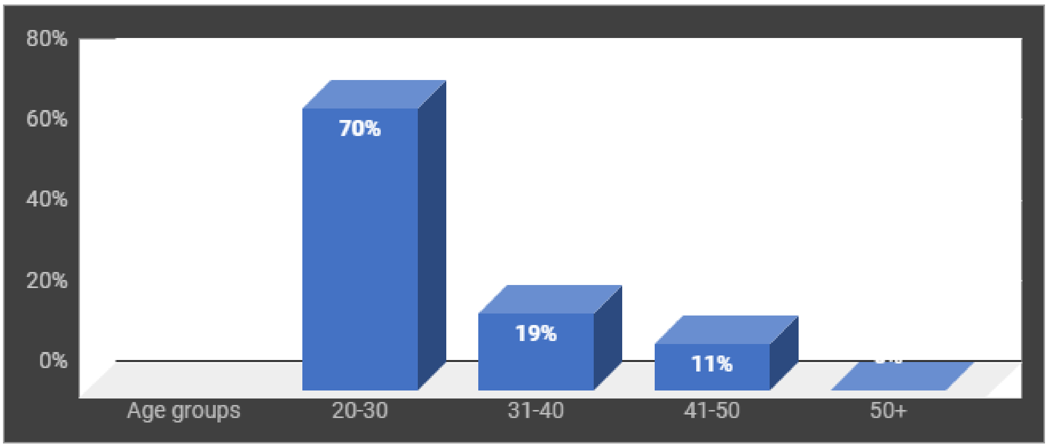


Figure 5.5: Age groups affected

5.4.1 Health Cost Model

All the above results serve as inputs in the newly compiled health cost model where the costs are divided into direct and indirect. The reason for such a division of the costs will be thoroughly explained in the discussion section. The indirect cost calculation includes factors such as absenteeism, presenteeism and turnover costs as seen in figures 5.6 and 5.7. In contrast to the absenteeism concept, presenteeism is a state in which an operator continues to work even after getting injured or showing signs of injury which leads to a dip in the efficiency of work. The concept of practicing presenteeism can have different motives and the reason to accommodate it in the model is motivated in the discussion section.

The direct cost calculation is based on predetermined costs for performing under-up tasks which was previously used at VCT. The document is in Appendix C. This is coupled with the number of worsening factor that depends on the nature of the task as seen in figure 5.8. The guidelines/instructions for this model are found in Appendix D.

HEALTH COST MODEL (Specific to the Tailgate assembly)

Period of time = 1year (2017)

Given	
To be filled	
Calculated	

INDIRECT COST CALCULATION

Factor1	**Sick leave/Absenteeism**	
a)	Total number of cases recorded	
b)	Estimated no. of workers expected to take leave upto 14 days (See Guidelines)	occasions
c)	Estimated no. of workers expected to take leave more than 14 days (See Guidelines)	occasions
d)	Total no. of absent days	days
e)	No. of hours affected depending on the work nature and body parts affected	hours
f)	Cost/hour for a blue collar job working regular time	SEK/hr
g)	Total Cost required to replace the absent employees	SEK
h)	Total sick leave salaries (Only for upto 14days)	SEK
i)	Total sick leave/absenteeism cost	SEK
Factor2	**Presenteeism**	
a)	Estimated number of workers expected to not take leave even after injury	occasions
b)	No. of additional hours worked to compensate reduced productivity (See Guidelines)	hours
c)	Cost/hour for an employee working overtime	SEK/hr
d)	Total Presenteeism cost	SEK

Figure 5.6: Indirect cost Calculation(1/2)

Factor3	**Personnel Turnover costs**	
a)	No. of workers affected due to work nature or injured body parts	
b)	No. of worker/s quitting their job/company	
c)	Expected cost for an employee leaving	SEK
d)	No. of worker/s newly appointed	
e)	Expected cost for hiring a new employee	SEK
f)	Total Personnel Turnover costs	SEK
Factor4	**Work-related disorder costs** (See Guidelines)	
a)	No of workers with MSD depending on the work nature and body parts affected	
b)	cost for work related disorder per worker	SEK
c)	Total work related disorder cost	SEK

Figure 5.7: Indirect cost Calculation(2/2)

	DIRECT COST CALCULATION		
a)	Total Number of cases reported for injuries		occasions
b)	Basic Calculation Factor (See Guidelines)		SEK/yr/op
c)	Cost to be added for each worsening Factor (See Guidelines)		SEK/yr/op
d)	Inflation factor (See Guidelines)		times
e)	Number of cases reported for injuries only due to the basic factor		occasions
f)	Number of cases reported for injuries only due to the basic factor+1 worsening factor		occasions
g)	Number of cases reported for injuries only due to the basic factor+2 worsening factor		occasions
h)	Number of cases reported for injuries only due to the basic factor+3 worsening factor		occasions
i)	Number of cases reported for injuries only due to the basic factor+4 worsening factor		occasions
j)	Total Direct ergonomic costs for work from underneath		SEK/yr
k)	Total Ergonomic costs at the Tailgate assembly		SEK
l)	Annual production of Cars at Torslanda in 2017		Cars
m)	Ergonomic cost /car in Tailgate assembly		SEK/car
n)	Estimated investment proposed		SEK/Intervention
o)	Payback period (years)		years

Figure 5.8: Direct cost Calculation

6

Discussions

This section addresses issues of research, quality and validity. These topics have had major influence on the results shown in chapter 5.

Disclaimer: Most of the documents referred by the authors of this thesis were available in Swedish. For better understanding of the available data, these documents were translated to English using online resources. Translated documents are not 100% reliable and may have altered the meaning of data. The readers are warned beforehand about this dilemma that the content discussed below is based on the authors understanding of these translations.

6.1 Effects of change in approach

Generally, the way of tackling ergonomic problems is a major concern in any industry regarding when to implement a change in the product development process [Discussion sessions]. This concern can be well addressed once these stages are comprehensively understood. As shown in figure 2.1, the stages in the product development process are the conceptual stage, pre-study stage and industrialization stage. To explain why the authors chose a change in the health cost model approach, it becomes necessary to touch upon the insights of each stage in detail.
The concept stage is subdivided into pre-concept and concept phase. The pre-concept phase is a basic outline where the organizational requirements are designed both on product and process levels. The ergonomic requirements are also considered at this stage. Such a strong start to the project triggers the next phase focusing on breaking down the ergonomic requirements using a simulation tool. Such an approach helps the engineers to analyze the concepts by foreseeing major problems and making appropriate changes. The conceptual stage is a very crucial and time-consuming one as it involves aggregation of several discussions based on internal and external data. This ground work is always in sync with the current market trend taking affordability, time and costs into account.
Once the feasibility of the design work is analyzed, the pre-study stage comes into picture, where the solution to the concepts are finalized. The requirement specifications are scrutinized to the detailed level forming incremental changes through the simulation tool. At this stage, minor product changes can be made since changes implemented at this point have lesser influence on the final product.
The industrialization stage involves physical testing of the objects and the plant facility to ensure a smooth real time process. At this point of the development

process, the solution is fixed and only minor changes in the product are advisable. Once the production starts, changes can be made only by improving working techniques, movements and postures or adding extra tools and fixtures, not by altering the determined manufacturing concepts and design.
After studying the pros and cons of when to implement changes in the development process, be it at the start of the project or at the start of the production, manufacturers prefer the former due to its advantages, as mentioned in section 2.3. VCT has a similar approach of acting proactively so as to eliminate problems in the early stages. Looking at the statistics provided by VCT coupled with the data collected through stakeholder interviews, acting proactively has not turned out as well as expected for VCT.

Demands of work on movements and support organs	Harmful effect of work on movement and support organs	Work should be manageable for	Classification of load level	Ambition
High	Harmful	Possibly young men, for short time	Very high High Rel. high	Shall be corrected
Rel. high/moderate	Harmful for work performed longer periods	Young people with correct working technique	Rel. high/moderate	Actionplan, further investigation needed
Moderate Low	Minimally harmful depending on time and frequency Not harmful	Ordinary woman or man All employees	Moderate Rel. low	Objective

Figure 6.1: Ergonomic Load level regions
[37] *(Image produced with permission from Volvo Cars, Torslanda)*

In the current scenario, the numbers emerging out of the model are unrealistic and the stakeholders feel that the model does not take consideration of certain essential factors, e.g. job rotation of operators, static forces acting during the assembly operations, repetitiveness of tasks etc. as mentioned in section 5.2. According to the interviews, if the job rotation is well organized, the chances of an injury occurring can be reduced and eventually the costs emerging from that can be avoided. It is said that the operator is not advised to work in the very high load level (red) region for more than 30 minutes according to their standards.
However, in some cases recorded, the operator shifts between tasks but ends up in the red region repeatedly [Discussion sessions]. Similarly, the static forces acting on the operator and repetitiveness of all tasks will not be the same and their impact on the operator getting injured varies with every task. Hence, these factors have to be quantified into cost based on the number of worsening factors acting on the body. In the current state analysis stage, the authors have seen that the existing health cost model does not include ergonomic load analysis into the calculation. For example, from the simulation phase, ergonomically deviating tasks that are classified in the red region as shown in figure 6.1 are considered to have the same impact of causing

an injury and their time duration is converted to TMU to calculate the costs. In reality, the red region is further divided into relatively high, high and very high load levels, and each of these levels have different impacts on causing an injury. Therefore, the ergonomically deviating tasks must be subjected to load categorization to understand the possibilities of an injury that can occur. In addition, the model considers all the operators involved in that particular assembly while calculating the costs, and fails to anticipate or estimate the percentage of the operators who are very likely to get injured from the above factors. Unfortunately, most of these factors cannot be derived from the simulation tool and are eventually not included in the model. This goes to show that adapting a proactive approach will not be suitable in this particular health cost analysis.
Therefore, the authors choose to compile a model based on a reactive approach where the above factors can be accommodated to demonstrate the health cost calculation. On surveying the recorded occupational health injuries of year 2017 [Discussion sessions], the injuries based on body parts, gender and age groups have been identified and categorized as per their occurrence in figure 5.3, 5.4 and 5.5 respectively.

6.2 Cost division

The current model at VCT has a completely different approach from both models X and Y, of addressing the cost factors. VCT's current model is dictated by using the time for working in the red region in the load levels (in TMU's) as a major factor to find the ergonomic costs [Discussion sessions]. Such an approach is applicable only when the engineers are analyzing the solution in the concept phase and is not suitable as a long term fixed solution. Consequently, practicing such an approach which does not classify the costs into traceable (direct) or non-traceable (indirect) costs to the production has not produced results as expected by the stakeholders [Discussion sessions]. Classifying the costs in the health cost model will help the management to better understand the costs and arrive at a conclusion of whether to approve or disapprove it. According to the interview outcomes mentioned in section 5.2, most of the factors suggested by the interviewees fall under the direct cost calculation. Due to this, it becomes necessary for the authors of this thesis to classify the costs satisfying both the suggestions of the interviewees and straightforward decision making for the management. Another way of classifying the costs can be dividing them into costs to individual, company and society [14]. Dividing the costs at these levels can be beneficial but does not satisfy the case at VCT. In addition to this, an US automaker has raised an awareness to classify the costs into direct and indirect costs and comparing them in terms of each other as seen in figure 5.1 [14].

6.3 Presenteeism

The term presenteeism is defined in numerous ways such as "going to work despite feeling unhealthy" to "reduced productivity at work due to health problems" and sometimes as antonym of absenteeism [42]. However, put into simple words, presenteeism is commonly addressed as "turning up at work despite being ill" [42]. The research work into the phenomenon of presenteeism has attained a steep increase in the past decade but the amount of research devoted to it is no match to that of absenteeism [43]. The most probable factors influencing presenteeism based on the theoretical hypotheses are : Work-related factors, personal circumstances and attitudes.

Work-related factors are further divided into :

- Time pressure - some workers consume more than average time to complete tasks, sometimes due to lack of resources that leads to a backlog of tasks. Also, in situations where the production needs to ramp up, the working routine needs to be accelerated

- Control over work tasks - there are some skilled workers who have a great control over their tasks and can manage their schedule well even when they fall sick

- Rapport with co-workers - working in teams and sharing a great rapport with colleagues will ease the burden and motivate the sick worker. At times, the size of the company also matters. In small companies, the tasks will be shared among the colleagues since their jobs are inter-dependent and one can witness high level of presenteeism

- Employment conditions - job insecurity has been the major reason, due to which workers are frightened to take sick leaves to evade lay-offs

Personal circumstances include :

- Financial conditions - not every company has the same policy for paid sick leave and sometimes when the paid sick leave limit is crossed it is more likely for presenteeism to occur

- Family life - this varies with every individual and backed by personal reasons

- Psychological factors - Some people are more enthusiastic and over-committed due to the fact that the company provides incentives for notable performances.

Attitude has got to do with one's work ethics and also some of the above mentioned factors put together which varies with every individual [44].

Usually, the inclusion of presenteeism in economic evaluation (which is commonly deemed as productivity costs) is highly debated when viewed from a societal perspective. The debate is whether the productivity costs should be considered on the cost or the outcome side [45]. From studies, it is seen that presenteeism costs are usually higher than the costs generated by absenteeism but often ignored. Some literature suggests that the reason for this is due to lack of a standard tool for measuring presenteeism and an evaluation method to generate monetary estimates. Exclusion of presenteeism from the economic evaluation will miscalculate the actual value of the intervention. Usually, presenteeism is calculated in terms of the number of hours lost i.e. productivity loss [45].

6.4 Process design and Product design

As mentioned in section 4.4.1, the authors have come to a conclusion that the reason for large number of injuries is due to bad process design (excessive force, high repetitiveness, awkward work postures) which can be seen in the figure 5.3. From discussions with the ergonomists and engineers at the manufacturing engineering department, VCT, the assembly tasks need to be organized and optimized to obtain better results. Based on the recorded reasons for injuries by the workers, it was calculated that almost 60% of the injuries are due to bad process design [38]. This statistics gives us an impression that VCT has a good product design for example, manufacturing concept, use of improper materials and workplace design, but the implementation of these concepts not carried out in the right way (bad process design). From the document: Occupational diseases, the product design explained 40% of injuries [38]. On the contrary, a research by Eklund and Falck showed that ergonomic impact is caused by product design at 60-70% and 30-40% by process design [15], [46]. Due to such contrast between the general case and the case at VCT, The authors have focused more on improving the process design with a reactive approach.

6.5 Model Validation - Sensitivity Analysis

The authors of this thesis have chosen to use sensitivity analysis as a means of validation to the model. Andersson suggests that performing sensitivity analysis can serve as a verification to the stability of the model's outcome [47]. Such an analysis brings out the pros and cons of the chosen factors and their impact on the final outcome of the model (Ergonomic cost per car).

The new model was tested with data available from VCT to check its feasibility and to give a sense of comparison with the existing health cost model and the calculation exists at VCT, Manufacturing Engineering department as a confidential document. The final output of the existing health cost model results in large numbers according to the management and the stakeholders. Considering the annual production of cars at VCT, the annual ergonomic costs are not believable to the system engineers and ergonomists at VCT [Discussion sessions]. To counter this setback, certain necessary factors are included to this calculation model (which can be seen in figures 5.6, 5.7 and 5.8) which results in reduction of the ergonomic costs to approximately $\frac{1}{3}$ rd of the previously calculated SEK value. These numbers are based on the calculations made for a certain number of injury cases recorded at the tailgate assembly for the year 2017. On an bigger scale, VCT could potentially reduce the margin of error by 67% of the annual ergonomic costs through such calculations. These figures are acceptable to the management and stakeholders convincing them to approve decisions [Discussion sessions]. This serves as a primary validating point to the created model.

6.5.1 Effects of Productivity and Quality

The above presented statistics are purely based on the health costs and do not include the productivity and quality effects on the final output of the intervention. Including these two aspects can further validate the model and this further motivates the management to get economically convinced and approve a proposed intervention. Accommodating productivity and quality aspects in the model will make it a holistic one. The output of such a comprehensive model will serve as a guide to designers and the engineers to make necessary incremental changes wherever required. Although productivity costs (Presenteeism) was not a part of the scope of this thesis work, the reason for its inclusion in the model is due to its substantial effect on health costs. Presenteeism accounts for 70% of the total recorded injuries and the costs emerging out of it could not be neglected as it is a consequence of the injuries that have occurred [38]. This reflects that the 3 factors - health, productivity and quality related costs are inter-related.

6.6 Sustainability aspects

This master thesis clearly addresses its objectives by compiling a health cost model that enables cost justifications to the management for ergonomic investments. While creating the new health cost model, the authors have made sure of including the sustainable aspect alongside the needs of the stakeholders. In doing so, the social and economic sustainability aspects have been mainly focused on, rather than the environment aspect which the authors feel has very limited scope in this context. The societal costs emerge due to bad workplace design that triggers the onset of injuries [14]. With the analysis of the occupational health injuries of 2017, the authors have found that nearly 40% of these injuries are caused by bad product design as mentioned in section 6.4. The societal costs have been camouflaged in the model in terms of the direct costs.

From an economic sustainability aspect, the model incorporates a convincing approach to calculate all the health related costs through extensive research and inputs from the stakeholders. By making a fair comparison between the existing and the new model, the latter proves to be more economically sustainable in evaluating the total ergonomic costs.

6.6.1 Ethical aspects

The aim of including the ethical aspects is to create an awareness of it while considering research and testing [48]. This also brings out the difference between the understanding and use of ethics by the ergonomists. The authors have considered a few ethical aspects while designing the new model. The created model can be said as ethical, as it helps to overcome a few ethical dilemmas adapted from an article [48].

- Creating awareness about job rotation and repetitiveness, promotes equal distribution of workload to the operators and in turn avoids their physical and mental suffering

- To avoid presenteeism, the operators must be informed of the level of complexity of their work such that they pick their jobs as per their capabilities

- Nullifying the above dilemma will in parallel offer flexibility to the operators to withdraw from injury causing tasks

- Load categorizing the injuries creates awareness to improve very high red zones and this avoids physical and mental suffering

In general, including the concept of job rotation and repetitiveness in the new model indicates a way of addressing specific aspects of most of the above points. The ergonomically deviating tasks are fairly distributed across the assembly plant. This supports the workload distribution aspect with an ethical point of view. All the above adjustments and additions of new factors in the model legitimize the idea of avoiding physical and mental injury of the workers.

7

Future Work Recommendations

This chapter describes the recommendations in different areas that VCT should consider exploring. Investigating and implementing these suggestions can further validate the model in order to improve its understanding.

7.1 General recommendations for Volvo Cars

The work with ergonomics and health cost calculation should not only be seen as an improvement potential, but should also be incorporated in the daily work procedures. With such an approach, where the assembly complexity and the costs pertaining to it are not seen as a hindrance, the situation becomes much easier to assess. To have this suggestion put into use, VCT must make it possible to accumulate the available data stored in different systems. Systematic and logical use of the available data can simplify cost calculations to a greater extent.
In addition to the above recommendation, VCT can use the proposed health cost model as a base model and continue its research in the following areas.

- Extended research on Presenteeism is required. In the current scenario, based on the verbal data of the injured operators, the authors have noticed that most of the injuries are due to extensive occurence of presenteeism. A solution to avoid this must be looked into.

- Research on accommodating the factors mentioned in the stakeholder interviews into the model with a proactive approach should be carried out.

- The simulation tool that VCT uses must be upgraded such that it includes assessment of static forces acting on the operator's body parts.

- The basic calculation factor used for direct ergonomic costs must be updated considering previously made interventions. Using an updated calculation factor increases the validity to the model.

- An extensive study on the relation between the concept of load categorization and the ergonomic standards is necessary. This can further help the management to easily relate the presented data and authorize the suggestions.

- Though the model is specific to the health costs at VCT, inclusion of an index factor (a cost conversion factor) can help Volvo use this model across all their plants worldwide. However, the absenteeism calculation is based on the Swedish conditions for sick-leave and hence has to be changed according to the respective regions.

- Investigate the other factors that influence the costs i.e the productivity and quality related factors must be examined and included, to make the model a holistic one. This will further contribute to the justification of investment.

8
Conclusions

The master thesis study focuses on suggesting changes to the current approach in calculating the health costs due to bad ergonomics. This chapter illustrates the main features of the master thesis study.

From the discussions on how and why the achieved results are deduced, it can be said that the authors have satisfied the purpose of this thesis and helped VCT to better understand the economic aspects of health cost calculation. The suggested model which is derived through established methodology is ready to use by the engineers at VCT or at least can be used as a base model for further improvement. In conclusion here are the highlights of this master thesis study.

- The relationship between production ergonomics and health costs has been strengthened

- Though the created new model is specific to the health cost calculation at Tailgate assembly, it can be made use of as a model for the entire assembly. The assembly of tailgate components is spread throughout the whole assembly of the car and hence the tailgate gives an overall picture of the entire assembly

- If the future work recommendations are implemented, VCT can have an optimized health cost model that can be monitored at a global scale

- It is possible to derive a much more detailed cost calculation model for health, productivity and quality at VCT. This can be tedious and a time consuming affair due to assessment of large quantities and multiple types

- The social and economical aspects of sustainability have been addressed by supporting better working conditions for the workers

- Though the created model reduces the ergonomic cost calculation results by a huge margin compared to the existing model, nonetheless a positive number still indicates room for improvement in the production ergonomics

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A

Appendix A: Interview Guide

Since the interviews were of semi-structured type, the authors may have altered a few questions and asked several follow up questions. However, the nature of questions has remained the same. The nature of questions has been adjusted such that the interviewees are able to answer according their category of work based on different function at VCT. The authors have summarized the useful and necessary answers to the below questions in the results section of this report. The answers may have been adjusted without harming the original meaning as described or explained by the interviewees.

Question addressed to the Core manufacturing engineers

- Which calculation model is used currently? Why? Is it suitable for all kinds of interventions?
- Please briefly explain how the existing model works? Terminologies?
- How are the manufacturing engineers involved in the calculation model?
- Why is there a need to make changes in the existing model?
- What additional factors you think can be added to make the model better?
- What expectations does Volvo have for the calculation model in the near future?
- On what basis do you categorize the factors for the given intervention?

Question addressed to the Ergonomists

- Is the model being used to its full potential?
- What kind of approach (proactive or reactive) is followed while using the model?
- How efficient is the existing model?
- What are the assumptions made for the existing model? Any boundary conditions?
- What additional factors you think can be added to make the model better?
- How are the intangible considered in the model? If yes how are they quantified? If no, why?

Question addressed to the Management

- For how long has Volvo being using the existing model?

- What kind of details does the management look into when an intervention is proposed?
- On what basis does the management assess the figures produced using the calculation model?
  - Is it in monetary terms?
  - Or in terms of quality and productivity?
  - in terms of well being of the employees?

B

Appendix B: Framework of the existing health cost model

Assembly Plant: Volvo Torslanda **Car Model:**

Assembly	Assembly times - 60 Jobs/hour plant (TMU)
Exterior	
Interior	
Electrical	
Total TF1 (Value adding time)	
TF1 + TF2 (Total time)	
Station time - TMU/station	
Number of Stations	

TF2: Non-value adding time

1 Time Measurement Unit (TMU) = 0.00001 hours or 0.036 seconds

Station Time = 1 hour or 100000 TMU / Jobs per hour

Number of Stations = Total TF1 / Station time

Underneath Operation Times

Assembly/Task: _____________

Stressed Body Parts: _________

Load level: _________________

Exposure: ___ hours/day

Direct ergonomic costs calculation:

a) Basic Factor for underneath operation: _________ SEK
b) Number of Worsening Factors: __________
c) Cost for each Worsening Factor: _________ SEK
d) Total direct ergonomic costs: (b*c) + a = ___________ SEK
e) Number of Operators per shift: _______
f) Number of shifts: _________
g) Total ergonomic costs: d*e*f = __________ SEK/year
h) Annual production at VCT = ____________

Total ergonomic costs per car = g/h = ________ SEK/car

Image recreated with permission from Volvo Cars, Torslanda

C

Appendix C: Basic calculation factors for Direct Ergonomic Costs for work from Underneath

Basic calculation factor for Work from underneath = 45300 SEK	1 Operator´s cost/year (SEK):	Influence on body and job performance:
	7. !! → not feasible	→ The job cannot be performed at all
Worsening factors: • Heavy tools/equippment	6. 38200 → 236300 (all 5 factors added)	→ The job can hardly be managed
• High force/torque	5. 38200 → 198100 (4 factors added)	→ Extremely high load on the body
•Hidden assembly/bad guidance/reachability	4. 38200 → . 159900 (3 factors added)	→ Very high load on the body
• High repetitivity of similar movements	3. 38200 → 121700 (2 factors added)	→ Very high load on the body
• Static work/high precision	2. 38200 → 83500 (1 factor added)	→ High load on the body
Each worsening factor above costs 38200 SEK extra	1. 45300 → 45300 (Basic factor)	→ High load on the body (hands above the head, neck bent backwards)

Image produced with permission from A.-C Falck

D

Appendix D: Guidelines to the new Health cost model

METHOD DESCRIPTION - CALCULATION MODEL

GUIDELINES TO FILLOUT THE MODEL

**All load standards are followed according to Volvo Standards for Ergonomics - "Requirement Specification for Load Ergonomics"*

**The numbers entered in the calculation model are strictly based on verbal description of the injured employees documented in injury reports.*

**The filled in data is extracted from the data provided at VCT.*

**The costs and values seen in the health cost calculation model are as of 2017*

**The calculations are limited to the tailgate assembly*

**Since it is a health calculation model, Quality and productivity related costs and errors are not monetised*

A) INDIRECT COSTS

1) Expected absence due to sick leave

-- The longer the exposure time, higher is the risk of long term sick leave
-- These costs are of more harmful to the company when their employees take prolonged sick leaves
-- The company must pay the individual sick leave salary which is upto 80% of the salary for a range of 2-14 days. (Internal document VCT)
-- The company does not pay the employee after this range and who is subjected to the rehabilitation process.
-- The company may also need to pay other employee called in to work overtime to compensate for the absent employees.

2) Expected costs due to Presenteeism

-- Presenteeism is a hidden cost that has managed to stay out of the limelight for decades.
-- When injured employees (physically or mentally) continue to work knowingly or unknowingly, they cause loss of productivity.
-- Here the loss of productivity is assumed to be 15% and is converted into affected man hours for further calculation.

3) Expected turnover costs

-- The higher the operation load (total physical and mental work load), the greater the risk that personnel will quit.
-- Lack of variation, work team composition and attitudes can be decisive.
-- Hourly average cost at VCT is 380 SEK/hr. This hourly cost of operators include wages, social charges, overtime, shift allowances, health care, working clothes, education and miscellanious.
-- For calculation purposes, the hourly cost of regular time is assumed to be 2/3rd of 380 SEK/hr = 254SEK/hr (Internal document VCT)
-- And the hourly cost for working overtime is assumed to be 3/4th of 380 = 285SEK/hr (Internal document VCT)

4) Expected work-related disorders

-- People who have continued to work despite their disorders far too long - i.e. prolonged presenteeism
-- People who have not been given the opportunity of another (more suitable) job
-- People who have been given the opportunitty of another job but have been a victim of unorganised job rotations

B) DIRECT COSTS

**The values entered are extracted from the document 'Occupational diseases' provided at VCT*

**The factors *repetitiveness *job rotation *high forces *improper workplace design *pace and *high workplace have been included in the calculation*

**These reasons for injuries are categorised into no. of worsening factors affecting the operator*

**A factor of inflation has been used to legitimise the calculation as of 2017*

-- The basic calculation factor of 45300 SEK/yr/op is calculated costs when the assembler has hands above the shoulders and the neck bent backwards. (Internal document VCT)
-- As each worsening factor adds a cost of 38200 SEK is added to the basic factor. (Internal document VCT)
-- An inflation factor is calculated by comparing the SEK value from the earlier example calculation with the corresponding SEK value of 2017