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Cost Analysis for Crushing and Screening – Part II

Development of a cost model for determination of the production cost for product fractions

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Preface

This Master thesis was performed during the spring of 2015 at Sandvik SRP AB in Svedala as the end of the candidates' education in Master of Science in Industrial Engineering and Management.

Special thanks go to Per Hedvall as a supervisor at Sandvik SRP how has been a great help throw-out the entire process with this Master Thesis. I will also thank all other supervisors Per Svedensten, Hamid Manouchehri and Fredrik Schultheiss.

Thanks to all other colleges at Sandvik SRP AB that have been helpful or just made my day a little bit better.

I will of course like to thank Jan-Eric Ståhl for his help, ideas and knowledge who helpt me out during this study.

Finally I would like to send a grateful tank to my family and friends that have supported me through my studies, without you it would not be possible.

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Svedala, June 29, 2015

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Abstract

Sandvik SRP has earlier studied a new way of calculating the cost in crushing and screening the results was a satisfactory, Sandvik SRP is now ready to go further in this study.

The purpose of this study is further develop of the earlier adopted generic cost model earlier developed by Heyman and Lindström in order to calculate the cost per metric ton within the world of crushing and screening. By implementing the cost calculation in Microsoft excel it would be more user friendly and applicable when calculating the cost in crushing and screening.

The model by Hayman and Lindstöm is based on the macroeconomic generic cost-model, developed and published by Ståhl. Heyman and Lindstöm developed a new model to fit the crushing and screening operations better. This model had some issues according to the payroll cost and the deprecation cost which the author now have solved in this study.

By implement the cost model in Microsoft Excel by using VBA (Visual Basic for Application) the calculations and simulations can be easy to use when most of the employees are well familiar with Microsoft Excel. To implement the model and to programming all macros that is used is very time consuming and this is the largest part of this study.

The results through this study were very accurate according to the results from previous study but the validation was an issue. To validate this study the comparison has been made with Heyman and Lindström results from the previous study. They had such good results and a more quantitative study was not made according to lack of time.

The recommendation from the results according to this study is to validate the model even further and not at least for a construction site before further implementation in for example Plant Designer etc.

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1. Introduction

This chapter will present Sandvik Rock Processing (SRP) Ab different business areas, give a short introduction as well as the background of this master thesis.

1.1 Company presentation

1.1.1 Sandvik AB[12]

Sandvik AB was founded in 1862 by Göran Fredrik Göransson who was the first in the world to use the Bessermermethod in the production of steel. The major strategy at Sandvik since start is to be to top class in research and development. Sandvik production is divided into five different business areas: Sandvik Mining, Sandvik Machining Solutions, Sandvik materials Technology, Sandvik Construction and Sandvik Venture. This study has been made on behalf of Sandvik Mining.

Figure 1: Sandvik business areas[3]

Sandvik is represented in over 130 countries and had a turnover in 2014 85.9 billion SEK.[4]

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[1] Sandvik.se
[2] Sandvik Mining and Construction intranät Sverige
[3] Sandvik Mining and Construction intranät Sverige
[4] Sandvik årsredovisning, 2014

1.1.2 Sandvik SRP AB Svedala[5]

Sandvik SRP AB in Svedala was founded in 1882 by the name Åbjörn Andersson & Co. Åbjörn Andersson himself was a blacksmith and in the beginning of Åbjörn Andersson & Co. the production was mainly agricultural machinery and brickyard equipment. Until the Russian revolution 1917 the brickyard equipment was the largest cash-cow for Åbjörn Andersson & Co. but when the Russian revolution occurred the export to Russia died. Around 1900 Åbjörn Andersson & Co. has started to produce a simple and transportable jaw-crusher for farmers to produce gravel for the earlier dirt roads. Paved roads became more and more important when the people started using cars instead of horses for traveling therefore Åbjörn Andersson & Co equipment became more popular. Åbjörn Andersson & Co. developed even more equipment for road maintenance such as graders. The road equipment developed during the early 1900 century and after the Second World War Åbjörn Andersson & Co. begins to produce a cone crusher on contract for Allis Chalmers. This was the start of what SRP is today. Åbjörn Andersson & Co. has been in many company fusions and has also been bought by other companies, but from 2001 Sandvik AB is the owner of the site in Svedala.

1.1.3 Process

1.1.3.1 Products

SRP produce most of the equipment for the crushing and screening process jaw crushers, cone crushers, gyratory crushers, HIS (High Speed Impact) and VSI (Vertical Shaft Impact) crushers and screening equipment. In Svedala the production is concentrated to jaw crushers and cone crushers.

1.1.3.2 Process Flow

The process flow described in figure.. is a typical process flow built up by a primary crushing stage, secondary crushing stage. The primary stage usually has a jaw or a gyratory crusher and screening equipment. The secondary have a single or several cone, VSI, HSI crushers and screening equipment. In a mining industry the main idea is to reduce particle size until the mineral can be extracted out of the ore. In construction the particle size is a lot more important when different aggregates are used as several different construction materials.

[5] ”Gjuteriet” 125 år, 2007

1.2 Background

As an attempt to develop a production cost model to forecast the costs for different crushed products in comminution plant a master project has been defined in collaboration between the division of Production and Materials Engineering of Lund University (LTH) and Sandvik Rock Processing (Sandvik SRP, Svedala). The first part of the project which has been completed during the spring 2014 resulted in developing of a primary model to be used to estimate/predict the cost for a single crushed product within a simple crushing/comminution circuit. However, there are needs to further develop the primary model to deal with more complicated crushing circuit in which more than one product is produced.

The main objective for the project is to develop a user-friendly model for Sandvik Rock Processing (SRP) which will be used by sales engineers as a tool for predicting the cost(s) for the crushing projects to satisfy customers.

So far, the achieved results from the first part of the project have been satisfactory, encouraging Sandvik SRP to proceed further. This means the model must be developed in a way to enable us to estimate/predict the costs for different/multiple crushed products within a designed crushing circuit.

1.3 Purpose and Goals

The purpose of this master thesis will be further development of the Cost Analysis for Crushing and Screening Model. The base of this project will be Cost Analysis for Crushing and screening – Part I.

The final outcome will be to present a comprehensive users-friendly model which can be implemented in the Microsoft Excel. This project will aim to get a result with <85% accuracy.

1.4 Delimitations

For this project there will be some delimitations:

- The costs before the crushing and screening stage are fixed (which includes drilling, blasting and hauling).
- The costs after the crushing and screening stage are not included (transportation out of the pit/mine etc.).

1.5 Report Structure

Chapter 1 – Introduction

This first chapter will include a short presentation of the company, background, purpose, goals and delimitations of this Master Thesis.

Chapter 2 – Methodology

In the second chapter the methodology for this project is described.

Chapter 3 – Theory

In the third chapter the theoretical models that have been used during the project is described. The background according to the Generic Cost Model by Ståhl and the Monte-Carlo simulation models[6] will be presented in this chapter.

Chapter 4 – Calculation model

In the fourth chapter the adopted Generic Cost Model that has been used within the Excel program will be presented in detail.

Chapter 5 – Results

In the fifth chapter the result from this project will be presented together with the validation of the program.

Chapter 6 – Conclusions and Recommendation

In the sixth chapter the conclusions out of this project will be presented and also a recommendation for further work to get an even more precise model.

Chapter 7- References

Chapter 8- Appendix

[6] Development of manufacturing Systems, 2013

2. Methodology

This chapter will present the different techniques and methods that have been used for this project. The main point of this study is further development of The Generic Production Cost Model by Ståhl to fit the crushing and screening process even better than earlier studies.

2.1 Approach

In order to build a simulation model there is a certain approach developed by Law[7]. This model includes seven steps described in figure 1. The author has used this model during the work of this report with emphasis on the upper part of the model.

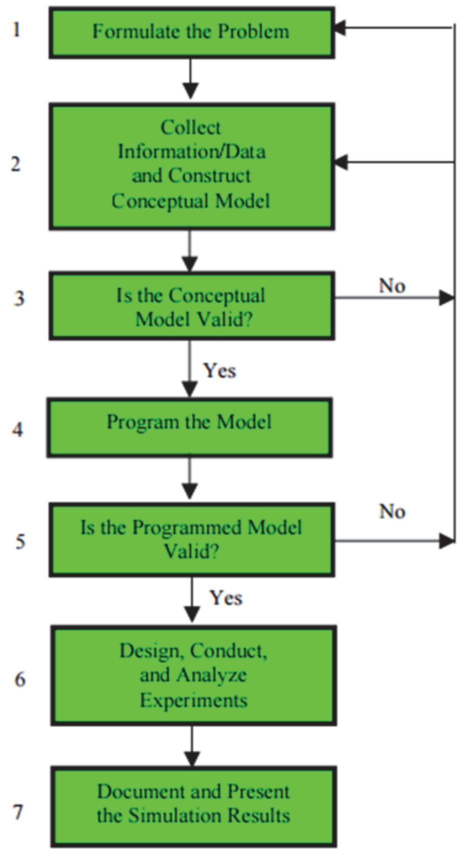

Figure 2: Laws model[8]

[7] How To Build Valid and Credible Simulation Models, 2001
[8] How To Build Valid and Credible Simulation Models, 2001

2.2.1 Formulate the Problem

The purpose and goals where defined and a project plan was made. All involved parties had to approve the project plan[9].

2.2.2 Collect information/Data

There are two types of data, primary and secondary[10]. The primary data is the one that the author himself collects and the secondary is the one already existing such as earlier thesis etc. During the work with this thesis data collection has been made throughout the whole process.

2.2.2.1 Literature studies

The literature studies were mainly done by reading books, articles and other master's thesis.

2.2.2.2 Lectures

To start off this project a lecture during three days were held. The purpose of the lecture was to get a good view of the company and also a basic education in process technology and Plant Designer.

2.2.2.3 Interviews

Throughout the work with this project interviews were held. The interviews where mostly dialog around areas where real data were impossible to get hold of. The interviews were held at the Sandvik SRP AB site in Svedala.

2.2.3 Concept and building the model

The concept of modeling is a simplification of reality to make it possible to analyze a real case. The model makes it easy to look at several different scenarios. To make the model three different parameters has to be taken in to account.[11]

- Delimitations – If the model is too large then it will be to complex and if the model is too small then it the model might lose some important aspects.
- Input/Output – The input that will affect the most should be prioritized. The input is the varying variable and the output is the parameter that will be analyzed.

[9] Att genomföra examensarbete, 2006
[10] Information för marknadsföringsbeslut, 2001
[11] Att genomföra examensarbete, 2006

- Level of abstractness – If the model is very detailed the model it will catch all the different aspects but it will also make the model to complex and there is a risk that some of the input variables doesn't affect the output.

Building the model and collection of data is the most time consuming part of the project.

2.2.4 Result and Analysis of the Output

The result will mostly be analyzed from the authors own thoughts and experiences, so if the reader shall be able to make own conclusions the material has to be well documented.[12]

2.2.5 Finalizing

The ending of this Master Thesis means that the final touches are made and it will be presented for Sandvik AB and the institution.

[12] Seminarieboken – att skriva, presentera och opponera, 2003

3. Theory

3.1 The Generic Production Cost Model

The following models will include plenty of formulas which the reader will find in appendix.

3.1.1 Generic Production Cost Model[13]

The generic production cost model developed by Ståhl gives the opportunity to connect the economic factors with the production. The idea of the model is to break down all cost into separate minor problems. The model, see figure, divides the cost into four categories raw material cost (k_B), production cost during up-time (k_{CP}), production cost during down-time (k_{CS}) and payroll cost (K_D).

$$k = \frac{k_B}{N_0}\left[\frac{N_0}{(1-q_Q)(1-q_B)}\right]_b + \frac{k_{CP}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\right]_{c1}$$
$$+ \frac{k_{CS}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RB}}{U_{RB}}T_{pb}\right]_{c2}$$
$$+ \frac{k_D}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{su} + \frac{1-U_{RB}}{U_{RB}}T_{pb}\right]_d$$

Equation 1: Generic Production cost model[14]

3.1.2 Earlier Adopted Production Cost Model[15]

To fit the generic production cost model to the crushing and screening process a lot of parameters has to be changed and adopted. The major difference is that the original model calculates the cost per part and in the C&S process the outcome is measured in metric tons. The adopted model developed by Lindström and

[13] Industriella Tillverkningssystem del II, 2010
[14] Development of Manufacturing Systems, 2013
[15] Cost Analysis for Crushing and Screening – Part I, 2014

Heyman is presented below. This model was the base of the new adopted production cost model which will be presented in the next chapter in detail.

$$
\begin{aligned}
k_j = \frac{1}{PF_j}\Bigg[& \left[k_B \cdot PF_j\right]_b \\
& + \sum_{1}^{i} \frac{k_{CPi}}{M_0} \left[\frac{t_{mfi} \cdot pf_{ij} \cdot M_0}{(1-D_i)(1-q_{Pi})}\right]_{c1} \\
& + \sum_{1}^{i} \frac{k_{CSi}}{M_0} \Bigg[\frac{t_{mfi} \cdot pf_{ij} \cdot M_0}{(1-D_i)(1-q_{Pi})} \frac{q_{Si}}{(1-q_{Si})} + T_{sui} \\
& + \frac{1-U_{RB}}{U_{RB}} \left(\frac{t_{mf} \cdot pf_{ij} \cdot M_0}{(1-D_i)(1-q_{Pi})(1-q_{si})} + T_{sui}\right)\Bigg]_{c2} \\
& + \frac{k_D}{M_0} \Bigg[\frac{t_{mfS} \cdot PF_j \cdot M_0}{(1-D_S)(1-q_{Ps})(1-q_{Ss})} + T_{suS} \\
& + \frac{1-U_{RB}}{U_{RB}} \left(\frac{t_{mfS} \cdot PF_j \cdot M_0}{(1-D_S)(1-q_{Ps})(1-q_{Ss})} + T_{suS}\right)\Bigg]_d \Bigg]
\end{aligned}
$$

Equation 2: Earlier adopted production cost model[16]

3.1.3 New Adopted Production Cost Model

The major goal of this study is to make a user-friendly program that can be used by many of the company's employees and applicable for all different kind of sites. This will cause that the new model to be a little bit less detailed. If all details in the previous model shall be included the level of user-friendliness would decrease that much that the model might not be used in the extend Sandvik would like.

The major differences:

1. T_{su} = 0, this is done due to the fact that the setup time is included in the wear part cost and in the deprecation cost.
2. The material flow is replaced with a better calculated balancing loss.

[16] Cost Analysis for Crushing and Screening – Part I, 2014

$$
\begin{aligned}
k_j = \Bigg[& \left[k_B \cdot PF_j\right]_b + \frac{K_{0i}}{T_{plan}} \\
& + \sum_{1}^{i} \left[\frac{k_{CPi}}{(1-D_{Si})(1-q_{Pi})}\right]_{c1} \\
& + \sum_{1}^{i} \left[\frac{k_{CSi}}{(1-D_{Si})(1-q_{Pi})} \frac{q_{Si}}{(1-q_{Si})} \right. \\
& \left. + \frac{1-U_{RBi}}{U_{RBi}} \left(\frac{k_{CSi}}{(1-D_{Si})(1-q_{Pi})(1-q_{Si})}\right]_{c2} \\
& + \left[\frac{K_{Di}}{(1-D_{Si})(1-q_{Pi})(1-q_{Si})} \right. \\
& \left. + \frac{1-U_{RBi}}{U_{RBi}} \left(\frac{K_{Di}}{(1-D_{Si})(1-q_{Pi})(1-q_{Si})}\right)\right]_d \Bigg]
\end{aligned}
$$

Equation 3: New adopted production cost model

3.1.3.1 Cost per metric ton k_j[17]

In earlier studies the generic cost model has to be changed to calculate the cost per metric ton instead of the production cost per part. The same method is used during this study.

3.1.3.2 Cost of raw material k_b[18]

The cost of raw material was supposed to be calculated but in the beginning of this project a decision was taken that the cost of raw material could be calculated as in previous study.

3.1.3.3 Yield of product PF_j

The Yield of different products is set out of known data regarding the out-put at each site. The yield is set to a percentage of the out-put.

[17] Cost Analysis for Crushing and Screening – Part I, 2014
[18] Cost Analysis for Crushing and Screening – Part I, 2014

3.1.3.4 Variable cost during up-time k_{CPi} in machine i

The variable machine cost during up-time is calculated as in the equation below:

$$k_{CP} = \frac{k_{wp} + k_{sp} + k_{to} + k_{en} * k_{kwh}}{T_{plan}}$$

Equation 4: Production cost during up-time

The information regarding the ware-part cost is well documented. The spare-part cost on other hand is estimated after interviews. Total cost for spare part is calculated see equation 5.

$$k_{sp} = \frac{k_{wp}}{0.6} \cdot 0.4$$

Equation 5: Spare part caluclation

3.1.3.5 Cost during down-time k_{CSi} in machine i

The cost during down-time includes all the fix costs, the variable machine cost is removed.

$$k_{CS} = \frac{k_{wp} + k_{sp} + k_{to}}{T_{plan}}$$

Equation 6: Production during down-time

3.1.3.6 Machine utilization U_{RB}

The machine utilization is the time when the equipment could be used but for some reason it is not. In this study the machine utilization is simulated.

3.1.3.7 Balancing loss D_S

When a plant is designed the aim is to get a line which is 100% balanced. This is almost impossible to get therefore the line will not work at its full capacity. When working with crushing and screening the line is designed to reach the cone-crushers full capacity which leads to balancing issues regarding screens and jaw-crushers. To calculate the balancing loss equation 7 is used.

$$D_S = \frac{(t_i - t_g)}{t_i}$$

Equation 7: Balancing loss calculation

3.1.3.8 Production-rate loss q_P

The production-rate loss occurs when the cycle time has to be increased, for example if the production has quality problems. This variable is simulated throughout this study.

3.1.3.9 Down-time rate q_S

The true production time t_p is longer than the nominal cycle time t_0 because of disturbances that result in downtime. In the crushing and screening process this can be caused of the raw material distribution which will differ a lot at the beginning to the end. By adding a downtime rate will deal with this problem.

3.1.3.10 Payroll cost K_D

The payroll cost is the total cost for the payroll during one year and then it is divided by the metric ton produced.

3.2 Building of the new Adopted Production Cost Model in Excel

The most time consuming part of this study was to implement the model in excel. Programing has to be tried out during the study, a lot of try and error testing has been made. One of the major advantages with the program is that it can easily be changed if the validation points in any direction.

3.2.1 Visual Basic for Applications

Visual Basic for Applications (VBA) is a programming language in Microsoft Excel. It is often used for writing macros in Excel. The author has used VBA for building the calculation program. This was the easiest way of making a user friendly interface in Microsoft Excel, which was one of the main tasks during this study.

3.2.2 Interface

The main goal of the interface is to give the user a good idea of what to fill in in order to make the calculations. The simplicity of the worksheet and the knowhow of Excel was the main reason for developing the program instead of using MathCad. There is a certain way of filling in the form in order to make the calculations which is presented in the user manual in appendix. This manual will also describe how the simulations are made.

3.2.3 Output

The Out-put shall be easy to overview and give the most relevant results at the top. This is done by putting the major cost groups at the top and then adding these up to get the final production cost. This will give the user a good view of what is included and what is the major cost driver that causes the production cost. If the user has a good idea of what the production cost shall be then the output worksheet can visualize if the user have done something wrong through the calculations. There is also a script written to get the top ten cost drivers which could be very efficient when using the program on a very large site.

3.2.5 User Manual

The user manual is supposed to make the calculations easy to make when using the program.

First of all the macro has to be enabling in Microsoft excel.

3.2.5.1 Input Variables Part I

The first step is to fill in the input variables in part – I.

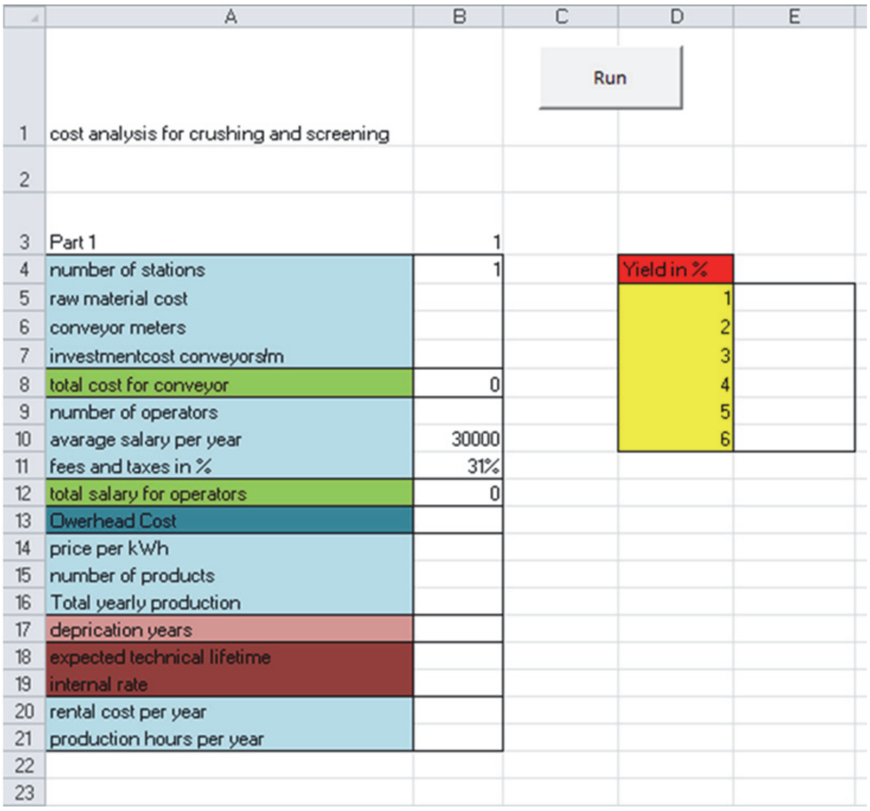

Figure 3: The interface of the developed program

1. The turquoise cells are costs which the user has to fill in in order to make the calculations.
2. The green cells will sum up when the turquoise once are correct filled in.
3. The dark blue overhead cost is optional if the cost is known.
4. The pink cell is used when the deprecation cost is calculated linier.
5. The dark pink cells are used when the deprecation cost takes the annuity in to account.
6. The Yield is the fraction in percent of each produced product at the end.

3.2.5.2Input Variables Part II

The second part is to fill in the input variables in part II. If all the costs are known the calculations are rather easy. For simulation read 3.2.5.3 Simulation Part III.

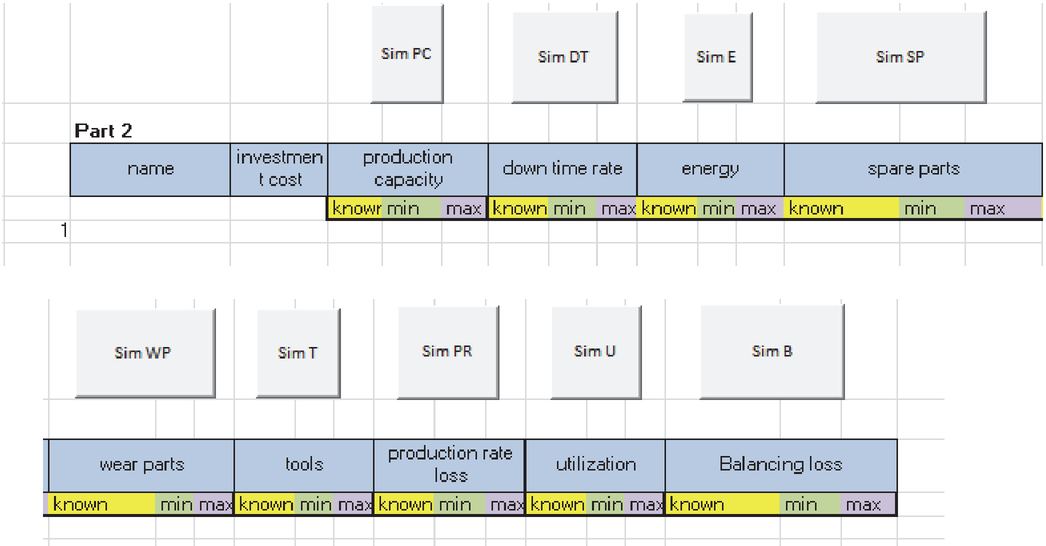

Figure 4: Second part of the interface

1. First of all the name of the station is filled in.
2. Fill in the investment cost of the equipment.
3. Production capacity is filled in and used for calculating the balancing loss.
4. Down time rate is filled in.
5. The energy consumption at each stage is filled in.
6. Total spare part cost is filled in.
7. Total ware part cost is filled in.
8. Tooling cost such as extra cost for example a bucket loader is filled in.
9. Production rate loss is filled in.
10. Utilization is filled in.
11. And the last to fill in in part II is the balancing loss.

3.2.5.3 Simulation Part III

If the values at these different stages are not known then the cost can be simulated. In order to simulate the cost the minimum and maximum value is filled in. the minimum value is not allowed to be zero or left empty this because the equation is divided with the minimum value. When the values are filled in then click on the Sim button that is placed above the specific cost. The user is allowed to know some of the values and then the program just simulate the once that is not.

3.2.5.4 Run Function

When the entire chart is filled in the calculations can be made by clicking the Run button.

3.2.5.5 Output Variables Part I

The first part of the output shows the total cost per product where six different costs are displayed.

1. Raw material
2. Labor cost fixed (over-head cost)
3. Conveyor cost
4. Rental cost (land)
5. Total production cost
6. Total cost per product

3.2.5.6 Output Variables Part II

The second part of the output variables display how the production cost is calculated and where the production costs occur. These costs are divided into four different groups and when these are added up the total production cost is displayed in the down right corner.

1. Deprecation
2. Production cost
3. Down time cost
4. Direct wages (payroll)

3.2.5.7 Top-Ten Cost Drivers

In order to get the top ten cost drivers the user push the “Top Ten Cost” button which then will pick out the ten major cost throughout the entire calculation chart.

3.2.5.8 Erase Function

To erase all values the user can either push the “Erase” button or just erase the values manually.

3.2.4 Assumptions

There have been done some assumptions for this study:

1. The conveyor cost only depend on the deprecation cost this because of the negligible cost for energy and maintenance cost.[19]
2. The spare part cost is calculated. The wear part cost is well known and after interviews the common way of calculation the spare part cost is shown in equation 5.
3. The simulated values are down time rate, production rate loss and utilization.
4. The cost for setup is set to zero. The setup cost is in this study included in the wear part cost because there is not any specific setup time when producing the aggregate.

3.3 Mont-Carlo Simulation[20]

Monte-Carlo Simulation (MCS) is most famous when it was used during the Manhattan Project. It is often used when regular solving tools cannot be used[21]. Ståhl describes how MCS can be used when there is a lack of historical data and series, qualified assumptions need to serve as the basis for describing the parameters in question in statistical terms. The most common distributions used are Normal distribution or Weibull distribution. To get the right distributions function at least two out of the five following questions has to be answered.

A – Is the frequency function symmetric or asymmetric?

B – What value does the most frequency occurring result for the parameter in question have?

C – What is the lowest value for the parameter in question which is found to occur have?

D – What is the highest value for the parameter in question which is found to occur?

E – What is the average value obtained for the parameter in question?

The easiness of answering question C and D made Weibull distribution most applicable for the program.

[19] Interview: Manouchehri, Hamid, 2015
[20] Development of Manufacturing Systems, 2013
[21] Introduction of Monte Carlo simulation, 2010

4 Results

This chapter will present the results from the calculations during this study. It will also compare the results to the earlier study made by Lindström and Heyman.

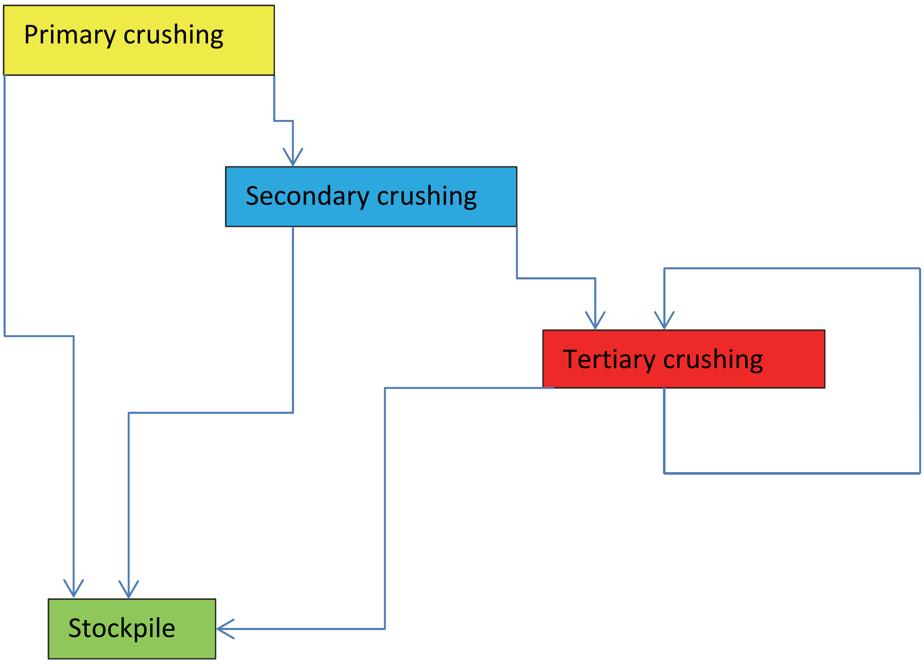

Figure 5: Flow sheet over the production

name	Depreciation	production cost	Down time cost	Direct wages	
sikt SW1252H	0,124772826	1,506399466	0,247678	0,57256502	
käftkross CJ412	0,47719391	0,834388786	0,150046157	0,7491339	
sikt SS1223H	0,110150152	1,030694371	0,169463895	0,34584353	
Konkross CS44(	0,391597969	3,337636494	0,630193859	1,29099418	
sikt MSO2060D	0,166675696	1,546041557	0,254195842	0,78497909	
Konkross CH66	0,517782611	2,881264468	0,463907412	1,48345675	
Konkross Vibrc	1,427683977	1,605087968	0,29055997	2,24128272	
Sikt MSO2160S	0,127379464	0,837439177	0,137689415	0,3249506	
Sikt MSO 2160S	0,127379464	0,966275973	0,158872401	0,374943	
	3,470616069	14,54522826	2,50260695	8,16814879	28,6866

Figure 6: The results from the production cost calculations

raw material	Labour cost fixed	Conveyor Cost	Rental Cost	Total production Cost	Total Cost
15,248	0	0,533333333	3,33333333	28,6866	47,801267

Table 1: Total cost for production at the company according to this study

4.1

4.1.1 Raw material cost

The raw material is taken from the early study made by Heyman and Lindström,it is set to 15.25 SEK/ton

4.1.2 Payroll cost

The payroll cost generated in this study is 8.27 SEK/ton and the previous result is 5.22 SEK/ton

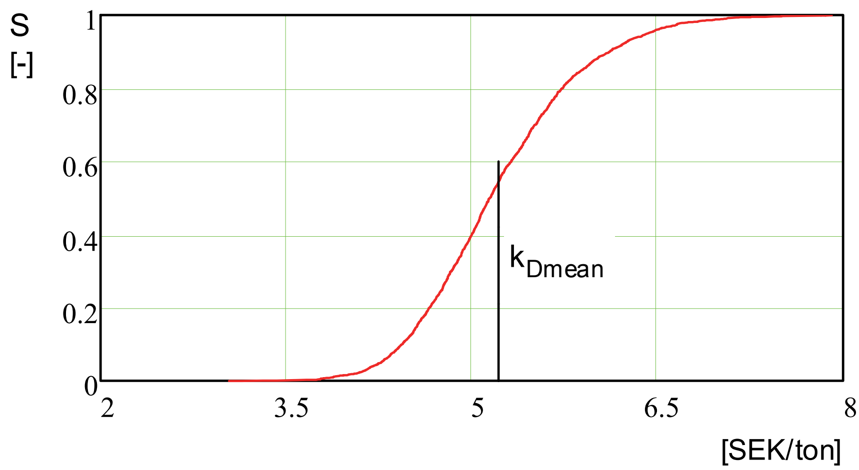

Figure 7: Payroll distribution function according to Heyman and Lindström[22]

The payroll cost is one of the factors that has been changed to more accurate way therefor the one and old results differ.

4.1.3 Machine cost during uptime

The machine cost during uptime is 14.55 SEK/ton and the previous result is 24.16 SEK/ton

[22] Cost Analysis for Crushing and Screening – Part I, 2014

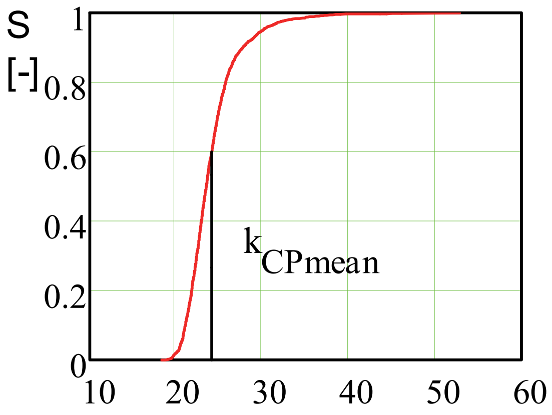

Figure 8: Distribution function over production cost during up-time according to Heyman and Lindström[23]

This result is not so surprising since the deprecation cost is not included in the production cost in the new calculation. When adding the deprecation cost to the production cost the result is 18.00 SEK/ton with liner deprecation. In previous study the deprecation cost is calculated with annuity and by using a residual value this affect the total machine cost during uptime.

4.1.4 Machine cost during downtime

The machine cost during downtime is 2.50 SEK/ton and the previous result is 3.19 SEK/ton

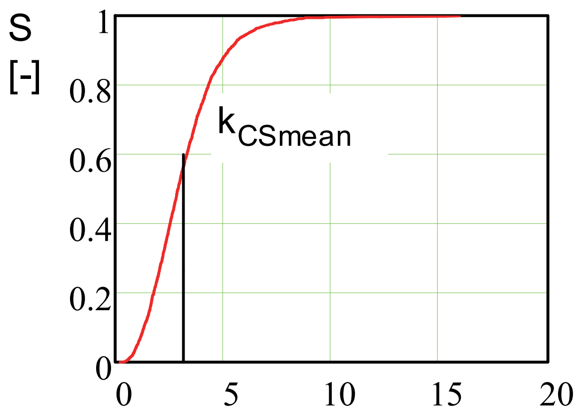

Figure 9: Distribution function over production cost during down-time according to Heyman and Lindström[24]

[23] Cost Analysis for Crushing and Screening – Part I, 2014

In this case the new calculation is placed well in the distribution function. The difference in this case can once again depend on the fact that the deprecation cost not is included in the sum of the production cost.

4.1.5 Total production cost per metric ton

The total cost is hard to compare when they differences between them is rather large when it comes to payroll cost and deprecation cost. There is also a rather large difference in the rental cost according to new input. When comparing the production costs, without payroll and deprecation cost. This study gave the result of 36.16 SEK/ton and the previous study gave the result of 31.93 SEK/ton. This study has a rental cost that is 3.33 SEK/ton and the previous one only calculated with 0.2 SEK/ton. With that removed the cost would have been 32.82 SEK/ton compared to 31.73 SEK/ton. This is well in the 85% accuracy that this study aimed for.

4.2 Result analysis

4.2.1 Total production cost

The total production cost does not differ substantially. In this study less parameters has been simulated then in the previous study and instead the parameters were estimated by persons with good insight in the crushing and screening process. This result is in line with the Mining Cost in diagram[25].. The cost of crushing and screening is 2/3 and the raw material is 1/3. This study gave the result of 47.80 SEK/ton where raw material is 15.25 SEK/ton.

[24] Cost Analysis for Crushing and Screening – Part I, 2014
[25] Sandvik Rock Processing Manual, 2011

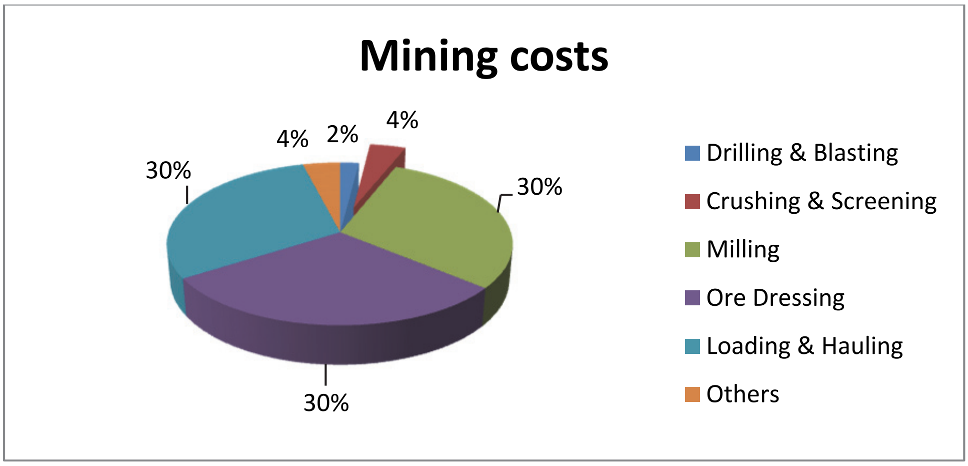

Figure 10: Split over mining costs

When using the program regarding calculations at construction sites it will be more interesting. At the construction site the churching and screening counts for 45 % of the total cost for production.

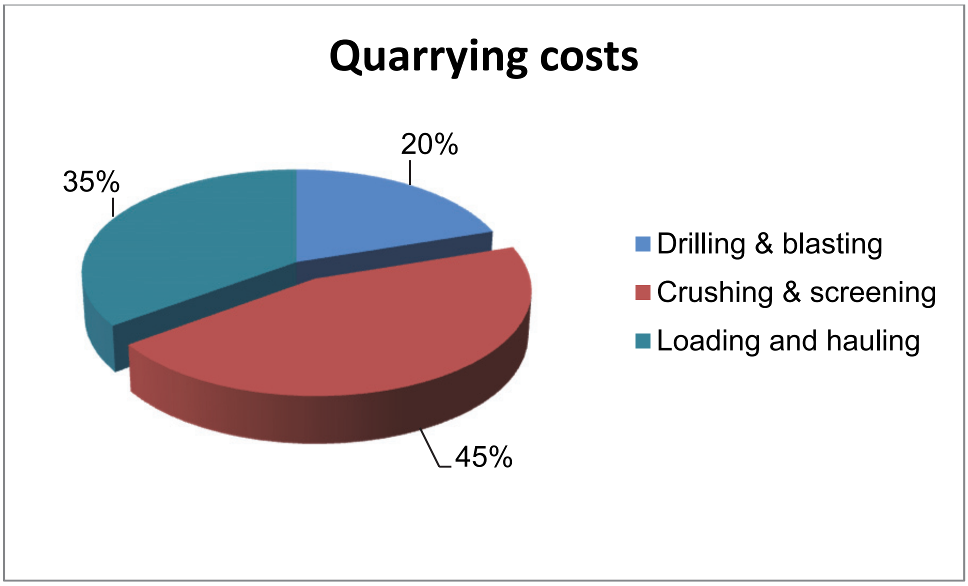

Figure 11: Split over production cost when producing construction aggregates

4.2.2 Differences between calculations

When using simulation we know that good input give good results. In this new study the input is a lot more accurate which gave a better result. There are also some changes made to the model which cause a variation between the calculations.

5 Conclusions

The program seems to give a rather precise value of the total production cost. The differences between this study and Heyman and Lindstöms result are due to fact that payroll cost and deprecation cost are calculated in a different way. The major problem is that the validation of the calculation could not be done because lack of sites willing to investigate their production cost.

In this study the ware part cost was well known which made the study more accurate than the previous one. This also caused the production cost to decrease but the payroll cost increased which made the total production cost to be at the same level.

The aim of reaching 85 % accuracy was even better than expected but without further validations this result cannot be seen as significant a quantitative study would prove this.

This result might show that a higher level of atomization could be preferred in a county as Sweden when the payroll cost has such a high impact on the result.

In this study there have still been many input variables which cause the calculations to be a little bit time consuming.

6 Further studies

The most important study that can be done is to validate the program by a quantitative study. This might show that a beta parameter have to be added to the calculation. The beta parameter is a value which can reduce volatility if there is cost that is not included in the program for example the small amount of dust which disappears when crushing. It would be interesting to see if the assumptions throughout this study are right. If so then the study could be done by just knowing very few input variables.

It would be interesting to study the connection between work index or abrasion index and the wear part cost, than the simulations could be done by greater accuracy.

Building a simulation program is an ongoing process which can always be improved. When the validation is made there could be some adjustments to the program which might give a more detailed result.

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Electronic resources

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Hedvall, Per. *Senior Advisor* (continously).

Paravac, Marijan. *Market & Sales Manager* (continously).

Svedensten, Per. Manager Crushing Chambers and Material Development (continuously)

Manouchehri, Hamid. Principal Advisor Sandvik SRP (continuously)

Hanny, Steven.

Appendix

Appendix A

AI	*Abression Index*	*kg/kWh*
C&S	*Crushing and Screening*	-
D	*Balancing loss for station*	-
HIS	*High Speed Impact*	-
K	*Production cost of prduct*	*SEK/ton*
K_0	*Original investment of equipment*	*SEK*
k_B	*Cost of raw material*	*SEK/ton*
k_{CP}	*Machine cost during up-time*	*SEK/ton*
k_{CS}	*Machine cost during down-time*	*SEK/ton*
K_D	*Payroll cost*	*SEK/ton*
k_{en}	Energy consumption	kW/h
k_{kwh}	Cost per kWh	SEK/kWh
k_{sp}	Spare part cost	SEK/year
k_{to}	Tooling cost	SEK/year
k_{wp}	Wear part cost	SEK/year
PD	Plant Designer	-
PF	Production factor at end of process	%
q_P	*Production rate loss*	-
q_S	*Downtime rate*	-
T_{plan}	*Planned production time per year*	*hours*
T_{SU}	*Set-up time*	*hours*

U_{RP}	*Machine utilization*	-
VSI	*Vertical Shaft Impact*	-
Y	*Yield*	*%*

Appendix B (Heyman and Lindström index)

a_f	Annuity	-
AI	Abrasion Index	kg/kWh
C&S	Crushing & Screening	-
CSS	Close Side Setting	mm
D	Balancing loss for station	-
F_{80}	The 80 % passing size of the feed	µm
HIS	High Speed Impact	-
h_{UH}	Number of hours of operation per hour maintenance	-
h_y	Number of hours per shift per year	hours/year
k	Production cost of product	SEK/part
K_0	Original investment of equipment	SEK
k_B	Cost of raw material per ton	SEK/ton
k_{CP}	Hourly cost of machine during production	SEK/hour
k_{CS}	Hourly cost of machine during downtime and setup times SEK/hour	
k_D	Payroll costs	SEK/hour
k_{ph}	Variable machine time cost	SEK/hour
k_{ren}	Average renovation cost	SEK
k_{renk}	Renovation cost	SEK
k_{UHh}	Maintenance cost per hour	SEK/hour
k_y	Cost per square meter	SEK/m^2
lön	Average salary	SEK/year

M	Tons of raw material used for 1 ton of main product	tons
M_0	1 ton of main product at end of process	ton
mf	Material flow	ton/hour
MIT	Massachusetts Institute of Technology	-
MLOC	Machine Lifetime Operating Cost	-
n	Expected length of time in use	year
N_0	Batch size	number
n_{op}	Number personnel connected to the production line number	
N_{ren}	Number of renovations during lifetime	-
N_{ren}	Number of renovations	number
n_{ren}	Year of renovation, from present time	years
n_{syren}	Number of shift-yeas between renovations	years
OFAT	One Factor At Time	-
p	Internal rate	-
P_{80}	The 80 % passing size of the ground product	µm
PD	PlantDesigner	-
PF	Product factor at end of process	-
pf	Product factor for station and product	-
PPM	Production Performance Matrix	-
PTC	Parametric Technology Company	-
q_B	Rejection rate	-
q_P	Production-rate loss	-
q_S	Downtime rate	-
$r_{\%}$	Residual value	-
r_a	Residual value factor	-
socavg	Social security costs	-
SPS	Swedish Production Symposium	-
t_0	Cycle time	min/part
T_{free}	Free capacity	hours

t_{mf}	Time to process 1 ton of material	hour/ton
T_{plan}	Planned production time per year	hours
T_{su}	Setup time for machine	hours
U_{RP}	Machine utilization	-
VSI	Vertical Shaft Impact	-
W	Work Impact Index	kWh/ton
Wi	Bond work index	kWh/ton
Yk_y	Cost for the C&S plant or facility in terms of rent or depreciations m^2	