GRINDING OR SHAVING – ECONOMIC DECISION SUPPORT IN THE PRODUCTION OF GEARS

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This paper describes a case study at an automotive company with the purpose of developing an economically based decision support tool, for strategic decision about whether to chose grinding or shaving as a finishing method in gear manufacturing. In the study different cost models are compared regarding input parameters in alignment with the required input data required to make a decision. With the performance driven cost model used during the analysis, shaving was shown to be the most cost efficient finishing method.

Keywords: cost analysis, performance, gear manufacturing.

1. INTRODUCTION

Staying competitive on an increasingly globalized market requires an updated manufacturing strategy together with reliable information about performance and development potentials within the manufacturing system. Manufacturing strategies often encompass a bundle of decision associated with operational management, were flexibility and capacity are frequently mentioned as well as cost, quality and customer satisfaction as important parameters building a successful manufacturing strategy. The development of decision support in production issues described in literature mainly covers three research topics:

- Design of Flexible Manufacturing Systems, often focusing on layout, and routing issues (Deb et al., 2005; Suri & Whitney, 1984; Bayasit, 2004; Chan et al., 2000). In these studies part cost can be, but not necessarily are, one out of many parameters included in the decision support.
- Selection of, investment in and replacement of single machine tools and new advanced manufacturing systems were Arslan et al. (2004) and Alberti et al. (2011) focus on machine parameters. Yurdakul (2003) and Tan et al. (2006) use AHP and fuzzy network methodologies as a basis to develop decision support systems.
- Cost analysis for pricing decision, were Kingsman & Souza (1997) present a work procedure rather a cost model and Lucas and Raffety (2007) analyze the difference between theory and practice in two case studies.

To support decision making in association with management of manufacturing operations, data on key parameters need to be acquired and processed. The number of key parameters included in the strategy will affect the ability to make well informed strategic decisions. Also the number of parameters included governs the improvement opportunities that could be found by a decision support. To conclude, the development of profitable manufacturing operations requires reliable data acquisition (of both economic and production Key Performance Indicators) and processing of data into information, and a management organization taking actions upon the continuous flow of information.

The automotive sector is an important part of the Swedish manufacturing industry, comprising of OEM car, truck and construction machine manufacturers as well as subcontractors. Competition from low wage countries and emerging markets are putting pressure on these companies, driving them to look for means and methods to increase their cost efficiency and competitiveness. An important issue in this strive is to have a clear picture of what is really driving costs, especially in the manufacturing system. There are a number of methods for cost calculations (that will be elaborated on in the literature section) that provide different strategies and opportunities. As a consequence of frequent use of e.g. Lean principles and Theory of Constraints (TOC) by practitioners in the automotive industry to drive improvement and change management work, new methodologies have emerged to analyze costs such as Lean accounting (Maskell et al., 2012) and throughput accounting (Bragg, 2007). An issue of implementing or developing models for cost calculations and integrate them in improvement work is the alignment of the level of detail in the cost model and the desired or expected improvement opportunities.

The world trend is an increasing demand for gears. The US market for gears is forecasted to increase 3,9% to $30,1 billion in 2013 according to The Freedonia Group Inc. (Freedonia Group 2014; Machine Design, 2014). The market for construction equipment experienced a steep decline after the global economic downturn in 2008, but has now recovered to its expected growth rate. The Indian and Chinese markets are growing and the markets in Africa and Middle East are promising according to Transparency Market Research (2014). They also points towards an increase in investments in China, mainly as joint ventures, leading to increased competition from new gear manufacturers. In the light of this it is even more important to constantly develop cost efficient manufacturing systems.

The motivation for this study is to develop a cost based decision support tool specially designed for gear manufacturers, to facilitate knowledge based decisions in strategic production development issues. The main motivation for the case study company to participate in the study was to use a cost calculation methodology providing more details when analyzing costs for different gear finishing operations, than the one presently used. The aim was to arrive at a conclusion on what gear finishing operation to choose from a cost perspective. The research questions pertaining to this motivation are:

- What parameters should be included in a cost analysis to be able to make strategic decisions between different finish operations?
- How should these parameters be allocated and linked to identify cost differences in the manufacturing chain?
- What is the most cost efficient gear finishing method: grinding or shaving?

The analysis was performed as a case study at a vehicle manufacturer. Yin (2003) To perform the case study, input about production configuration and performance as well as economic data about different resources were required. Based upon the required information a project team was assembled consisting of a controller, a production specialist and a production manager at the case study company. The choice of cost methodology was supported by literature study and interviews with personal at the case study company. Since the aim of the study was to develop a decision support for strategic decision on production technology choices, overhead costs were omitted from the analysis. Only the costs that would be affecting the manufacturing of the gear wheel were chosen to be included in the analysis. This lead to the omission of maintenance costs and costs for process additives. These costs would not be affected to a very small extent in relation to the two different finishing operations. Since the different finishing operations incurred differences in the value stream, the total costs from raw material to finished gear wheel were included in the cost calculations.

2. COST MODELS (ACCOUNTING) IN MANUFACTURING

Both practitioners and scientists have devoted time and effort on manufacturing cost calculations with different purposes such as cost accounting, product cost estimation, prizing, estimating total lifecycle cost etc. Traditional cost accounting includes fixed and variable costs in the production system, such as direct and indirect material and labor costs, and some additional overhead costs such as manufacturing overhead, sales and administrative costs.

Standard costing is a method for accounting and has been used in manufacturing industry since a hundred years back (Oakes & Miranti, 2006), and is still commonly used. The standard cost of a finished product is the standard costs of the following input (VanDerbeck, 2013); direct material, direct labor and manufacturing overhead (variable and fixed manufacturing OH).

Standard costs are used instead of real costs for direct materials; direct labor and manufacturing OH, since the effort of retrieving these costs are larger than using the standard cost. As a result of this the standard cost always differs from the actual costs, and the difference is known as variance. The variance is used as a measure for profit, a positive variance (actual costs are bigger than standard costs) shows that the profit will be less than expected (Accounting Coach, 2014)

Activity Based Costing (ABC) is a concept introduced by Cooper and Kaplan (1988) aiming to allocate overhead costs more correctly by tracing them to activities and then connect the activity costs to the order, costumer or product level. The ABC methodology is divided into two stages. The first stage entails allocating costs based on the main activities occurring in various departments to form activity cost pools, called resource cost drivers. The second stage entails allocating these costs to objects (products, customers, etc) by identifying activity cost drivers. There are numerous papers on ABC implementations (Koltai et al., 2000; Özbayrak et al., 2003). There are reports on positive associations between the use of ABC and financial performance (Cagwin & Bouwman, 2002) as well as reports on declining interest of implementing ABC (Innes et al, 2000).

Many practitioners attempting to implement ABC perceived obstacles such as the method being too time-consuming to implement, sustain and modify. Some users also doubted the accuracy of the results. This lead to the development of the Time Drive Activity Based Costing (TD ABC) concept. In this concept the two parameters Unit cost of used resources and Time required to perform an activity are important. The time driven approach consist of 6 steps (Everaert et al, 2007):

1. Identifying resource groups and the activities for which they are used,
2. Estimate the total costs of each resource group
3. Estimating the practical capacity of each resource group
4. Calculating unit cost of each resource group
5. Determining the required time units for each activity
6. Calculating cost per transaction (multiplying the results from step 4 and 5)

Even if TD ABC has the potential of capturing different characteristics of an activity by time equations (in which time consumed in an activity is a function of different characteristics) the methodology is often implemented as a department cost. In this case there are similarities between TD ABC and SC.

The principles of Throughput Accounting (TA) originate form the concept of Theory Of Constraints (TOC) introduced by Goldratt & Cox (1984) in their book The goal. The rationale of TOC is that a company must decide on its overall goal, and then create a system that clearly defines the main capacity constraint that will allow it to maximize that goal Bragg (2007). TOC is used to identify the constraining bottleneck in a system and TA is used to estimate profit opportunities if the capacity in the bottle neck is increased. The costs included in the analysis are e.g. material cost, employee cost machine cost, outside costs, product development costs and other costs (Myrelid, 2013). There are researchers that advocate that TA is emphasizing short term optimization and Activity Based Costing (ABC) is a better choice for long term decision making as well as researchers that find that TA provides clarity of meaning to ensure the inclusion of only the relevant issues in decision making (Pretorius, 2004).

A lean enterprise is focusing on eliminating waste from the value stream. The value stream perspective is also central in Lean Accounting (LA). Maskell et al. presents an array of measures to take into consideration, such as lead time, inventory costs, OEE, WIP, First-Time-Through, but the cost calculations contain approximately the same cost items as TA. In the case study presented by Myrelid the following cost items were included in the value stream cost: material cost, employee cost machine cost, outside costs and other costs. Even if OEE is an important lean measure it is not integrated in the cost calculations.

Production Performance Costing (PPC) (Ståhl et al. 2007) is based on the value stream principle. The costs for each manufacturing step in the total value stream is calculated by the use of Equation 1, were the raw material is accounted for in the first step. The major difference between PPC and other costing method is the integration of OEE and unutilized capacity in the model. With the cost model presented in Equation 1 the manufacturing part cost is calculated, where the input parameters are briefly described and categorized in Table 1:

$$k = k_A + \frac{k_B}{Q} + \frac{k_{CP} \cdot t_0}{Q \cdot P \cdot 60} + \frac{k_{CS}}{60}\left(\frac{(1-A)\cdot t_0}{Q \cdot P \cdot A} + \frac{T_{SU}}{N_0} + \frac{T_b}{N_0} \cdot \frac{1-U_{IC}}{U_{IC}}\right) + \frac{k_D}{60}\left(\frac{(1-A)\cdot t_0}{Q \cdot P \cdot A} + \frac{T_{SU}}{N_0} + \frac{T_b}{N_0} \cdot \frac{1-U_{IC}}{U_{IC}}\right) + \frac{K_M}{60} + \frac{K_{SUM}}{N_0} \qquad (1)$$

The total manufacturing cost is calculated as the accumulated cost from each step (cell or line) required to manufacture a finished part or product, were the raw material is included in the first manufacturing step.

Table 1. Definition of parameters in the manufacturing cost model.

Cost parameters		Performance parameters		Time parameters		Other parameters	
k_B	Raw material cost (€/part)	Q	Quality (approved parts) (%)	t_0	Ideal cycle time (min)	N_0	Batch size
k_{CP}	Machine cost during operation (€/min)	A	Availability (based on downtime losses) (%)	T_{SU}	Set up time (min)	U_{IC}	Idle capacity
k_{CS}	Machine cost during downtime (€/min)	P	Performance (based speed losses) (%)	T_b	Production time for a total batch (min)		
k_D	Wage cost (€/min)						
k_A	Tool cost (€/part)						
k_M	Maintenance cost (€/part)						
K_{sum}	Sum of remaining costs (€)						

Further explanation of the cost parameters in the first column in Table 1 are:

- k_B is the cost for raw material in the first processing step
- k_{CP} is the cost for the machine tool and automation equipment (including facility costs) during operation. This means that energy costs and costs for process additives should be included.
- k_{CS} is the cost for the machine tool and automation equipment (including facility costs) during downtime, which means that no energy (or only idle energy) and process additives are consumed.
- k_D is the total wage cost including any additional costs e.g. social expenses.
- k_A is the total cost for tools and fixtures based on estimated tool life.
- K_{sum} is the sum of additional costs that can be allocated to a batch.

The purpose of a cost analysis governs the amount of different cost items to include in the parameter K_{sum}. This parameter should include costs for maintenance if the puropse is to compare new and old equipment, and could also include production support costs such as materials handling or quality assurance in e.g. a production location analysis.

There are different purposes of using different accounting and cost calculation methods. If the purpose is financial reporting Lean Accounting is accepted by GAAP (Generally Accepted Accounting Principles). For the purpose of tracking profitability ABC, Lean Accounting and Throughput Accounting would be suitable. For identifying costs at product and process level both TD ABC and Production Performance Costing (PPC) would be the primary chose. For developing decision support for identifying improvement activities on production process level the PPC methodology is preferable for it´s capacity to simulate development scenarios and taking equipment performance into consideration. Therefore the PPC methods will be used in the case study presented here.

3. GEAR MANUFACTURING

Gear manufacturing encompass a series of production steps generally starting with a forged blank in a case hardening steel quality to be turned and hobbed with a specially designed worm cutter before entering the hardening process. After hardening the gear wheel is then subjected to hard machining before the final gear profile geometry is shaped in a finishing operation, to meet the specified tolerances. The quality requirements on gear wheels are high regarding both surface and shape, since small deviations can cause noise, poor lubrication conditions and premature failure of the transmission. There are a few options regarding finishing operations in gear manufacturing, and the two methods commonly used are grinding and shaving.

The question from the case study company was to estimate the real costs for these two finishing methods. To be able to identify the differences between these two methods and for different gear wheels manufactured with these methods, a set of parameters to separate them needs to be identified. Also activities that are not included in the standard cost calculations, but do contribute to the total cost, also need to be identified.

One activity that adds to the total cost, not included in the standard cost, is quality assurance and costs caused by poor quality. It was decided to include these costs since the two different finishing methods can result in different quality rates. Equipment performance is another important cost driver not included in the standard cost. This was also chosen to be included since the different value streams contained equipment of different age and with different performance. The principle of tracking a part through the entire value chain, from raw material to finished part, will provide the final cost as the accumulated costs from each manufacturing step. A manufacturing step could be a single piece of equipment or a manufacturing line/cell in which a bottle neck can be identified. This is a difference compared with SC where the cost of a department is split into costs for single machines or one piece flow manufacturing cells. The use of the PPC method leads to a higher level of detail when it comes to allocate costs for different resources to manufactured parts.

Initially an analysis of the different production flow setups for the two different finishing method were made, to identify bottle necks, equipment setup, tooling and performance parameters associated with both time and quality. Figure 1 show the major manufacturing steps for a gear wheel operation, were both the value streams containing grinding and shaving are illustrated. Green is illustrating the “soft” machining operations and blue illustrates “hard” machining operations.

Fig. 1. The major manufacturing steps in a gear wheel manufacturing, were the value stream at the top contains grinding and the value stream at the bottom contains shaving.

Two different products with identical geometry was chosen for comparison of the different finishing methods, currently manyfactured at the site. One of them was a high volume product and one was a low volume product.

4. COST BASED DECISION SUPPORT

There are some main differences between the standard cost (SC) accounting principles used at the case study company and the methodology used in this study. A major differernce is that SC include overhead costs and is calculated once a year based on inverstments, product mix and production volumes. Another big difference concern production perormance tahat is not included in SC. The are also differences in level of detail, i.e. the number of parameters included in the cost calculations and the nomenclature for the included parameters. In Standard Costing (SC) the cost for each set of equipment is calculated including the following:

- Direct material cost
- Manufacturing overhead – direct wage costs, hourly equipment costs
- Common costs – wage costs for white collars, facility, depreciation and common equipment

The standard cost for a product is accumulated by multiplying processing time in each set of equipment with the manufacturing overhead, and adding costs för material and common costs distributed over the total product mix with an allocation key. The main purpose of calculating stands costs is to distribute the total amount of costs over the total amount of products produced in one year, i.e. a strategy for monitoring rather to serve as a decision support.

The cost calculation method used required a rather comprehensive set of input data. Figure 2 shows the extent of indata requirement in different cost categories. The majority of the input data (over 80% of the total amount of parameters) were easy to access directly from the company´s database. The rest of the parameters required some estimations and calculations to fit into the parameter setup in Equation 1.

General	Equipment	Tooling	Personnel	Quality
Shifts	Life-span	Purchase cost	Operators (Numbers and costs)	Frequency
Cost of capital	Investment	Sharpening cost	Technicians (Numbers and costs)	Time in measurement dept.
Rent	Year of investment	Sharpening interval		Cost for measurement dept.
Energy price	Space Requirements	Master cost		Quality rate
Batch size	Cycle time	Coating		
Annual volume	Setup time	Life-span		
	OEE			

Fig. 2. Input parameters to the cost analysis.

The fact that a hob tool is reground and ecoated several times before end of life affects the amount of required tooling parameters.

5. RESULTS

The cost model in Equation 1 was implemented in an Excel tool. The choice of software application was driven by the fact that the company had competence and licence to operate the software. The costs distribution for the two different value streams are compared in Figure 3. The costs for fluids and maintenance are rough estimations, since the total costs in Figure 3 were compared with the standard costs calculated by the company.

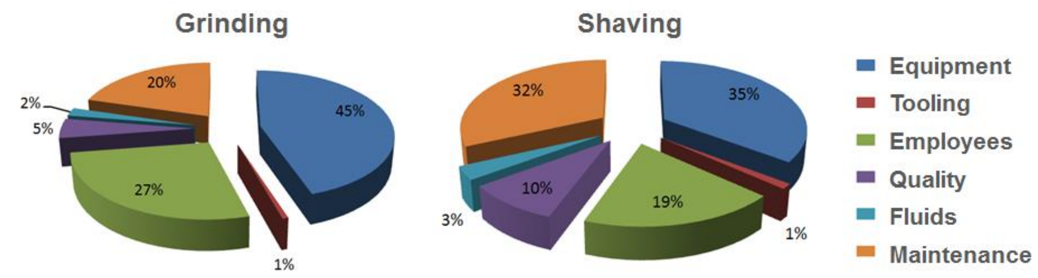

Fig. 3. Cost distributions for the two different finishing metods grinding (left) and shaving (right).

During the analysis phase it was discovered that the raw material costs for the two products differed. Since the cost of raw material did not influence the costs for processing, the raw material cost was omitted during the comparison of the manufacturing costs. The analysis of the total cost for the two differernt equipment setups showed in Figure 1, resulted in that the cost for the values stream containing the shavning process was 26 – 46% cheaper than the value stream containing the grinding process. According to the standard cost calculations used at the case study company the shaving value stream was 57% cheaper than the grinding value stream.

With the developed cost analysis tool, it is possible to analyse different development scenarios. The influence of two parameters that are sometimes not considered as important cost drivers are OEE and setup time, were specifically analysed, se Figure 4. The reason for choosing these parameters is that knowledge about their influence on cost in lacking and that the company wished to increase their knowledge about this relation. The left diagram in Figure 4 also show that OEE has a substantial impact on cost.

The diagram showing part cost as a function of OEE illustrates that an improvement of 10% in OEE could lower the part cost with approximately 80 SEK/part. If the annual volume would be 10 000 parts the potential annual saving is 800 000 SEK for this part. This of course if the OEE improvement could be realized without any additional investments. The reduction of setup time from 2 hous to 1 hour would save an additional 15 SEK/part for the batch size analysed in the case study. If the batch size is reduced to half, the potential savings of cutting the setup time to 1 hour would be 29 SEK/part. This points out the cost dependency between setup time and batch size, being important to consider if there are demands for increased flexilbility. A conclusion drawn here is also that the part cost could be reduced by the increase of batch size, if the setup time is significant.

The software allows for different kinds of analysis e.g. the combined estimated effects of equipment update (increased equipment costs in combination with increased equipment performance and/or reduced number of operators). Since the company didn´t plan any major equipment updates at the time of the study, these types of scenario anaysis were not performed.

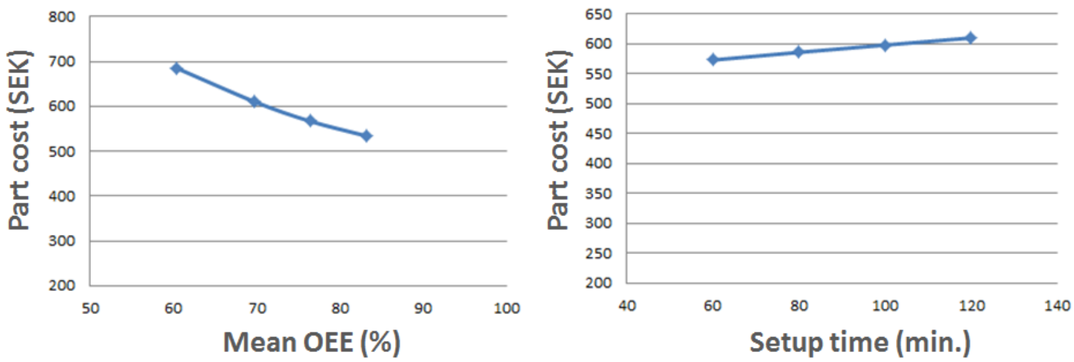

Fig. 4. Part cost as a function of OEE (left) and as a function of setup time (right).

Since the cost analsyis showed that shaving is cheaper than grinding, but the grinding process is considered to provide slightly higher quality, it would be interesting to analyse what would be required for grinding to be more cost efficient. The grinding process is rather time consuming, and there are equipment available on the market today with higher grinding speed.With a new equipment investment of 10 MSEK, the cycle time could be increased by approximately 1/3 of the present cycle time. Using this information in the cost calculation tool, the cost for the grinding process decreases to the extent that the difference between the two alternatives is decreased to half of the preseent cost difference. Still, shaving would be the cheapest choice.

6. CONCLUSIONS AND DISCUSSION

In this case study an analysis of which gear finish method is most cost efficient. This was done by using the selected cost methodology (PPC). This methodology is different from the Standard Costing (SC) method presently used at the company, and provide a larger set of input parameters as well as a different opportunity to allocate costs. The cost methodology used shows that the gear finishing method shaving is cheaper than gringing of gear wheels. The standard cost calculation used at the company came to the same conclusion, but the difference in cost was much greater. With the PPC method shaving was 26 – 46% cheaper and with the standard cost method shaving was 57% cheaper. The difference in results is a consequence of the differences between the PPC and the SC metods. The major differences are the following:

- PPC does not involve overhead costs, since the purpose is to serve as a decision support for production development purposes.
- PPC include a larger set of input parameters than SC, providing opportinities to develop different development scenarios
- In the PPC methodology the costs are calculated by following each part through the value stream. The total part cost is accumulated by adding the costs for each manufacturing step. In SC the department costs are calculated and the cost is a function of the total time a part is manufactured in each department.

With the SC methodology different parts machined following different routes in the same department, could result in the same manufacturing cost. With the PPC methodology each set of equipment are contributing to the total costs. This allows for a richer possibility to identify explicit improvement activities. The possibility to compare the impact of different combined activities (e.g. increased investment costs together with a decreased number of operators).

The follwing comments summarize the conclusions and link back to the three reseach questions posted in the Introduction section:

- Strategic decisions concerning production development issues require more detailed information on costs that those commonly accessible among the standard set of financial measures. The parameter setup should include parameters that can identify differencens between different steps in the two value chains compared here.
- To arrive at clear picture of the combined effects of a set of changes, both technical and financial input needs to be interlinked. They also need to be defined for the resource that is driving costs. If a singel piece of equipment is a cost driver, data about this equipment needs to be aquired and included in the analysis. It is important to include each step in the value stream, in order not to miss out on any improvement opportunity.

- From a cost perspective shaving would be the first choice for finishing of gear wheels in the setup at the case study company. There could however be other strategic factors not considered here, that would influence the final choice of finishing method.

This study on manufacturing costs for different value streams in gear manufacturing has provided the case study company with a new type of cost based decision support, and an Excel tool to be used to analyse differernt development scenarios in manufacturing of gears. How the company will use the decision support and what conclusions they arrive at when weighing costs together with other strategic factors lay beyond the scope of this study.

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