Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 48 (2016) 102 – 107

www.elsevier.com/locate/procedia

23rd CIRP Conference on Life Cycle Engineering

Machining Equipment Life Cycle Costing Model with Dynamic Maintenance Cost

Marcus Bengtsson[a][b], Martin Kurdve[b][c]*

[a]Volvo Construction Equipment, SEM05, SE-63185 Eskilstuna, Sweden
[b]Mälardalen University, box 325, SE-63105 Eskilstuna Sweden
[c]Swerea IVF, box 104, SE-43122, Mölndal, Sweden

* Corresponding author. Tel.: +46 707806132; fax: +46(0)31-276130. *E-mail address:* martin.kurdve@swerea.se

---

Abstract

This paper presents how a Life cycle cost or Total cost of ownership analysis has been performed on machining equipment in a Swedish company. Life cycle cost models used in case studies are compared to an empirical model, used at the company, where dynamic energy, fluid, and maintenance cost are included. Linear and variable factors in the models are analyzed and discussed regarding data availability and estimation, especially with emphasis on maintenance. The life cycle cost aspect of the equipment give guidelines to consider operation, maintenance, tools, energy, and fluid cost in addition to acquisition cost, when designing/specifying the equipment.

Keywords: Life Cycle Costing; Total cost of ownership; sustainable manufacturing; Maintenance management; equipment design

---

1. Introduction

1.1. Background

Researchers suggest use of Life cycle costing (LCC) as a preferred option when making investments, and there are several models and processes described of how to do so. However, in metal working industry when buying machine tools or similar equipment the uses of these models are rare. A survey in UK showed that 78% of industrial respondents rarely use LCC [1]. The academic models given may be too complex and LCC-tools for practical use may miss crucial aspects with regards to machine tools.

There are few case studies published with examples of LCC use in manufacturing and how to get the required data into the models. This paper presents how a Life cycle cost or Total cost of ownership (TCO) analysis has been performed on manufacturing equipment in a Swedish company. In this paper a customer perspective on the LCC is taken (i.e. a TCO) where although the life of equipment can be said to comprise of initiation, pre-study, project, realization, closing on commission, and disposal phase [2], all supplier development costs (R&D, initiation, pre-study, and projecting) are included in the price or acquisition cost.

1.2. Aim and research questions

This paper elaborates on theory and difficulties in practical use of LCC for machine tools. It is a case study of descriptive and empirical character and aims to show how LCC, or TCO, if you will, has been used in practice from the user company perspective, and discuss collection and application of data. The paper presents some theory regarding LCC as well as Life cycle profit (LCP); and suggestions on how to use LCC for machine tools. In the case, LCC is utilized in order to make a decision on whether to acquire a new machine, recondition existing machines, or run the existing machines with an increased cost and risk. Depending on in which phase

doi:10.1016/j.procir.2016.03.110

the LCC is made there might be need to use different types of scenarios, i.e. predictive (in acquisition phase) explorative (early design phase) and normative (pre-acquisition) [3]. This case is mainly predictive.

The research questions for the paper are:

- How can LCC (or TCO) and LCP be used in assessing a new acquisition compared to reconditioning/renovation?
- What are the crucial parameters to include?
- How is stochastic and dynamic maintenance accounted for?

2. Research Methodology (materials and methods)

The researchers have used a combination of literature analysis and action research to facilitate analysis of the findings from a case study research [4].

The case study context is a large automotive driveline systems manufacturing site. The site fabricates, assembles, and paints components. Roughly 700 employees tend roughly 300 manufacturing machines, various assembly equipment, test benches, a hardening shop, and a paint shop. Historical cost outcome of machining equipment were used as input in modeling the future LCC of reconditioning or investing in new equipment.

A review of related research within the area of manufacturing equipment design with aid of LCC, LCP, and TCO is a base for the paper. The major part of the literature analysis was performed in Scopus and Google Scholar to find cited models and to search for case studies involving metalworking equipment.

The researchers have been working in the company's Maintenance engineering department and Production development engineering department respectively. The empirical models have been used in these roles and thus the empirical research mainly points out gaps and possibilities in using these models. Action research is useful to achieve thorough understanding and to get access to data in order to e.g. formulate hypotheses [5], although less useful for proving general theories.

3. Frame of reference/Literature analysis/Background

3.1. Life cycle cost

The term Life Cycle Cost (LCC) applied on manufacturing equipment can be used in different settings and thus have different definitions. First it can be used from the viewpoint of equipment users as in the case studied, or the supplier, (or even the society). With a user's viewpoint LCC and TCO have often been defined in similar ways and both may include not only cost aspects but also LCP, performance and profit aspects [6, 7, 8, 9, 10]. Wååk [11] further separates LCC by two different applications, and Hermann et al. [8] and Thiede et al. [9] give a similar definition of TCO:

- LCC is a measure of a system's or equipment's collected economic consequences during its entire life length [11].
- LCC is a comparative figure for a system's or equipment's collected economic consequences during its entire life length where some simplifications and exclusions have been performed in order to facilitate the utilization of the comparative figure [11].
- TCO subsumes all costs that occur for the operator of a machine [8, 9].

As much as 66% of production equipment's future life cycle cost is tied in the production planning and concept design phase and up to 85% of the total LCC is tied in the system design phase [12, 13], see Fig. 1. However, the cost outcome is more or less reversed as the major costs occur in the use phase of the production equipment. Therefore, having a LCC approach early in the equipment management process is valuable for decision-making.

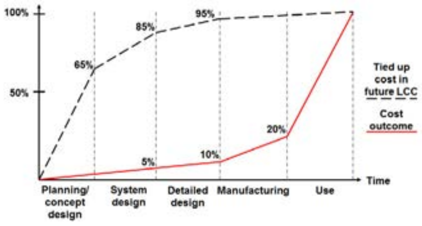

Fig. 1.Cost structures in life cycle costing [13].

In LCC-analysis it is common to separate the analysis in different machine life stages [14]. Only considering acquisition cost can lead to severely higher costs in the operational phase where costs are to a high degree dynamic [8, 9]. The stochastic and variable natures of maintenance cost are mentioned in 3.3. Fig. 2 shows how different costs occur at different life cycle stages and that they vary over time. The dynamics of increasing corrective maintenance in later lifetime is shown. The difference in costs due to market fluctuation is not shown in fig 2, but is important for the difference between historical cost outcome and future LCC.

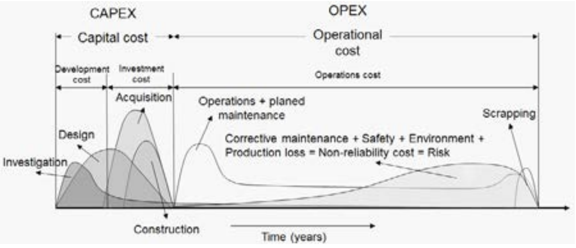

Fig. 2. Life cycle cost analysis [15].

It can be wise to visualize the costs in a Pareto analysis or similar such as a pie chart in order to visualize that the project and acquisition costs are often much smaller than the life support and operations costs. It is quite common to include all supplier costs, research, development design project and equipment production costs into the acquisition cost and to disregard disposal costs [10].

3.2. Life cycle profit

Having a low LCC does not necessarily mean having a high Life Cycle Profit (LCP). There are a number of different options in working to achieve a high LCP. Reducing LCC can be one option; however, sometimes it might be of value to increase LCC in order to reduce or eliminate losses that will increase LCP more than the increases in LCC, see Fig. 3. Spending extra on Acquisition or Life Support to increase capacity or life length give higher LCC but may increase LCP, although it is market dependent.

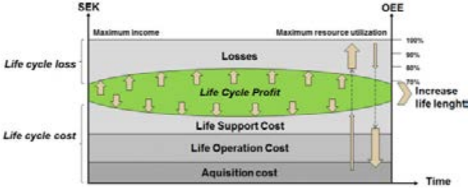

Fig. 3. Life cycle profit concept, visualizing trade-offs in life cycle cost and life cycle losses to increase life cycle profit [16].

Both LCC and LCP are highly influenced by operations running time and production volumes. A company with full order books, running operations 24/7 will obviously have a different situation from a company in a production volume downturn only running their machines in, for instance, daytime. The need of operations will be different which influence LCC. More specific a trade-off between LCC and losses can be made on the basis of the operation needs [16].

In a stable market it is important to work with decreasing cost as well as losses while retaining the goals of utilization. In a booming market, with increasing production volumes, it might be necessary to increase life cycle cost, for instance, life support cost, in order to increase the goal levels. Whereas in a recession, with decreasing production volumes, it might be wise to decrease goal levels so that also life cycle cost can be decreased. All examples imply a higher LCP but accomplished in different ways [16].

3.3. Literature analysis of LCC and LCP models

Although there are several papers describing LCC methodology, there are less papers with case studies presenting LCC in use for machining equipment. In a review article of LCC studies [10] where applications and theoretical LCC-models are investigated, 2/3ds of publications originated from construction, only 6 out of 55 cases were from manufacturing, five of these used deterministic cost data and did not take stochastics into account. Only one was on machining equipment. A search was made in Scopus on “Life cycle cost” OR “Total cost of ownership” AND “case” gave 4713 hits, of which the majority were published after 2001, see Fig 4. Most of these regarded power and energy industry and/or construction industry, in line with [10].

By adding “and machining tools” in the Scopus search reduced the hits to only 12, of these, 6 abstracts were selected, 2 of them were not available for download (conferences without electronic proceedings) and of the remaining only 1 relevant full articles was found [17]. With additional searches on “machine tools” and searches within the reference lists also two more papers with three case studies on machining equipment were found [11, 14]. Finally, dropping AND “case” gave 47 hits of which 2 presented LCC in use for machine tools [18, 19].

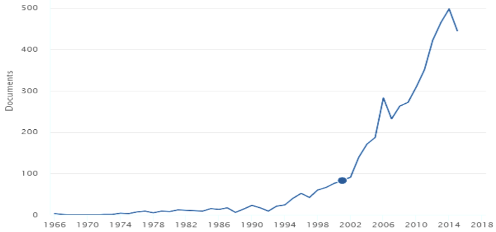

Fig. 4. The number of LCC or TCO case studies published in Scopus.

The use-cases found do not follow a common standard but Zhang and Haapala [17] show a case, where tool costs are higher than labor costs which are higher than energy and coolant costs; however acquisition, end of life and maintenance costs are not included. Heinemann et al [19] similarly address energy cost of machine, infrastructure and building. Lad and Kulkarni [18] instead only address maintenance costs. Enparantza et al. [14] show two cases where acquisition and man-time costs are the largest while also tools, energy, fluids and spare parts give significant contributions. Wååk’s [11] case show man-time (operation and maint.) is half the cost, material (incl. tools and fluids) is a third of the cost and acquisition costs stands for the rest. In conclusion the following has been included in practice:

Acquisition costs (including project, installation, tests and all suppliers internal costs etc.)

Running costs:

- *Operator and maintenance man-time*
- *Tools and materials (incl spare parts)*
- *Cost of stopped line and lost production(one case[18])*
- *Energy and media (electricity, press.air, fluids, lubricants)*
- *Waste management (e.g. cutting fluids, chips recycling)*

End of life costs (is usually omitted)

The activities included in a LCC should be all those causing direct costs or benefits to the decision-maker during the economic life of the equipment [3], (i.e., a LCP approach) and e.g. energy and maintenance cannot be deducted by static calculations. Two types of dynamics, time dependent variation and stochastics have to be accounted for [8, 9].

Some of the LCC and most of the LCP data depend on the user environment in combination with the design, while some of the LCC data may be mainly dependent on the equipment design, e.g. MTBF may be mainly due to component design (although maintenance cost also depends on infrastructure), while MTTR depends not only on the design for maintenance but also on the skill and availability of maintenance personnel. Similarly, plant staffing (number of shifts etc.) will be important in some of the cost parameters [20].

There are two dynamic implications, time dependent variation and uncertainty/stochastic. For time dependency, ex-post experience may give estimates and some distributions may be used e.g. for increase of breakdowns [20], for stochastic uncertainties’ what-if scenarios [3], possibly an

FMEA type cost risk analysis could be applied and historical data may give the probability of different events [15]. Alternatively to overcome difficulties, stochastic uncertainties' can be analyzed using simulation [8, 21] or by calculating using failure distributions and QFD matrix or similar [18, 22]. Material Flow Cost Accounting (MFCA) or Resource Consumption Accounting (RCA) is operations management based and may be useful for input of operating cost estimates [20]. Finally in practice it may be most important to keep the model as simple as possible [11] since the result should be easy to communicate to decision makers.

4. Case study

To collect empirical evidence, a case study was performed where dynamic energy, fluid and maintenance cost were included. Linear and variable factors in the models were analyzed.

4.1. Case study context

The manufacturing site continuously works with optimizing the procurement processes. An alternative in procurement is to recondition existing machines instead of acquiring new. A decision-making tool in this process that has been exploited is a LCC applied on the various options.

The case in this study regards two turning machines fabricating components to the automotive driveline industry. The existing turning machines had surpassed their life lengths regarding electrical system (control system) and were in need of mechanical overhaul. Three options were considered: 1) *purchasing one new turning machine* (development in system capacity makes it possible to run the same operation with only one turning machine), 2) *recondition the existing machines*, both electronically and mechanically, and 3) *run existing machines* but with increased cost (e.g. spare parts and maintenance) and risk (e.g. additional cost for downtime). Below, the process of developing the model as well as results from using the model is presented. The results are partly fictitious for confidentiality reasons. All of the options are evaluated within the sites infrastructure, e.g. using central metal working fluid systems with standardized fluids and standardized lubricants, which keep maintenance costs for support systems down. Earlier work has shown the importance of equipment design with regards to life support cost emphasizing that equipment should be easy to clean, easy to maintain and easy to monitor and control [23].

4.2. Life cycle cost-model

The LCC-model used was developed through a cross-functional team within the manufacturing site. The team used various sources of literature as input into the development [15, 16, 24]. The cross-functional team consisted of employees from e.g.: maintenance, production engineering, production management, finance, logistics etc. The cost parameters in the model were divided into four stages: project costs, acquisition costs, life support costs, and life operations costs, close to what has been suggested by [14], see Table 1. End of life cost was neglected since there is low or no cost in recycling of the material. The project costs include all related (internal) costs to the project of acquiring a new machine or the reconditioning of an existing machine. Mostly wages, travel, and allowances are included in the cost but it could also include, e.g. test-runs of the products to be produced. In the acquisition cost, all (external) costs related to the equipment and installation are brought up. It includes for instance, the equipment or reconditioning cost, cost for tools and spare parts, cost for installation, including costs for running buffers when installing new equipment or reconditioning existing. In life support cost, the dynamic maintenance costs are highlighted. In this model cost for wages (repairman and maintenance engineers), external services, and spare parts are brought up as stochastic costs where the average risk of occurrence (based on historical data and supplier data) is included. In life operation cost, cost for wages (operators, measuring technicians, production engineering, etc.), tools and fixtures, rent, energy, media (cutting fluids), cost of poor quality, and down time are brought up, these are in turn dependent on the production rate which in turn is dependent on the dynamic market situation. The model starts at year -2 years to include project time but it can easily be arranged to start at year 0 if wished. The model can be arranged to run calculation for as many years as wished, but 8-16 years are most common. In below case, the LCC is run from -2 to 12 years for all options, in order to simplify comparison, even though, particularly, the new machine option will typically have a longer technical life length than 12 years. The model in itself is developed in Excel with one sheet per option as well as two sheets with overall results. One result sheet contains a summation on the net present value of the options, see Fig. 6. The other result sheet contains breakdown of cost structures for the options as pie charts, see Fig 5. The net present value is calculated based on 12% weighted average cost of capital.

4.3. Case study results

The cost data input to LCC calculation of the three options were collected in the same cross-functional team that developed the LCC-model. Historic maintenance and operational data of same and similar machines were used to estimate (stochastic) costs. Cost history has been the foundation for estimation of the future costs of all three options. With regards to energy costs the internal guidelines for estimation of future rising energy prices have been used.

Viewing the three options as explained above in more detail will tell more on the cost structure of machines during its life cycle, see example in Fig. 6. The first option, replacing the existing turning machines with one new will imply a higher investment cost but a decreased cost for both life support as well as life operations cost. The cost for spare parts and running maintenance will be decreased. As the existing machines will be replaced with one machine, cost will also be reduced in, for instance, electricity, media, tools, cost of operations (wages). This alternative will also be the one alternative that will give the longest life length. The second option, recondition the existing machines, will have a smaller investment cost for reconditioning investment. However, life support and life operations cost will be larger than in the first option as two machines will have to be serviced and tended to. The third option is the cheapest from an investment perspective; it needs purchasing of spare parts to have in spare part storage at site, more or less just to be safe. The option will be the most expensive though in both life support and life operations cost. The LCP risks is viewed as high in this option as one or both of the machines can breakdown and require great maintenance actions that will be both lengthy as well as expensive. From a total cost perspective it looks as the first option is to recommend even if the investment cost are greater.

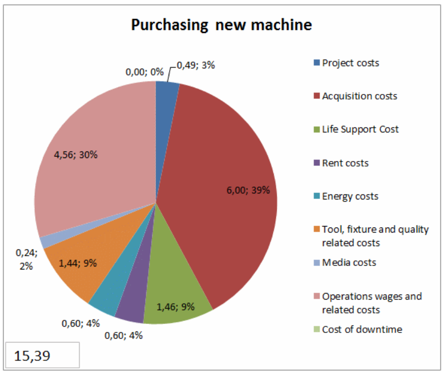

Fig. 5. The figure visualizes the cost structure of the option of purchasing one new machine for 12 years.

This birds-eye view of costs is not only beneficial from an investment perspective but can also be used and updated during an entire equipment life cycle. Various options during the entire life cycle will have different financial outcomes. The view, Pareto or pie chart, also gives visualization on what is possible to affect in terms of costs.

If viewing the results from a net present value perspective also "payback times" on different options become visible, see Fig. 6. Still the first option, acquiring a new machine, looks to be the most financially sound. However, this is only the case if it is certain that the manufacturing of this component is stable and it is certain that it will be in operations for several years. If the component will drop out from the market in two or three years it might be more financial to run the existing machines as they are and risk an increased life support cost.

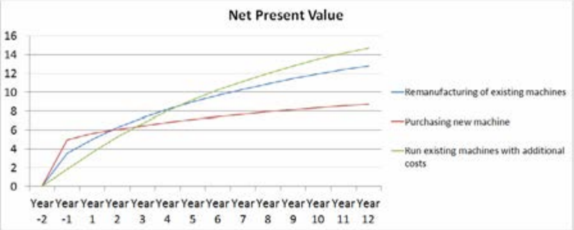

Fig. 6. Net present value of the three options.

Table 1. The cost parameters in the LCC-model.

Hierarchy 1	Hierarchy 2	Influencing factors
Project costs	Wages and related costs	Production engineering
		Operators
		Project managers
		Maintenance
Acquisition costs	Equipment costs	
	Reconditioning costs	
	Tool cost	
	Spare part cost	
	Installation cost	
	Education and training cost	
	Cost for buffer/lego production during installation/ reconditioning	
	Cost for running-in (ramp-up)	
	Future scrapping cost	
Life support cost	Wages and related costs	Repairmen
		Maintenance engineering
	Cost for external services	
	Cost for acute spare parts	
	Cost for stored spare parts	
Life operation cost	Wages and related costs	Operators
		Measuring technicians
		Production engineering
		Material handling
	Tools and fixtures	
	Rent costs	Space
		Heating
		Ventilation
	Energy costs	Electricity
		Gas
		Compressed air
	Media costs	Water
		Emulsions
		Cutting fluids
	Cost of poor quality	
	Downtime cost due to unavailability	

5. Discussion

In the case study, project and acquisition costs are fairly easy to obtain from previous projects since several projects are run every year. Most of the deterministic data on life support and operation costs were acquired from internal maintenance and operation databases and experiences, possible since the user is a large company with many years of machining experience. Suppliers cannot be expected to give estimates of costs that are dependent on the user production system, e.g., many of the costs like man-time, cost of downtime, tools, quality, and media. Cost for acquisition and reconditioning, spare parts and possibly energy can be estimated by suppliers.

This may be a reason why those three factors are most described in literature and standardized models. Energy and fluid price estimates may be volatile over time but since energy costs in these cases are less than 10% that is an acceptable risk. However the risk of downtime and maintenance is a stochastic risk and may need statistical calculations or FMEA type risk-calculations. Regarding stochastic costs, the available internal statistical data may not give accurate estimates. Furthermore the market of the products may fail or boom which will affect downtime and operation costs. In order to handle this, additional cost-risk-analysis is proposed.

An important experience from the company is to use central cooling to lower electrical use for the machine as well as the need for facility ventilation, lower cost of HFC-control, and risk of quality and breakdown issues due to high temperature. Machines with no need of cooling will use less energy overall (need of cooling means that unnecessary excess heat is generated). Centralized cutting fluid systems also decrease man-time cost for fluid maintenance, filters etc.

Although several papers present LCC methodology, less presents actual use off LCC for machining equipment.

Performing LCC analysis in early phases of production system design, where capital intense decision needs to be made can increase the awareness on different options from a financial perspective. Thereby visualizing that over-hasty or ill-considered potential “savings” in the early phases may have undesired potential of costing much more in later life cycle stages. The major problem is determining the significant costs.

Since a great part of future life cycle costs are determined in an early stage LCC is an important activity to perform. However, LCC can be used all through the life cycle of production equipment as choices on different options in midlife can also have great impact on cost structures.

6. Conclusion

The LCC/TCO aspects of the equipment can be used to give guidelines on what components to consider when designing/specifying the equipment. In purchasing machining equipment in addition to a functional design with short set-up and changeover times, aspects like operation man-time, energy use, maintenance and repair costs, downtime costs, process fluids and chemicals, some of which increase with equipment age, should be considered. It gives implications on equipment design to be easy to maintain, easy to clean and easy to operate. Stochastic parameters may require additional cost risk analysis or simulation.

Acknowledgements

This research has been funded by the Knowledge Foundation, VINNOVA, and Mälardalen University. It is a part of the initiative for Excellence in Production Research (XPRES), cooperation between Mälardalen University, the Royal Institute of Technology, and Swerea. XPRES is a governmentally funded Swedish strategic initiative for research excellence within Production Engineering.

References

[1] Higham A., Fortune C. James H. Life cycle costing: evaluating its use in UK practice, Structural Survey; 2015, Vol. 33 Iss 1 pp. 73 – 87.

[2] Wiktorsson, M. Consideration of Legacy Structures Enabling a Double Helix Development of Production Systems and Products. Technology and Manufacturing Process Selection. Springer London, 2014.p. 21-32.

[3] Höjer M. Alroth S. Dreborg K-H, Ekvall T. Hjelm O. Hochschorner E. Nilsson M. Palm V. Scenarios in selected tools for environmental systems analysis. J. of Cleaner Production 2008; 16.18:1958-1970.

[4] Yin, RK., Applications of case study research 2nd ed. London: Sage; 2003.

[5] Coghlan, D., Brannick, T. Doing Action Research in your Own Organization, 2nd ed. London: Sage; 2005.

[6] Rühl, J., and Fleischer J. Life cycle performance for manufactures of production facilities. 14th CIRP international conference on life cycle engineering. Tokyo, Japan. 2007.

[7] Geissdoerfer, K, Gleich, R, Wald, A, Motwani, J. Towards a standardised approach to life cycle cost analysis. Int. J. of Procurement Management 2012; 5.3: 253-272.

[8] C. Herrmann , S. Kara & S. Thiede (2011) Dynamic life cycle costing based on lifetime prediction, International Journal of Sustainable Engineering, 4:3, 224-235, DOI:10.1080/19397038.2010.549245

[9] Thiede, S, Spiering, T, Kohlitz, S, Herrmann, C, Kara, S. Dynamic total cost of ownership (TCO) calculation of injection moulding machines. In Leveraging Technology for a Sustainable World 2012 pp. 275-280. Springer Berlin Heidelberg.

[10] Korpi, E, and Ala-Risku T. Life cycle costing: a review of published case studies. Managerial Auditing Journal, 2008; 23.3: 240-261.

[11] Wååk, O. LCC – Ett beslutsverktyg som ger effektivare tekniska utrustningar med lägre totalkostnad (in Swedish). Systecon Luleå University, Sweden 1992

[12] Nakajima S. Introduction to TPM. Cambridge: Productivity Press; 1988.

[13] Hagberg L, Henriksson T. Underhåll i världsklass (in Swedish). 1st ed. Lund: OEE Consultants; 2010.

[14] Enparantza R, Revilla O, Azkarate A, Zendoia J. A life cycle cost calculation and management system for machine tools. 13th CIRP international conference on life cycle engineering; 2006. p. 717-722.

[15] Márquez AC, de León PM, Fernández G, Márques CP, Campos ML. The maintenance management framework A practical view to maintenance management. J of Quality in Maintenance Eng., 2009; 15.2:167-178.

[16] Ahlmann H. Maintenance effectiveness and economic models in the terotechnology concept. Maintenance Management International; 1984; 4:131-139.

[17] Zhang, H, Haapala, KR. Integrating sustainable manufacturing assessment into decision making for a production work cell. J of Cleaner Production, 2015; 105:52-63

[18] Lad, B. K., Kulkarni, M. S. (2012). Optimal maintenance schedule decisions for machine tools considering the user's cost structure. International Journal of Production Research, 50(20), 5859-5871.

[19] Heinemann, T., Schraml, P., Thiede, S., Eisele, C., Herrmann, C., & Abele, E. (2014). Hierarchical evaluation of environmental impacts from manufacturing system and machine perspective. Procedia CIRP, 15, 141-146.

[20] Jönsson, M. Cost-conscious manufacturing–Models and methods for analyzing present and future performance from a cost perspective. Ph.D thesis. Lund University, 2012

[21] Kleyner, A. and Sandborn, P., 2008. Minimizing life cycle cost by managing product reliability via validation plan and warranty return cost. International Journal of Production Economics, 112 (2), 796-807

[22] Kobayashi H. A systemsatic approach to eco-innovative product designbased on life cycle planning. Journal of Advanced Engineering Informatics 2006; 20.2:113-125.

[23] Kurdve, M, Daghini L. Sustainable metal working fluid systems: best and common practices for metal working fluid maintenance and system design in Swedish industry. Int. J. of Sust. Manuf. 2012; 2.4:276-292.

[24] Woodward DG. Life cycle costing-theory, information acquisition and application. Int J of Project Management; 1997; 15.6:335-344.