# ANALYTICAL HIERARCHY PROCESS APPLICATION IN GREENNESS COMPARISON OF MACHINE TOOL SYSTEM

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*To my beloved mother and father and brothers who are my motivations*
*for continuing my life*
*Thanks for the love, supports and memories*

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# ABSTRACT

Recently, some activities for environmental protection have been attempted to reduce environmental burdens in many fields. The manufacturing field also requires such reduction. Machine tools are mother machines and widely utilized in the manufacturing fields. Therefore, one of the most important issues to be solved is to develop a system to evaluate environmental burden related to the machine tools. The development of the evaluation system enables us to select among different machining process. This project has developed a framework based on which different machining process can be compared in terms of their environmental impact. Several environmental indicators of machining process were identified based on greenness concept and those with main influence were selected based on expert opinion and by applying MINITAB 14. The analytical hierarchy process (AHP) was mainly employed as it provides a comprehensive and rational environment for structuring the decision problem at each level. The priority of each indicator was also obtained by AHP method and using EXPERT CHOICE 11.5. These indicators and their assigned priorities were then used to develop the framework. Using the framework developed in this research different machining process can be compared from the greenness aspect.

# ABSTRAK

Baru-baru ini, beberapa aktiviti bagi perlindungan alam sekitar telah cuba untuk mengurangkan beban alam sekitar dalam pelbagai bidang. Bidang pembuatan juga memerlukan pengurangan. Mesin alat merupakan mesin utama dan digunakan secara meluas dalam bidang pembuatan. Oleh itu, salah satu isu yang paling penting yang perlu diselesaikan adalah untuk membangunkan satu sistem untuk menilai beban kepada alam sekitar yang berkaitan dengan alat mesin. Pembangunan sistem penilaian membolehkan kita untuk memilih antara proses pemesinan yang berbeza. Projek ini telah membangunkan satu rangka kerja berasaskan proses pemesinan yang berbeza yang boleh dibandingkan dari segi kesan alam sekitar mereka. Beberapa penunjuk alam sekitar proses pemesinan telah dikenal pasti berdasarkan konsep kehijauan dan mereka dengan pengaruh utama telah dipilih berdasarkan pendapat pakar dan dengan menggunakan MINITAB 14. Proses hierarki analisis (AHP) terutamanya pekerja kerana ia menyediakan persekitaran yang menyeluruh dan rasional untuk penstrukturan masalah keputusan di setiap peringkat. Keutamaan setiap petunjuk juga telah diperolehi oleh kaedah AHP dan menggunakan EXPERT CHOICE 11.5. Petunjuk dan keutamaan yang diberikan mereka kemudiannya digunakan untuk membangunkan rangka kerja. Menggunakan rangka kerja yang dibangunkan dalam proses ini pemesinan penyelidikan yang berbeza boleh dibandingkan dari perspektif kehijauan.

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| | |
|---|---|
| MTS | Machine Tool System |
| GHG | Greenhouse Gas |
| EHS | Environmental, Health, and Safety |
| AHP | Analytical Hierarchy Process |
| UNEP | United Nations Environment Program |
| BUE | Built-up Edge |
| HSS | High-speed Steel |
| PVD | Physical Vapor Deposition |
| CVD | Chemical Vapor Deposition |
| DM | Dry Machining |
| NDM | Near-dry Machining |
| CLF | Cooling Lubricating Fluid |
| VOC | Volatile Organic Compound |
| MSDS | Material Safety Data Sheet |
| LCA | Life Cycle Assessment |
| MQL | Minimum Quantity Lubrication |
| LCIA | Life Cycle Impact Assessment |
| MWF | Metal Working Fluid |
| NMVOCs | Non-CH4 Volatile Organic Compounds |
| CR | Consistency Ratio |
| CI | Consistency Index |
| RI | Random Index |

# LIST OF SYMBOLS

| | |
|---|---|
| $\mu$ | Mean of population |
| n | Sample size |
| $\sigma^2$ | Variance |
| t | Test statistic of t-distribution |
| $\bar{x}$ | Sample mean |
| $\mu_0$ | Value of interest |
| s | Sample standard deviation |
| $\alpha$ | Significance level |
| $H_0$ | Null hypothesis |
| $H_1$ | Alternative hypothesis |
| $\boldsymbol{\lambda}_{max}$ | Maximum eigen value of the matrix of the importance ratio |
| G | Geometric mean |
| $w_i$ | Final weight of indicator i |
| $x_i$ | Normalized value of indicator i |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

The world today finds itself in the worst financial, economic, and environmental crises in generations. Twenty percent of people in the developing world lack access to sufficient clean water and people are increasingly affected by climate change and its subsequent consequences (Cai *et al*., 2011).

Scientists have almost universally accepted that global climate change is a reality. As a result, many nations are making concerted efforts to reduce the buildup of carbon dioxide (CO2) and other greenhouse gas (GHG) emissions either by reducing the use of fossil fuels or by finding ways to prevent emissions from entering the atmosphere (Global Insight, 2008).

Environmental standards are intended to motivate any organization to be 'clean and green'. They are generally voluntary and based on the principle of continuous improvement. The ISO 14001 standard is the most widespread environmental-related standard. It prescribes how a firm can develop an environmental policy, identify environmental aspects and impacts of its activities, products and services, define the significance of these impacts, rank them, identify legal and other requirements governing the organization's operation, establish objectives and targets, implement programs to meet those standards, establish an

auditing system and procedures for management review and implement corrective action, if needed. The latest data available indicates that up to December 2008, at least 188,815 ISO 14001 certificates had been issued in 155 countries (Grolleau *et al*., 2012).

The notion of green jobs has become something of an emblem of a more sustainable economy and society, that aims to preserve the environment for both present and future generations and to be more equitable and inclusive of all people and all countries. Determining what is ultimately sustainable has become highly contested, resulting in the green label being applied to a wide range of occupations (Goods, 2011).

In recent years, going green has become a strategic priority in manufacturing, which has evolved from the growing awareness of the need for environmentally friendly processes and products. Recent trends in developing new machining strategies able to support environmental protection and prevention of pollution in balance with socioeconomic needs and technical requirements inevitably require significant efforts in fundamental understanding of the actual energy and material flows needed to meet the machining requirements (Avram *et al.*, 2010).

Machining is unique, among manufacturing processes, in that it can be used both to fabricate products and to finish products (Kundrák *et al*., 2006). Machining is a general term that may be applied to all material removal operations. Conceptually, material removal operations should be avoided since they focus on eliminating material from a part with some inherent value. Technological advancements in casting and forming processes are constantly being sought so as to avoid unnecessary material removal operations. Still, material removal operations are widely used and are capable of creating geometries, surface finishes, and providing the precision not achievable by other operations. Traditional machining or cutting operations rely on a shearing mechanism in which the action of a sharp cutting tool is used to remove material. Non-traditional machining operations do not rely on as hearing mechanism to remove material; instead, they utilize thermal, chemical, and electro-chemical

means to eliminate unwanted material (Sutherland and Gunter, 2001).

To an extent, all industrial processes have pollution issues and waste streams. For the most part, metal fabrication processes do not generate wastes as hazardous as those produced by other processes involved in the manufacturing of complex metal parts (i.e., metal finishing or metal coating). However, cutting and shaping processes may generate significant volumes of spent metal working fluid, which require proper storage, handling, manifesting and overall management. In metal shaping and cutting operations, the generation of spent metalworking fluids and scrap metal are the two major waste streams (NEWMOA and US EPA, 2001).

This study attempts to identify the major environmental indicators of machining process by employing greenness concept. These indicators will then be used to develop a model to compare different machining process from environmental aspect.

## 1.2 Background of Study

In recent years, increased attention to the environment is presenting manufacturers with new challenges. The manufacturing industry produces a considerable amount of non-hazardous and hazardous waste each year. These wastes include: sand with additives produced by metal-casting operations, fluids from heat treating, and welding gases. Ever more attention is being focused on reducing the environmental, health, and safety (EHS) consequences of process waste, as reflected by the tightening standards, increased fines, and growing litigation associated with the waste. It is clear that organizations that are to be competitive in the future must be able to avoid minimize the costs concomitant with being (or not being) “green” (Sutherland and Gunter, 2001).

One of the critical issues surrounding the discussion of greenness and green jobs is that there is no agreed understanding of the term or measures to ensure claims of ‘greenness’ (Goods, 2011). The International Labor Organization (ILO) defines a green job as one, which simply “reduces the environmental impact of enterprises and economic sectors, ultimately to levels that are (ecologically) sustainable” (2008).

The society has generally two kinds of interactions with the environment: as a source for natural resources, and as a landfill for solid, gaseous and liquid wastes. The damages act as depletion and the reduced quantity and quality of resources and as unbalancing the conditions of previously natural processes. The change in balance takes usually years to detect and can be influenced by a variety of factors. This issue makes identification and isolation of the problems difficult and sometimes controversial. The studies done in this direction leads to identification of several aspects concerning the environment depreciation: ozone depletion, global warming, acidification, and eutrophication.

The interest in pollution prevention is continuously growing. This determines several industries, including manufacturing, to develop and implement various environmentally-friendly strategies. Product design, selection of raw materials, manufacturing process, product delivery and reuse or recycling options for products’ end of life have influences for the of environmental degradation level. The manufacturing processes seem to be quite benign compared to materials extraction and primary processing, but manufacturing processes set many of the requirements for primary processing outputs. Normally, the processes with higher scrap rates require more energy in primary processing, while processes which use large quantities of recycled materials will have reduced primary energy needs.

Concluding the manufacturing uses materials and energy (not directly incorporated into the product) and then eliminates them as wastes or emissions to the environment. In addition to work pieces, tools and energy, a second environmentally important category of auxiliary materials used in manufacturing processes is metalworking fluids, cleaning fluids and coatings. Lubricants and solvents are of

particular concern, being used to remove the coolant or lubricants from the surface of the parts (Gutowski, 2004).

Figure 1 depicts an input-output relationship for a traditional machining operation. As is evident from the figure, there are a number of outputs from the process in addition to the desired product. Recently, the role of cutting fluids in machining operations has received increased attention because of environmental and industrial hygiene concerns. Fluid splashing, spillage, and chip carry-off can lead to inadvertent contamination of groundwater with the fluid as well as metal fines (Sutherland and Gunter, 2001).

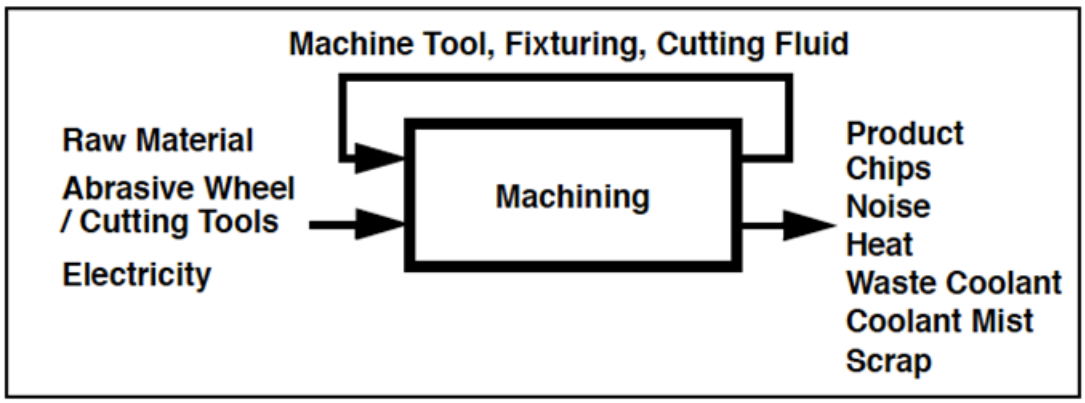


**Figure 1.1** Input-Output diagram of a traditional machining process

*Source*: Sutherland and Gunter, 2001

Even though cutting fluids have been seen traditionally as a solution rather than a problem, they have variety of environmental liabilities associated with human chronic diseases and costly schemes applied for their disposal. According to German automotive industry surveys, 7% to 17% of the manufacturing cost of components is attributable to cutting fluids when associated costs of cutting fluid procurement, monitoring, maintenance, health precautions, and absenteeism are taken into account and are several times higher than the tool costs which in the same report are quoted at 2% to 4% (Avram *et al*., 2010).

Metal fabricators, machines, and researchers have been increasingly interested in the elimination of metalworking fluid use in the machining of ferrous and nonferrous metals. Dry machining (DM) may alleviate some of the following fluid management issues:

i. Need for continuous treatment of the fluid
ii. Need to maintain fluid composition
iii. Disposal of the fluid if and when it reaches the end of its useful life
iv. Continual use of biocides to prevent or reduce microbial growth (NEWMOA and US EPA, 2001)

Efforts are currently focused to efficient consumption of resources and conserve energy, minimize the environmental effects of energy production and improve waste management system. Several aspects regarding the environmental impact of manufacturing process and the necessity of changed process for increasing their sustainability and thus, preventing polluting generation has been presented by Fratila (2012). It is mainly focused on investigating various aspects of machining process from an environmental perspective.

## 1.3 Problem Statement

In the literature, various papers proposed decision support system models based on the analytical hierarchy process in order to solve the machine tool selection problem. However, the selection is made mainly based on process requirements with respect to technical and economic criteria and environmental criteria were often ignored.

Generally, research studies focus on the cutting energy in machining systems, that is, the amount of energy required to remove a specific amount of material. However, from the point of view of green manufacturing, the energy consumption

should be considered systematically for the whole machine tool system and not limited solely to the cutting energy which represents just a variable amount highly dependent on process parameters.

Although significant information related to the performance of machine tools, machining processes, cutting tools, and materials already exists, there is no unified methodology to combine all this information to give a meaningful justification for the choice of a certain machining strategy in the manufacturing of a specific part. Although major environmental hazards in machining operations are due to the use of cutting fluids, direct exposure of the production worker to these fluids can lead to skin diseases and respiratory disorders and other increased health risks.

## 1.4 Research Question

i. What are the major categories based on which green concept is defined?
ii. What are the environmental indicators of machining process in each category?
iii. How important is each of the indicators relative to others?
iv. What is the method to be used to combine the indicators?
v. How could the different machining strategies be compared based on the indicators?

## 1.5 Objectives of Study

Objectives of this study are:

i. Identifying the major environmental indicators of machining process

ii. Developing a model for comparing machining process based on environmental indicators

## 1.6 Scope of Study

i. This study considers only the environmental impact of the material removal process itself but not the impact of the associated processes such as the material preparation, and the scrap processing.
ii. A five-point Likert scale questionnaire and an AHP questionnaire was used during this research.
iii. MINI TAB 14 and SPSS (PASW) 18 Software were used for analyzing of data.
iv. This project has adopted analytical hierarchy process (AHP) method to derive weights of indicators and EXPERT CHOICE 11.5 software to analyze the resulting data.

## 1.7 Significance of Findings

The adoption of new machining strategies is an important issue for any machine tool system. In real machining decision conditions, more than one criterion is present and the problem becomes a multi-criteria decision-making one. If simultaneous improvements were feasible, then a part could be machined with zero cost, perfect quality, and no environmental impact which is totally unrealistic. Actually, the improvement of one factor is not always possible without the worsening of another one when considering a complex system and an elaborate set of criteria.

Since the simultaneous improvement of all the criteria to be taken into account is almost impossible to achieve, the aim of the proposed method is to find a compromise solution by using the analytic hierarchy process (AHP), which provides a comprehensive and rational environment for structuring the decision problem at each level. The model can be used for any machining process as long as it is adopted within the scope.

Furthermore, not only the minimization or complete reduction of the cutting fluid in machining processes as well as the decrease of the energy requirements in machining could be a powerful indicator for sustainable manufacturing but also the companies have the potential to save costs and to improve their environmental performance even the production stays on the same size or it is decreased. This is possible with the implementation of the sustainability principles in the manufacturing processes. Finally, developed model helps the policy maker and decision maker to know where to put their investment and what policy can help most to make the transformation toward green economy and green environment faster.

## 1.8 Research Organization

This research consists of six (6) chapters and the flow of them is as follows: Chapter 1 is the introduction of the study. This chapter explains about the research statement, problem statement, objective of study, scope of study and matters that have relate to the introduction of project.

Chapter 2 is the literature review of the project and contains on several topic related to this study such as green jobs, machining pollution, machine tool system. Books, journals and previous works are reviewed in order to get a better and clear picture of the current situation of the study being undertaken.

Next, Chapter 3 provides the detail in methodology used in collecting information and data that reliable towards the project. The methodology covers all the steps that take place during this project execution and shown in the flow chart of research.

Chapter 4 highlights the results and data from the questionnaires that being distributed to respondent who comes from the experts.

Chapter 5 covers the final result presentation, and the development of evaluation framework. In this chapter a case study is covered as well.

Chapter 6 consists of a summary of whole study. In this chapter recommendations and suggestion for future research essential to minimize and eliminate machining environmental impact is provided.

## 1.9 Conclusion

This chapter described a general introduction about the entire study including background of the problem, scope and objective of this research. The next chapter covers the literature review on the related topics relevant to the project.

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