THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

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Environmental analysis of Mechanical Engineering Workshop Conventional Manufacturing Processes.

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Notation:

α_b	Back rake angle
α_s	Side rake angle
α_s	Helix angle
ρ	Density
μ	Kinematic viscosity
ν	Dynamic viscosity
Cp	Specific heat capacity
η	Efficiency
d	Depth of cut
D	Diameter
f	Feed rate
M	Mass
W	width
σ	Tensile strength
k	Thermal conductivity
Kc	MRR constant
Lc	Cutting length
Gr	Garshoffs number
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
V	Linear speed
w	Angular speed
N	Rotational speed
T	Torque
t	Time
ti	Initial temperature
tf	Final temperature
Q	Energy
Ce	End cutting edge angle
Cs	Side cutting edge angle.
Ra	Relief angle.
SRA	Side relief angle.
SERA	Secondary Relief angle
Mi	Material intensity
Qi	Energy intensity

Te	Toxic intensity
EBM	Environmental Benign Manufacturing
pH	potential of Hydrogen
MRR	Material removal rate
LD	Lethal dosage
TLV	Threshold limit value

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Summary

The environmental analysis of the work shop involved the evaluation of selected conventional manufacturing processes using a developed process level system based on material usage, energy consumption, toxic reduction and cooling medium consumption.

The model identified and accounted for all the processes highlighting the short falls of each process in terms of its environmental performance. Then the next step was to mitigate the problems so as to elevate the performance to the required environmental standards.

Further alternative processes were suggested, that was machining using compressed air as the cooling medium. All the processes were compared against their performances and thereafter a cost analysis was done.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Conventional machining is a material removal process that typically involves the cutting of metals using various cutting tools. It is a process that is particularly useful due to its reasonably high dimensional accuracy, flexibility of its process and cost effectiveness in producing part components. However since it is inherently a process that involves material removal, conventional machining is wasteful in its material use and energy consumption. In addition its operations are ubiquitous in material manufacturing, the coolants and lubricants used in machining processes generating water and air pollution problems; which can further contaminate scrap metal which is recyclable. As a result, measures should be put in place, leading to the development of methods aiming to reduce:

- Energy consumption,
- Material wastage,
- Coolant consumption and its environmental ramifications,
- Toxic emissions and
- Eventually reduce the manufacturing costs.

These do have an impact on the cost control and carry important environmental ramifications for instance cutting fluids with serious health and environmental issues stemming from their use and disposal; these are often studied as an area for potential improvements.

While a great deal of research has been conducted in this area, much of it has been focused on the process level activities and improvements, that is optimization of material use, reducing coolant and toxic emission as suggested by Dahmus and

Gutowski (1). In Environmental Benign Manufacturing (EBM) Life Cycle Analysis is adopted for improving efficiency and material (1); this involves reducing liability and establishes the baseline for analyzing input related costs, as well as output related costs by reducing wastes and emissions. To go beyond this stage requires a corporate strategy to target opportunities and an organizational structure to facilitate the implementation. This then presents a system level analysis of machining, which not only considers the environmental impact of the material removal process itself but also the impact of associated processes such as material preparation, cutting fluid and lubrication. The system views results in a more complete assessment of the process.

1.1.1 DRY MACHINING

The challenge for manufacturing is to be able to produce machined products in an environmental and sustainable way without increasing the cost. Traditional cutting fluid have been used to remove heat from the work piece due to the thermal capacity and conductivity of the cutting fluid. But due to numerous environmental and health hazards, the removal of cutting fuid is an absolute necessity which may be expensive and requires appropriate regulatory process to be put in place.

The largest hurdle to the use of dry machining is the short life of the tool due to the low convective heat removal rates associated with convectional air cooling methods.

Methods have been developed over the years to over come the problems faced in dry machining some of these are summarized by Broswell and Chandratilleke (2) include:

(i) Coating tools gives the tools longer life than non coated tools this is because coating provides insulation and slight lubrication in cutting thus reducing the problem of reduced tool life and failure experienced in dry machining. Materials used for tool cutting include Titanium Aluminum Nitride (TiAN).

(ii) Use of passivating air is considered as an alternative to the traditional dry machining methods. For instance the use of vortex air cooling clearly indcate indicate a significant reduction in environmental impacts and in tool tip temperature.

1.1.2 NEAR -DRY MACHINING

In near dry machining the cutting fluid is supplied in a measured quantity to the cutting point. This makes it an expensive undertaking as it involves the set up of external equipment. For instance the fluid is carried to the nozzle by compressed air from a compressor; further the amount cutting fluid usually vegetable oil is controlled by a metering device as suggested by Rob Myers (3).

1.2 SAFETY REGULATIONS

Apart from complying to the required safety, health and quality regulations, the project attempted to increase the environmental and quality performance by:

- Abandonment of environmentally unacceptable actions and mitigation to the point of acceptability of the environmental effects of proposals which are improved.
- The need to identify and predict the effects on the environment and human health and well being of legislative proposals, policies, programs, projects and operational procedures.
- To prevent environmental damage by requiring implementation of feasible alternatives or mitigation measures.

1.3 PROBLEM STATEMENT

The practice is most work shops in recent years has neglected the importance of recognizing sustainable and environmental benign manufacturing leading to an increase in material and energy usage, increase in toxicity as well as material wastes. This consequently leads to high input and output costs.

From reported research conducted by Dahmus and Gutowski (1), for workshops using conventional machining processes their attempt to improve the environmental performance has been faced with the following:

- Lack of tools to examine trade offs between environmental issues, and issues such as cost and quality.
- Lack of consistent data and metrics on the environmental attributes of materials
- Need for certain key technologies specific to the individual industrial sector.

The mechanical work shop at the School of Engineering exhibited similar problems.

1.3 OBJECTIVES

The project aimed to investigate various aspects of the conventional manufacturing processes from an environmental perspective (found in the Mechanical Workshop at the School of Engineering) and then attempt to reduce energy consumption, material usage, fluid wastes and gaseous emissions. In this event the expected input as well as the output related costs were to be reduced.

Special objectives were to:

(i) Develop equipment level models for Environmental Performance Evaluation.

(ii) Establish the baseline Environmental Performance of selected process in the work shop based on Energy consumption, material usage, toxic emissions and cutting fluid usage.

(iii) Propose mitigating measures to improve the environmental performance of selected processes.

1.5 RATIONALE

Sustainable manufacturing should no longer serve as a new concept but as a basic necessity to any workshop using conventional machining as the principle manufacturing process. For both the small scale and large scale industries there is a great concern at the rate of deterioration of their manufacturing processes especially when environmental performances are considered, notably;

- Increased material wastage and emissions. For instance some manufacturers believe in using large volumes of cutting fluid than necessary convincing themselves falsely that it is the required volume.
- Increased energy consumption, in a lot of cases the energy required for material removal far exceeds the energy required for the machine tool in the machining process.
- Very little or no concern is taken into consideration during machining to reduce the amount of toxics emitted which have a profound effect on the environment that is the manufacturing process itself, contamination of recyclable materials, safety and health of the operator.

Such unforeseen practices have an effect on operational costs in that input, manufacturing and output costs are increased. Therefore the project sought to produce a system level environmentally focused analysis of the conventional machining whose suggested improvements should be able to provide solutions to these set backs.

1.6 SCOPE OF WORK

The project attempted at developing equipment level models which were used to analyze the environmental performance of typical conventional processes found at the mechanical work shop. The processes included were Drilling, Milling, Turning and Shaping. All these processes produced waste in form of metal chips. Although the work shop does contain s computer controlled control (CNC) machining center, this will not be included in the project.

A baseline profile of the work shop was determined and improvements to be made suggested. Respective costs for the baseline and improvements were estimated.

CHAPTER TWO:

LITERATURE REVIEW

2.1 INTRODUCTION:

This chapter familiarizes the concepts, metrics and methods employed in analyzing the environmental performance of the conventional manufacturing processes, that is tracking any progress or research in line with the investigations. This section covers the models developed, metrics, analysis approach and conclusions in an attempt to develop an analysis model that best suits the workshop.

2.2 E.B.M METRICS

In this research it important to use certified terms or metrics for evaluating and monitoring the E.B.M status. Some of the metrics according to "Bridges to Sustainability" (4) include:

(i) Composition of materials
(ii) Number of materials
(iii) Commodity material review that is:
(iv) Fluid property review:
(v) Process energy review:
(vi) Process monitoring related to material balance

- Material intensity [Mi] : mass of the material wasted per unit mass of the output product.

$$Mi = \frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}} \quad \text{.........(1)}$$

- Energy Intensity [Qi] : measure of the net energy consumed per unit mass output.

$$Qi = \frac{\text{net energy consumed in producing the part product}}{\text{Output}} \quad \text{.........(2)}$$

- Coolant Intensity [Ci] : amount of the coolant used per unit mass of the output.

$$Ci = \frac{\text{amount of the coolant used in producing the part product}}{\text{Output}} \quad \text{.........(3)}$$

- Toxic Emissions [Te] : amount of toxic emissions released per unit mass of the output.

$$Te = \frac{\text{amount of toxic emissions released in producing the part product}}{\text{Output}} \quad \text{.........(4)}$$

(vii) Input, operation and output related costs [K],
(viii) Ergonomics,
(ix) Recyclability,
(x) Recoverability,
(xi) Useful life.

2.3 PROCESS- SYSTEM MODELLING

There has been extensive research on environmental sustainable methods of manufacturing followed by a number of publications due to the increasing concern of the industries on the environmental performance and subsequent ramifications of the manufacturing processes. The international Technology of Research Institute, World Technology (WTEC) constituted a panel of experts to carry out research on E.B.M practices in Europe and Japan in comparison to the United States of America, in April 2003 (5). They categorized the process for system modeling into three basic stages (5):

- Strategic view manufacturing; analysis of the current manufacturing.
- Strategic vision; defining the terms associated with E.B.M and identify the driving forces then subsequently frame the goals in order to implement E.B.M
- Systems Level Issue; The collection of the findings of the panel and implementation of the policies to improve performance.

2.3.1 SYSTEMS DIAGRAM

In any system analysis it is important to first identify the boundaries of the system to be examined. In the case of machining the overall system includes activities as:

- Material production,
- Tool preparation,
- Coolant preparation
- Material removal and
- Cleaning, among others.

Figure 1 below shows a broad view of machining with the important processes shown in the rectangular boxes.

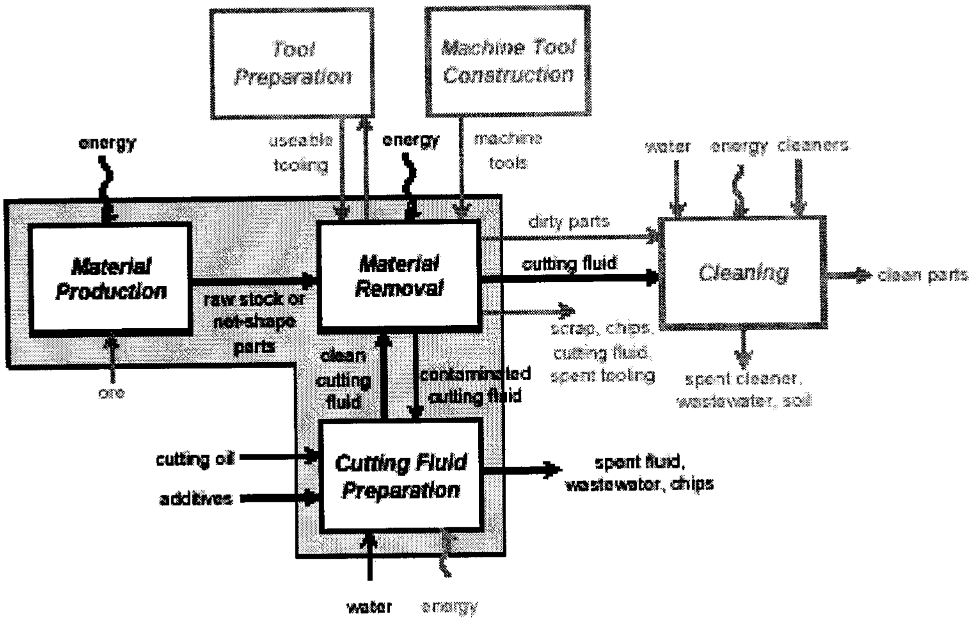

Figure 2.1: System Diagram for Machining

The system illustrated above represents a general scenario; the analysis has the shaded regions and the flows in dark text as processes that require a more detailed examination than the processes shown in grey, which are examined to provide a rough estimate of the environmental impact.

2.3.2 MATERIAL SELECTION

Most of the environmental impact from the material removal process stems from the energy in use that is attempting to use the optimum cutting energy. The aim in E.B.M is to select processes and material that are low in energy and resource consumption; ease to manufacture using the basic machining processes and availability of the material; and reduce on the related costs. In this case the material properties are considered in the selection, further are cardinal in calculations when analyzing environmental performance.

Among other material properties the most important to our analysis include:

- density; ρ [kg/m^3]

- thermal conductivity; k [W/m^{0}C]
- coefficient of linear expansion; [μm/m/^{0}C]
- specific gravity
- tensile strength, σ [MPa]

These properties depend on the knowledge base available and are categorized under engineering requirements.

2.3.3 MACHINE SCENARIO

This involves the selection of the parameters required for specific machining process necessary to carry out the analysis. These parameters are essential in the energy analysis, by maintaining the same parameters for both baseline and improved performances, comparisons can be made indicating places that require improvement.

Machine parameters include:

- Feed rate, f [mm/rev]
- Spindle speed, Vs [rev/min]
- Depth of cut, d [mm]
- Time, t [s]

These properties again depend upon knowledge base and fall under Engineering Requirements.

2.3.4 TOOL PARAMETERS

These are the Engineering Requirements concerning selecting the optimum angles required for machining. Material wastes and cutting energy also depend on the sharpness of the tools, blunt tools have higher material output as well as the specific energy is increased, that is dull tool increase specific energy by 1.25. This reduces on the environmental performance due to increased material waste, energy consumption and related costs.

Below are the recommended tooling parameters according to Kalpakjian (6).

(A) **Recommended angles High Speed Steel (H.S.S) Turning tool:**

- End cutting edge [Ce] ranging from 8^0 to 15^0
- Side cutting angle [Cs] ranging from 5^0 to 30^0
- Lead angle = 10^0
- Side Relief angle [S.R.A] ranging from 5^0 to15^0
- Back rake angle [αb] ranging from 8^0 to 10^0
- Side rake angle [αs] ranging from 10^0 to 12^0

(B) **Recommended angles H.S.S Milling cutters:**

- Helix angle [γm] ranging from 10^0 to 15^0
- Relief angle [R.A] ranging from 1^0 to 4^0
- Secondary Relief angle [S.E.R.A] = 2 x R.A.

(C) **Recommended angles for H.S.S Drilling tools:**

- Relief angle [R.S.A] ranging from 10^0 to 15^0
- Rake angle = 25^0
- Recommended nose radius ~ 1mm

2.3.5 CUTTING FLUID PREPARATION AND MONITORING

A successful fluid management plan as compiled by the NC division of Pollution Prevention and Environmental Assistance (7) should provide:

- Environmental compliance and reduced liability.
- A cleaner, safer and more environmentally sound.
- Reduced costs due to increased fluid life, reduced purchase and waste disposal costs.
- Reduced Labour due to fewer change out and less maintenance.

In order to accomplish these requirements the following steps should be carefully analyzed:

- Product Selection.
- Inventory management and chemical handling.
- Fluid monitoring.
- Contamination removal and prevention.

Product selection

Minimizing the number of different cutting fluids can help benefit inventory control, eliminate extra storage space and reduce coolant maintenance and disposal. Selecting the fluids most suitable for your application is the first step towards an environmental sustainable system.

- Selecting a fluid solely based on its initial cost can be a great misrepresentation; the true cost of the fluid is the cost per liter divide by its life expectancy. Although the initial cost of a premium product may seem higher, the long term cost of the fluid will likely be lower because of its fluid life.

$$\text{Cost} = \text{cost per liter/ Life expectancy} \qquad (6)$$

- Factors to be considered when selecting a fluid include:

- Fluids cost and life expectancy;
- Fluids cutting and grinding abilities,
- Fluids resistance to bacteria,
- Chemical restrictions and reactivity of fluids
- Biodegradable,
- Ease of fluid recycling and disposal,
- Corrosion protection the fluid offers,
- Optimal concentration and pH ranges,
- Ability to separate fluid from the work piece,
- Speed, feed and depth of cutting operation,
- Type, hardness and structure of metal being machined.

- Types of cutting fluid; there are basically two type, these are oil based and water based fluids. Table 1.1 shows the advantages, disadvantages and applications of each fluid.

Table 2.1 Types of cutting fluids

	Advantages	Disadvantages
Straight Oils	Excellent lubricity; good rust protection; good sump life; easy maintenance; rancid resistant.	Poor heat dissipation; increased risk of fire; limited to low-speed cutting operation.
Soluble Oils	Good lubrication; improved cooling capability; suitable for light and medium- duty operations involving a variety of ferrous and nonferrous applications.	More susceptible to rust problems, bacterial growth, tramp oil contamination and evaporation losses.
Synthetics	Excellent microbial control and rancid resistant; relatively nontoxic; superior cooling qualities; easy maintenance; relatively long service life; capable of handling heavy-day cutting operations.	Reduced lubricity; may cause misting,, foaming and dermatitis; may emulsify tramp oil; easily contaminated by other machine fluids.
Semi-synthetics	Good microbial control and rancid resistant; relatively nontoxic; superior cooling qualities; easy maintenance; relatively long service life.	Water hardness affects stability; may emulsify tramp oil; easily contaminated by other machine fluids.

(a) Inventory management and Chemical handling:

Coolant mixture is usually prepared according to the manufacturer's direction. Fluid mixing should be done in a container outside the sump. Hardness and dissolved solids in the water can cause corrosion problems and enhance microbial growth. Using distilled water with additives help reduce these problems.

(b) Fluid Monitoring

Over time cutting fluids can become contaminated by chips, tramp oil, bacteria and dissolved salts. Therefore monitoring the pH, fluid hardness, specific component concentration etc allows the fluid personnel to take appropriate steps

Fluid concentration:

- Water evaporation should be monitored to ensure proper coolant to water ratio.
- Refractometers are usually used, though these are fairly expensive, titration is an alternative.

pH

- Proper pH levels to be kept normally between 8.5 and 9.0
- Litmus paper provides a low cost means of fluid pH estimate
- Portable pH meters provide accurate readings

Microbial Growth

- Bacteria can cause the fluid to become rancid producing a bad scent.
- Major food source is tramp oil for bacteria.
- Tramp oil is measured as a percentage of the total fluid in the sump.

(c) Contamination Removal and Prevention:

Bacteria

- Sump cleaning during fluid change out.
- Use of biocides to control bacteria growth.

Tramp oil

- Use of skimmers that is removal of the tramp oil as it floats in the sump using floating rope, plates or wheels.

Metal chips

- Use of screens to collect the majority of the metal chips.

2.3.6 DRY MACHINING

In an attempt to eliminate cutting fluids due to its environmental ramifications and associated costs, dry machining has been employed over the years. These involved air which is initially cooled at a certain temperature and compressed at an initial pressure. This has proven the most effective and cheapest to maintain but has a high initial cost as may require installing auxiliary equipment.

Some processes have run on "natural drying systems" such as shapers or planers over some years; where they use the forward stroke for cutting and the back stroke is left for cooling the surface.

2.3.7 METAL REMOVAL PROCESS

Figure 2 basically summarizes the process involved in the metal removal processes.

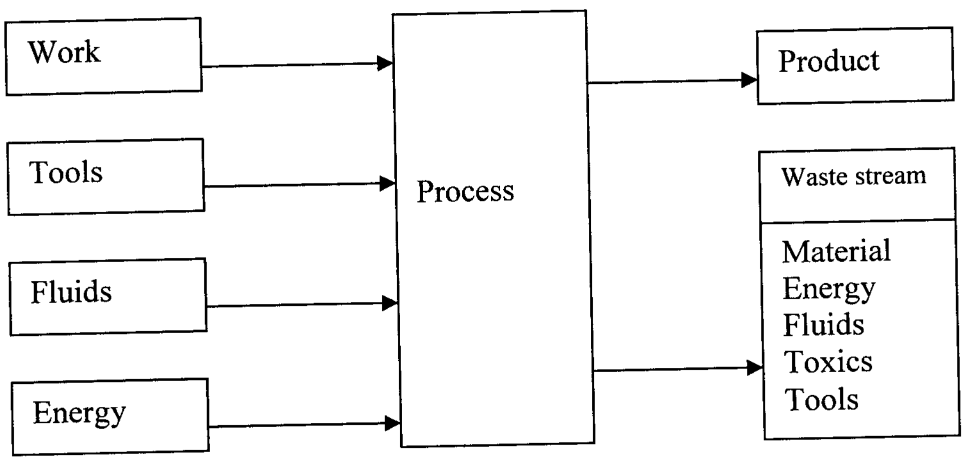

Fig2.2: Waste Streams in Traditional Machining

The inputs to the process have been discussed in the previous sections of this chapter except for the energy and work inputs. For each particular process there are certain parameters that are required to calculate the energy input, energy used for metal cutting and energy lost to the waste streams. As for energy input into the process entirely depends on the power delivered by the machine according to the selected operating parameters. The energy input equations and the subsequent power required for machining are shown below according to Kalpakjian (6).

(1) Energy input in turning processes:

$Ps = Fr. Vs$ .... (6)

Where;

Ps: Power at the Spindle delivered to the work piece,

Fr: Force of the rotating work piece,

Vs: Spindle speed.

- Energy required for the cutting of the metal:

N= Rotational speed of the work piece, rpm

f = feed rate, mm/rev

v = linear speed of the tool along the work piece, mm/s

Vs= speed of the work piece, m/min.

$= \pi DoN$ (for maximum speed)........................(7)

$= \pi DavgN$ (for average speed)...........................(8)

L= length of cut, mm

Do= original diameter of the work piece, mm

Df = final diameter of the work piece, mm

Davg = average diameter

$$= \frac{Do + Df}{2} \quad \text{...(9)}$$

D = depth of cut, mm

$$= \frac{Do - Df}{2} \text{...(10)}$$

t = cutting time, s or min

$$= \frac{L}{fN} \text{..(11)}$$

Material Removal Rate (**M.R.R**), mm^3/min

$= \pi$ **DavgdfN** ....(12)

In cases were the optimum tooling parameters are met then equation [13] can be used:

Pc = Power used for cutting, W

= M.R.R x specific energy

= M.R.R x ut...(13)

In cases where the tooling parameters fall outside the Engineering requirements:

Pc = Torque (T) x angular speed (w)......................... (14)

T = Fc x davg/2

w = 2 π N

(2) Energy input for the Milling Process

Ps = Fr. Vs .... (15)

Where;

Ps: Power at the Spindle delivered to the tool,

Fr: Force of the rotating tool,

Vs: Spindle speed.

- Energy required for milling the metal

N= rotational speed of the cutter, rpm

f = feed, mm/ tooth

D =cutter diameter, mm

n = number of teeth on the cutter

v = linear speed of the work piece

V = surface speed of the cutter, m/min

$$= \frac{v}{Nn} \quad \text{.......(16)}$$

L = length of cut, mm

t = time of cut

$$= \frac{L + Lc}{v} \quad \text{.......(17)}$$

Lc = extent of the cutters first contact.

M.R.R = w d v n ....(18)

In cases where the tooling requirements are met

Pc = M.R.R x ut...(19)

In cases where the tooling requirements are not met

Pc = Torque (T) x angular speed (w)............................. (20)

T = Fc x D/2

w = 2 πN

(3) Energy Input For Drilling Processes

Ps = Fr. Vs .... (21)

Where;

Ps: Power at the Spindle delivered to the tool,

Fr: Force of the rotating tool,

Vs: Spindle speed.

- **Energy required to drill the metal**

N = Rotational speed.

f = feed, mm/tooth

$$\textbf{M.R.R} = \frac{\pi D^2 fN}{4} \text{ (mm/ min)} \quad \text{......... (22)}$$

In cases where optimum tooling parameters are met

Pd = M.R.R x ut.. (23)

In cases the required angles are not met

Pc = Torque (T) x angular speed (w).......................... (24)

T = Fc x D/2

w = 2 πN

(4) Energy input for Shaping

Pt = Ft. Vt .... (25)

Where;

Pt: Power delivered to the tool,

Ft: Force of the tool,

Vt: linear speed of the tool.

- Energy required for shaping:

M.R.R= wdL .... (26)

w = width of cut

L = length of cut

Pt = M.R.R x ut.. (27)

2.3.8 WASTE STREAMS IN CONVENTIONAL MANUFACTURING

There are five main streams involved in conventional machining these are:

- Material Streams,

- Energy waste stream,
- Fluid stream,
- Toxic streams and
- Tools streams.

Material stream

The manufacturing section of the product life begins when raw metal enters the manufacturing system in order to be machined into the desired part. Loss of virgin material during production has significant environmental repurcations in terms of:

- The amount of material lost
- The associated economical value and
- The environmental hazard associated with the loss of material.

The amount of material removed and the rate at which it is removed depends on the machine and tooling parameters that are set. Material removal rate is related to the machining time which in turn is constrained by the production rate and indicates the rate at which material is being lost or disposed.

It is economically viable to recycle large volumes of chips rather than small volumes. Another constrain in recycling is the contamination of the stream due to the presence of dissimilar materials.

Energy Stream

This basically consists of:

- Heat generation lost to the work piece, chip and the tool.
- Cutting fluid or air heat transfer.

Heat generation lost to the work piece [Qw] is basically carried away by the chip and the cutting fluid, heat generated to the tool forms a small portion of the total heat generated and is usually neglected. Below are the assumed equations that are used to predict haet transfer during the processes as depicted from R.K Rajput (8).

$$Qw = \frac{kA(t_1 - t_2)}{L} \qquad (28)$$

Where

k= thermal conductivity of the work piece

A= cross sectional area of the cut material

t_1= temperature of the material during the machining

t_2= temperature of the material before machining.

- Cutting fluid heat transfer [Qf] is the heat taken by the fluid in the process.

$$Qf = h.As(t_1 - t_2) \qquad (29)$$

Where:

h= heat transfer coefficient.

As = surface area of the work piece

t_1 = temperature of the fluid during machining.

t_2 = temperature of the fluid before machining.

$$h = \frac{Nu.k}{L} \qquad (30)$$

Nu= Nusselt number.

L= length of cut for time

$$Nu = 0.644(R_{el})^{0.5}(\mathrm{Pr})^{0.333} \qquad (31)$$

Rel= Reynolds number

Pr= Prandtls number

$$R_{el} = \frac{V_l L}{v} \qquad (32)$$

V_L = velocity of the cutting fluid

=(flow of the fluid)/ π Dn, where Dn= nozzle diameter

v = viscosity.

Pr=μCp/k.. (33)

μ= kinematic viscosity.

Cp=Specific heat

-In cases of dry machining heat transfer [Qa] is by free 'air' convection:

$Qf = h.As(t_1 - t_2)$ .... (34)

$$h = \frac{Nu.k}{L}$$

Nu = 0.59 (Gr.Pr)

Gr = Garshofs number

$$= \frac{L^3 \beta g(t_1 - t_2)}{v^2} \quad \text{.. (35)}$$

$$\beta = \frac{1}{T} \quad \text{... (36)}$$

Toxic Waste Stream

In conventional manufacturing, toxics are released from material production, material removal and cleaning among others. The biggest hurdle over the years according to Jim Walsh (9) has been to link the material toxic releases information to the actual processes toxic release information. In manufacturing toxic information can be analyzed using the model shown in figure 3 below

This model suggests that the main sources of the toxics on manufacturing emerge from:

(a) Material contents of the work piece,

(b) Treatment chemical material,

(c) Cleaning processes involved.

And then considers the toxics released, their quantity and the form in which they are released that is gaseous emissions (mist, dry gas etc.), waste water (includes slurry) and solid wastes.

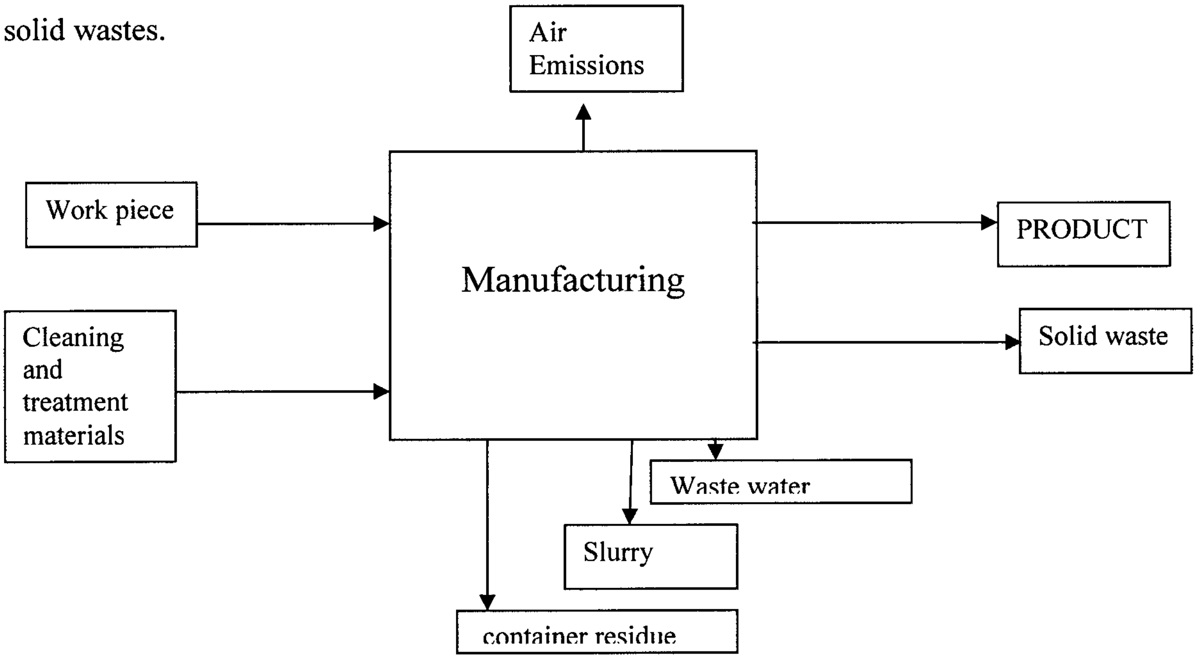

Figure 2.3: Toxic waste stream diagram

These emissions are neither easy to measure nor monitor; making it difficult to monitor toxic intensity, however the emissions can be estimated over a reasonable period of time; and can be measured as follows:

(1) Bag House Performances:

- Toxic Efficiency = ηti.
- Number of containers of the treatment materials used in the stipulated period = ne
- Weight gain per bag in kgs = wti

(2) Offsite Disposal (kgs)

$$= \eta ti \text{ ne wti} \qquad (37)$$

(3) Air Emissions (kgs)

$$= \frac{1-\eta_{ti}}{\eta_{ti}} \text{ ne wti} \quad \ldots\ldots (38)$$

Toxic emissions are harmful to the environment that includes the processes, operators and the general surroundings; thus measures should be taken to mitigate these problems without antagonizing with the performance of the manufacturing process. According to CFEST program developed at the University of Ilunious (10), the acceptable safety practices (for no observable effect) when it comes to toxic releases include:

1. Oral toxicity: Lethal Dosage should be less than 50 mg/ kg (LD50< 50mg/kg).
2. Inhalation Toxicity: Threshold Limit value (T.L.V) should be 50 mg/kg (LC50< 50mg/kg).
3. Eye Irritation: Dosage should be less than 50mg.
4. Dermal Irritation: Dosage should be less than 200mg.
5. Carcinogenicity: Evidence of ornogenicity from epidemiological studies.

As for the reactivity to the work piece surfaces care should be taken in selecting the chemicals used in manufacturing for instance in cutting fluids, cleaning and treatment reagents, these may include oxidizing agents, acids, bases, moist etc.

2.3.9 CLEANING IN E.B.M

Cleaning plays a major role in the environmental performance of manufacturing process and is usually involved from the machining stage all the way through to the finishing processes of the products life cycle.

Of the processes that play a major role in machining cleaning has been cited as one of the most important when it comes to discussing environmental impact due to the large array of chemicals used in different situations. Of current practices, the solvent and aqueous cleaners are the most commonly used.

In manufacturing it is necessary to clean off the dirty material such as scrap, cutting fluid, chemicals, spent tooling during or after the process improving on the environmental performance. Another reason could be to prepare the work piece for further processes.

2.3.10 SAFETY PRACTISES:

In Manufacturing to reduce the effect of the toxics and other wastes on the environment that is the processes, machine and the operator the following measures have been set according to the developers of the CFEST program (10)

(a) FACILITIES:

Presence of well located windows in the vicinity to allow natural ventilation to take place .

(b) MACHINE CONDITION:

- The should be well covered and enclosed.

-The cutting fluid flow should be continuous.

- There should not be severe leakage from the machine.

(c) PROTECTIVE GEAR :

Employees should wear Personal Protective Equipment necessary to protect them from the particular process.

(d) SITE PRACTISE:

- Work place to be thoroughly cleaned.
- Workers to continuously stand within 3 meters of the process.
- Human health and safety to be monitored on a regular basis especially in cases where workers handle or remove waste.

2.3.11 COSTING ANALYSIS APPROACHING

In E.B.M cost control should be practiced as all these activities are introduced and monitored. Among other parameters the following are closely monitored:

MACHINE COSTS:

- Estimated work piece transferring cost
- Estimated unloading and loading costs
- Estimated cutting costs
- Estimated overhead costs

MATERIAL COSTS:

- Cost Tool purchasing price
- Tool regrinding
- Tool disposal cost
- of raw material
- Cost of scrap material
- Disposal cost of un used material

TOOLING COSTS:

- purchasing costs
- regrinding costs
- disposal costs

CUTTING FLUID COSTS:

- Cost of cutting fluid
- Cost of distilled water
- Fluid treatment costs
- pH monitoring costs
- hardness costs
- viscosity costs
- ppm testing costs
- fluid disposal costs:

CHAPTER THREE:

METHODOLOGY

3.1 PROCESS SYSTEM MODELING:

The model adopted is an 'activity model" which has been developed to represent the machining process planning activities, wet or dry machining processes according to Dahmus and Gutowski (1) . It is decomposed into four activities as shown in figure 3.1

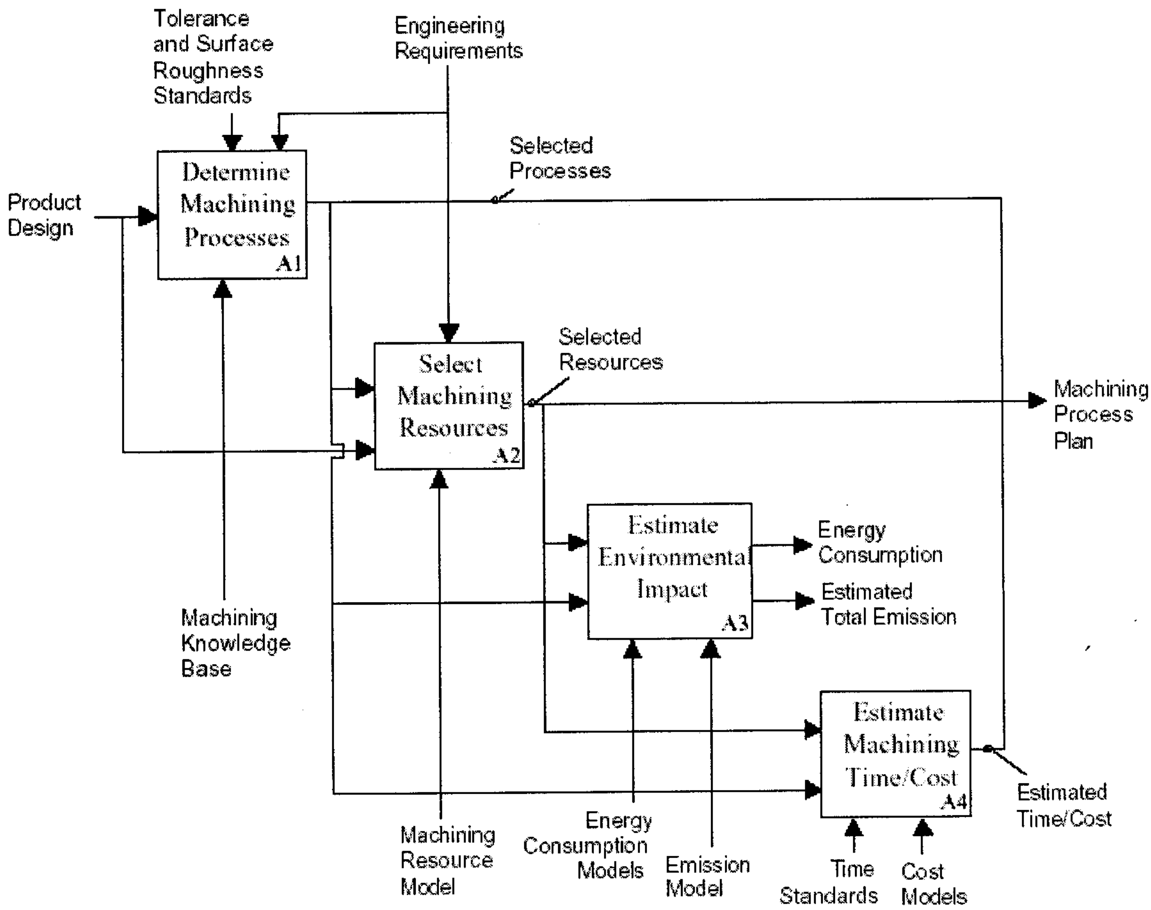

Figure 3.1 Process System Modeling

3.1.1 MACHINING PROCESS BASED ON PRODUCT DESIGN

The first sub activity [A1] is to determine the machining process based on product design under knowledge base. It includes specifying detailed operations and choosing process parameters, such as cutting speeds, feed rates and depth of cut.

The second activity [A2] is to determine the machining resources which includes: machine tools' cutting tools, fixtures, stock material etc. A2 can be decomposed into three sub activities as shown in figure 3.2:

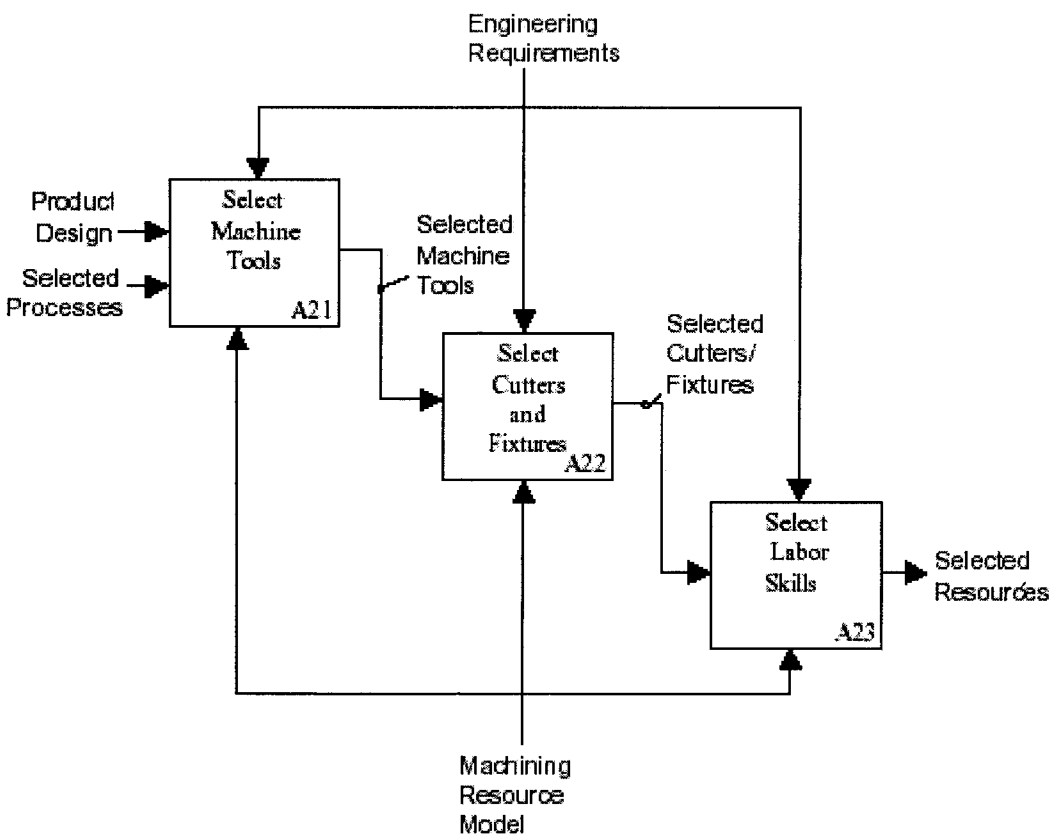

Figure 3.2: Select Machining Process

A21: Activity to select appropriate machine tools

A22: Activity to select cutting tools and fixtures.

A23: Activity to select labour to operate the processes.

These activities are controlled by the Engineering requirements of the product and supported by a machining resources model.

3.1.2 ESTIMATED ENVIRONMENTAL IMPACT

The third activity [A3] is to estimate environmental impact. Specifically in wet machining, handling of coolant, chips handling, power consumption should be carefully analyzed. A3 can be further be decomposed into four parts as shown in figure 3.3:

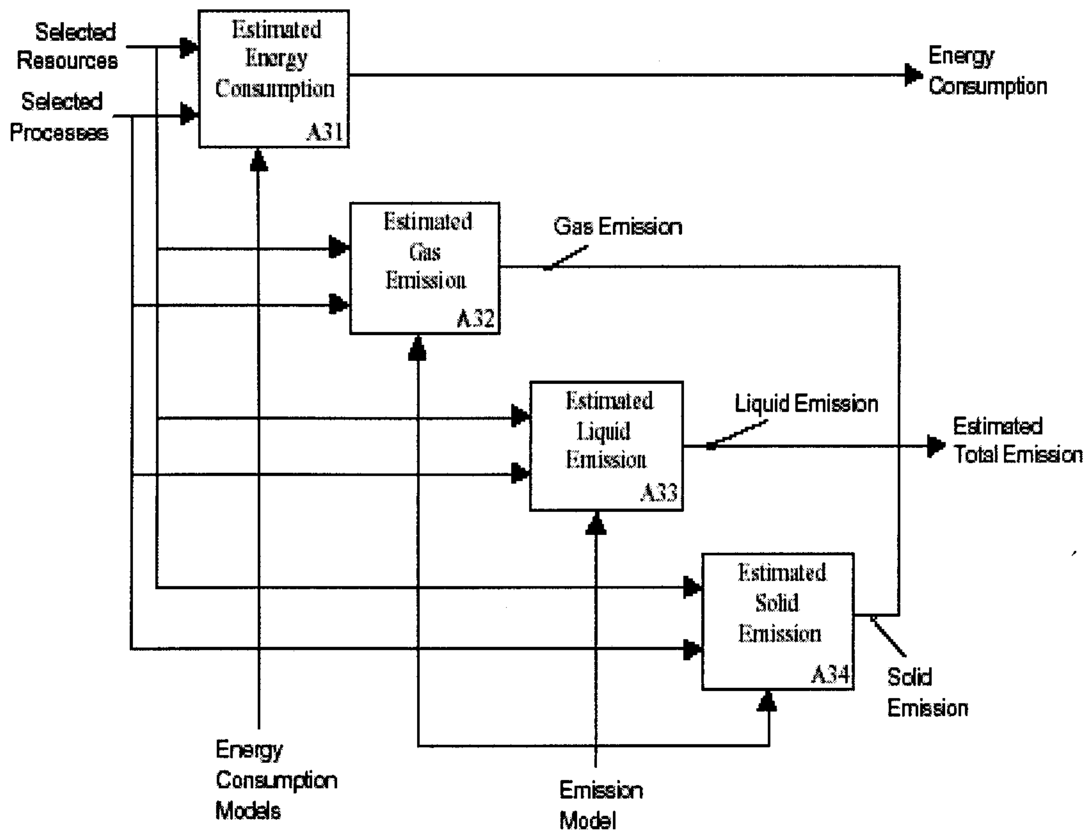

Figure 3.3: Environmental Impact Evaluation

This is the part in which this project hopes to improve the Environmental Performance. The sub activities are:

A31: Activity to estimate the energy consumption of the whole machining process, based on some Energy assumptions and models.

A32: Activity to estimate gas emissions.

A33: Activity to estimate fluid consumption as well as emissions.

A35: Activity to estimate solid wastes.

It is important to track and record the above activities to monitor E.B.M performance.

3.1.3 ESTIMATED MACHINING TIME AND COST:

The fourth activity [A4] is to estimate the machining time and cost, so as to ensure that the product is made within manufacturing cost and time limits

3.2 IMPLEMENTATION OF THE MODEL

The model was applied to each of the processes as follows:

3.2.1 Turning:

Three experiments were carried out namely baseline evaluation, improved evaluation and alternative evaluation.

For the baseline and Improved evaluation the coolant used was soluble oil cutting fluid and as for the alternative method compressed air was used for cooling.

The baseline experiment was done and then analyzed. This was followed by recognizing the problems then mitigating them so as to apply these improvements to the model. Then the alternative method of using compressed air as the coolant was carried out and analyzed as well.

The results of the three experiments where compared in order to recommend on the methods to be adopted.

(a) Engineering requirements:

The activities below were maintained for all experiments done.

(i) Machine scenario:

This activity involved selecting the operating parameters. The lathe machine was set to the following parameters.

-Speed was 160 rpm, feed rate was 0.07mm/min and the depth of cut was 0.25mm.

-The machine was run for two hours taking note of the of the idle and equipment handling time.

- the flow rate of the coolant being supplied by the machine was measured.

(ii) Material commodity review:

The material was a cylindrical round work piece and the properties that were collected include:

-density= 6920 kg/mm^3

-thermal conductivity = 50.2 W/m^0C

The onsite measurements included:

- initial diameter, Do
- final diameter, Df
- initial mass, Mo
- Final mass, Mf
- Initial temperature, ti

- Average operating temperature, tf

(ii) Tooling parameters:

These measurements were taken to ensure that requirements were met. The angles measured were; lead angle, end and side cutting angles, relief angles, side and back rake angles and the nose radius. These values were tabulated and recommendations were stated.

(iii) Cutting fluid preparation:

The cutting fluid for the baseline and Improved evaluation were done outside the sump taking note of the following:

- fluid pH, hardness, viscosity and density.
- initial temperature, ti.
- average operating temperature, tf
- treatment information if any.

(b) <u>Environmental Requirements</u>

These using the data collected the following are calculated to evaluate the performance of the process.

(i) Practical Material Removal Rate (MRR)

MRR= volume of the material removed/ cutting time

(ii) theoretical Material Removal Rate (MRR)

$MRR = M.R.R = \pi \mathbf{D avgdfN}$

(iii)Material intensity for both the theoretical results:

$$Mi = \frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}}$$

(iv)Estimated Energy:

-The energy required to cut the Energy , Qc = M.R.R x ut

Were the average specific energy (ut)= $6 Ws/mm^3$

-The energy dissipated as heat to the cutting fluid:

$$Qf = h.As(t_1 - t_2)$$

- the energy dissipated as heat to the work piece:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

- the total energy required for the process:

Qi=Qf+Qw+Qc

(v) Energy Intensity

$$Qi = \frac{\text{net energy consumed in producing the part product}}{\text{Output}}$$

(vi) Coolant volume

Co= coolant flow rate x cutting time.

(vii) Coolant intensity

$$Ci = \frac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$$

(viii) Toxic Intensity:

$$Te = \frac{\text{amount of toxic emissions released in producing the part product}}{\text{Output}}$$

3.2.2 Milling:

Three experiments were carried out namely baseline evaluation and improved evaluation.

The coolant used was soluble oil cutting fluid and as for the alternative method compressed air was used for cooling.

The baseline experiment was done and then analyzed. This was followed by recognizing the problems then mitigating them so as to apply these improvements to the model.

The results of the three experiments where compared in order to recommend on the methods to be adopted.

(a) Engineering requirements:

The activities below were maintained for all experiments done

(i) Machine scenario:

This activity involved selecting the operating parameters. The lathe machine was set to the following parameters.

-Speed was 25 rpm, feed rate was 40mm/min and the depth of cut was 0.4mm .

-The machine was run for two hours taking note of the of the idle and equipment handling time.

- the flow rate of the coolant being supplied by the machine was measured.

(ii) Material commodity review:

The material was a rectangular work piece and the properties that were collected include:

-density= 6920 kg/mm^3

-thermal conductivity = 50.2 W/m^0C

The onsite measurements included:

- Length of cut, Lc
- Width of cut, Wc
- initial mass, Mo
- Final mass, Mf
- Initial temperature, ti
- Average operating temperature, tf

(ii) Tooling parameters:

These measurements were taken to ensure that requirements were met. The angles measured were; lead angle, relief angles and secondary relief angle. These values were tabulated and recommendations were stated.

(iii) Cutting fluid preparation:

The cutting fluid for the baseline and Improved evaluation were done outside the sump taking note of the following:

- fluid pH, hardness, viscosity and density.
- initial temperature, ti.
- average operating temperature, tf
- treatment information if any.

(b) <u>Environmental Requirements</u>

These using the data collected the following are calculated to evaluate the performance of the process.

(viii) Practical Material Removal Rate (MRR)

MRR= volume of the material removed/ cutting time

(iv)theoretical Material Removal Rate (MRR)

MRR = M.R.R = w d v nN

(v) Material intensity for both the theoretical results:

$$Mi = \frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}}$$

(vi)Estimated Energy:

-The energy required to cut the Energy , Qc = M.R.R x ut

Were the average specific energy (ut)= $6 Ws/mm^3$

-The energy dissipated as heat to the cutting fluid:

$$Qf = h.As(t_1 - t_2)$$

- the energy dissipated as heat to the work piece:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

- the total energy required for the process:

Qi=Qf+Qw+Qc

(vii) Energy Intensity

$$Qi = \frac{\text{net energy consumed in producing the part product}}{\text{Output}}$$

(viii) Coolant volume

Co= coolant flow rate x cutting time.

(ix) Coolant intensity

$$Ci = \frac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$$

(viii) Toxic Intensity:

$$Te = \frac{\text{amount of toxic emissions released in producing the part product}}{\text{Output}}$$

3.2.3 Drilling:

Three experiments were carried out namely baseline evaluation, improved evaluation and alternative evaluation.

For the baseline and Improved evaluation the coolant used was soluble oil cutting fluid and as for the alternative method compressed air was used for cooling.

The baseline experiment was done and then analyzed. This was followed by recognizing the problems then mitigating them so as to apply these improvements to the model. Then the alternative method of using compressed air as the coolant was carried out and analyzed as well.

The results of the three experiments where compared in order to recommend on the methods to be adopted.

(a) Engineering requirements:

The activities below were maintained for all experiments done .

(i) Machine scenario:

This activity involved selecting the operating parameters. The lathe machine was set to the following parameters.

-Speed was 250 rpm, feed rate was 0.018mm/min and the depth of cut was 10 mm.

-The machine was run for two hours taking note of the of the idle and equipment handling time.

- the flow rate of the coolant being supplied by the machine was measured.

(ii) Material commodity review:

The material was a flat metal sheet work piece and the properties that were collected include:

-density= 6920 kg/mm^3

-thermal conductivity = 50.2 W/m^0C

The onsite measurements included:

- Thickness= t
- initial mass, Mo
- Final mass, Mf
- Initial temperature, ti
- Average operating temperature, tf

(ii) Tooling parameters:

These measurements were taken to ensure that requirements were met. The angles measured were; chisel angle, point angle, lip angle and helix angle. These values were tabulated and recommendations were stated.

(iii) Cutting fluid preparation:

The cutting fluid for the baseline and Improved evaluation were done outside the sump taking note of the following:

- fluid pH, hardness, viscosity and density.
- initial temperature, ti.
- average operating temperature, tf
- treatment information if any.

(b) <u>Environmental Requirements</u>

These using the data collected the following are calculated to evaluate the performance of the process.

(v) Practical Material Removal Rate (MRR)

MRR= volume of the material removed/ cutting time

(vi)theoretical Material Removal Rate (MRR)

$$MRR = M.R.R = \frac{\pi D^2 fN}{4}$$

(vii) Material intensity for both the theoretical results:

$$Mi = \frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}}$$

(viii) Estimated Energy:

-The energy required to cut the Energy , Qc = M.R.R x ut

Were the average specific energy (ut)= 6Ws/mm^3

-The energy dissipated as heat to the cutting fluid:

$$Qf = h.As(t_1 - t_2)$$

- the energy dissipated as heat to the work piece:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

- the total energy required for the process:

Qi=Qf+Qw+Qc

(ix)Energy Intensity

$$Qi = \frac{\text{net energy consumed in producing the part product}}{\text{Output}}$$

(x) Coolant volume

Co= coolant flow rate x cutting time.

(xi) Coolant intensity

$$Ci = \frac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$$

(xii) Toxic Intensity:

Te = amount of toxic emissions released in producing the part product
Output

3.2.4 Shaping:

Three experiments were carried out namely baseline evaluation and improved evaluation .

For the baseline and the coolant used was natural free convective air and as for the Improved method compressed air was used for cooling.

The baseline experiment was done and then analyzed. This was followed by recognizing the problems then mitigating them so as to apply these improvements to the model. Then the method of using compressed air as the coolant was carried out and analyzed as well.

The results of the experiments where compared in order to recommend on the methods to be adopted.

(a) Engineering requirements:

The activities below were maintained for all experiments done

(i) Machine scenario:

This activity involved selecting the operating parameters. The lathe machine was set to the following parameters.

-Speed was 25 strokes/min, feed rate was 0.3mm/stroke and the depth of cut was 2 min.

-The machine was run for two hours taking note of the of the idle and equipment handling time.

- the flow rate of the coolant being supplied by the machine was measured.

(ii) Material commodity review:

The material was a flat metal sheet work piece and the properties that were collected include:

-density= 6920 kg/mm^3
-thermal conductivity = 50.2 W/m^0C

The onsite measurements included:

- Thickness= t
- initial mass, Mo
- Final mass, Mf
- Initial temperature, ti
- Average operating temperature, tf

(ii) Tooling parameters:
These measurements were taken to ensure that requirements were met. The angles measured were; relief angle, rake angle and nose raduis. These values were tabulated and recommendations were stated.

(iii) Cutting fluid preparation:

The cutting fluid for the baseline and Improved evaluation were done outside the sump taking note of the following:
- fluid pH, hardness, viscosity and density.
- initial temperature, ti.
- average operating temperature, tf
- treatment information if any.

(b) Environmental Requirements

These using the data collected the following are calculated to evaluate the performance of the process.

(V) Practical Material Removal Rate (MRR)

MRR= volume of the material removed/ cutting time

(vi) theoretical Material Removal Rate (MRR)

MRR = M.R.R = **wfNd**

(vii) Material intensity for both the theoretical results:

$$Mi = \frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}}$$

(vii) Estimated Energy:

-The energy required to cut the Energy , Qc = M.R.R x ut

Were the average specific energy (ut)= 6Ws/mm^3

-The energy dissipated as heat to the cutting fluid:

$$Qf = h.As(t_1 - t_2)$$

- the energy dissipated as heat to the work piece:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

- the total energy required for the process:

Qi=Qf+Qw+Qc

(viii) Energy Intensity

$$Qi = \frac{\text{net energy consumed in producing the part product}}{\text{Output}}$$

(ix) Coolant volume

Co= coolant flow rate x cutting time.

(x) Coolant intensity

$$Ci = \frac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$$

(viii) Toxic Intensity:

$$Te = \frac{\text{amount of toxic emissions released in producing the part product}}{\text{Output}}$$

CHAPTER FOUR
ENVIRONMENTAL ANALYSIS OF THE WORKSHOP.

4.1 INTRODUCTION:

.The selected processes where run for two to three continuous hours and necessary on site readings where taken. This chapter analyses the collected information, using the formulae and assumptions stated in the section 3.2 of chapter 3 for the basic practices of the workshop and then improvements are made where shortfalls in environmental performance are noticed.

In the first case the base line analysis of the current practices based on the models discussed in the previous chapters; in the second case suggestions were made and then consequently applied to the processes, and then compared to the initial baseline findings. In the final case costs for both results were costed, in an attempt to asses the cost of improving the environmental performance.

4.2 BASELINE ANALYSIS:

4.2.1 Data Input:

This is the required information in order to calculate the parameters necessary for the environmental evaluation for each of the processes.

4.2.1.1 Machine scenario:

These are based on the Engineering Knowledge used to select the optimum parameters required to cut the material having taken into consideration the surface roughness.

Table 4.1 Operational machine parameters.

Parameter	**Milling**	**Turning**	**Drilling**	**Shaping**
Speed	250 rpm	160rpm	250rpm	25 strokes/ min.
Feed rate	40 mm/min	0.07mm/min	0.018mm/min	0.3mm/stroke
Depth of cut	0.4 mm	0.25mm	10mm	2mm

These parameters where maintained throughout the investigations for easier comparison to the suggested improvements to the manufacturing processes.

4.2.1.2 Tooling Parameters

These are the angles and other parameters used in the machining processes:

(a) Turning:

Cutting tool material: High Speed Steel (H.S.S).

Cutting tool type: Single point.

Table 4.2 Turning tool parameters

Tool Parameters	Measurement	Comment
Lead angle	10^{o}	Within recommended range
End cutting edge angle	12^{0}	Within recommended range
Side cutting edge angle	23^{0}	Within recommended range
Side Relief angle	7^{0}	Within recommended range
Back Rake angle	10^{0}	Within recommended range
Side Rake angle	21^{0}	Out of recommended range
Nose Radius	3mm	Out of recommended range

(b) Milling:

Cutting tool material: High Speed Steel (H.S.S).

Cutting tool type: Four teeth milling cutter

Table 4.3 Milling tool parameters

Tool Parameters	Measurement	Comment
Lead angle	12^{0}	Within recommended range
Relief angle	7^{0}	Out of recommended range
Second Relief Angle	22^{0}	Out of recommended range

(c) Drilling:

Cutting tool material: High Speed Steel (H.S.S).

Cutting tool type: Standard point Drill:

Table 4.4 Drilling tool parameters

Tool Parameters	Measurement	Comment
Chisel angle	133^0	Within recommended range
Point angle	125^0	Within recommended range
Lip Relief	23^0	Out of recommended range
Helix angle	22^0	Out of recommended range

(d) Shaping

Cutting tool material: High Speed Steel (H.S.S).

Cutting tool type: Single point.

Table 4.5 Shaping tool parameters

Tool Parameters	Measurement	Comment
Relief angle	20^0	Out of recommended range
Rake angle	23^0	Out of recommended range
Nose radius	3mm	Not Recommended

4.2.1.3 Material Preparation:

In all the four processes the material selected was Mild Steel due to its abundance and relatively low cost.

(a) Turning

The work piece was cylindrical in shape and had the following specifications:

Table 4.6 Turning: Work piece parameters

Material used	_	Mild Steel
Density, ρ	Kg/mm^3	6920
Specific heat capacity, Cp	J/KgK	448
Thermal Conductivity, K	W/m^oC	50.2
Length of cut, Lc	mm	81.1
Initial mass, Mo	Kg	0.9898
Initial temperature, ti	^0C	22.6

(b) Milling

The work piece was rectangular and had the following specifications:

Table 4.7 Milling: Work piece parameters

Material used	_	Mild Steel
Density, ρ	Kg/mm^3	6920
Specific heat capacity, Cp	J/KgK	448
Thermal Conductivity, K	W/m^oC	50.2
Length of cut, Lc	mm	12.3
Width of cut	mm	57.8
Initial mass, Mo	Kg	2.5872
Initial temperature, ti	^0C	22.2

(c) Drilling

The work piece was a flat sheet metal had the following specifications:

Table 4.8 Drilling: Work piece parameters

Material used	–	Mild Steel
Density, ρ	Kg/mm^3	6920
Specific heat capacity, Cp	J/KgK	448
Thermal Conductivity, K	W/m^oC	50.2
depth of drill	mm	10
Initial mass, Mo	Kg	0.890
Initial temperature, ti	^0C	21.8

(d) Shaping

The work piece was rectangular and had the following specifications:

Table 4.9 Shaping: Work piece parameters

Material used	–	Mild Steel
Density, ρ	Kg/mm^3	6920
Specific heat capacity, Cp	J/KgK	448
Thermal Conductivity, K	W/m^oC	50.2
Width of cut	mm	20.3
Length of cut	mm	57.3
Initial mass, Mo	Kg	0.890
Initial temperature, ti	^0C	26.3

4.2.1.4 Cutting Fluid Preparation:

A sample of cutting fluid was taken from each of the processes and was analyzed as follows:

(a) Turning

Table 4.10 Turning: Cutting Fluid Parameters

Coolant type	Soluble oil
Fluid concentration	20%
Flow rate	300 ml/min
Jet nozzle diameter	8mm
Height of jet above work piece	80mm
Fluid system capacity	20 L
Fluid viscosity	1.0211x 10^{-6} m^2/s
Fluid density ρ	984 kg/m^3
Fluid pH	8.8
Fluid hardness	60mg/L
Amount of tramp oil	2.83 L
Fluid rancidity levels	High bacterial content
Treatment information	None
Initial Temperature	23^0C

(b) Milling

Table 4.11 Milling: Cutting Fluid Parameters

Coolant type	Soluble oil
Fluid concentration	20%
Flow rate	857 ml/min
Jet nozzle diameter	8mm
Height of jet above work piece	80mm
Fluid system capacity	20 L
Fluid viscosity	1.0346x 10^{-6} m^2/s

Fluid density ρ	984 kg/m^3
Fluid pH	7.9
Fluid hardness	60mg/L
Amount of tramp oil	3.45 L
Fluid rancidity levels	High bacterial content
Treatment information	None
Initial Temperature	22.2^{0}C

(c) Drilling

Table 4.12 Drilling: Cutting Fluid Parameters

Coolant type	Soluble oil
Fluid concentration	20%
Flow rate	300 ml/min
Jet nozzle diameter	6mm
Height of jet above work piece	80mm
Fluid system capacity	None
Fluid viscosity	1.018x 10^{-6} m^2/s
Fluid density ρ	984 kg/m^3
Fluid pH	8.8
Fluid hardness	60mg/L
Amount of tramp oil	None
Fluid rancidity levels	Acceptable condition
Treatment information	None
Initial Temperature	21.8^{0}C

4.2.1.5 Dry Machining Considerations:

In the case of Shaping processes where there is no coolant used instead takes advantage of the backward toke allowing free convectional air to do the cooling:

Table 4.13 Dry Machining considerations

Initial temperature, ti	26.2^{0}C
Density, ρ	1.177 kg/m^3
Thermal conductivity, K	0.0261 W/m^{0}C
Viscosity	1.57x10^{-5} m^2/s

4.2.2 OPERATING AND OUTPUT DATA ANALYSIS:

This section analyses the input, operating and output data for all the processes representing them in tabular form as well as graphical form where necessary.

As it was difficult to measure the toxicity levels an assumption was made that all the processes produced the same amount of toxics. Therefore the Toxic Intensity estimated was as given below according to:

Table 4.14 Estimated toxic emissions

chemical	**T.L.V (mg/m^3)**
Iron Oxide Fumes	5
Graphite	2
Mill Scale Ferrous Metal	5
Silicon (Mist)	10
Manganese Film	0.2
Cellulose	2

Total : 22.2mg/m^3

(a) TURNING:

This analysis will be used for sample calculation to represent all the similar calculations in this project:

(i) Material Removal Rate (M.R.R):

Practical M.R.R = (Material Removed / Cutting Time)

Mass of the material removed= 291g

Volume of the material removed $= \frac{m}{\rho} \frac{.291x10^9}{6920} = 42052.023mm^3$

$$M.R.R = \frac{42052.023}{(97 + 39/60)} = 436.45mm^3/\min$$

Table 4.15 Material Removed and MRR

Material removed	0.291 kg
Total machining time	154min
Volume of material removed	42052.023mm^3
Idle / handling time	56min 21s
Cutting time	97min 39s
M.R.R	**436.45 mm/min**

Theoretical M.R.R $= \pi$**DavgdfN** ...

Using equation 12 in chapter 3:

Do = 40.2mm
Df = 39.7mm
Davg= 39.95mm
N= 160 rpm
d= 0.25mm
f= 0.07mm/ min
M.R.R = π x 39.95 x 0.25 x 40 x 0.07
M.R.R = 351.419 mm^3/min

Ks= (M.R.R practical/ M.R.R thearitical)

And so the machining material removal factor is Ks = 1.184.

(ii) Estimated Energy Dissipation:

- Energy used for cutting, Qc= M.R.R x ut

Using the equation 13 and average specific energy (ut)= 6Ws/mm^3:

Ut= (6/60)W.min/mm^3= 0.1Wmin/mm^3

Qc practical = 436.45 x 0.1= 43.645W

Qc thoeritical= 351.419 x 0.1= 35.142W

Table 4.16 Energy Required for cutting

Qc (practical)	**42.6298 W**
Qc (theoretical)	**35.1419 W**

- Energy lost as heat to the work piece, Qw, using equation 28 in chapter 3:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

k=50.2 W/m°C

As= $\pi d^2/4$

$$= \pi \frac{0.25^2}{4} \quad = 0.196x10^{-6} m^2$$

L=2 πDavg

=2x π x 0.0397

=24.94mm

$$Qw = \frac{50.2x0.196x10}{24.94x10^{-3}}(1.8)$$

= **0.007101W**

- Energy lost as heat to the coolant, Qf, using equation 29 in chapter 3:

$Qf = h.As(t_1 - t_2)$

flow rate = 100ml/ 20s

= 5 x $10^{-6}m^2/s$

$$vf = \frac{flowrate}{\frac{\pi Dn^2}{4}} = \frac{5x10^{-6}}{\frac{\pi x0.008^2}{4}} = 0.099472 m^2/s$$

Lc = π Davg

= π x .02494

= .09236m

$$R_{el} = \frac{V_l L}{v}$$

$$= \frac{0.099472x.09236}{1.0098x10^{-6}} = 90098$$

Pr=μCp/k= 1.0098 x 10^{-3} x 4180/ 0.607

=6.941

$$Nu = 0.644(R_{el})^{0.5}(\Pr)^{0.333}$$

$$Nu = 0.644(90098)^{0.5}(6.941)^{0.33} = 1163.786$$

$$h = \frac{Nuk}{L} = \frac{1163.786x0.607}{0.09236}$$

=7643.36

As= Lc x tool nose radius= 0.09236 x3x10^{-3}m^2

$$Qf = 0.09236x0.003x7643x(1.9)$$

= **4.0237W**

Table 4.17 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	23^{0}C
Final Temperature	24.9^{0}C
Net Temperature	1.9^{0}C
Dynamic viscosity, μ	1.0098 x 10^{-3} kg/ms
Kinematic Viscosity, v	1.0211 x10^{-6}m^2/s
Density, ρ	984 kg/m^3
Thermal Conductivity, K	0.607 W/m^{0}C
Fluid velocity, Vf	0.009947 m/s
Length of application. Lc	0.1255m
Reynolds number, Re	90098
Prandtls number, Re	6.941
Nusselt number, Nu	1163,789
Heat transfer coefficient, h	7643.36 W/m^2 ^{0}C
Cross Sectional Area, As	0.2771 x 10^{-3}m^2
Heat Transfer, Qf	**4.0237 W**

(iv) Coolant Consumption:

Fluid flow rate = 100mL/20s
=5 x10^{-3}L/s

Co= flow rate x cutting time
= 5 x 10^{-3} x (97 x60 + 39)
= 29.295 L

(v) Applying E.B.M standard metrics:

Mi= $\frac{\text{mass of the raw material} - \text{mass of part product}}{\text{Output (mass of the part product)}}$ = **0.291/ 0.6988 =0.4614**

Qi = $\frac{\text{net energy consumed in producing the part product}}{\text{Output}}$ =**46.6955/ 0.6988=67.7537 W/kg**

Ci = $\frac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$ = **29.295/ 0.6988= 41.113 l/kg**

Te = **22.2mg/m^3**

(v) Applying E.B.M standard metrics:

Table 4.18 EBM standard metrics

	Practical	**Theoretical**
Material Intensity [Mi]	0.4164	0.31562
Energy Intensity [Qi], W/kg	67.7537	52.607
Coolant Intensity [Ci] L/kg	41.113	38.408

(b) MILLING

(i) Material Removal Rate (M.R.R):

Practical M.R.R= Practical M.R.R = (Material Removed / Cutting Time)

Table 4.19 Material Removed and MRR

Material removed	0.565 kg
Total machining time	96min 06s
Volume of material removed	81464.9mm^3
Idle / handling time	24min
Cutting time	72min 06s
M.R.R	**1131.3 mm/min**

Theoretical M.R.R= **M.R.R** = w d v nN

Using equation 18 from chapter 3:

d = 0.4mm

(v) Applying E.B.M standard metrics:

Mi= $\dfrac{\text{mass of the raw material – mass of part product}}{\text{Output (mass of the part product)}}$ = **0.291/ 0.6988 =0.4614**

Qi = $\dfrac{\text{net energy consumed in producing the part product}}{\text{Output}}$ =**46.6955/ 0.6988=67.7537 W/kg**

Ci = $\dfrac{\text{amount of the coolant used in producing the part product}}{\text{Output}}$ = **29.295/ 0.6988= 41.113 l/kg**

Te = **22.2mg/m^3**

(v) Applying E.B.M standard metrics:

Table 4.18 EBM standard metrics

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Material Intensity [Mi]	0.4164	0.31562
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Table 4.19 Material Removed and MRR

Material removed	0.565 kg
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Volume of material removed	81464.9mm^3
Idle / handling time	24min
Cutting time	72min 06s
M.R.R	**1131.3 mm/min**

Theoretical M.R.R= **M.R.R** = w d v nN

Using equation 18 from chapter 3:

d = 0.4mm

f = 0.04mm/rev
v =40mm/ rev
N = 250 rpm
n = 4
D = 125mm
M.R.R = 924 mm/min

And so so the machining material removal factor is Ks = 1.22..
Using the equation19and average specific energy 6Ws/mm^3:

Table 4.20 Energy Required for cutting

Qc (practical)	**113.1 W**
Qc (theoretical)	**92.4 W**

- Energy lost as heat to the work piece, Qw, using equation 28 in chapter 3:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

Qw= 0.667W

Energy lost as heat to the coolant, Qf, using equation 29 in chapter 3:

$$Qf = h.As(t_1 - t_2)$$

Table 4.21 Energy Required for cutting

Initial Temperature	22.4^{0}C
Final Temperature	24.9^{0}C
Net Temperature	2.5^{0}C
Dynamic viscosity, μ	1.018 x 10^{-3} kg/ms
Kinematic Viscosity, v	1.03 x10^{-6}m^2/s
Density, ρ	984 kg/m^3
Thermal Conductivity, K	0.607 W/m^{0}C
Fluid velocity, Vf	0.284 m/s
Length of application. Lc	0.0123m
Reynolds number, Re	3376
Prandtls number, Re	7.0102
Nusselt number, Nu	716.132

Heat transfer coefficient, h	$35340.8 W/m^{2}\,{}^{0}C$
Cross Sectional Area, As	$0.1538 \times 10^{-3} m^2$
Heat Transfer, Qw	**13.584 W**

(iv) Coolant Consumption:
Co =82.29 L

(v) Applying E.B.M standard metrics:

Table 4.22 EBM standard metrics

	Practical	**Theoretical**
Material Intensity [Mi]	0.27942	0.2001
Energy Intensity [Qi], W/kg	62.982	52.745
Coolant Intensity [Ci] L/kg	40.65	38.68

(c) <u>DRILLING</u>

(i) Material Removal Rate (M.R.R):

Practical M.R.R = (Material Removed / Cutting Time)

Table 4.23 Material Removed and MRR

Material removed	0.0349 kg
Volume of material removed	$5037.9 mm^3$
Cutting time	12min 26s
M.R.R	**404.54mm/min**

Theoretical M.R.R= - Energy used for cutting, Qc= M.R.R x ut

Using equation 22 from chapter 3:

D = 9.5mm
f = 0.0185mm/rev
N = 250 rpm
M.R.R 328.1 mm/min

And so the machining material removal factor is Ks = 1.608.

Using the equation 23 and average specific energy 6Ws/mm^3:

Table 4.23 Energy Required for cutting

Qc (practical)	**40.45 W**
Qc (theoretical)	**32.81 W**

- Energy lost as heat to the work piece, Qw, using equation 28 in chapter 3:
- Energy used for cutting, Qc= M.R.R x ut

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

Qw= 0.667W

- Energy lost as heat to the coolant, Qf, using equation 29 in chapter 3:

$$Qf = h.As(t_1 - t_2)$$

Table 4.24 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	22.4^{0}C
Final Temperature	26.9^{0}C
Net Temperature	4.5^{0}C
Dynamic viscosity, μ	1.018 x 10^{-3} kg/ms
Kinematic Viscosity, v	1.03 x10^{-6}m^2/s
Density, ρ	984 kg/m^3
Thermal Conductivity, K	0.607 W/m^{0}C
Fluid velocity, Vf	0.284 m/s
Length of application. Lc	0.010m
Reynolds number, Re	3137
Prandtls number, Re	7.0102
Nusselt number, Nu	66.032
Heat transfer coefficient, h	4008 W/m^2 ^{0}C
Cross Sectional Area, As	0.2835 x 10^{-3}m^2
Heat Transfer, Qw	**5.222 W**

(iv) Coolant Consumption:

Co = 3.79 L

(v) Applying E.B.M standard metrics:

Table 4.25 EBM standard metrics

	Practical	**Theoretical**
Material Intensity [Mi]	0.0407	0.032
Energy Intensity [Qi], W/kg	46.32	38.685
Coolant Intensity [Ci] L/kg	5.08	5.03

(d) <u>SHAPING:</u>

(i) Material Removal Rate (M.R.R):

Practical M.R.R== (Material Removed / Cutting Time)

Table 4.26 Material Removed and MRR

Material removed	0.1552 kg
Total machining time	92min
Volume of material removed	22430.13 mm^3
Idle / handling time	24min 56s
Cutting time	67min 04s
M.R.R	**334.778 mm/min**

Theoretical **M.R.R =wfNd** (mm/ min)

Using equation 18 from chapter 3:

w = 0.4mm
f = 0.3mm/stroke
N = 25strokes/ mm
d = 2mm
M.R.R =304.5 mm/min

And so the machining material removal factor is Ks = 1.09

Using the equation 26 and average specific energy 6Ws/mm^3:

Table 4.27 Energy Required for cutting

Qc (practical)	**33.478 W**
Qc (theoretical)	**30.45 W**

- Energy lost as heat to the work piece, Qw, using equation 28 in chapter 3:

$$Qw = \frac{kA(t_1 - t_2)}{L}$$

Qw=7.66W

- Ener $\frac{L^3 \beta g(t_1 - t_2)}{v^2}$ gy lost as heat to the free convective air, Qh, using equation 29 in chapter 3:

$Qf = h.As(t_1 - t_2)$ and the sample calculations:

t1-t2 = 40.9- 26.2 = 14.7^{0}C.
L = 57.3 x 10^{-3}m/s

$\beta = \frac{1}{T}$ = (1/(273.15 + 40.0) = 0.0146

g= 9.81m$^{2/}$/s
v= 0.76 x 10^{-5}m^2/s

Gr= $\frac{L^3 \beta g(t_1 - t_2)}{v^2}$

$$= \frac{(57.3x10^{-3})^3 0.0146x9.81x14.7}{(0.76x10^{-5})^2} = 472\ 093\ 172.3$$

Pr= 0.74
Nu=0.59 (Gr.Pr)
=0.59(472 093 172.3)$^{0.25}$= 80.661

$$h = \frac{Nu.k}{L} = \frac{80.661x0.018}{57.3x10^{-3}} = 25.33 \text{W/m}^{2\,0}\text{C}$$

As= 0.0609x10 $^{-3}$ m2

$Qf = h.As(t_1 - t_2)$
= 0.0609x10 $^{-3}$ x 25.33 x 14.7
= 0.02256 W

Table 4.28 Natural convective air parameters and energy lost to the surrounding

Initial Temperature	26.2^0C
Final Temperature	40.9^0C
Net Temperature	14.7^0C
Dynamic viscosity, μ	1.34×10^{-5} kg/ms
Kinematic Viscosity, v	$0.76 \times 10^{-5} m^2/s$
Density, ρ	1.766 kg/m^3
Thermal Conductivity, K	0.0181 W/m^0C
Length of application. Lc	0.057.8m
Garshoffs number	472093172.3
Prandtls number, Re	0.74
Nusselt number, Nu	80.661
Heat transfer coefficient, h	$25.33 W/m^{2\,0}C$
Cross Sectional Area, As	$0.0609 \times 10^{-3} m^2$
Heat Transfer, Qw	**0.02256W**

(v) Applying E.B.M standard metrics:

Table 4.29 EBM standard metrics

	Practical	**Theoretical**
Material Intensity [Mi]	0.075	0.068
Energy Intensity [Qi], W/kg	47.82	45.07

4.3 DEVELOPMENT AND APPLICATION OF AN IMPROVED PROCESS LEVEL SYSTEM.

This section offers possible solutions to the problems identified faced by the workshop so as to improve the environmental performance. The method of improving the performance proceeded as suggested in the models developed in the methodology:

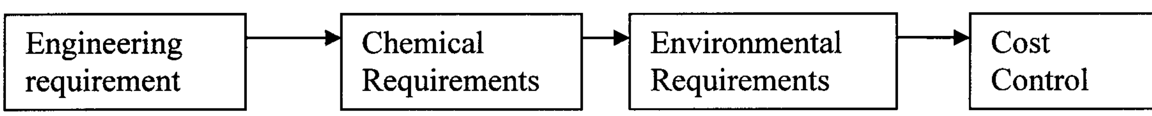


Figure 4.1: Summary of process level model

4.3.1 ENGINEERING REQUIREMENTS:

For the workshop to meet the required Environmental performance all the engineering requirements should be met. By not meeting these standards there is reduced performance effect making it more difficult to practice sustainable manufacturing:

(a) Tooling requirements:

The workshop had tools that were worn out as can be clearly seen in the baseline analysis. The practice in the workshop is the use of one common tool to cover a number of processes the recommended parameters easily fell out of range these affected the machining processes in the following ways:

Turning:

The large rake angles, that is the side rake angles = 21^0 and the large nose radius leads to:

- high temperatures during operation as high as 26.8^0 C
- increased material removal, having an increased M.R.R constant, Ks =1.18 (dull Tool)

and having high Energy output = 42.6955W ; this increases the Material Intensity and the Energy intensity eventually the operating cost of the processes.

Regrinding the tool to reduce the Rake angle and to reduce the cutting edges in attempt to the sharpen the tool

Milling

The high relief angles that is both the relief and Secondary Relief angles = 21^0 leads to:

- Poor surface finish
- high temperatures during operation as high as 29.6^0C
- increased material removal , having an increased M.R.R constant, Ks =1.22 (dull Tool) and having high Energy output = 133.1W ; this increases the Material Intensity and the Energy intensity eventually the operating cost of the processes.

Regrinding the tool to reduce the relief angles in attempt to the sharpen the tool though anew cutting tool is recommended.

Drilling

The large Lip Relief = 23^0 and the large nose radius leads to:

- Affects the total thrust and Torque
- high temperatures during operation as high as 49.2^0C
- increased material removal , having an increased M.R.R constant, Ks =1.608 (dull Tool) and having high Energy output = 40.455W ; this increases the Material Intensity and the Energy intensity eventually the operating cost of the processes.

Regrinding the tool to reduce the lip relief angle.

Shaping

The cutting angles require regrinding to reduce the nose radius form 3mm to less than 1mm; other than that this leads to:

- high temperatures during operation as high as 43.8^0C
- increased material removal , having an increased M.R.R constant, Ks =1.12 (dull Tool) and having high Energy output = 33.478W for the selected operating parameters ; this increases the Material Intensity and the Energy intensity eventually the operating cost. Of the processes.

(b) Chemical Requirements

This largely involves cutting fluid, dry machining and treatment methods:

Cutting Fluid

The cutting fluid is wrongly mixed, not monitored and has not been replaced for a long time. This has resulted in:-

- low pH levels making the process very corrosive hindering the workshop of manufacturing part with reactive components.
- presence of tramp oil provides a breeding ground for bacteria forming organic compounds such as cellulose which may react with some metals. The oil even though increases lubrication it increases the operation temperature and hence Energy intensity.
- large concentration of soluble oil also has an adverse effect on the environmental performance of the processes in that it increases the pH, temperature and Energy. Intensity of the processes. Huge soluble consumption is also expensive.
- Presence of bacteria can pose a threat to the health of the Operator
- use of hard water (tap water) contains carbonates approximately 60 mg/L which reacts with corrosive metals and fluids.
- Below is a table that summarizes the cutting fluid properties:

Table 4.30 Cutting fluid parameters

	TURNING	MILLING	DRILLING	SHAPING
pH	8.8	7.9	8.3	N/A
Tramp oil (%)	18	23	23	N/A
Bacterial growth	Evident	Evident	Evident	N/A
Soluble oil (%)	14.7	18.3	N/A	N/A
Treatment	None	None	None	None
Hardness mg/L	60	60	60	60

In order to mitigate this problem the following procedures are carried out :

Empty the all the sumps for complete fluid change.

Prepare the cutting fluid meeting the following parameters

Amount of soluble: 10%

pH = 8.0 to 8.9

$\nu = .905 \times 10^{-6}\ m^2/s$

Hardness < 10mg/L

Sulphates = 18g/10L

Then the fluid should be monitored after a monthly basis and consequently maintained to top up distilled water and soluble oil; skim off the tramp oil and add sulphates to prevent bacterial growth.

Alternatively dry machining cooled by compressed air is an option eliminating these Environmental concerns yet maintaining the recommended conditions.

Dry Machining

This is only practiced when the process being considered is Shaping and to some extent when the machining process has no automated coolant supply thereby making it cumbersome to operate the machine simultaneously lubricating the machinery. Dry machining without effective cooling may have reduced chemical effects but carry some Environmental repurcations due to high temperatures such as 49.8^0C:

- tool performance is reduced hence reducing its life and increasing the expense due to regular regrinding or eventual replacement.
- High energy processes which lead to high operating costs and may distort the internal structure of the work piece.
- Increased respirable toxics which are trapped in the used cutting fluid of in the case of wet machining.

In order to mitigate these issues revolving around dry machining is to introduce spot compressed air cooling, that is taking advantage of the compressor and the flexible hose pipes leaving the purchase of the nozzle and general equipment organization as the only hurdle.

(c) Environmental Requirements

Most of the issues have been discussed that center on material removal and Energy consumption relying entirely on the engineering requirements and the chemical considerations. But the analysis further trickles down to the toxic emissions, safety practices and cleaning

As for toxic emissions there are threshold limits that have been set. Beyond these limits the operation is deemed unsafe. Fortunately for the workshop, due to the 'job shop practices' these limits are never met for instance 22.2 mg/mm^3 found in the machining of mild steel which is less than 50mg/mm^3.

As for the safe practices the following were the short falls:

- facilities: windows too high and so free flowing air does not easily escape to clear off dust, mist and toxics adequately
- most of the machinery do not have guards to protect the operator from the splashing fluids, shooting chips and so on.
- No health monitoring schemes.
- Cleaning done on a weekly basis allowing material and toxic accumulation.
- No proper disposal methods

In order to mitigate these environmental issues will require a corporate strategy of ensuring certain targets are met which include:

- adequate facilities that allow and undisturbed air circulation.
- proper protection gear for particular processes as recommended by the safety sheet.
- carrying out health inspections regularly.

- Abiding by the recommended Environmental Council of Zambia for waste material.

(d) Cost control

All these suggestions for improvements carry costs and are only appreciable after some time. The improvements up grade the operating standards of the work shop and do have a payback period if the costs are carefully monitored. The unit costs are analyzed and projected as costs per annum.

4.4 IMPROVED PROCESS LEVEL SYSTEM

This section applies the improved suggestions discussed in the previous section to the processes being analyzed.

4.4.1 DATA INPUT:

4.4.1.1 Machine scenario

The parameters shown in table 4.1 are acceptable cutting ranges for mild steel and are consequently maintained for comparison of the improved analysis to the baseline analysis.

Table 4.1 Operational machine parameters.

Parameter	Milling	Turning	Drilling	Shaping
Speed	250 rpm	160rpm	250rpm	25 strokes/ min.
Feed rate	40 mm/min	0.07mm/min	0.018mm/min	0.3mm/stroke
Depth of cut	0.4 mm	0.25mm	10mm	2mm

4.4.1.2 Tooling Parameters

The most cost efficient method of ensuring that tool parameters are met is by re grinding but where this seems difficult new tools must be purchased.

Turning

The tool in table 4.1 was re ground to:

- reduce the rake angle from 21^0 to14^0
- reduce the side cutting angle from 23^0 to 12^0
- reduce the end cutting angle to about 7^0
- reduce nose radius to about 1mm

Milling:

Due to the difficulties in regrinding the 4 tooth milling cutter, a new tool to perform similar tasks was employed with the parameters given in table :

Table 4.31 Milling tool parameters

Tool Parameters	Measurement
Lead angle	12^0
Relief angle	21^0
Second Relief Angle	42^0

Drilling:

The drilling tool used in the in the first experiment was re ground to reduce the lip angle from 23^0 to about 15^0.

Shaping:

The shaping tool in table 4.4 was re ground to:

- reduce the relief angle to 10^0

- reduce the cutting edge angles to give a nose radius of about 0.8mm.

4.4.1.3 Material Preparation:

The material was prepared for both wet and dry machining. The parameters were almost the as those of the previous runs for each of the processes for easier comparisons, any deviation was due to the material irregularities for instance mass distribution in the work piece.

4.4.1.4 Cutting Fluid Preparation:

The optimum cutting fluid was prepared meeting the recommended environmental requirements as shown in table 4.4.2:

Table 4.32 Optimum Cutting fluid Parameters

Coolant type	Soluble oil
Fluid concentration	10%
Jet nozzle diameter	8mm
Height of jet above work piece	80mm
Fluid system capacity	20 L
Fluid viscosity	$0.891 \times 10^{-6}\ m^2/s$
Fluid density ρ	$984\ kg/m^3$
Fluid pH	8.8
Fluid hardness	10mg/L
Amount of tramp oil	2.83 L
Fluid rancidity levels	acceptable
Treatment information	600mg sulphate

- Energy dissipation due to cooling using soluble oil:
-

Table 4.35 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	22^0
Final Temperature	23.8^0
Net Temperature	1.8^0
Dynamic viscosity, μ	$0.891 x 10^{-3}$ kg/ms
Kinematic Viscosity, v	$0.905 x10^{-6} m^2/s$
Density, ρ	984 kg/m^3
Thermal Conductivity, K	0.607 W/m^0C
Fluid velocity, Vf	0.009947 m/s
Length of application. Lc	0.1255m
Reynolds number, Re	13794.2
Prandtls number, Re	6.13571
Nusselt number, Nu	1383.862
Heat transfer coefficient, h	6693,26$W/m^{2\,0}C$
Cross Sectional Area, As	$0.3675 x 10^{-3}m^2$
Heat Transfer, Qw	**4.536 W**

-Energy dissipation due to cooling using compressed air:

Table 4.36 Compressed air parameters

Initial Temperature	17^0
Final Temperature	18.9^0
Net Temperature	1.8^0

- Energy dissipation due to cooling using soluble oil:
-

Table 4.35 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	22^0
Final Temperature	23.8^0
Net Temperature	1.8^0
Dynamic viscosity, μ	$0.891 \mathrm{x}\ 10^{-3}$ kg/ms
Kinematic Viscosity, v	$0.905\ \mathrm{x}10^{-6}\mathrm{m}^2/\mathrm{s}$
Density, ρ	$984\ \mathrm{kg/m}^3$
Thermal Conductivity, K	$0.607\ \mathrm{W/m}^0\mathrm{C}$
Fluid velocity, Vf	0.009947 m/s
Length of application. Lc	0.1255m
Reynolds number, Re	13794.2
Prandtls number, Re	6.13571
Nusselt number, Nu	1383.862
Heat transfer coefficient, h	$6693,26\mathrm{W/m}^{2\,0}\mathrm{C}$
Cross Sectional Area, As	$0.3675\ \mathrm{x}\ 10^{-3}\mathrm{m}^2$
Heat Transfer, Qw	**4.536 W**

-Energy dissipation due to cooling using compressed air:

Table 4.36 Compressed air parameters

Initial Temperature	17^0
Final Temperature	18.9^0
Net Temperature	1.8^0

Kinematic Viscosity, v	1.8 x$10^{-5}m^2/s$
Density, ρ	1.244 kg/m^3
Thermal Conductivity, K	0.018 W/m^0C
Fluid velocity, Vf	89.2 m/s
Length of application. Lc	0.1255m
Reynolds number, Re	564150.7
Prandtls number, Re	0.714
Nusselt number, Nu	43261
Heat transfer coefficient, h	6204.764$W/m^{2\,0}C$
Cross Sectional Area, As	0.3675 x $10^{-3}m^2$
Height of the nozzle Hn	30mm
Nozzle diameter	6mm
Heat Transfer, Qw	**4.536 W**

(iv) Coolant Consumption:

With flow rate remaining constant **Co=29.295 L**

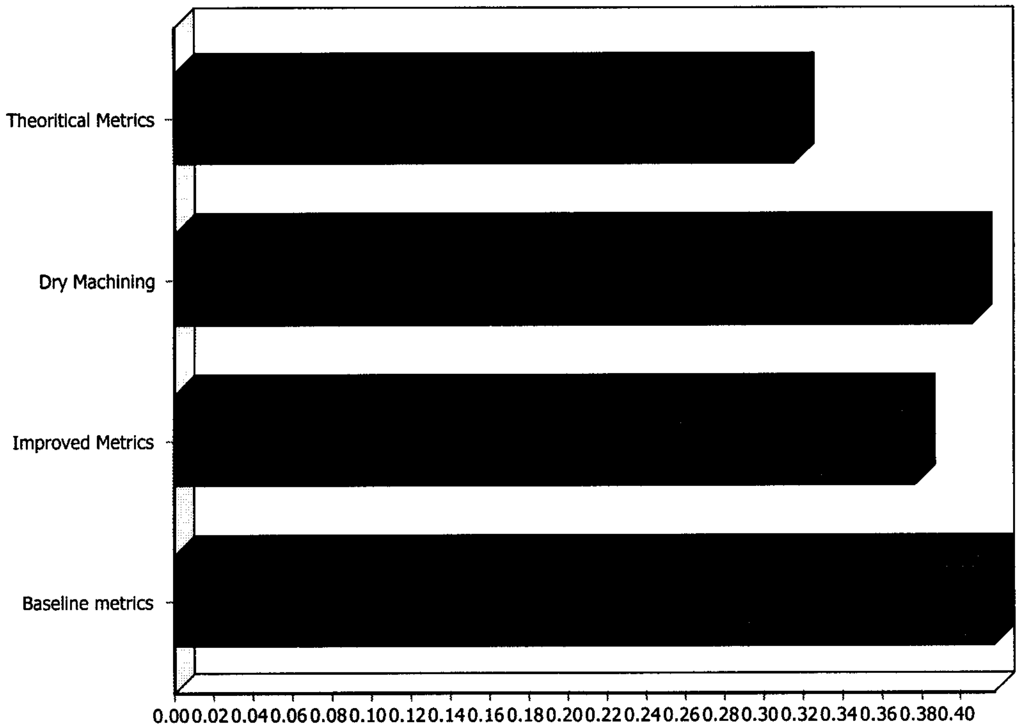
(v) Applying E.B.M standard metrics and comparing them to baseline metrics:

Table 4.37 EBM standard metrics

	Wet machining Baseline Metrics	Wet machining Improved Metrics	Dry machining- with compressed air	Theoretical metrics
aterial Intensity [Mi]	0.4164	0.3764	0.40527	0.31562
iergy Intensity [Qi], /kg	67.7537	62.195	64.339	52.607
oolant Intensity [Ci] /kg	66.113	65.193	N/A	61.408

Graphical Presentation of the E.B.M standard Metrics:

(i) Material Intensity:



Kg/kg

Fig 4.2 Material intensity

(ii) Energy Intensity:

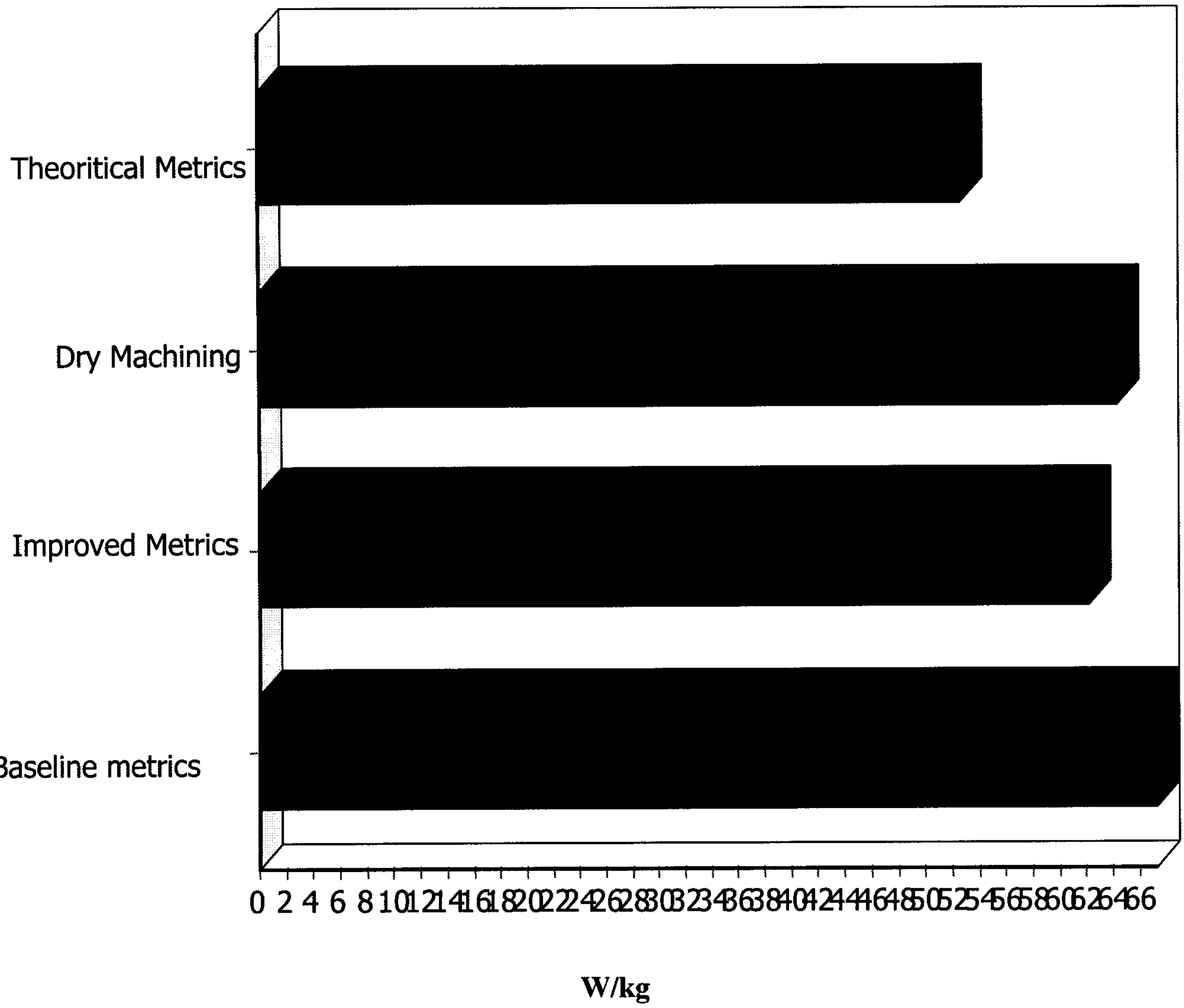
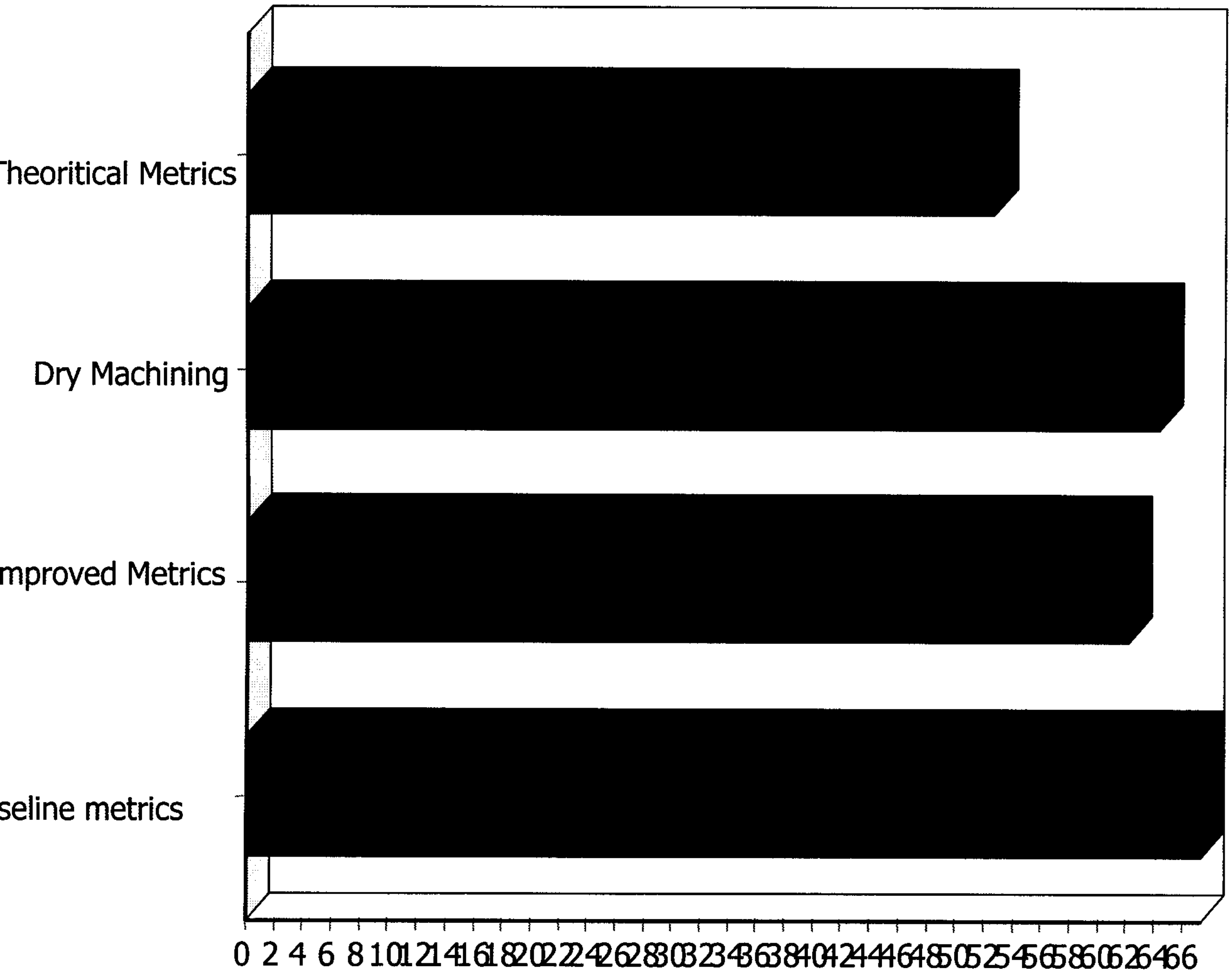


Fig 4.3 Energy Intensity

(ii) Energy Intensity:



W/kg

Fig 4.3 Energy Intensity

(iv) Coolant Intensity:

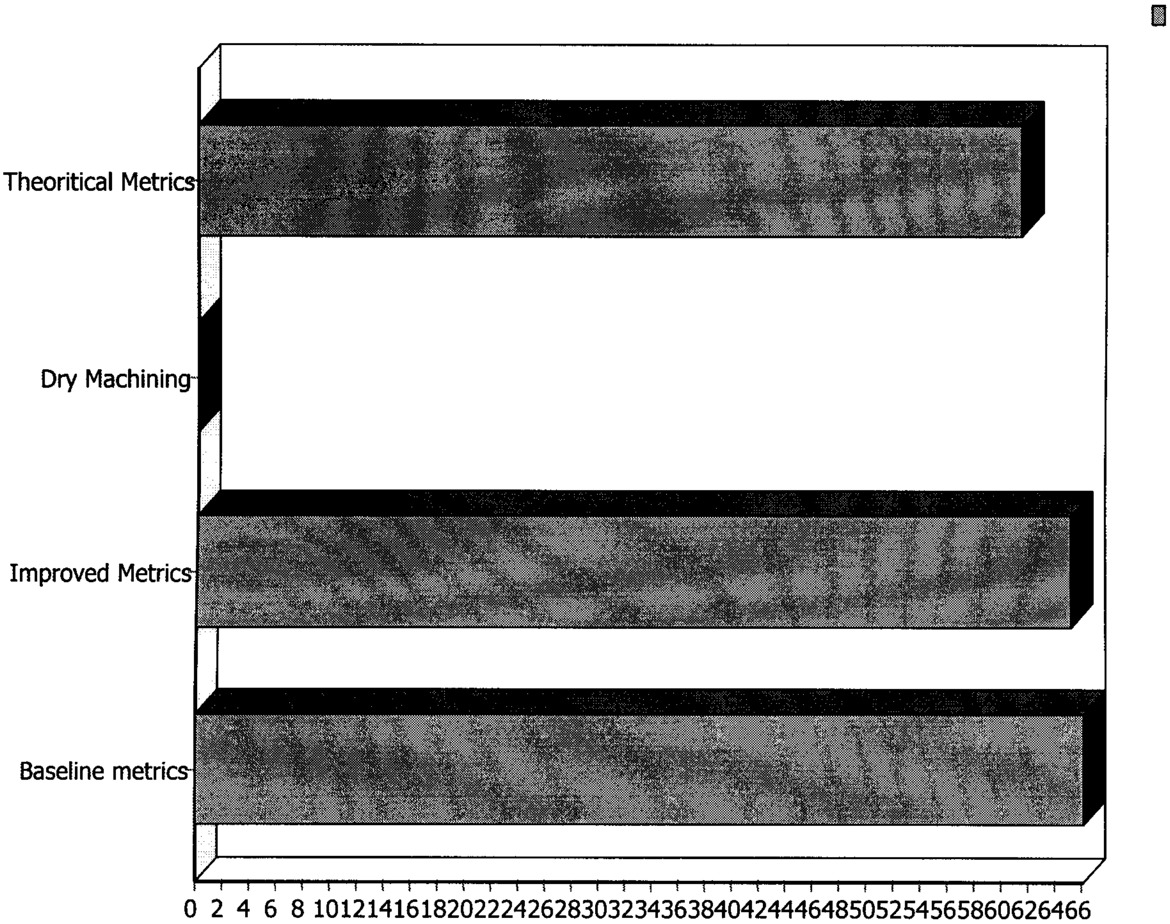


Figure 4.4 Coolant Intensity

(b) MILLING

(i) Material Removal Rate:

Table 4.38 Material Removed and MRR

Material removed	0.542 kg
Total machining time	102min
Volume of material removed	40 635mm^3
Idle / handling time	29min 22s
Cutting time	72min 39s
M.R.R	**1078.34mm^3/min**
Ks	**1.16**

(ii) Energy Dissipation:

- Energy dissipation due to cutting heat loss to the work piece
-

Table 4.39 Energy Required for cutting

Qc (Cutting)	**107.34W**
Qw (heat loss to work piece)	**0.667W**

- Energy dissipation due to heat loss to the coolant

Table 4.40 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	22.8^0
Final Temperature	25.2^0
Net Temperature	2.4^0
Dynamic viscosity, μ	0.891×10^{-3} kg/ms
Kinematic Viscosity, v	$0.905 \times 10^{-6} m^2/s$
Density, ρ	984 kg/m^3
Thermal Conductivity, K	0.607 W/m^0C
Fluid velocity, Vf	0.284 m/s
Length of application. Lc	0.0123m
Reynolds number, Re	3859.88
Prandtls number, Re	6.1357
Nusselt number, Nu	7732.434
Heat transfer coefficient, h	$36145.33/m^{2\,0}C$
Cross Sectional Area, As	$0.1538 \times 10^{-3} m^2$
Heat Transfer, Qw	**13.892 W**

(iv) Constant fluid flow rate: Co= 82.285 L

(v) Applying E.B.M standard metrics and comparing them to baseline metrics:

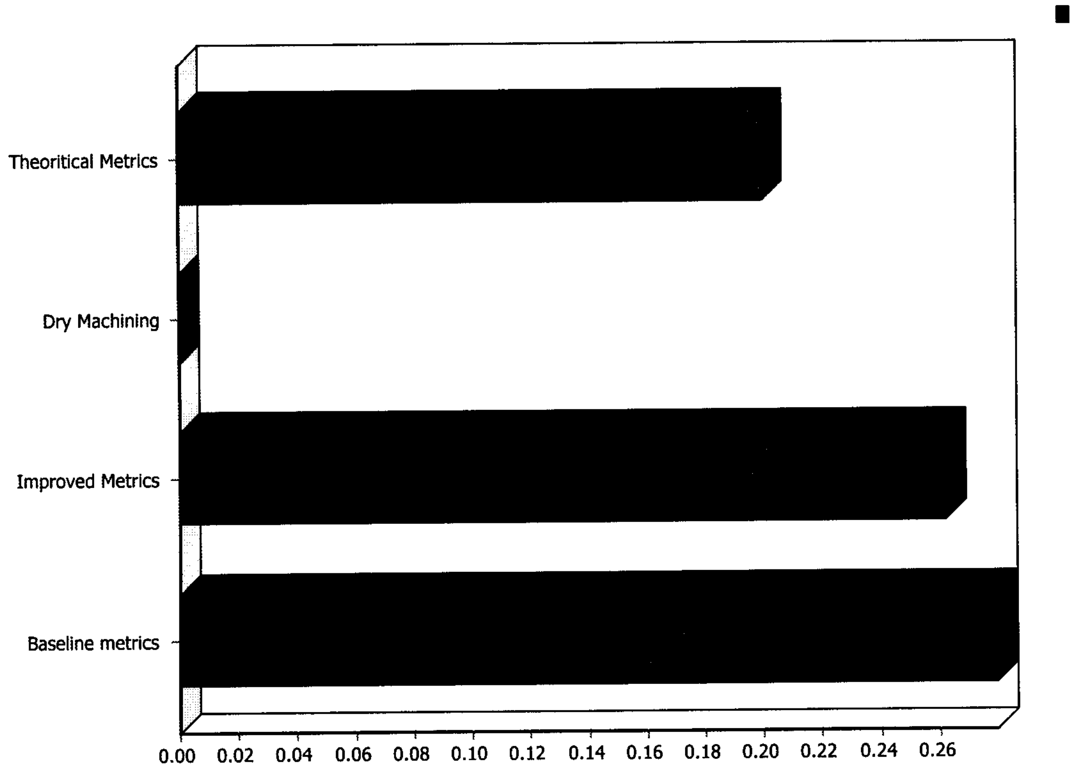
Table 4.41Material Removed and MRR

	Wet machining Baseline Metrics	Wet machining Improved Metrics	Theoretical metrics
terial Intensity [Mi]	0.27942	0.2619	0.2001
rgy Intensity [Qi], kg	62.982	58.910	52.745

lant Intensity [Ci] g	40.65	39.752	38.68

Graphical Presentation of the E.B.M standard Metrics:

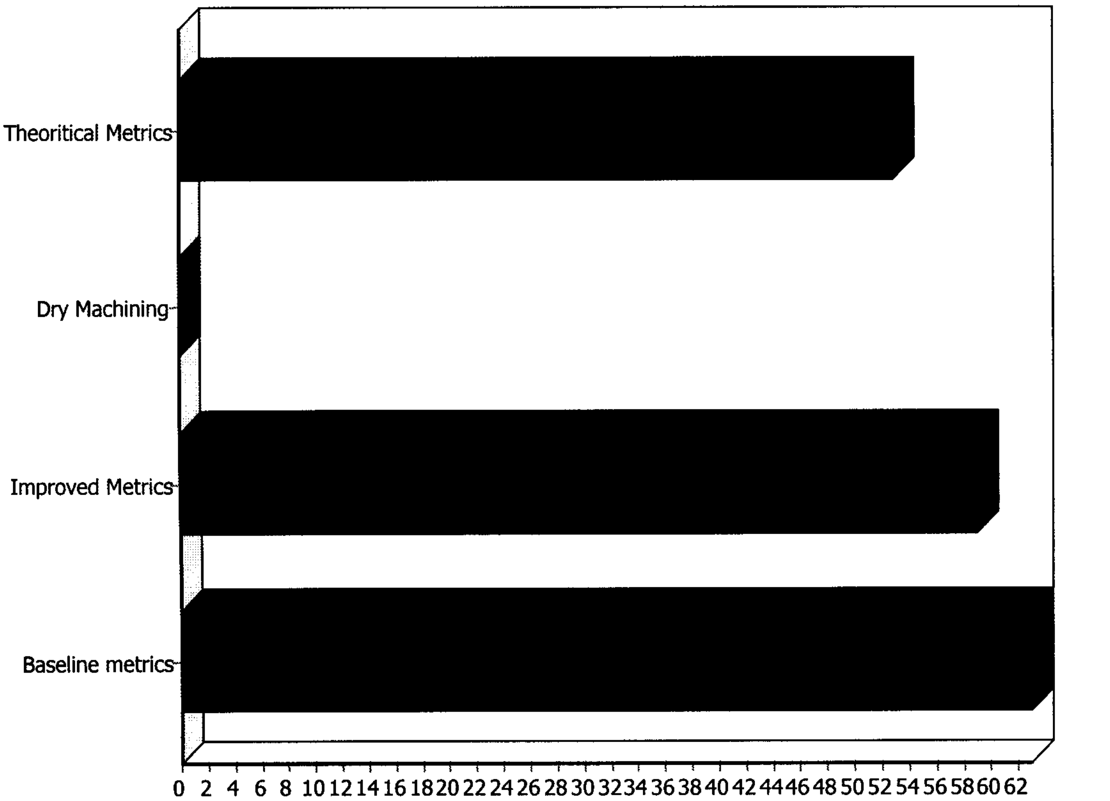
(i) Material Intensity



Kg/kg

Fig 4.5 Material Intensity

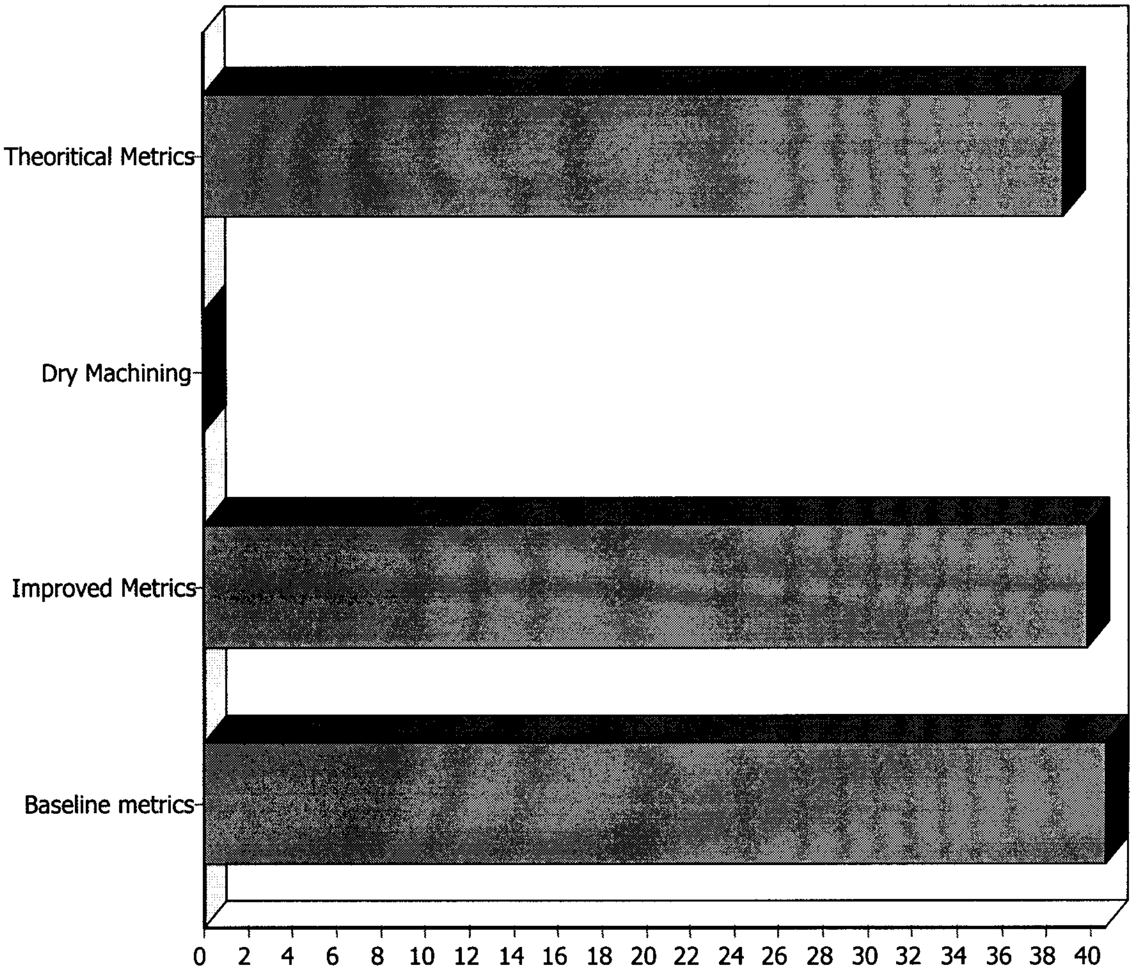
(iii) Energy Intensity:



W/kg

Figure 4.6 Energy Intensity

(iv) Coolant Intensity



L/ kg

Figure 4.7 Coolant Intensity

(c) <u>DRILLING</u>

(i) Material Removal Rate :

Table 4.42 Material Removed and MRR

	Wet machining	**Dry machining** (using comp. air coolant)
Material removed	0.0342 kg	0.0283 kg
Cutting time	12min 56s	156min
Volume of material removed	4942.2 mm^3	39450mm^3
M.R.R	**393.487mm^3/min**	**393.96mm^3/min**
Ks	**1.12**	**1.12**

(ii) Estimated Energy Dissipation:

Table 4.43 Energy Required for cutting

	Wet machining	**Dry machining** (using comp. air coolant)
Qc (Cutting)	**39.35W**	**39.39W**
Qw (heat loss to the work piece)	**0. 653W**	**0. 653W**

- Energy dissipation due to cooling using soluble oil:

Table 4.44 cutting fluid parameters and energy lost to the cutting fluid

Initial Temperature	22^0
Final Temperature	26.5^0
Net Temperature	4.5^0
Dynamic viscosity, μ	0.891×10^{-3} kg/ms
Kinematic Viscosity, v	$0.905 \times 10^{-6} m^2/s$
Density, ρ	$984 kg/m^3$
Thermal Conductivity, K	$0.607 W/m^0C$
Fluid velocity, Vf	0.236 m/s
Length of application. Lc	0.01m
Reynolds number, Re	3137.2
Prandtls number, Re	6.13571
Nusselt number, Nu	66.032
Heat transfer coefficient, h	$4008.13/m^{2\,0}C$
Cross Sectional Area, As	$0.3675 \times 10^{-3} m^2$
Heat Transfer, Qf	**5.222 W**

-Energy dissipation due to cooling using compressed air:

Table 4.45 Compressed air parameters

Initial Temperature	16^0
Final Temperature	19.1^0
Net Temperature	2.2^0
Kinematic Viscosity, v	$1.8 \times 10^{-5} m^2/s$
Density, ρ	$1.244 kg/m^3$
Thermal Conductivity, K	$0.018 W/m^0C$
Fluid velocity, Vf	89.2 m/s

Length of application. Lc	0..01m
Reynolds number, Re	564150.7
Prandtls number, Re	0.714
Nusselt number, Nu	37654.35
Heat transfer coefficient, h	$4264.79 W/m^{2\,0}C$
Cross Sectional Area, As	$0.2895 \times 10^{-3} m^2$
Height of the nozzle Hn	30mm
Nozzle diameter	6mm
Heat Transfer, Qw	**5.253 W**

(iv) Coolant Consumption:

With flow rate remaining constant **Co=3.279 L**

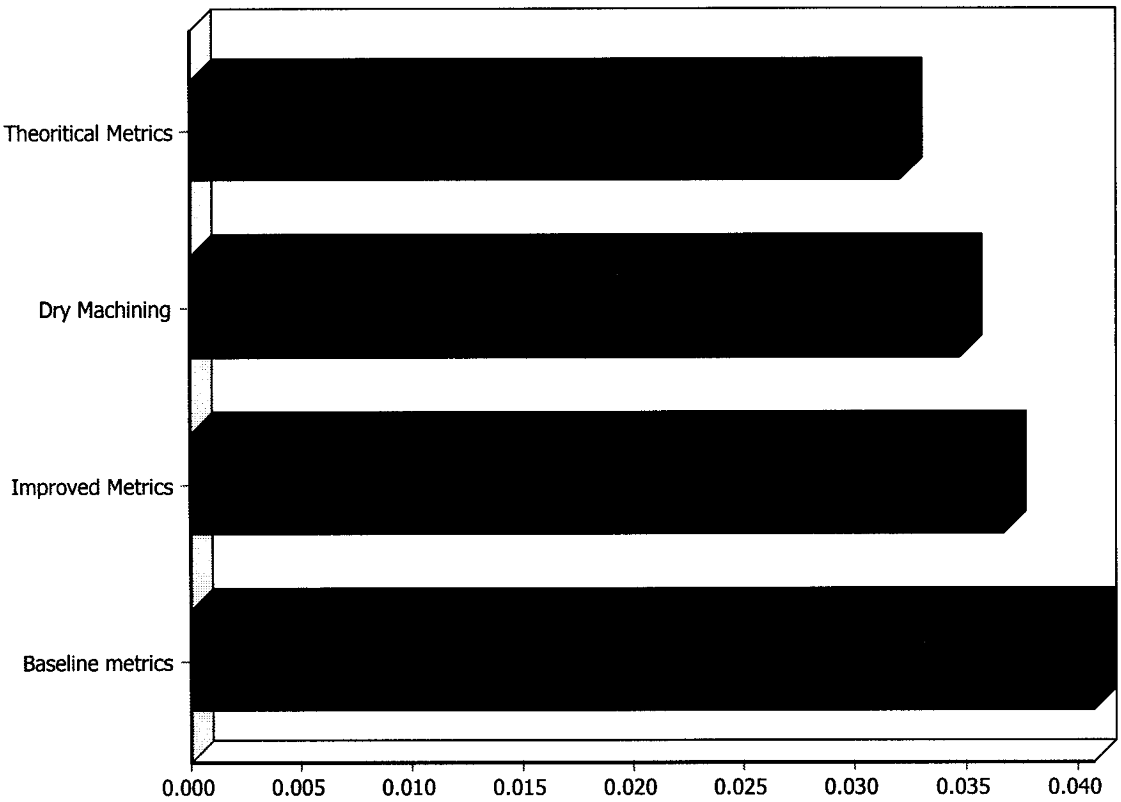
(v) Applying E.B.M standard metrics and comparing them to baseline metrics:

Table 4.46 EBM standard metrics

	Wet machining Baseline Metrics	**Wet machining Improved Metrics**	**Dry machining- with compressed air**	**Theoretical metrics**
erial Intensity [Mi]	0.0407	0.03668	0.0347	0.032
rgy Intensity [Qi], g	46.32	42.894	40.937	38.685
lant Intensity [Ci] g	5.08	5.04	N/A	5.03

Graphical Presentation of the E.B.M standard Metrics:

(i) Material Intensity:



Kg/kg

Figure 4.8 Material Intensity

(ii) Energy Intensity:

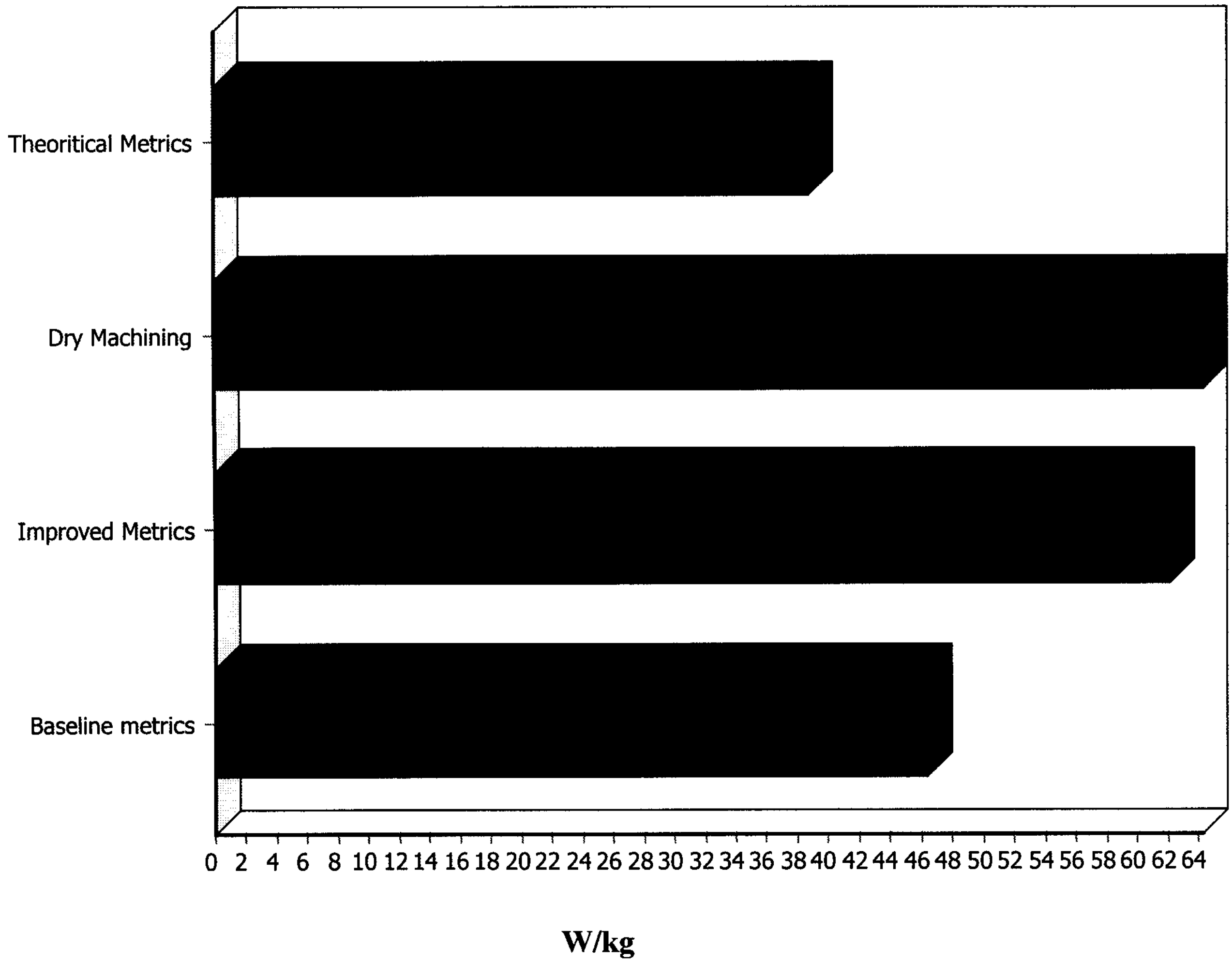
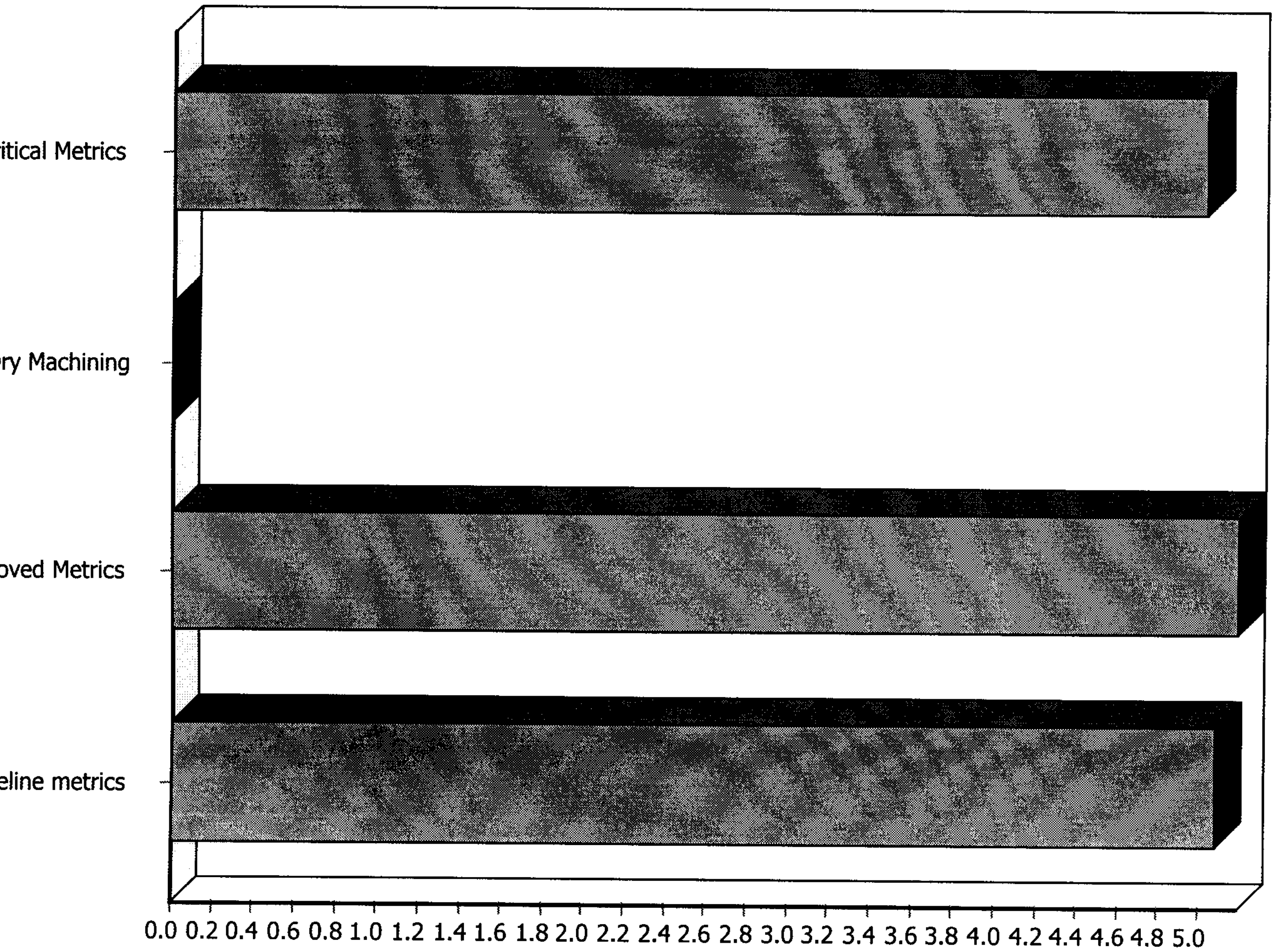


Fig 4.9 Energy Intensity

(iv) Coolant Intensity:



<u>Fig</u> 12 Coolant Intensity

(d) SHAPING

(i) Material Removal Rate:

Table 4.47Material Removed and MRR

Material removed	0.1543 kg
Total machining time	109min
Volume of material removed	22297.21mm^3
Idle / handling time	40min 03s
Cutting time	68min 57s
M.R.R	**323.38mm^3/min**
Ks	**1.16**

(ii) Energy Dissipation:

- Energy dissipation due to cutting heat loss to the work piece

Table 4.48 Energy Required for cutting

Qc (Cutting)	**32.34 W**
Qw (heat loss to work piece)	**0.766W**

- Energy dissipation due to heat loss to the coolant

Table 4.49 Compressed air parameters

Initial Temperature	17^0
Final Temperature	18.9^0
Net Temperature	1.8^0
Kinematic Viscosity, v	$1.8\ x10^{-5}m^2/s$
Density, ρ	$1.244\ kg/m^3$
Thermal Conductivity, K	$0.018\ W/m^0C$
Fluid velocity, Vf	89.2 m/s
Length of application. Lc	0.01m
Reynolds number, Re	460555
Prandtls number, Re	0.714
Nusselt number, Nu	3906.68
Heat transfer coefficient, h	$7032W/m^{2\ 0}C$
Cross Sectional Area, As	$0.0609\ x\ 10^{-3}m^2$
Height of the nozzle Hn	30mm
Nozzle diameter	6mm
Heat Transfer, Qw	**4.536 W**

(iv) Constant fluid flow rate: Co= 82.285 L

(v) Applying E.B.M standard metrics and comparing them to baseline metrics:

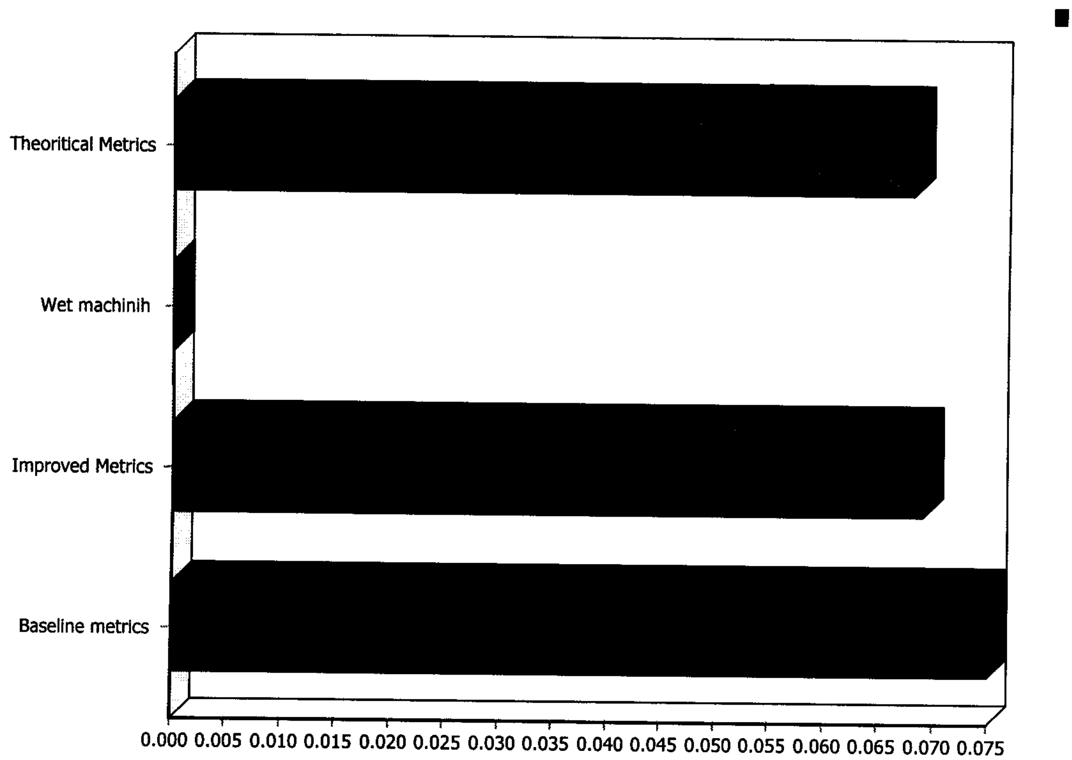
Table 4.50 EBM standard metrics

	Dry machining Baseline Metrics	**Dry machining Improved Metrics**	**Theoretical metrics**
·ial Intensity [Mi]	0.075	0.0691	0.068
:y Intensity [Qi],	47.82	46.323	45.07

ic Intensity [Te] mm^3	**2.22**	**2.22**	**2.22**
lant Intensity [Ci] g	40.65	39.752	38.68

Graphical Presentation of the E.B.M standard Metrics:

(i) Material Intensity:



Kg/kg

Fig 4.13 Material Intensity

(ii) Energy Intensity:

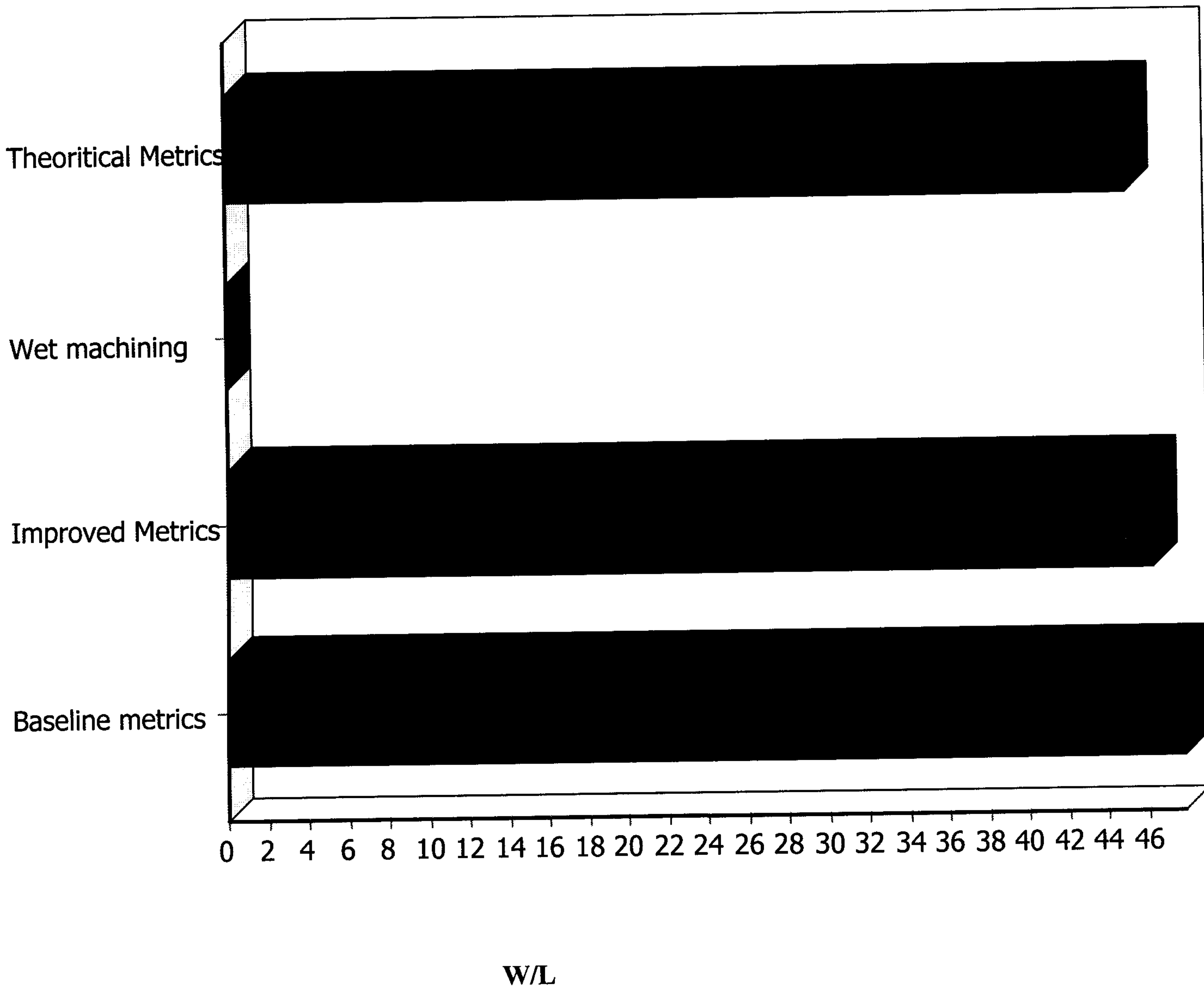


Fig 4.14

4.5 COMPARISON OF THE COSTS OF THE IMPROVED PROCESS MODEL TO THE BASELINE ANALYSIS:

In the cost analysis of the workshop it was difficult to obtain costs due to the 'job shop practice' and that the machinery operating costs could not be isolate as power costs were handled by the University of Zambia Administration as a block figure of all the cost.

Another hurdle was that there is no sustainable manufacturing being practiced and so there were no expenses in maintaining up to standard E.B.M practices. However it was important that the Environmental performance be applied to the work shop, such an investment is key to manufacturing and eventually reduces the input costs as well as the output costs in the long run.

Considering the price list shown in shown in table:

Table 4.52 Price List

Activity/ Utility/ Commodity	**Expense**	**Source of price Information**
Power	K117.8 per KWh	ZESCO
Mild steel	K2704 per kg	TDAU
Regrinding costs	K27000 per tool	Mechanical Work shop UNZA
Distilled water	K2500	Environmental laboratory UNZA
Soluble oil	K360000 per 20 L	TDAU
Treatment costs	K28750 per kg	Environmental laboratory UNZA
pH costs	K4000 per sample	Environmental laboratory UNZA
Hardness costs	K12000 per sample	Environmental laboratory UNZA
Viscosity costs	K7000 per sample	Environmental laboratory UNZA

ppm costs	K 17 000 per sample	Environmental laboratory UNZA

Some assumptions that were made include:

(1) The estimated coolant change according to the N.C division (7):

- For the coolant that is not monitored and maintained the sump change out should be done every 3 months.
- With careful management of cutting fluid sump change out could even increase to upto 6 months.

(2) Regrinding was done on an average of five months of continuous usage before the tool grinding machine seized operating

(a) <u>Turning;</u>

Sample calculation for 2 hours continuous operation the improved metrics:

Work piece cost = cost of raw material per kg x mass of raw in kgs

= K2704 x 0.9898 = K2676.4.

Monthly costs = K 52520.00

Energy costs = energy consumption (KW) x charge per KW x number of hours

= 43.761 x 2 x K117.8 =K10992.00

Monthly costs = K219598.

Regrinding cost= k 27000.00

Cost of soluble oil = cost of soluble oil per liter x percentage of soluble oil in coolant x coolant x sump capacity.

= k 18 000 x 0.2 x 10 = k 36 000

Cost of distilled water= cost of distilled water x percentage of distilled water x sump capacity.

= k 2500 x 0.8 x 20 = k 40000

Treatment cost = cost of sulphates per kg x consumption per month

= k28750 x 0. 5 kg = k14375.00

The rest of the costs are direct cost, assuming that treatment and fluid tests are done on a monthly basis:

Table 4.52 Cost comparison

	Baseline wet machining	**Improved wet machining**	**Dry cooled by compressed air**
Energy costs	K219598	K175044	K180824
Material cost			
W/P cost	K52 520	K52520	K52520
Fluid cost			
Soluble oil costs	K80000	K40000	K0
Distilled water costs	K0	K50 000	K0
Treatment costs	K0	K 27 000	K0
pH costs	K0	K4000	K0
Hardness test cost	K0	K12000	K0
Viscosity tests cost	K0	K7000	K0
ppm tests cost	K0	K17000	K0
Tooling costs			
Regrinding costs	K0	K27000	K27 000
Total cost for a month	K352118	K461564	K260334
Total cost for 6 months	K1792708	K1499384	K522 944
Total cost for a year	K3585416	K3078768	K2854128

4.5.2 Milling

Table 4.53 Cost comparison

	Baselin wet machining	Improved wet machining
Energy costs	K596 715	K571659
Material cost		
W/P cost	K52 520	K52520
Fluid cost		
Soluble oil costs	K80000	K40000
Distilled water costs	K0	K50 000
Treatment costs	K0	K 27 000
pH costs	K0	K4000
Hardness test cost	K0	K12000
Viscosity tests cost	K0	K7000
ppm tests cost	K0	K17000
Tooling costs		
Regrinding costs	K0	K27000
Total cost for a month	K729 000	K823235
Total cost for 6 months	K4055410	K391074
Total cost for a year	K7533100	K7207908

4.5.3 Drilling

_Table 4.54 Cost comparison

	Baseline- wet machining	**Improved wet machining**	**Dry cooled by compressed air**
Energy costs	K215 197	K210033	K210023
Material cost			
W/P cost	K52 520	K52520	K52520
Fluid cost			
Soluble oil costs	K80000	K40000	K0
Distilled water costs	K0	K50 000	K0
Treatment costs	K0	K 27 000	K0
pH costs	K0	K4000	K0
Hardness test cost	K0	K12000	K0
Viscosity tests cost	K0	K7000	K0
ppm tests cost	K0	K17000	K0
Tooling costs			
Regrinding costs	K0	K27000	K27 000
Total cost for a month	K348277	K442277	K289543
Total cost for 6 months	K1769662	K1749318	K1602258
Total cost for a year	K3532604	K3398636	K3204516

4.54 <u>Shaping:</u>

Table 4.56 Cost comparison

	Dry machining	**Dry_ cooled by compressed air**
Energy costs	K157757	K147712
Material cost		
W/P cost	K52 520	K52520
Regrinding costs	K0	K27 000
Total cost for a month	K210277	K237277
Total cost for 6 months	K1261662	K1228392
Total cost for a year	K2523324	K2352784

CHAPTER FIVE

DISCUSSION:

5.1 Introduction

This project has extensively covered the Environmental Performance of the four major machining processes that always involved in the manufacture of any product. These were turning, milling, shaping and drilling. The processes were analyzed under the process model described in chapter 3 beginning from the baseline metrics to improved models which were used to compare with alternative processes. Then the benefits, shortfalls and cost were clearly stated, tabulated and graphed making it easy for the manufacturer to select the process that best suits his work shop capabililities.

5.2 Engineering requirements:

In the first case of the modal analysis Engineering requirements were considered using the basic knowledge to first establish operating parameters of the machines. This was meant to ensure the operating parameters fell within acceptable range. Next the tooling parameters were analyzed and it was clearly seen that the workshop lacked in this area in that worn out tools were prevalent. The observed the short falls were corrected in readiness for the improved runs and the dry runs using compressed air as the coolant.

(a) TURNING:

The tooling parameters in turning process were reground to meet the engineering standards:

The tool in table 4.1 was re ground to:

- reduce the rake angle from 21^0 to14^0
- reduce the side cutting angle from 23^0 to 12^0
- reduce the end cutting angle to about 7^0
- reduce nose radius to about 1mm

This measure to reduced the material removal rate from 436.45mm^3/min to 394.05mm^3/min. The alternative process using compressed air as the coolant had a reduction in the material removal rate which came to 406.77 mm^3/min. The cutting energy also reduced from 42.63W for the baseline profile to 39.405W for the improved method and 40.67W for the alternative method. Consequently there was noticeable reduction in material and energy intensities reducing the operational and output costs. The material intensity [Mi] reduced from 0.4164 for the baseline profile to about 0.3764 for the improved process and 0.40527 for the alternative method. The energy intensity[Qi] reduced as well from 67.35 W/kg for baseline profile to 62.195W/kg the improved processes and 64.339W/kg for the alternative processes.

(b) MILLING

Due to the difficulties in regrinding complications a new tool was used with parameters shown in the table 5.1 below:

Table 5.1 Milling tool parameters

Tool Parameters	Measurement
Lead angle	12^0
Relief angle	21^0
Second Relief Angle	42^0

This measure was done to reduce the material removal rate from 1131.1mm^3/min to 1078.34mm^3/min. The cutting energy also reduced from 113.1W for the baseline profile to 107W for the improved method and 40.67W for the alternative method. Consequently there was noticeable reduction in material and energy intensities reducing the operational and output costs. The material intensity [Mi] reduced from 0.27942 for the baseline profile to about 0.2619 for the improved process. The energy intensity[Qi] is reduced as well from 62.982 W/kg for the improved processes to 658.910W/kg .

(c) DRILLING

The parameters in drilling process were reground to meet the engineering standards as shown in table 5.2:

Table 5.1 Milling tool parameters

Tool Parameters	Measurement
Chisel angle	133^0
Point angle	125^0
Lip Relief	10^0
Helix angle	22^0

This measure was done to reduce the material removal rate from 404.54mm^3/min to 393.487mm^3/min. The alternative process using compressed air as the coolant had a reduction in the in the material removal rate which came to 393.96 mm^3/min. The cutting energy also reduced from 42.63W of the baseline profile to 39.35W for the improved method and39.39W for the alternative method. Consequently there was noticeable reduction in material and energy intensities reducing the operational and output costs. The material intensity [Mi] reduced from 0.0407 for the baseline profile to about 0.03668 for the improved process and 0.0347 for the alternative method. The energy intensity [Qi] reduced as well from 46.32W/kg for the baseline profile improved processes to 42.894W/kg for the improved processes and 40.937W/kg for the alternative processes.

(d) SHAPING:

The parameters in shaping process were reground to meet the engineering standards:
- reduce the relief angle to 10^0
- reduce the cutting edge angles to give a nose radius of about 0.8mm.

This measure reduce the material removal rate from 334.7 mm^3/min for the baseline profile to 323.38mm^3/min for the process for using compressed air as the coolant. The cutting energy also reduced from 32.32W for the baseline profile to 33.47W for the improved method. Consequently there was noticeable reduction in material and energy intensities reducing the operational and output costs. The material intensity [Mi] reduced from 0.075 for the baseline profile to about 0.0691 for the improved process. The energy intensity [Qi] is reduced as well from 47.82 W/kg for the baseline profile to 46.323 W/kg of the improved process.

5.3 Chemical requirements:

The next assessment was the chemical considerations which stem from the reactions during machining, coolant preparation and usage, treatment methods and so on. It was seen that the work shop paid very little attention to such activities putting the processes at high risk of practices that are not supported by sustainable manufacturing resulting in poor performance, high Energy consumption, high toxic emissions, increased health risk and increased input and operational costs. Initially, it is costly to mitigate these problems in the long term this but eventually pays back due to improved quality performance and environmental standards supported by cost control scheme.

(a) TURNING, MILLING AND DRILLING

The cutting fluid had evidence of bacterial growth, relatively low pH (about 8.8 for turning and 7.9 for both milling and drilling) , high levels of hardness about 60mg/mm^3 and tramp oil (about 18% for turning and 23% for both milling and drilling). This deteriorates the performance of the cutting fluid. Presence of tramp oil increases lubricity and hence increases the operational temperatures reaching as high as 27^{0}C and the use of hard water reacts with emulsifiers creating build up of residues on the work piece and tool (7). Low pH makes the fluid more sustainable to reactive action. The presence of bacteria increases the health risk of the operator. The use of more coolant than required increases the input, operating and disposal costs. These problems were mitigated by mixing the fluid in the following manner:

Amount of soluble oil: 10%

pH = 8.0 to 8.9

$v = .905 \times 10^{-6}\ m^2/s$

Hardness < 10mg/L

Sulphates = 18g/10L

Essentially the larger the temperature difference the more effective the cooling and this does not only depend on the fluid properties alone but the prevailing surrounding condition making it difficult to estimate amount of Energy dissipated. For turning the energy [Qf] dissipated to the fluid was 4.0237 W in the baseline profile and 4.536W was slightly higher and similar to the value when compressed air was used. As for milling the energy [Qf] dissipated to the fluid was 13.58 W in the baseline profile and 13.892W was slightly higher. And for drilling the energy [Qf] dissipated to the fluid was 5.222 W in the baseline profile and 5.223W was same and similar to the value when compressed air was used.

(b) SHAPING:

There are very little chemical requirements involved with both cases of dry machining. However the increased operational temperatures that is 48.2^0C in the baseline profile may lead to increased oxide films

The energy dissipated in the baseline profile was as low as 0.02256W due to the ineffective convective properties of air and when compressed air was used temperatures dropped to about 17^0C and the energy lost as heat was 4.536W.

5.4 ENVIRONMENTAL REQUIREMENTS

Then the Environmental requirements were considered in which the processes were analyzed in terms of the material intensity, energy consumption and intensity, toxic emissions and safety practices. From the comparisons in chapter 4 the baseline analysis in all the four processes gave the highest material intensity; this means that the workshop pH = 8.0 to 8.9

$\nu = .905 \times 10^{-6}\ m^2/s$

Hardness < 10mg/L

Sulphates = 18g/10L

Essentially the larger the temperature difference the more effective the cooling and this does not only depend on the fluid properties alone but the prevailing surrounding condition making it difficult to estimate amount of Energy dissipated. For turning the energy [Qf] dissipated to the fluid was 4.0237 W in the baseline profile and 4.536W was slightly higher and similar to the value when compressed air was used. As for milling the energy [Qf] dissipated to the fluid was 13.58 W in the baseline profile and 13.892W was slightly higher. And for drilling the energy [Qf] dissipated to the fluid was 5.222 W in the baseline profile and 5.223W was same and similar to the value when compressed air was used.

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The energy dissipated in the baseline profile was as low as 0.02256W due to the ineffective convective properties of air and when compressed air was used temperatures dropped to about 17^{0}C and the energy lost as heat was 4.536W.

5.4 ENVIRONMENTAL REQUIREMENTS

Then the Environmental requirements were considered in which the processes were analyzed in terms of the material intensity, energy consumption and intensity, toxic emissions and safety practices. From the comparisons in chapter 4 the baseline analysis in all the four processes gave the highest material intensity; this means that the workshop makes losses from high material consumption. The improved metrics and alternative methods showed similar improvements in material consumption after mitigating the causes for the problems. Due to the short machining hours the toxic intensity was not as pronounced. However measures were put in place to reduce or eliminate any potentially hazardous practices during operations, storage and disposal. It was noticed that the work shop did not abide to most of the safety practices and these were improved upon in the suggested models.

5.5 COST CONTROL

Finally the costs were analyzed for all the processes. It was seen that the initial cost of the improved methods were high but after a period of 24 months with certain assumptions they become relatively cheaper. Operating costs of dry machining using compressed air were by far the lowest despite the high initial set up costs.

Chapter Six

Conclusion and Recommendation:

6.1 CONCLUSION

From the analysis and observations made, the following were the conclusions:

(1) An equipment level model was developed and used to analyze the baseline profile clearly outlining the requirements of the processes to elevate them to the required environmental standards.

(2) The baseline profile of the selected processes found in the work shop, that is drilling, milling, turning and shaping, revealed that they all performed poorly in terms of their environmental performance based on energy consumption, material usage and cutting fluid handling and usage

(3) The processes environmental performance could clearly be improved by simply ensuring that all engineering and chemical requirements were maintained within recommended ranges and practices

(4) The proposed process using compressed air as the cooling medium proved to be the best method to reduced environmental ramification and operations cost, even though the initial set up costs are high.

6.2 RECOMMENDATIONS

The recommended approach is to begin with the improved methods and slowly build up on to the dry machining using compressed air as the coolant to eliminate the operational and maintenance costs that are involved in manufacturing methods that involve wet machining that is:

(1) applying methods that support sustainable manufacturing. This will enable the work shop to produce quality products, operate efficiently, reduce on the material wastes, operate efficiently due to low Energy consumption hence reducing the input, operating and out put costs.

(2) The next step is to adopt the method that involves dry machining (using compressed air as the coolant) produced the most cost efficient operation. This can be done gradually setting up the required apparatus.

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