A decision making framework for foundry sand using life cycle assessment and costing techniques.

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A DECISION MAKING FRAMEWORK FOR FOUNDRY SAND USING
LIFE CYCLE ASSESSMENT AND COSTING TECHNIQUES

By
Nandini Saha

A Thesis
Submitted to the Faculty of Graduate Studies and Research through the
Department Of Industrial And Manufacturing Systems Engineering
in Partial Fulfillment of the Requirements for the
Degree of Master of Applied Science at the
University of Windsor

Windsor, Ontario, Canada

1996
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ABSTRACT

A Framework for decision making in the foundry industry on the lines of Life Cycle Assessment has been proposed. It attempts to provide a common normalised ground on which alternative technologies and options may be compared on the basis of economic costs and environmental effects. The framework estimates the total life cycle costs of sand in the foundry. Total life cycle costs is made up of two sub costs - economic cost and environmental cost. Individual cost components that make up these sub costs are calculated and added up. This cost structure is then used to compare processes in a Criterion Function Decision Matrix. Weights of the Criterion Variables are decided using the Analytical Hierarchy Process. The alternative with the minimum Criterion Function is judged the best.

A Software using DELPHI was developed on basis of this framework.
DEDICATION

To

My Parents
ACKNOWLEDGEMENTS

I would like to thank my supervisors Dr. S. P. Dutta and Dr. M. Wang for supervising my research. They have been very considerate and consistently supportive and encouraging. I will bear in mind the advice they have given me.

I would like to extend my gratitude to Dr. J. Sokolowski for his advice and help in my completing my research. Working in the IMSE department has been made easier and more pleasant by Ms. Jacquie Mummery and Mr. Tom Williams, who were always helpful whenever I was in need.

I owe so much to my beloved parents for bringing me to this wonderful world, for molding me into the person I am and encouraging me throughout the years. I am equally grateful to the members of my family and all my friends for their love, support and belief in me, which helped keep my spirits high at all times.
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CHAPTER I

INTRODUCTION

1.1 GENERAL INTRODUCTION

Foundry waste, consisting of 60 to 70% sand, accounts for 7 to 15% of all waste disposed of in the United States (Granlund, 1991). As the amount of landfill area decreases, and legislations become more stringent, both small and large foundries will be forced to look at reclamation and other environmental friendly measures as important strategies, even though it would be difficult to justify it solely on an immediate economic basis alone. Environmental regulations have resulted in an increased requirement of controls for dust, water and solid waste in the foundry. Government agencies are increasingly tightening their grip on waste disposal and raw material conservation. Regulations are increasingly becoming so stringent that foundries are and will be forced to look at its waste production in a new light. Current estimating and costing in the metal manufacturing industry looks at the economic cost of sand alone. Environmental costs are either treated as overheads, detached from the product and processes or simply ignored (White et al, 1995). Ignoring the environmental effects and costs of sand wastes and emissions resulting from its processes (including reclamation) will bring down severe governmental bans and shutdowns on any industry. Pollution prevention is now considered the wisest course of action to deal with environmental issues. Technology which minimises both economic and environmental effects is now preferred over ones which are just economics oriented. Supporting pollution prevention is the focus of life cycle thinking as an integral part of the well considered local
and global strategy to prevent pollution while maintaining optimal efficiency and effectiveness (Anon, 1995). Successful strategies must consider total-life-cycle product costs to address environmental concerns properly. It is a more equitable and integrated approach to ensure sustainable local and global economic growth and environmental protection. For this reason, life cycle management as a main part of the pollution prevention view of the environmental strategy, is critical in dealing with future legislation. Reclamation is a big step towards environmental friendliness with respect to sand in the foundry. But it is not even worth reclaiming sand if the emissions during reclamation, and the process wastes are not controlled in an economic and environmentally cost effective way. Also, one hundred percent reclamation may not be the answer to our problems, as the reclamation may save us from land pollution, but might lean towards other kinds of pollution (Granlund, 1991).

A venture is profitable now, only if it makes both environmental and economic sense. As the once-easy route of landflling or stockpiling spent foundry sand is practically blocked now, metalcasters everywhere are examining options in reclamation (Couture, 1991). Also, realising that inevitable government mandates are expensive to implement, Larry Stahl, senior project engineer, General Motors said: "We want to be proactive and already be ahead before they say we have to" (Lessiter, 1994). Environmental regulators, as well as managers in government and industry, must look beyond compliance. They must focus their efforts on preventing pollution - and include the environment, occupational health and safety, as well as recycling as part of their mainstream decision making process (Anon, 1995).

Thus decision making can be said to be increasingly based on two criteria - economics and the environment. Life Cycle Assessment is a tool that can be used for such decision making criteria. It has been used by progressive and competitive corporations on the global level. It is a framework used to
evaluate the environmental impact of a product over the entire life cycle from the first stage of procuring raw material to final stage of waste management. It can be described to be an environmental panacea, capable of providing engineers designers and managers with everything that they need to know to make environmentally correct decisions. In many cases, traditional disposal may be the most cost-effective solution when looking at economic costs alone. But decisions taken based on this may have to be reversed when environmental costs are taken into consideration. This is what LCA helps to do. As the cost of foundry waste disposal goes up, and the availability of landfill sites goes down, the search for alternative use of waste will increase. The price of sand, freight and disposal cost are making reclamation a more viable economic alternative. Waste minimisation makes good business sense. Reducing or eliminating the amount or toxicity of chemicals used and waste generated can result in a number of benefits for a business, including direct dollar savings, reduction of health and safety risks to employees and the public, enhanced environmental protection, improved operations and reduced liability risk related to regulatory compliance (Keildgaard, 1993).

Normally LCA begins when the raw material is extracted and would not end until product disposal. But the scope of this study is to track the material when it enters the plant and ends when the product leaves the plant for secondary use or for disposal. In the approach followed to develop the framework, the costs associated with each process used in making the part (or in this case the cost of the process that the material goes through) are added as portion of the Total Cost for evaluation purposes.

The consumers’ present day environmental consciousness demands that the results of product LCA’s be communicated to them. But the practical aspect of this eco-information limits the use of PLCA (Product Life cycle Assessment) directly on product labels. It needs to be reflected in an easily
understood index. The price system, taken for granted in a market economy may be answer to this. According to Portney, This price can summarise all information. It can fluctuate easily when the underlying technology changes. But price alone is not enough to reflect the true cost to society of a product (Portney, 1994). Some environmental effects are difficult to model, let alone put a dollar figure in price to them. These effects need to be communicated in an effective, yet easily understandable way to the consumer. So what is needed is a normalised scale, which can reflect a wide range of parameters even if the effect of some of these parameters may at times be fuzzy and uncertain.

Together, PLCA, strict environmental regulations, market prices and a good normalised scale will prove to be a potent combination.

The complexity of performing Cost - Based LCA in a foundry is increased by the nature of the casting metal. This is because every metal has many unique costs which are difficult to capture is an all-encompassing LCA according to the present state of knowledge. Aluminium metal (Alloy 319) has been chosen for study here due to its growing popularity in the casting world. Al is being increasingly used for its favourable properties for a large number of applications, including in the automotive and aircraft industry. Aluminium is light, strong, ductile, a good electrical conductor, non magnetic and has good thermal properties. It is of advantage to the manufacturer due to its low melting point, ready availability, easy handling, good machinability and good weldability. The end user prefers it due to its ease of handling, ease of maintenance, economical and has high scrap value.
1.2 PROBLEM OVERVIEW

1.2.1 WHAT IS SAND RECLAMATION?

By definition of AFS Division - Committee S,

"Sand Reclamation is the physical, chemical, or thermal treatment of a refractory aggregate to allow its reuse without significantly lowering its original useful properties as required for the application on hand." Sand Reclamation aims at restoring original screen analysis, removing accumulated coatings of binders and other coatings, and removing excess fines, dust and other impurities. For good quality casting, it is necessary to retain physical properties, chemical characteristics and thermal properties.

1.2.2 ADVANTAGES OF SAND RECLAMATION

The incentive for sand reclamation in the foundry industry is growing due to a number of reasons:

ECONOMIC

Purchase costs of new sand, transportation costs, and disposal costs of used sand has increased manifold in the last decade. Sand Reclamation reduces total sand costs by eliminating the need to purchase or transport and dispose large quantities of sand.
**TECHNICAL**

Sand Reclamation is of interest since in some cases the need for binder and catalysts have been found to have been reduced on reclaimed sand. Also in many reclaimed sand trials, when the sand has been cleaned properly, the casting results are as good, if not better than in new sand (Granlund, 1991). One explanation for this is “survival of the fittest”. On each cycle, some of the grains are given a thermal shock from the metal and then they receive mechanical shocks in shakeout, lump-breaking and scrubbing. Sands poor in chemical structures will fracture and the fragments in turn will be removed by the dust collection system.

**ENVIRONMENTAL**

Sand reclamation reduces the burdening of the environment by avoiding disposal of toxic waste sand which leaches out into the neighbouring soil when landfilled. Deposits of high grade sand would last longer if used more efficiently.

**1.2.3 WHAT IS LIFE CYCLE ASSESSMENT - LCA AND THE FOUNDRY**

The most commonly used definition of LCA was established in SETAC Foundation, 1991, A TECHNICAL FRAMEWORK FOR LIFE CYCLE ASSESSMENTS. It is:

"Life cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials used and released on the environment." The assessment includes the entire life cycle of a product, process or activity,
encompassing extraction and processing of raw materials, manufacturing, transportation and distribution, use/re-use/maintenance, recycling and final disposal.

In recent years, much attention has been focused on reducing the environmental impacts of products and manufacturing processes. Concerned about rising compliance costs and stringent regulatory requirements, companies are carefully evaluating the environmental impacts of their products. In response, designers, engineers and managers are beginning to use life cycle analysis, and environmentally conscious manufacturing concepts as tools to help them to not only do what is best for the environment, but also to do what is best for their company. These tools are also a useful aid in evaluating the trade-offs that may exist between different products and process alternatives.

Foundries have input and output at almost every stage of processing. Toxic and non toxic wastes are produced and there is relatively less control over them. Sand, though a big part of many foundries, has been ignored through the ages, simply because of

* The relative abundance of it at procurement.
* It was always inexpensive to buy
* Easy to be disposed of, in the sense, it could be sent to a landfill, or just dumped almost anywhere and everywhere (often in the foundry’s own backyard!).

The scenario can be said to be changing now and sand reclamation is becoming more of a necessity rather than a luxury due to a number of reasons, which can be grouped under 3 main categories - Economic, Environmental, and Technical. Also, environmental consciousness is becoming one of the core competencies of a company. Customers require environmentally friendly products and the society is demanding environmentally conscious manufacturing from the company. This is another
reason, besides the three mentioned above, why the company must take environmental conscious seriously in its technology strategy as part of the business strategy.

1.2.4 LIFE CYCLE ASSESSMENT AND COSTING

Good environmental cost accounting is important in the realm of capital budgeting and pricing. Industry managers face a disturbing and growing dilemma when it comes to environmental costs. On one hand, regulatory requirements, voluntary standards and market pressures continue to impose continually to hire, and more costly, demands for environmental excellence. On the other hand, the information essential to fashioning a rational response to such expectations is typically unavailable in a timely, rigorous, and consistent way. The result is decisions on capital projects, material choices, product pricing and product mix often serve neither the best interests of the firm nor in many cases the environment. For industry managers, charged with environmental performance, as well as production, pricing decisions, conventional, aggregated financial information is of minimal value. Many environmental costs traditionally have been lumped into pooled or overhead accounts that are detached from the products and processes responsible for creating costs in the first place. Also many environmental costs are contingent. Liability, future regulatory compliance costs, and shutdown costs owing to sudden environmental releases are examples of environmental costs whose timing and magnitude are difficult to access. According to White et al, Environmental accounting serves a wide range of management decisions, including determining optimal product mix and process designs, accessing the priorities and economics of waste management and pollution prevention options, benchmarking and environmental performance at the same facility over time, across facilities or in
relation to industry wide performance and bringing true cost to bear on pricing decisions (White et al, 1995).

1.2.5 LIFE CYCLE STAGES OF SAND

1.2.5.1 OVERALL STAGES

Sand Extraction involves excavation of the material from lakes, rivers, banks, etc. (Refer Appendix1.1 for Flow Chart). Sand Preparation includes crushing, primary classification(screening) and cleaning of sand. Sand is then transported to the foundry for Primary Usage. Used sand may be recycled inside the foundry, and sent directly for disposal, or it may be sent for Secondary Usage. Secondary Usage occurs in Cement and Asphalt industries. New uses of used sand are being researched into. The sand which is unsuitable for any kind of usage is sent to a Landfill.

1.2.5.2 FOUNDRY USAGE

Sand input is through the two processes of Mold Sand Preparation and Core Sand Preparation(Refer Appendix1.2 for Flow Chart). The input sand includes new and reclaimed sand in proportions required by the foundry. Sand is prepared by mixing sand, binder, additives, and water in a Muller. The Core Making process converts the core sand prepared into cores. These are then put into copes and drags along with molding sand to form the mold. This step in the life cycle has been called Mold Making. There is often a lot of sand spillage in this process, which is collected and added back
to Mold Sand Preparation. Molten metal (Casting Metal) is poured into the mold, and the mold is allowed to cool. Some of the heat of the molten metal is transferred onto the sand of the mold, as a result of which the Loss on Ignition property of sand changes, and the sand gets burnt black. Binders on the surface of sand also get burnt at this time, and hazardous air pollutants are emitted out. After cooling, the casting is taken for shakeout. This maybe mechanical or thermal. Dust and fumes (especially when thermal) are emitted at this stage. The waste sand is reclaimed, or sent out of the foundry (system boundary). Reclamation may be wet, dry, mechanical, pneumatic, thermal, or any combination of the former as required by the sand system. The input is as shown in Fig 1. The output is necessarily the same - clean sand, emissions, waste sand and dust. The waste sand is sand that cannot be reused in the foundry because it does not confirm to the foundry standards for input sand. It is sent out of the system boundary for reuse in cement industries or disposal to a Landfill. The post foundry use of sand might need further processing, and thus depends on the economics of the situation.

FIG 1: Constituents of Refuse Sand
1.3 OBJECTIVE

A Framework has been designed to find the best decision regarding reclamation using Life Cycle Analysis and Costing concepts. It attempts to provide a common normalised ground on which alternative technologies and options may be compared on the basis of economic costs and environmental effects. It calculates the total Life Cycle Cost of sand per run in the foundry. The framework may be used to

1) Decide whether reclamation or traditional disposal is best suited for a particular case based on minimum life cycle costs and emission factors.

2) Compare alternative technologies based on minimum life cycle costs and emission factors.

A total cost analysis of sand in the foundry has is done. The results of this is put in a Criterion Function Decision Matrix. Weights of the Criterion Variables are decided using the Analytical Hierarchy Process. The alternative with the minimum Criterion Function is judged the best.

The Framework has been used to develop a Software for the same purpose.

Since specifications vary from production system to production system, a comprehensive technical methodology is beyond the scope of this research.
CHAPTER II

LITERATURE REVIEW

Sand reclamation is the number one sand related topic in the foundry industry at the present time. Foundry waste, 60 - 70 % sand accounts for 7 - 15 % of all waste disposed off in the United States (Granlund, 1991). Constructive use of foundry waste is not a new idea. Most foundry personnel can remember when foundry process wastes were commonly used in constructions and land development. Recent environmental regulations and citizens concern for pollution caused by waste disposal have changed all this. New federal, state and even local solid waste laws in both United States and Canada restrict what foundries can do with their wastes. The total tonnage of industrial sand and gravel produced in the US was 28.5 million tons in 1988. Foundry sand consumed 27 %. This percentage translates into 7,00,000 tonnes in 1988 (Granlund, 1991).

While many things are heard about spent foundry sand reclamation, one that comes up often is “if you don’t do it now, chances are you will have to in the next few years.” The reasons are well known: closing landfills, increased transportation costs, tipping and disposal fees, changing environmental regulations and increased material costs. Many foundries still have easy, inexpensive access to their local landfills. A few may be lucky enough to have a beneficial reuse alternative for their spent sands. But there is no guarantee of continued landfill access and progress on reuse applications is slow. As per the work of Petch (1991), reclamation was attempted to be justified in terms of capital investment and amount of throughput. Leidel et al. (1994) observed that many foundry persons view waste reduction as a burden imposed by government regulators. However, the fact is that contrary to
being a “burden”, waste reduction makes economic sense by lowering production costs and improving competitiveness. Philbin (1995) stated that, “Whatever you do with your spent sand must make economic sense. In many cases, traditional disposal may be the most cost-effective solution”. In 1991, AFS Plant Engineering Committee (Statler, 1991) prepared a sand reclamation costs savings worksheet as per which cost savings would be summation of

1) cost of new sand being replaced by reclaimed sand
2) plus waste hauling and landfilling costs of the spent sand
3) minus the costs of hauling and landfilling the reclamation process waste products.

The Federal Resource and Conservation and Recovery Act (RCRA) in the USA requires that all generators of waste determine whether any of their waste fit the federal definition of hazardous waste. The Canadian Environmental Protection Act (CEPA) emphasizes the prevention of pollution rather than curative measures. It advocates the adoption of technologies that are environment friendly and has put down strict guidelines to make environmental compliance a reality. Hence foundries must be aware of regulations. The enactment of federal laws has brought on many state and local laws for controlling waste disposal and reuse. According to Granlund (1991), Foundry Systems Control, “Before deciding to recycle or constructively use a waste, a foundry must consider the waste’s physical and chemical properties”.

To extend forward the thinking of Petch, Philbin, the AFS Plant Engineering Committee and Granlund, and keep up with government regulations, reclamation of sand should not only make economic sense, but also environmental sense. Life Cycle Assessment is one of the techniques that takes into consideration both the costing and the environmental effects. Several guidelines have been released by the US Environment Protection Agency (EPA) and the Canadian Standards Association
(CSA) which help carrying out the LCA technique. LCA is rapidly gaining acceptance as a tool that can provide a more precise and realistic view of a product's environmental consequences. At all foundry stages an LCA approach could be used to identify, quantify, compare and assess environmental damage related to:

1) Energy Consumption
2) Water Consumption
3) Air Pollution
4) Soil Contamination
5) Solid & Hazardous Wastes
6) Consumption of natural resources and effects on eco-systems.

Product Life Cycle Analysis (PLCA) is akin to environmental cost accounting. It helps consumers make informed choices about products. PLCA is a complicated methodology for identifying the energy and other resource requirements as well as the environmental impacts associated with every stage in the life of a product. It encompasses air and water pollution and solid waste generated and the energy used. But the information generated in a typical PLCA is difficult to communicate with the consumers. Another mechanism through which ever changing information about technologies, the availability of inputs to production, and many other phenomenon are neatly, almost instantly, summarised for producers and consumers is the price system in market economy. Consumers need not read labels detailing the amounts of labour, energy, capital investment, rates of interest, description of raw materials and pollution control technologies required to make a product. The price summarises all this information and that price can fluctuate easily with any change in the underline production technology. Product markets have to be made international in scope else in countries that pay less
attention to environmental concerns price may not reliably indicate environmental stewardship. Together the use of PLCA, strict environmental regulations and market prices might prove to be a potent combination. (Portney, 1993-1994)

Creese and Atluri (1995) investigated the effect of scrap rates upon profits and costs. A generalised casting cost model was developed and the effect of cost changes on profits was examined. The cost items considered were metal costs, core costs, molding sand costs, labour costs, pattern costs, overheads and contingency costs. Core and mold costs were affected by scrap rates at each stage of the casting process. Core sand was assumed to have no reuse, and was disposed off. But Molding sand was recycled. The total cost of molding sand was calculated as the sum of the recycled molding sand, the new system sand and the waste disposal costs. Waste disposal costs included the landfill costs only.

Choi (1994) presented a screening method for inventory analysis for industrial material. The screening method identifies and assesses material characteristics of the product being surveyed throughout the entire life cycle, from acquisition to disposal. Material Flow Analysis was used to evaluate the material’s Useful Life, which is a measure of its depletion.

A costing model should not only include the economic costs of reclamation, but also its environmental costs. A process should be chosen only after both sides have been considered. Price cannot be a perfect reflection of the true cost to society of a product unless all detailed costs are reflected in the prices that forms charge. The price system cannot yet fully reflect all the environmental consequences associated with processes and products. PLCA should be used here to identify and evaluate environmental effects and a good normalised scale is needed to represent it. The criteria examined in the scale should be detailed economic costs, environmental costs and environmental effect.
In addition the Material Useful Life should also be a criteria in choosing alternatives since it is a measure of material depletion and one of the aims of any alternative would be to preserve as much raw material as possible.

Hence, process alternatives should be chosen on a common normalised basis, which considers the life cycle of sand, its costs, its environmental effects and its Material Useful Life. Decision making regarding reclamation has to made based on minimum life cycle costs and emission factors.

Decision Making on adopting new manufacturing technologies are often biased when deliberations are limited to strictly financial impacts. Managers faced with manufacturing decisions can no longer rely solely on traditional methods measures of financial worth because so many impacts cannot be readily denominated into dollars (Sullivan, 1986). They must consider all the significant effects of their decisions. The impacts often ignored can be classified as quantitative or qualitative. Nonfinancial quantitative impacts can be measured in physical terms but cannot be easily converted into dollars (for e.g. : cost of short term environmental effects). In contrast Nonfinancial qualitative impacts cannot even be measured in physical terms (for e.g. : cost of long term effects on the environment). Ignoring these intangible effects may bias decisions against or for new technologies (Weber, 1993).

Approaches that include more than one measure of performance in the evaluation process are called multi-attribute or multi-criteria decision methods (Canada and Sullivan, 1989). Literature surveys and reviews have revealed a plethora of studies, models and methods for Project selection. Methods which provide for the measurement and aggregation of the various project selection criteria seem most appropriate for prioritising and ranking projects (Liberatore, 1987). Once the prioritisation for the criteria are obtained, standard methods can be used to help determine ranking of projects. Goal Programming has been recently applied to project selection (Keown et al, 1979). But Goal
Programming provides no methods for ensuring that the goals selected adequately reflect the organisational and environmental factors related to the project selection decision (Liberatore, 1987). AHP has been effective in structuring many types of complex multicriteria business problems. Since 1975, AHP developed by Saaty (Saaty, 1980) has been applied in a variety of priority setting and resource allocation problems in marketing (Wind and Saaty, 1980), electric power allocation (Saaty and Mariano, 1979), conflict resolution (Saaty and Bennett, 1977), transportation planning for a national economy (Saaty, 1977), new product development (Saaty, 1980) among others. The AHP enables decision makers to capture managerial decision preferences through a series of pairwise comparisons of relevant factors or criteria. The AHP is relatively easy to use, and provides a method to measure the consistency of these judgements (Liberatore et al, 1992). AHP has been used here to find the weightages of the identified criteria, of the Decision.

Forman et al (1983) suggested that AHP could be linked with a spreadsheet model. The combined AHP-spreadsheet approach would be much easier to use. The Criterion Function Approach is one such spreadsheet Model. The Criterion Function Approach is a Linear Additive Model (Sullivan, 1986). These models aggregate information from different criteria in a linear fashion to arrive at an overall score to rank each alternative considered in the evaluation. The score for each alternative is the summation of the rating assigned to each decision factor. The alternative with the highest score is preferred. Many different types of Linear Additive Models have been developed and reviewed over the years (Moore and Baker, 1969). A simple and direct model is ranking and rating (Morris, 1977). According to Morris, this method had been found by decision makers to be easy to use, had led to evaluations that they found useful, and had produced orderings which corresponded closely to their actual ultimate choices. Scoring models also have the ability to adequately process
economic data (Moore and Baker, 1969). The Criterion Function Approach has been used for Decision Making.

Based on the Literature review outlined herein, the objectives proposed in Chapter 1 have been formulated. Subsequent Chapters describe the methodology used to achieve these objectives.
CHAPTER III

PROPOSED METHODOLOGY

3.1 METHODOLOGY - AN OVERVIEW

This chapter introduces a framework for conducting Life Cycle analysis on Sand and setting up a matrix for decision making. It attempts to provide a common normalised ground on which alternative technologies and options may be compared on the basis of economic costs and environmental effects.

This framework is conducted as per the following broad steps:

1) Identification of Material Flow of Sand in the Foundry.
2) Implementation of Life Cycle Inventory analysis with respect to the above identified Material Flow and finding the Material Useful Life.
3) Identification of individual economic cost components (These are the Criterion Variables).
4) Implementation of Total Economic Life Cycle Costing of sand per run in the foundry (This calculates the values of the Criterion Variables).
5) Identification of the Environmental cost components and Emission Factors (These are the Criterion Variables).
6) Assignment of Weights to the Criterion Variables using the Analytical Hierarchy Process (AHP).
7) Identification of Decision Variables (Alternatives).
8) Assignment of the calculated values to the Criterion Variables in the decision matrix.
10) Selection of Best alternative.

3.2 FACTORS AFFECTING RECLAMATION DECISIONS

The factors affecting reclamation decisions may be categorised into two main groups - Cost and Non Cost. Cost factors determine the decision to reclaim and the optimal percentage of sand that may be sent through the system based on dollar costs. Non Cost factors decide the amount of sand to be sent out of the system boundary as it no longer retains the desired properties. This study concentrates on Cost factors only. It has been assumed that Non Cost factors are considered parallel, though outside the scope of this study, and the results of this are used in determining Cost factors. The Material Useful Life of Sand for each alternative has also been looked at.

3.2.1 COST FACTORS

Total cost is expressed as the sum total of economic and environmental costs (Refer Appendix1.3 for complete Cost Break-Up used in this study). Environmental effects has also been included in this category, though they are not represented in dollar costs, since they cost us the degradation of the environment.

Economic Costs are the Costs of Energy, Raw Material and Disposal. Cost of Energy is the sum total of individual costs of energy required by each processing step in the Life Cycle of sand. Cost of Raw Material includes the Costs of purchasing New Sand and the Costs of cleaning up sand (Reclamation). The Operational, Maintenance, and Overhead (Capitalised) costs of Sand Reclamation
are included in this. Cost of Disposal includes the transportation costs for used sand and charges for the Landfilling of used sand. This costs is usually very high due to the scarcity of space and the toxicity of foundry used sand.

Environmental Costs are the costs of cleaning and environmental effects due to pollution. Costs of cleaning include the costs of Operation, Maintenance, and Overhead (Capital), of cleaning equipment associated with the processes under consideration including the reclamation process. Environmental effects include the effect of wastes on soil, water and air. Soil pollution is primarily the effect of disposal of sand in landfills. Water and air pollution are mostly a product of the reclamation process and subsequent cleaning processes. The environmental cost of sand may also be used to compare the best kind of binder for a system, exclusively on an environmental basis.

3.2.2 NON COST FACTORS

These are Sand Properties. Sand when passing through its Life Cycle loses many of its properties that are crucial for a good cast. The extent of recovery of Sand properties through reclamation decides the suitability of the sand to reuse. Sand is rejected once it fails to conform to the standards required in the foundry for input sand. This is reflected as the amount of sand going into the dust collection system and disposal. In some cases (as mentioned earlier in Introduction), the reclaimed sand may even have better properties than new sand. Non conformation of sand to properties results in increased rejection rates, which in turn increases disposal costs, and soil pollution costs.
3.3 ASSUMPTIONS

1) Energy consumed is the same per machine irrespective of whether new or reclaimed sand is being treated.

2) All calculations have been based on Al-Alloy 319.

3) Life Cycle of Energy, Binder and Additives have not been considered.

4) All heat is transferred to the sand when pouring, i.e., no losses by Aluminium metal.

5) All quantitative data as required for each sub system can be obtained.

6) The percentage of casting scrap, core scrap, sand mold losses, fraction of sand lost as dust emissions remain constant.

7) Amount of reclaimed sand needed as input to system is available after reclamation, i.e. the properties of sand allow its reclamation.

8) Sub Costs of individual processes that deal exclusively with sand has been considered. Other processes costs which just effect sand has not been split up since it is assumed that they are should be included into the metal life cycle rather than the sand life cycle.
3.4 SYSTEM BOUNDARIES

3.4.1 INVENTORY

Life Cycle of Sand inside the foundry has been taken for analysis. Energy consumption, waste production, and material requirement have been modelled. Costs associated with each process that the Sand goes through with the metal is added up as a portion of the total cost for evaluation purposes.

3.4.2 MATERIAL

Life cycle of Energy, Binder and Additives have not be considered. Materials used to make fundamental tools and equipment as well as those indirectly consumed during the production and operation of a transportation vehicle are outside project boundary.

3.5 NOMENCLATURE

<table>
<thead>
<tr>
<th>CSP</th>
<th>Core Sand Preparation</th>
<th>(1a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP</td>
<td>Mold Sand Preparation</td>
<td>(1b)</td>
</tr>
<tr>
<td>CM</td>
<td>Core Making</td>
<td>(2)</td>
</tr>
<tr>
<td>MM</td>
<td>Mold Making</td>
<td>(3)</td>
</tr>
<tr>
<td>P</td>
<td>Pouring</td>
<td>(4)</td>
</tr>
<tr>
<td>CS</td>
<td>Casting shakeout</td>
<td>(5)</td>
</tr>
<tr>
<td>R</td>
<td>Reclamation</td>
<td>(6)</td>
</tr>
<tr>
<td>C</td>
<td>Cleaning</td>
<td>(7)</td>
</tr>
</tbody>
</table>
MOS_RATIO  Ratio of amount of Mold Sand to Total Sand used for the casting.
RSC_RATIO  Percentage Reclaimed Sand to Total Sand used for making Cores.
RSM_RATIO  Percentage Reclaimed Sand to Total Sand used for making Mold Sand mix.
MS_RATIO  Ratio of amount of Metal to Sand used for the casting.
SRF(i)  Sand retained factor at stage i.
SUF(i)  Sand loss factor at stage i.
ASRU(i)  Total available sand for reuse at stage i.
RUS(i)  Reusable sand at stage i.
SLO(i)  Sand Loss at stage i.
TCW  Total sand input for core, i.e. total weight of core before losses.
TMW  Total sand input for mold, i.e. total weight of mold before losses.
S_{nc}  Amount of New Sand Input into Core Sand Preparation.
S_{rc}  Amount of Reclaimed Sand Input into Core Sand Preparation.
S_{c}  Net amount of sand output from Core Sand Preparation, remaining the same through Core Making.
S_{nn}  Amount of New Sand Input into Mold Sand Preparation.
S_{rn}  Amount of Reclaimed Sand Input into Mold Sand Preparation.
S_{n}  Net amount of sand output from Mold Sand Preparation.
S_{mm}  Amount of sand involved in Mold Making(after spill sand taken out), Pouring and going into Casting Shakeout.
S_{u}  Amount of useful sand after Casting Shakeout.
MUL  Material Useful Life
TOU  Time of Utilisation if no recycling.
RCY  Proportion of sand recycled after product is used.
SNR_{i}  Amount of Sand needed for the Life Cycle at stage i.
E_{cp}  Energy required / Mold at Core Sand Preparation.
E_{mp}  Energy required / Mold at Mold Sand Preparation.
\( E_{cm} \) Energy required / Mold at Core Making.

\( E_{mm} \) Energy required / Mold at Mold Making.

\( E_p \) Energy transferred from molten metal to sand / Mold at Pouring.

\( E_{ca} \) Energy required / Mold at Casting Shakeout.

\( E_r \) Energy required / Mold at Reclamation.

\( C_p \) Specific Heat of AL = 963J/Kg.K

\( E_f \) Latent Heat of Fusion = 389KJ/Kg

TPE Total Process Energy Used.

TRE Total Reclamation Energy Used.

SNRNREC New Sand Requirement of Non Recycling System

SNRREC New Sand Requirement of Recycling System

MUL Material Useful Life

TOU Time of Utilisation if no recycling

RCY Proportion of Sand reclaimed after use

Index Use Rate Amount by weight of Binder Used per Mold

Emission Factor Amount of Emissions of a particular kind per gm of resin.

HAP Amount of Emissions of a particular kind per cast during pouring, cooling and shakeout

RAP Amount of Emissions of a particular kind per cast during Reclamation.

TCNS Total Cost of New Sand

CNS Purchasing Cost including transportation of New Sand / Ton

casts yr No of casts per Year

NCC No of Cores per Casting

CCW Casting Core Weight per Casting

SMW Sand Mold Weight per Casting

BINDER Percentage of binder in Sand

MET Amount of Metal in Mold

FSLO5 Fraction of Sand Lost as Dust Emissions during Casting Shakeout

FSLO6 Fraction of Sand Lost during Reclamation due to loss of properties
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKWH</td>
<td>Cost of energy per KWH</td>
</tr>
<tr>
<td>CSR</td>
<td>Core Scrap Rate</td>
</tr>
<tr>
<td>SML</td>
<td>Sand Mold Losses</td>
</tr>
<tr>
<td>SR</td>
<td>Casting Scrap Rate</td>
</tr>
<tr>
<td>FSR</td>
<td>Finishing and Cleaning Rate</td>
</tr>
<tr>
<td>CLF</td>
<td>Cost of Landfilling sand per Ton</td>
</tr>
<tr>
<td>PCSPi</td>
<td>Power Rating of Equipment i of the process CSP</td>
</tr>
<tr>
<td>TPCSPi</td>
<td>Throughput of Equipment i of the process CSP</td>
</tr>
<tr>
<td>PMSPi</td>
<td>Power Rating of Equipment i of the process MSP</td>
</tr>
<tr>
<td>TPMSpi</td>
<td>Throughput of Equipment i of the process MSP</td>
</tr>
<tr>
<td>PCMij</td>
<td>Power Rating of Equipment i of core j of the process CM</td>
</tr>
<tr>
<td>TCMij</td>
<td>Time per core on Equipment i of core j of the process CM</td>
</tr>
<tr>
<td>PMMi</td>
<td>Power Rating of Equipment i of the process MM</td>
</tr>
<tr>
<td>TMMi</td>
<td>Time per mold of Equipment i of the process MM</td>
</tr>
<tr>
<td>PCSi</td>
<td>Power Rating of Equipment i of the process CS</td>
</tr>
<tr>
<td>MPDi</td>
<td>Molds per day processed on Equipment i for the process CS</td>
</tr>
<tr>
<td>Pri</td>
<td>Power Rating of Equipment of the process R</td>
</tr>
<tr>
<td>TPRi</td>
<td>Throughput of Equipment i of the process R</td>
</tr>
<tr>
<td>PCI</td>
<td>Power Rating of Equipment of the process C</td>
</tr>
<tr>
<td>TPCI</td>
<td>Throughput of Equipment i of the process C</td>
</tr>
<tr>
<td>TCPE</td>
<td>Total Cost of process energy per cast</td>
</tr>
<tr>
<td>TPE</td>
<td>Total Joules Energy consumed during casting process</td>
</tr>
<tr>
<td>TCRE</td>
<td>Total Cost of reclamation energy per cast</td>
</tr>
<tr>
<td>TRE</td>
<td>Total Joules Energy consumed during reclamation per cast</td>
</tr>
<tr>
<td>PE</td>
<td>Principal Invested in buying Reclamation Equipment</td>
</tr>
<tr>
<td>i</td>
<td>Interest</td>
</tr>
<tr>
<td>nr</td>
<td>Life of Reclamation Equipment</td>
</tr>
<tr>
<td>Ar</td>
<td>Capital Recovery</td>
</tr>
<tr>
<td>CAPR</td>
<td>Capital Recovery per Ton of Sand</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>MCR</td>
<td>Maintenance Costs of reclamation equipment per Year</td>
</tr>
<tr>
<td>MR</td>
<td>Maintenance Costs of reclamation equipment per Ton of Sand</td>
</tr>
<tr>
<td>CCR</td>
<td>Chemical Costs of reclamation</td>
</tr>
<tr>
<td>RLC</td>
<td>Reclamation Labour Cost per minute.</td>
</tr>
<tr>
<td>TPR</td>
<td>Throughput of the net reclamation system (= Throughput of the last equipment in the reclamation system)</td>
</tr>
<tr>
<td>RMH</td>
<td>Man Hours needed to run reclamation equipment per day</td>
</tr>
<tr>
<td>LR</td>
<td>Labour Cost of reclamation equipment per ton of sand</td>
</tr>
<tr>
<td>AVS</td>
<td>Air Volume Sampled (cu.m)</td>
</tr>
<tr>
<td>AIR_CONC</td>
<td>Average Measured Air Concentration for a chemical (mg / cu.m)</td>
</tr>
<tr>
<td>PCAIR</td>
<td>Principal Invested in buying Cleaning Equipment for air</td>
</tr>
<tr>
<td>PCLND</td>
<td>Principal Invested in buying Cleaning Equipment for land</td>
</tr>
<tr>
<td>PCWTR</td>
<td>Principal Invested in buying Cleaning Equipment for water</td>
</tr>
<tr>
<td>NCAIR</td>
<td>Life of air cleaning Equipment</td>
</tr>
<tr>
<td>NCLND</td>
<td>Life of land cleaning Equipment</td>
</tr>
<tr>
<td>NCWTR</td>
<td>Life of water cleaning Equipment</td>
</tr>
<tr>
<td>Ac</td>
<td>Capital Recovery</td>
</tr>
<tr>
<td>CAPCAIR</td>
<td>Capital Recovery per Ton of Sand for air cleaning Equipment</td>
</tr>
<tr>
<td>CAPCLND</td>
<td>Capital Recovery per Ton of Sand land cleaning Equipment</td>
</tr>
<tr>
<td>CAPCWTR</td>
<td>Capital Recovery per Ton of Sand water cleaning Equipment</td>
</tr>
<tr>
<td>MCCAIR</td>
<td>Maintenance Costs of air cleaning equipment per Year</td>
</tr>
<tr>
<td>MCCLND</td>
<td>Maintenance Costs of land cleaning equipment per Year</td>
</tr>
<tr>
<td>MCCWTR</td>
<td>Maintenance Costs of water cleaning equipment per Year</td>
</tr>
<tr>
<td>MC</td>
<td>Maintenance Costs of cleaning equipment per Ton of Sand</td>
</tr>
<tr>
<td>CCCAIR</td>
<td>Chemical Costs of air cleaning</td>
</tr>
<tr>
<td>CCCLND</td>
<td>Chemical Costs of land cleaning</td>
</tr>
<tr>
<td>CCCWTR</td>
<td>Chemical Costs of water cleaning</td>
</tr>
<tr>
<td>CLCAIR</td>
<td>air cleaning Labour Cost per minute.</td>
</tr>
<tr>
<td>CLCLND</td>
<td>land cleaning Labour Cost per minute.</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CLCWTR</td>
<td>Water cleaning Labour Cost per minute.</td>
</tr>
<tr>
<td>TPCAIR</td>
<td>Throughput of the net air cleaning system ( = Throughput of the last equipment in the cleaning system )</td>
</tr>
<tr>
<td>TPCLND</td>
<td>Throughput of the net land cleaning system ( = Throughput of the last equipment in the cleaning system )</td>
</tr>
<tr>
<td>TPCWTR</td>
<td>Throughput of the net water cleaning system ( = Throughput of the last equipment in the cleaning system )</td>
</tr>
<tr>
<td>CMHAIR</td>
<td>Man Hours needed to run air cleaning equipment per day</td>
</tr>
<tr>
<td>CMHLND</td>
<td>Man Hours needed to run land cleaning equipment per day</td>
</tr>
<tr>
<td>CMHWTR</td>
<td>Man Hours needed to run water cleaning equipment per day</td>
</tr>
<tr>
<td>LC</td>
<td>Labour Costs of cleaning equipment per Ton of Sand</td>
</tr>
<tr>
<td>TCRS</td>
<td>Total Cost of Reclaimed Sand per Cast</td>
</tr>
<tr>
<td>CRS</td>
<td>Cost of Reclaimed Sand per Ton</td>
</tr>
<tr>
<td>CD</td>
<td>Cost of Disposal per Cast</td>
</tr>
<tr>
<td>ASD</td>
<td>Amount of Sand disposed per cast</td>
</tr>
<tr>
<td>TCE</td>
<td>Total Joules of Energy Used for Cleaning per gm of Emission</td>
</tr>
<tr>
<td>TCCE</td>
<td>Total Cost of cleaning energy per unit treated</td>
</tr>
<tr>
<td>EAIR</td>
<td>Energy for cleaning air</td>
</tr>
<tr>
<td>ELAND</td>
<td>Energy for cleaning land</td>
</tr>
<tr>
<td>EWTR</td>
<td>Energy for cleaning water</td>
</tr>
<tr>
<td>TCC_AIR</td>
<td>Total cost of air cleaning per cast</td>
</tr>
<tr>
<td>TCC_LND</td>
<td>Total cost of land cleaning per cast</td>
</tr>
<tr>
<td>TCC_WTR</td>
<td>Total cost of water cleaning per cast</td>
</tr>
<tr>
<td>CC</td>
<td>Cost of cleaning per gm of emission treated</td>
</tr>
</tbody>
</table>
3.6 MATERIAL FLOW ANALYSIS

Material Flow Analysis is important to find the Material Useful Life (MUL), which is a measure of material depletion. Any alternative should aim at increasing the MUL resulting in reduced material depletion.

The flow of sand in the foundry was defined. Material flow analysis was used to draw up balance equations for each stage. Inputs and outputs of each sub system can be identified using the following diagram.

![Diagram showing material flow]

FIG 3.1 : Generalised Material Flow of Subsystem

3.6.1 MATERIAL BALANCE EQUATIONS

Material Balance Equations essentially follow the same pattern:

\[ \text{INPUT MATERIAL INTO PROCESS} = \text{OUTPUT MATERIAL FROM PROCESS} \]

Material Balance Equation for each step of the casting process affecting sand are defined as follows.

STEPS
Sand Preparation (1.a)

\[ \text{ASRU}(1a) + S_{nc} = S_c \]  \hspace{1cm} (3.1)

\[ \text{ASRU}(1a) = S_{rc} \]

\[ = (S_{mn} - \text{SLO}(5) - \text{SLO}(6))(1 - \text{MOS\_RATIO}) \]  \hspace{1cm} (3.2)

Sand Preparation (1.b)

\[ \text{ASRU}(1b) + S_{nm} = S_m \]  \hspace{1cm} (3.3)

\[ \text{ASRU}(1b) = \text{RUS}(3) + S_{nm} \]  \hspace{1cm} (3.4)

\[ S_m = (S_{mn} - \text{SLO}(5) - \text{SLO}(6))(\text{MOS\_RATIO}) \]  \hspace{1cm} (3.5)

Core Making (2)

\[ S_c = S_c \]  \hspace{1cm} (3.6)

Mold Making (3)

\[ S_c + S_m = S_n + \text{RUS}(3) \]  \hspace{1cm} (3.7)

\[ \text{RUS}(3) = (S_c + S_m)\text{SUF}(3) \]  \hspace{1cm} (3.8)

\[ S_{nn} = (S_c + S_m)\text{SRF}(3) \]  \hspace{1cm} (3.9)

\[ \text{SRF}(3) + \text{SUF}(3) = 1 \]  \hspace{1cm} (3.10)

Pouring (4)

\[ S_{mn} = S_{mn} \]  \hspace{1cm} (3.11)

Casting shakeout (5)

\[ S_{mn} = S_{mn} \text{SRF}(5) + S_{mn} \text{SLF}(5) \]  \hspace{1cm} (3.12)

\[ S_{mn} = S_c + \text{SLO}(5) \]  \hspace{1cm} (3.13)

\[ S_c = S_{mn} \text{SRF}(5) \]  \hspace{1cm} (3.14)

\[ \text{SLO}(5) = S_{mn} \text{SLF}(5) \]  \hspace{1cm} (3.15)
SRF(5) + SLF(5) = 1

(3.16)

**Reclamation (6)**

Sₐ = SLF(6)Sₐ + SRF(6)Sₐ

(3.17)

Sᵣ = SRF(6)Sₐ

(3.18)

SLO(6) = SLF(6)Sₐ

(3.19)

SLF(6) + SRF(6) = 1

(3.20)

**Material Useful Life (MUL)**

The balance equations are then used for the calculations of sand requirement of both recycling and non-recycling systems. The material useful life is estimated from them. (Choi, 1994)

\[
MUL = \frac{TOU}{1 - RCY}
\]

(3.21)

Where

TOU = Time of Utilisation of sand if no recycling.

RCY = Proportion of sand reclaimed after use.

\[
RCY = \frac{\left( SNR_{NREC} - SNR_{REC} \right)}{SNR_{NREC}} \times 100
\]

(3.22)

Where

SNR = Amount of Sand input needed for the Life Cycle right at the first stage.

\[
SNR_{NREC} = S_{\text{min}} = S_r + SLO(5) + SLO(6)
\]

(3.23)
\[ \text{SNR}_{\text{REC}} = S_{nc} + S_{nm} \]
\[ = S_{nm} \left[ (RSC_{\text{RATIO}})(1-MOS_{\text{RATIO}}) + (RSM_{\text{RATIO}})(MOS_{\text{RATIO}}) \right] \]

(3.24)

The Material Useful Life is the time the sand would be in the foundry between procurement and disposal.

3.6.2 DISPOSAL

The dust from casting shakeout and the waste sand and dust during reclamation are the main waste streams needing disposal. The specific amounts are calculated during the material balance.

For a non reclaiming system, the sand disposed is

\[ \text{TMW} + \text{TCW} = S_r + \text{SLO(5)} + \text{SLO(6)} = \text{SNR}_{\text{NREC}} \]

(3.25)

For a reclaiming system, the sand disposed is

\[ \text{ASD (Tons / Cast)} = (\text{TMW} + \text{TCW}) - [ RSM_{\text{RATIO}} \times \text{TMW} + RSC_{\text{RATIO}} \times \text{TCW} ] \]

(3.26)

3.7 MATERIAL REQUIREMENTS

The Casting Scrap Rate (SR), the Finishing and Cleaning Scrap Rate(FSR), the Core Scrap Rate(CSR) and the Sand Mold Losses(SML) - losses during the mixing of sand due to spilling and other reasons are used to calculate the total required input of sand to the system. It is important to
consider these losses since though they don't directly affect the Life Cycle of Sand, they effect the share of Sand in the Cost of production.

Total Core Weight / Casting =

\[
TCW(\text{Tons} / \text{Casting}) = CCW \times \frac{1}{1-CSR} \times \frac{1}{1-SR} \times \frac{1}{1-FSR} \quad (3.27)
\]

Total Mold Weight / Casting =

\[
TMW(\text{Tons} / \text{Casting}) = SMW \times \frac{1}{1-SML} \times \frac{1}{1-SR} \times \frac{1}{1-FSR} \quad (3.28)
\]

3.8 ENERGY REQUIREMENTS ANALYSIS

3.8.1 ENERGY EQUATIONS

The casting process is assumed to be a combination of subprocesses of core sand preparation, mold sand preparation, core making, mold making, pouring, casting shakeout and reclamation. Total energy used is the sum total of energies required for individual processes.

\[
TPE = \text{Total Process Energy Used (Joules} / \text{Cast}) \quad (3.29)
\]

\[
= \sum_{p=1}^{n} \text{Energy Used per process (Joules} / \text{Cast})
\]

\[n : \text{Total number of processes}\]
\[ \text{TRE} = \text{Total Reclamation Energy Used (Joules / Cast)} \]  
\[ = \sum_{p=1}^{n} \text{Energy Used per sub - process (Joules / Cast)} \]  
\[ n : \text{Total number of processes} \]

Energy for individual processes (except for pouring) is calculated in the following way. Each process can be said to be executed with the help of one or more machines. Energy requirement per process is the sum total of energy requirements of all machines used in that process.

\[ \text{Energy Used per process (Joules / Cast)} \]  
\[ = \sum_{p=1}^{n} \text{Energy Used per machine per process (Joules / Cast)} \]  
\[ r : \text{Total number of machines in process} \]

Each machine needs to be run for a fixed amount of time to complete the job it has. Therefore, energy requirement per machine can be calculated as follows.

* If the time spent on every mold/cast is discrete (for e.g., the processes of Core Making and Mold Making, then energy consumed may be evaluated as

\[ \text{Energy Used per machine per process (Joules / Cast)} \]  
\[ = \text{Wattage (J / Sec)} \times \text{Time its used (Sec / Cast)} \]  
\[ (\text{For processes: Core Making, Mold Making}) \]
* If the time spent on every mold/cast is not discrete and processing is done on the sand rather than the Mold (for e.g., the processes of Core Sand Preparation, Mold Sand Preparation and Reclamation), then energy consumed may be evaluated as:

Energy Used per machine per process (Joules / Cast)

\[
= \frac{24 \times 3600 \times \text{Wattage (Joules / Sec)}}{\text{Throughput (Tons / Day)}}
\]  

(3.33)

* Total Weight of Core / Mold / Amount Reclaimed

(For processes: Core Sand Preparation, Mold Sand Preparation, Reclamation)

* If the time spent on every mold/cast is not discrete and processing is done on the Mold (for e.g., the processes of Casting Shakeout), then energy consumed may be evaluated as:

Energy Used per machine per process (Joules / Cast)

\[
= \left[ \frac{24 \times 3600 \times \text{Wattage (Joules / Sec)}}{\text{Molds_per_Day (Molds / Day)} \times \frac{1}{1 - \text{SR}} \times \frac{1}{1 - \text{FSR}}} \right]
\]  

(3.34)

(For processes: Casting Shakeout)

**Exception**

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Energy of Pouring process is the heat energy transferred from metal to mold during pouring of molten metal. Energy received by Sand during pouring = Energy lost by metal during pouring. Hence this has been calculated as follows:

Heat Evolved per mass = $C_p \Delta T$

$$= (963 \text{J} / \text{Kg.K})(1033 - 288)$$

$$= 707.8 \text{KJ} / \text{Kg(Al)}$$

Heat of Fusion evolved per mass $E_f = 389 \text{KJ} / \text{Kg(Al)}$

$E_{\text{sub-total}} = E + E_f$

$$= 707.8 + 389$$

$$= 1096.8 \text{KJ} / \text{Kg(Al)}$$

If mass ratio of Al:Sand is 1:MS_RATIO then

$E_{\text{total}} = 1096.8 \text{KJ} / \text{MS\_RATIO Kg Sand}$

Where:

Initial Temperature of Metal(Pouring Temp) = 1033 K \quad (\text{For processes : Pouring})

Final Temperature of Metal(Ambient Temperature) = 288 K

3.9 WASTE EMISSIONS

The source of waste emissions is the binder used in the sand. Hazardous Air Pollutants (HAP) are emitted when the sand is fired. Ammonia, Hydrogen Sulphide, Nitrogen Oxides, Sulphur Dioxide, Total Hydrocarbons, Acrolein, Benzene, Formaldehyde, Hydrogen Cyanide, M-Xylene, Naphthalene, O-Xylene, Phenol, Toluene, Aromatic Amines, C$_2$ to C$_3$ Aldehydes are the primary chemicals emitted
during foundry processes. During the process, HAPs are normally emitted during pouring and casting shakeout. Binders are burnt off during reclamation to return sand to its original condition. If sand is reclaimed, the total emissions from the system are the sum total of emissions from the processes and reclamation.

Total Emissions = Process HAP + Reclamation HAP \hspace{1cm} (3.38)

Process or Reclamation HAP is taken to be the sum total of all kinds of individual kinds of emissions.

\[
\text{Process or Reclamation HAP} = \sum_{i=1}^{n} \text{HAP}_i \hspace{1cm} i: \text{Ammonia, Benzene} \ldots
\hspace{1cm} (3.39)
\]

Where

\[
\text{HAP} = \text{Index Use Rate} \times \text{Emission Factor}
\hspace{1cm} (3.40)
\]

\[
\text{Emission Factor} = \frac{\text{AIR\_CONC (mg / cu.m)} \times \text{AVS (cu.m)}}{\text{MS\_RATIO} \times \text{MET (kg)} \times \text{BINDER \_1000} \times \text{1000} \times .95}
\hspace{1cm} (3.41)
\]

3.10 COSTING

Economic and Environmental Costs of Sand are calculated. The costs of reclaiming sand in various percentages and not reclaiming sand are compared with each other. The decision of whether to reclaim or not is determined by which alternative is more cost-effective. Non Reclamation of Sand is
treated as a special case of reclamation where the percentage of reclaimed sand in total input sand is zero.

### 3.10.1 ECONOMIC COSTS OF RECLAIMED SAND


\[ (3.42) \]

### 3.10.1.1 COST OF NEW SAND

Total Cost of New Sand =

\[ \text{TCNS} = \text{CNS} \text{ (Cost per Ton)} \times [ \text{TCW} \times (1 - \text{RSC\textunderscore RATIO}) + \text{TMW} \times (1 - \text{RSM\textunderscore RATIO}) ] \quad (3.43) \]

### 3.10.1.2 COST OF RECLAIMED SAND

Total Cost of Reclaimed Sand =

\[ (3.44) \]

\[ \text{TCRS} ( \text{\$ / Cast} ) = \text{CRS} \text{ (Cost per ton)} \times \frac{[ \text{TCW} \times (\text{RSC\textunderscore RATIO}) + \text{TMW} \times (\text{RSM\textunderscore RATIO}) ]}{1 - \text{FSLO6}} \]

Cost per Ton of Reclaimed Sand (CRS) =

\[ \text{CRS (\$ / Ton)} = \text{Capital Costs + Chemical Costs + Maintenance Costs + Labour Costs} \quad (3.45) \]
Capital Costs

Capital Recovery \( = Ar = PE \left( \frac{Ar}{PE}, i, nr \right) \)

\[
= PE \times \frac{i(1 + i)^{nr}}{(1 + i)^{nr} - 1}
\]

\[\text{CAPR ($/Ton)} = \frac{Ar ($/Year)}{TPR (Tons/Day) \times 365}\]  \hspace{1cm} (3.47)

Maintenance Costs

\[\text{MR ($/Ton)} = \frac{MCR ($/Year)}{TPR (Tons/Day) \times 365} \times \frac{1}{1 - FSLO6}\] \hspace{1cm} (3.48)

Labour Costs

\[\text{LR ($/Ton)} = \frac{RMH (Man Hours/Day) \times 60 \times RLC ($/min)}{TPR (Tons/Day)} \times \frac{1}{1 - FSLO6}\] \hspace{1cm} (3.49)

3.10.1.3 COST OF PROCESS ENERGY

\[\text{TCPE ($/Cast)} = \frac{TPE (Joules/Cast) \times CKWH ($/KWH)}{36 \times 100000}\] \hspace{1cm} (3.50)
3.10.1.4 COST OF RECLAMATION ENERGY

\[
TCRE \ (\$ \ / \ Cast) = \frac{TRE \ (\text{Joules} / \ Cast) \times CKWH \ (\$ \ / \ KWH)}{36 \times 100000} \quad (3.51)
\]

3.10.1.5 COST OF DISPOSAL

\[
CD \ (\$ \ / \ Cast) = ASD \ (\text{Tons} / \ Cast) \times CLF \ (\$ \ / \ Ton) \quad (3.52)
\]
3.10.2 ENVIRONMENTAL COSTS OF RECLAIMED SAND

Total Environmental Cost of Sand = Cost of Cleaning Land
+ Cost of Cleaning Water
+ Cost of Cleaning Air

(3.53)

3.10.2.1 COST OF CLEANING LAND

This is the cost incurred to clean up the sand disposal site if the sand is disposed in and around
the foundry instead of in landfills.

Total Cost of Cleaning Land = TCC\_LAND( $ / Cast ) \hspace{1cm} (3.54)

= CC (Cost / Ton of Sand Disposed )
* ASD( Tons / Cast )

Amount of Sand Treated = Amount of Sand Disposed

Cost per gm of Emission = \hspace{1cm} (3.55)

CC ( $ / Ton of Sand Treated ) = Capital Costs + Chemical Costs + Maintenance Costs
+ Labour Costs + Energy Costs

Capital Costs (per machine)

Capital Recovery = Ac = PC\_LND( Ac / PCLND, i, NCLND )

= PCLND * \frac{i(1 + i)^NCLND}{(1 + i)^NCLND - 1} \hspace{1cm} (3.56)
CAPC (\$/gms) = \frac{\text{Ac (\$/Year)}}{\text{TPCLND (Kgs/Day)} \times 365 \times 1000} \quad (3.57)

\textbf{Maintenance Costs}

MC (\$/gms) = \frac{\text{MCCLND (\$/Year)}}{\text{TPCLND (Kgs/Day)} \times 365 \times 1000} \quad (3.58)

\textbf{Labour Costs}

LC (\$/gms) = \frac{\text{CMHLND (Man Hours/Day)} \times 60 \times \text{CLCLND (\$/min)}}{\text{TPCLND (Kgs/Day)} \times 1000} \quad (3.59)

\textbf{Energy Costs}

Energy Used per machine (Joules/gms)

= \frac{24 \times 3600 \times \text{Wattage (Joules/Sec.)}}{\text{TPCLND (Kgs/Day)} \times 1000} \quad (3.60)

\text{ELAND} = \text{Energy Used for process (Joules/gms)}

= \sum_{p=1}^{n} \text{Energy Used per machine (Joules/gms)} \quad (3.61)

\text{r} : \text{Total number of machines in process}

\text{TCCE (\$/gms)} = \frac{\text{ELAND (Joules/gms)} \times \text{CKWH (\$/KWH)}}{36 \times 100000} \quad (3.62)
3.10.2.2 COST OF CLEANING WATER

This is the cost of cleaning the water that has been used to clear the air emissions of the foundry.

Total Cost of Cleaning Water = TCC_WTR ( $ / Cast )

= CC (Cost / Gallon of Water Cleaned )

* \( \frac{TPCWTR \times 365}{casts_{yr}} \) (Gallons / Cast)

Cost per gm of Emission =

(3.64)

CC ( $ / Gallon of Water treated ) = Capital Costs + Chemical Costs + Maintenance Costs + Labour Costs + Energy Costs

Capital Costs (per machine)

Capital Recovery = Ac = PCWTR (Ac / PCWTR, i, NCWTR )

= PCWTR \( \frac{i(1 + i)^{NCWTR}}{(1 + i)^{NCWTR} - 1} \)

(3.65)

CAPC ($ / gms ) = \( \frac{Ac (\$ / Year)}{TPCWTR (Gallons / Day) \times 365 \times 1000} \)

(3.66)

Maintenance Costs

MC ($ / gms ) = \( \frac{MCCWTR (\$ / Year)}{TPCWTR (Gallons / Day) \times 365 \times 1000} \)

(3.67)

Labour Costs
LC ($/gms) = \frac{\text{CMHWTR (Man Hours/Day)} \times 60 \times \text{CLCWTR ($/min)}}{\text{TPCWTR (Gallons/Day)} \times 1000} \quad (3.68)

\textbf{Energy Costs}

\text{Energy Used per machine (Joules/gms)}

= \frac{24 \times 3600 \times \text{Wattage (Joules/Sec)}}{\text{TPCWTR (Gallons/Day)} \times 1000} \quad (3.69)

\text{EWTR} = \text{Energy Used for process (Joules/gms)}

= \sum_{p=1}^{n} \text{Energy Used per machine (Joules/gms)} \quad (3.70)

r : \text{Total number of machines in process}

\text{TCCE ($/gms)} = \frac{\text{EWTR (Joules/gms)} \times \text{CKWH ($/KWH)}}{36 \times 100000} \quad (3.71)

3.10.2.3 \textit{COST OF CLEANING AIR}

\text{Total Cost of Cleaning Air} = \text{TCC}_\text{AIR($$/\text{Cast})} \quad (3.72)

= \text{CC (Cost per Unit of Emission)} \times \text{HAP (Emissions/\text{Cast})}

\text{Cost per gm of Emission} = \quad (3.73)

\text{CC ($/gm of Emission treated)} = \text{Capital Costs + Chemical Costs + Maintenance Costs + Labour Costs + Energy Costs}
Capital Costs (per machine)

Capital Recovery = \( Ac = PC \left( \frac{Ac}{PC} , i , nc \right) \)

\[ = PC \times \frac{i(1+i)^{nc}}{(1+i)^{nc} - 1} \]  

(3.74)

\( \text{CAPC ($/gms)} = \frac{Ac ($/Year)}{TPC (Kgs/Day) \times 365 \times 1000} \)  

(3.75)

Maintenance Costs

\( \text{MC ($/gms)} = \frac{MCC ($/Year)}{TPC (Kgs/Day) \times 365 \times 1000} \)  

(3.76)

Labour Costs

\( \text{LC ($/gms)} = \frac{CMH (Man Hours/Day) \times 60 \times CLC ($/min)}{TPC (Kgs/Day) \times 1000} \)  

(3.77)

Energy Costs

Energy Used per machine (Joules/gms)

\[ = \frac{24 \times 3600 \times \text{Wattage (Joules/Sec)}}{\text{Throughput (Kgs/Day) \times 1000}} \]  

(3.78)

\( \text{TCE} = \text{Energy Used for process (Joules/gms)} \)

\[ = \sum_{p=1}^{n} \text{Energy Used per machine (Joules/gms)} \]  

(3.79)

\( r \) : Total number of machines in process

45
TCCE ($/gms) = \frac{TCE (\text{Joules/gms}) \times \text{CKWH (\$/KWH})}{36 \times 100000} \quad (3.80)

3.11 ENVIRONMENTAL EFFECT OF FOUNDRY WASTES

Total Waste = Waste on Land

+ Waste on Air

+ Waste on Water \quad (3.81)

3.11.1 WASTE ON LAND

This is the effect of solid wastes disposed on land.

3.11.2 WASTE ON AIR

Reclamation cleans up sand for reuse but emits a lot of hazardous air pollutants into the atmosphere. Also the processes of pouring, cooling and casting shakeout emit hazardous air pollutants. This component evaluates the effect of total airborne emissions.

3.11.3 WASTE ON WATER

Emissions of reclamation are normally cleaned up using water. This brings the HAP levels in air into the permissible range, but then the foundry has to deal with water pollution as well. This considers the total pollution on water.

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3.12 THE CRITERION FUNCTION APPROACH

The Criterion Function Approach (also known as Weighted Factor Scoring Model) is a method to express a value system as a mathematical statement in order to choose the best solution when several tentative alternatives are available (Meredith and Mentel, 1995). It determines the "best" alternative by normalising the values of the Criterion Variables. The Decision with the minimum Criterion Function is judged the "best".

A Decision Matrix is a value system that can be applied to competing choices in order to determine which is the best one. The Criterion Function Approach employs such a Decision Matrix. It is possible to express a value system as a mathematical statement showing what factors are to be considered and their relative importance in any decision making process. The Decision Matrix technique provides for both systematic and consistent applications of both subjective and objective criteria in the evaluation process.

3.12.1 CRITERION FUNCTION

A value system can be expressed as a Criterion function, C.F, in the form:

\[
CF = \sum_{i=1}^{m} W_i \frac{C_i}{|C_i|_{\text{max}}} \tag{3.82}
\]

Where

\( C_i \) = Criterion variable ‘i’.

\( w_i \) = weighting coefficient indicating the relative importance of the criterion variable ‘i’.
$|C_{i}|_{max}$ = maximum absolute value that the criterion variable ‘i’ assumes for all alternatives being evaluated.

The criterion function is evaluated for each alternative considered, and then compared with each other for selection.

### 3.12.2 Criterion Variables

An alternative is judged in terms of numerous variables such as cost of new sand, cost of reclaimed sand, cost of energy, cost of cleaning, amount of soil pollution, amount of air emissions, etc. An alternative may be judged in terms of two to hundreds of variables.

### 3.12.3 Weighting Coefficients

Each variable must be assigned a weight $W_i$. The weights may be negative or positive depending on the nature of the particular criterion variable.

$$\sum_{i=1}^{m} |W_i| = 1.0 \quad (3.83)$$

The particular weights assigned represent the relative importance of the variables. Weighting is done using the Analytical Hierarchy Process.
3.12.4 DECISION MATRIX

The decision matrix offers a convenient format for tabulating the data required in the evaluation of the Criterion Function. (Refer Appendix 1.4)

\( C_i \) : Value of Criterion Variable

\( W_i \) : Weight of Criterion Variable

![Unit Block of Decision Matrix](image)

FIG 3.2: Unit Block of Decision Matrix

3.12.5 PROCEDURE FOR COMPLETING DECISION MATRIX

Step 1: Assignment of values to Criterion Variables

When each alternative is rated with respect to a particular criterion variable, \( C_i \), that variable takes on a numerical value.

It is easy to assign values to criterion variables that can be discussed objectively in terms of readily measurable quantities. For subjective quantities, an arbitrary number scale such as 0 to 10 must
be created so that each unit under consideration can be rated. The scale values can then be assigned to reflect excellent or poor qualities in a more objective manner.

Step 2: Determination of Maximum Absolute Value of each Criterion Variable

Once each variable is applied to all the alternatives, the maximum absolute value, \( |C_{i\text{max}}| \), can be established.

Step 3: Normalisation of Values of Criterion Variables

The values of Criterion Variables, \( C_i \), are normalised by their maximum absolute value, \( |C_{i\text{max}}| \). The problem of adding quantities with different dimensions is also eliminated by this normalising procedure.

Step 4: Weighting the Criterion Variables

The sign of the weights are assigned consistent with whether to maximise or to minimise the criterion function, and with the nature of the variable. The criterion function here needs to be minimised, and all the costs will be given positive weights. The product of the weighting coefficient, \( w_i \), and the normalised value of the criterion variable is the weighted criterion variable.
Step 5: Determining the "Best" Alternative

For each alternative, the value of the weighted criterion variables are summed, to provide the magnitude of the criterion function. The alternative with the minimum criterion function will be judged the "Best".

3.13 ESTABLISHING WEIGHTS USING ANALYTICAL HIERARCHICAL PROCESS

Most people prefer a problem-solving approach that can be easily understood. The strength of the Analytical Hierarchy Process (Saaty, 1980) is that it is easy to understand and still robust enough to handle the complexities of real-world decisions. It has been designed to solve complex problems involving multiple criteria. AHP will be used to assign weights (priorities) to the Criterion Variables of the Criterion Function. This will involve four steps (Boucher & MacStravic, 1991): 1) breaking down the decision into a hierarchy of decision elements as shown in Fig 3.3 (identification of criteria) 2) collecting input data by pairwise comparison of decision elements 3) checking the consistency of the input data using the eigen value method 4) computing the relative weights of the decision elements as the eigen vector of the pairwise judgement matrix.
AHP has the decision maker specify his or her judgements about the relative importance of each criterion in terms of its contribution to the achievement of the overall goal. A mathematical process is then used to synthesise the information and provide priorities to the criteria.

Pairwise comparisons are the fundamental building blocks to establish weights for criterion variables (Saaty, 1980). AHP employs an underlying scale with values from 1 to 9 to rate the relative preferences for two items.

<table>
<thead>
<tr>
<th>VERBAL JUDGEMENT OF PREFERENCE</th>
<th>NUMERICAL RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Preferred</td>
<td>9</td>
</tr>
<tr>
<td>Very Strongly to Extremely</td>
<td>8</td>
</tr>
<tr>
<td>Very Strongly Preferred</td>
<td>7</td>
</tr>
<tr>
<td>Strongly to Very Strongly</td>
<td>6</td>
</tr>
<tr>
<td>Strongly Preferred</td>
<td>5</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Moderately to Strongly</td>
<td>4</td>
</tr>
<tr>
<td>Moderately Preferred</td>
<td>3</td>
</tr>
<tr>
<td>Equally to Moderately</td>
<td>2</td>
</tr>
<tr>
<td>Equally Preferred</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE 3.1: Pairwise comparisons Scale for AHP Preferences**

### 3.13.1 PAIRWISE COMPARISON MATRIX

The first step in AHP is the construction of the Pairwise Comparison Matrix. It is a $n \times n$ matrix where 'n' is the number of criterion variables considered. Let $\text{IMP}_{ab} = \text{Importance of A over B}$ towards selection of alternative.

<table>
<thead>
<tr>
<th>Criterion Variables</th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>......</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCNS</td>
<td>1</td>
<td>$\text{IMP}_{TCRS,TCNS}$</td>
<td>$\text{IMP}_{TCPE,TCNS}$</td>
<td>....</td>
</tr>
<tr>
<td>TCRS</td>
<td>$1/\text{IMP}_{TCRS,TCNS}$</td>
<td>1</td>
<td>$\text{IMP}_{TCPE,TCRS}$</td>
<td>...</td>
</tr>
<tr>
<td>TCPE</td>
<td>$1/\text{IMP}_{TCPE,TCNS}$</td>
<td>$1/\text{IMP}_{TCPE,TCRS}$</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>......</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE 3.2: Pairwise Comparison Matrix.**
3.13.2 SYNTHESISATION

**Step 1**: The values of each column of the comparison Matrix is summed.

<table>
<thead>
<tr>
<th>Criterion Variables</th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>......</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCNS</td>
<td>1</td>
<td>IMP_TCRS_TCNS</td>
<td>IMP_TCPE_TCNS</td>
<td>....</td>
</tr>
<tr>
<td>TCRS</td>
<td>1/IMP_TCRS_TCNS</td>
<td>1</td>
<td>IMP_TCPE_TCRS</td>
<td>...</td>
</tr>
<tr>
<td>TCPE</td>
<td>1/IMP_TCPE_TCNS</td>
<td>1/IMP_TCPE_TCRS</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>......</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>COLTOTAL_TCNS</td>
<td>COLTOTAL_TCRS</td>
<td>COLTOTAL_TCPE</td>
<td>COLTOTAL_..</td>
</tr>
</tbody>
</table>

**TABLE 3.3**: Pairwise Comparison Matrix With Column Totals

**Step 2**: Normalised Pairwise comparison Matrix is constructed by dividing each element in the Pairwise comparison Matrix by its column total.

<table>
<thead>
<tr>
<th>Criterion Variables</th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>......</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCNS</td>
<td>1/COLTOTAL_TCNS</td>
<td>IMP_TCRS_TCNS/ (COLTOTAL_TCRS)</td>
<td>IMP_TCPE_TCNS/ COLTOTAL_TCPE</td>
<td>....</td>
</tr>
<tr>
<td>TCRS</td>
<td>1/(IMP_TCRS_TCNS* COLTOTAL_TCNS)</td>
<td>1/(COLTOTAL_TCRS)</td>
<td>IMP_TCPE_TCRS/ COLTOTAL_TCPE</td>
<td>...</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>TCPE</th>
<th>1/(IMP\textsubscript{TCPE,TCNS}* \text{COLTOTAL\textsubscript{TCNS}})</th>
<th>1/(IMP\textsubscript{TCPE,TCRS}* \text{COLTOTAL\textsubscript{TCRS}})</th>
<th>1/ COLTOTAL\textsubscript{TCPE}</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>......</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**TABLE 3.4 : Normalised Pairwise Comparison Matrix.**

**Step 3 :** The Row Average of the elements of the Normalised Pairwise comparison Matrix provides an estimate of the relative weights of the elements being compared.

<table>
<thead>
<tr>
<th>Criterion Variables</th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>...</th>
<th>ROW AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCNS</td>
<td>1/ COLTOTAL\textsubscript{TCNS}</td>
<td>IMP\textsubscript{TCRS,TCNS}/(COLTOTAL\textsubscript{TCRS})</td>
<td>IMP\textsubscript{TCPE,TCNS}/ COLTOTAL\textsubscript{TCPE}</td>
<td>...</td>
<td>ROWAVER\textsubscript{TCNS}</td>
</tr>
<tr>
<td>TCRS</td>
<td>1/(IMP\textsubscript{TCRS,TCNS}* \text{COLTOTAL\textsubscript{TCNS}})</td>
<td>1/ (COLTOTAL\textsubscript{TCRS})</td>
<td>IMP\textsubscript{TCPE,TCRS}/ COLTOTAL\textsubscript{TCPE}</td>
<td>...</td>
<td>ROWAVER\textsubscript{TCRS}</td>
</tr>
<tr>
<td>TCPE</td>
<td>1/(IMP\textsubscript{TCPE,TCNS}* \text{COLTOTAL\textsubscript{TCNS}})</td>
<td>1/(IMP\textsubscript{TCPE,TCRS}* \text{COLTOTAL\textsubscript{TCRS}})</td>
<td>1/ COLTOTAL\textsubscript{TCPE}</td>
<td>...</td>
<td>ROWAVER\textsubscript{TCPE}</td>
</tr>
<tr>
<td>......</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>ROWAVER...</td>
</tr>
</tbody>
</table>

**TABLE 3.5 : Normalised Pairwise Comparison Matrix with Row Average**
3.13.3 ESTIMATING CONSISTENCY RATIO

An important consideration in terms of the quality of the ultimate decision relates to the consistency of judgements that the decision maker demonstrated during the Pairwise comparisons. The Consistency Ratio provided by AHP evaluates the degree of consistency of judgements for Pairwise comparison. This ratio is designed in such a way that values of ratio exceeding 0.10 are indicative of inconsistent judgement, values of less than 0.10 are indicative of consistent judgement. If the degree of consistency is unacceptable, then the Pairwise comparison judgements need to be revised before proceeding with the analysis.

**Step 1:** Each value in the first column of Pairwise comparison matrix is multiplied by the relative priority of the first term considered. The same is done for the other columns. The sum of values across the rows is results in a vector of values called the “Weighted Sum Vector”.

\[
\begin{bmatrix}
WSV_{TCNS} \\
WSV_{TCRS} \\
WSV_{TCPE}
\end{bmatrix} = \begin{bmatrix}
1 \\
1/IMP_{TCRS, TCNS} \\
1/IMP_{TCPE, TCNS}
\end{bmatrix} \times
\begin{bmatrix}
IMP_{TCRS, TCNS} \\
1/IMP_{TCPE, TCNS} \\
1
\end{bmatrix} + \begin{bmatrix}
IMP_{TCPE, TCNS} \\
IMP_{TCPE, TCRS} \\
1
\end{bmatrix}
\]

**TABLE 3.6 : Weighted Sum Vector**
**Step 2**: Each element of above matrix divides corresponding row average to give another set of values.

**Step 3**: The average of values in step 2 is calculated and denoted by $\lambda_{\text{max}}$.

**Step 4**: Calculating Consistency Index ‘CI’

\[
\text{CI} = \lambda_{\text{max}} - n
\]

\[
= \frac{n - 1}{n - 1}
\]  \hfill (3.84)

where

\[ n = \text{number of criterion variables.} \]

**Step 5**: Calculating Consistency Ratio ‘CR’

\[
\text{CR} = \frac{\text{CI}}{\text{RI}}
\]

\hfill (3.85)

where RI, the random index is the Consistency Index of a randomly generated pairwise comparison matrix. RI depends on the number of elements being compared, and its values can be obtained from tables.

If CR $\leq 0.1$ the weights are acceptable, else the comparisons have to be revisited.
CHAPTER IV

LIFE CYCLE DECISION MAKING TEMPLATE

4.1 THE USE OF DELPHI

The software to be developed will be a graphical-windows based environment software, and will be written in Delphi.

Delphi is a component-based application development environment supporting rapid development of highly efficient Microsoft Windows based applications with a minimum of coding. Many of the traditional requirements of programming for windows are handled within the Delphi Class Library. Delphi provides design tools such as application and form templates to create and test application prototypes. Delphi’s database tools help develop powerful desktop database applications.

4.2 LIFE CYCLE DECISION MAKING SOFTWARE

This section explains how to use the Software to perform the Life Cycle Costing for any alternative. In order to have a clear image of the procedure as it is described, pictures of the actual windows of the program will be illustrated along with explanation for demonstration purposes. The executable file of the Software can be run directly under windows by clicking the respective icon as shown.
FIG 4.1: Icon of the Software in Windows

Upon running the program, an About Box appears with Version and Copyright details of the Software.

FIG 4.2: About Box

The user is asked for the number of alternatives to be compared.

FIG 4.3: Number of Alternatives
This leads to the main screen of the Software. Fig 4.4 shows the screen which has a menubar with six menu titles: Alternatives, Selection, Data Input, Assessment, Analysis and Exit. The user is guided through the whole software by successfully enabling and disabling items as required depending on the flow of the software. All menu items and their functions will be explained in the order in which they are used.

![Menuform](image)

**FIG 4.4 :** Menus Window

The Alternatives menu has a list of alternatives that have to be chosen in order, according to the alternative being looked at, at that time. For e.g., if Alternative 1 is chosen, Data is input and assessed for that particular alternative.

![Menuform.MainMenu](image)

**FIG 4.5 :** Menu items of the Alternatives menu

The Selection Menu has three items: Environmental Effects, Costs and Material Useful life. Environmental Effects has been set up for future development. The item Material Useful Life asks the user if he wants it to be considered as a criteria in the decision making. The Costs item when clicked leads to another form where the user is given a choice with respect to environmental costs and direct economic costs.
FIG 4.6: Menu items of the Selection menu

As shown in Fig 4.8, the user is given a choice with respect to environmental costs and direct economic costs as to the criteria desired for decision making.

FIG 4.7: Selection of Types of Costs

The environmental costs, sub divided into the Air, Water and Land Cleaning Costs, are again further divided. The user can select the particular environmental costs required as decision making criteria.
FIG 4.8: Selection of Environmental Costs

The Direct Economic Costs are also sub divided as shown in Fig 4.9. The user can select the specific Costs required as decision making criteria.
FIG 4.9: Selection of Direct Economic Costs

After the Criteria that the user wants to consider in his decision making are selected, the user is shown a complete list of data that will be needed for further calculations. This is shown individually for every criteria that has been chosen. For e.g., Fig 4.10 shows the data required for calculating the cost of new sand.
Data Availability

Data Required for Energy Cost of Core Sand Preparation

- Power of respective Equipment
- Casting Core Weight
- Core Scrap Rate
- Casting Scrap Rate
- Finishing and Cleaning Scrap Rate
- Cost of Energy per KWH
- No of equipment required for Core Sand Preparation
- Throughput of each Equipment

FIG 4.10: List of Data Required

The user may choose to go through all the criteria, or if reasonably confident about the availability of data, may proceed with the “OK” button. This prompts a message that asks the user if all the data required is available, and gives the user the option to quit right there if any data is unavailable and the user does not wish to go through the software.

If the user does have the required data for running the software, then control is returned to the menu form. The Data Input Menu has items: General, Core, Mold, Cast, Reclamation and Cleaning. Each leads to Data Input forms of the particular process.
The General Data Form (FIG 4.12 and 4.13) inputs data required for calculations, that are common to all processes. Only data required for the criteria under consideration are asked for.
The Core menu item consists of Core Sand Preparation and Core Making.

The Mold menu item consists of Mold Sand Preparation and Mold Making.
FIG 4.15: Menu Items of the Mold Menu

The Cast menu item consists of Pouring and Casting Shakeout.

FIG 4.16: Menu Items of the Cast Menu

The Cleaning menu item consists of Cleaning of Air, Water and Land.

FIG 4.17: Menu Items of the Cleaning Menu
The Core Sand Preparation, Mold Sand Preparation, Core Making, Mold Making, Pouring, Casting Shakeout and Reclamation screens input process and energy data of the particular process respectively.

One of the screens (Core Sand Preparation) is shown here as an example.

![Data for Core Sand Preparation](image)

**FIG 4.18 : Data Input for Core Sand Preparation**

The Reclamation screen inputs capital, process and energy data of the particular process.
FIG 4.19: Data Input Screen for Reclamation Process Data
The Cleaning data input screens input process and energy data of the particular process respectively. The screens for Air cleaning data have been shown as an example.
FIG 4.21: Data Input Screen for Air Cleaning Process Data
FIG 4.22: Data Input Screen for Air Cleaning Chemicals and Energy Data

After all the Data has been input, the control goes back to the menu screen. Assessment is done using data collected in previous screens. Menu items of Assessment menu are: Environmental Effects, Costs, and Material Useful Life. Environmental Effects are set up for future program development. The Material Useful Life will display the calculated Useful Life of the product. The Costs menu splits up into sub-menus of Environmental and Direct Economic Costs.
The Environmental Costs menu item when clicked calculates the Costs of Cleaning Air, Water and Land and displays the results in respective screens such as:

![Cost of Cleaning Air Results](image)

Similar screens display water and sand cleaning data.
The Direct Economic Costs menu item when chosen calculates the Costs of New Sand, Cost of Reclaimed Sand, Cost of Process Energy, Cost of Reclamation Energy and Cost of Disposal and displays the results in respective screens such as:

![Raw Material Run Results - New Sand](image)

**FIG 4.25 : Cost of New Sand**
### RECLAIMED SAND RESULTS

<table>
<thead>
<tr>
<th>Cost per Ton Of Reclaimed Sand per Cost (In Dollars/Ton)</th>
<th>Total Reclaimed Sand per Cast In Dollars/Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs :</td>
<td></td>
</tr>
<tr>
<td>Chemical Costs :</td>
<td></td>
</tr>
<tr>
<td>Maintenance Costs :</td>
<td></td>
</tr>
<tr>
<td>Labour Costs :</td>
<td></td>
</tr>
<tr>
<td>Net Cost per Ton :</td>
<td></td>
</tr>
</tbody>
</table>

FIG 4.26: Cost of Reclaimed Sand
<table>
<thead>
<tr>
<th>Process</th>
<th>Amount of Energy Consumed per Cast</th>
<th>Cost of Energy Consumed per Cast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Sand Preparation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mold Sand Preparation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Making</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mold Making</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pouring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casting Shakeout</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Cost of Energy Consumed per Cast (in Dollars / Cast):
After cost assessment, the control goes back to the menu screen. If there is only one alternative to be considered, then the user may start Analysis right away. If more than one alternative, the user needs to go back to the beginning, choose the next alternative number, and repeat the same process as
alternative one. Analysis consists of Analytic Hierarchy Process, Criterion Function Approach and Ranking And Decision.

FIG 4.30 : Menu Items of the Analysis Menu

The of Analytic Hierarchy Process is chosen first since it is used to calculate weights for input into the Criterion Function Calculations. The Pairwise Comparison Matrix is displayed, to be filled by the user.

After filling, on clicking the “OK” button, AHP calculations are performed, and weights determined, to be used in subsequent calculations. Control is passed back to the menu form.

FIG 4.31 : The Analytic Hierarchy Process Pairwise Comparison Matrix
The Criterion Function menu has three components: Direct Economic Costs, Environmental Costs and Environmental Effects and Material Useful Life. Each displays the relevant part of the Criterion Function Matrix such as:

### Criterion Function Decision Matrix - Direct Economic Costs

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cost New</th>
<th>Cost Reclaimed</th>
<th>Cost Process En</th>
<th>Cost Reclam En</th>
<th>Cost Dispose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Weight</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
</tr>
<tr>
<td>Alternative 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.020960</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.020960</td>
</tr>
</tbody>
</table>

**FIG 4.32**: Criterion Function Matrix - Direct Economic Costs

### Criterion Function Decision Matrix - Environmental Costs

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cleaning Water</th>
<th>Cleaning Land</th>
<th>Cleaning Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Weight</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
<td>Weight = 0</td>
</tr>
<tr>
<td>Alternative 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**FIG 4.33**: Criterion Function Matrix - Environmental Costs
Finally, the Criterion Function for each alternative is calculated, ranked and displayed as shown in Fig 4.35.

The Control once again passes back to the menu screen. The program can then be halted using the menu item ‘Exit’.
4.3 EXPECTED RESULTS

A common normalised ground on which alternative technologies and options may be compared on the basis of economic costs and environmental effects has been attempted. The Criterion Function approach and AHP were adopted. The total Life Cycle Cost of sand per run in the foundry can be evaluated with the help of this framework.

The Material Useful Life gives an idea of the increased life of sand, as a result of which lesser virgin sand will be used. It will be used as one of the Criterion Variables.

The framework will help compare alternative technologies based on minimum life cycle costs and emission factors.
CHAPTER V

EXAMPLE DEMONSTRATION

In this chapter, the software for the framework for decision making has been demonstrated. Data has been obtained from literature (Busby, 1995; Naro et al, 1993) and from information obtained through Ashland Chemicals, Foundry Products Division, Columbus, Ohio.

In this example, the economics of Green Sand versus Chemically Bonded Sand is compared. Green Sand uses ‘natural’ inorganic Clay Water binders. Organic additives are made to Green Sand, but overall this is seen as a minor factor compared to the use of Chemical binders. This is Alternative 1. Alternative 2 looks at a Cold-Box alternative to Green Sand. Amine Cured Urethane binder system was used. The product considered was Ventilated Disc Brake castings. Ventilated Disc Brake castings are normally produced in Green Sand. The Cold Box method to achieve the same production rate was examined to compare economics. Product Characteristics were:

Ventilated Disc Brake castings

Typical Diameter : 260 mm
Typical Weight : 6.5 Kg
Core Weight : 1.65 Kg
Mold Size : 600 mm * 480 mm * 330 mm

The data required depends on the criteria selected for Decision Making. An attempt was made to cover all costs that figured in a life cycle costing of sand as well as the environmental effects. The criteria that can be considered for decision making are:

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1) Cost of New Sand

2) Cost of Reclaimed Sand
   - Capital Cost of Reclaimed Sand
   - Maintenance Cost of Reclaimed Sand
   - Labour Cost of Reclaimed Sand
   - Chemical Cost of Reclaimed Sand
   - Energy Cost of Reclaimed Sand

3) Cost of Process Energy
   - Energy Cost of Core Sand Preparation
   - Energy Cost of Mold Sand Preparation
   - Energy Cost of Core Making
   - Energy Cost of Mold Making
   - Energy Cost of Pouring
   - Energy Cost of Casting Shakeout

4) Cost of Reclamation Energy

5) Cost of Disposal

6) Cost of Cleaning Air
   - Capital Cost of Cleaning Air
   - Maintenance Cost of Cleaning Air
   - Labour Cost of Cleaning Air
   - Chemical Cost of Cleaning Air
   - Energy Cost of Cleaning Air
7) Cost of Cleaning Water
   - Capital Cost of Cleaning Water
   - Maintenance Cost of Cleaning Water
   - Labour Cost of Cleaning Water
   - Chemical Cost of Cleaning Water
   - Energy Cost of Cleaning Water

8) Cost of Cleaning Land
   - Capital Cost of Cleaning Land
   - Maintenance Cost of Cleaning Land
   - Labour Cost of Cleaning Land
   - Chemical Cost of Cleaning Land
   - Energy Cost of Cleaning Land

9) Environmental Effects of Air Pollution

10) Environmental Effects of Water Pollution

11) Environmental Effects of Land Pollution

12) Material Useful Life

Data may be clustered into two categories:

General Data:

These data are of a general nature and are not related to any process, for e.g.: the weight of the sand core, the number of casts produced per year, etc.
Process Data:

These data are process specific, e.g., the input and output data of any process, its emissions, etc.

Due to the nonavailability of some data and to ensure ease of demonstration, only specific criteria have been selected for consideration. They are: Cost of New Sand, Cost of Reclaimed Sand, Cost of Energy for Mold Making, Cost of Energy for Pouring, Cost of Disposal.

5.1 USER DATA INPUT:

5.1.1 ALTERNATIVE 1: GREEN SAND - CLAY WATER BOND

1) Data Required for Cost of New Sand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting Core Weight</td>
<td>3.3 Kgs</td>
</tr>
<tr>
<td>Sand Mold Weight</td>
<td>144 Kgs</td>
</tr>
<tr>
<td>Core Scrap Rate</td>
<td>15%</td>
</tr>
<tr>
<td>Casting Scrap Rate</td>
<td>35 %</td>
</tr>
<tr>
<td>Finishing and Cleaning Scrap Rate</td>
<td>3%</td>
</tr>
<tr>
<td>Sand Mold Losses</td>
<td>5 %</td>
</tr>
<tr>
<td>Purchasing Cost of New Sand including Transportation</td>
<td>$30 / Ton</td>
</tr>
<tr>
<td>Percentage of Reclaimed Sand to Total Sand Used for Making Cores</td>
<td>0 %</td>
</tr>
<tr>
<td>Percentage of Reclaimed Sand to Total Sand Used for Making Molds</td>
<td>70 %</td>
</tr>
</tbody>
</table>
2) Data Required for Capital Cost of Reclaimed Sand

Casting Core Weight = 3.3 Kgs
Sand Mold Weight = 144 Kgs
Core Scrap Rate = 15%
Casting Scrap Rate = 35%
Finishing and Cleaning Scrap Rate = 3%
Sand Mold Losses = 5%
Initial Cost of Reclamation Equipment = $900,000
Percentage of Reclaimed Sand to Total Sand Used for Making Cores = 0%
Percentage of Reclaimed Sand to Total Sand Used for Making Molds = 70%
Life of Equipment = 20 Years
Interest Rate = 6%
Throughput of Reclamation Equipment = 618,106 Tons / Year
Sand Lost during Reclamation due to Loss in properties = 30%

3) Data Required for Energy Cost of Mold Making

Cost of Energy per KWH (Average) = 7 Cents
No of equipment required for Mold Sand Preparation = 1
Time per Mold per Equipment = 10.29 Sec / Mold
Power of respective Equipment = 750 KWatts
4) Data Required for Energy Cost of Pouring

Cost of Energy per KWH (Average) = 7 Cents
Specific Heat of Metal = 963 J / Kg.K
Latent Heat of Fusion = 389 KJ / Kg
Sand To Metal Ratio = 10

5) Data Required for Cost of Disposal

Casting Core Weight = 3.3 Kgs
Sand Mold Weight = 144 Kgs
Core Scrap Rate = 15%
Casting Scrap Rate = 35 %
Finishing and Cleaning Scrap Rate = 3%
Sand Mold Losses = 5 %
Percentage of Reclaimed Sand to Total Sand Used for Making Cores = 0 %
Percentage of Reclaimed Sand to Total Sand Used for Making Molds = 70 %
Cost of Disposal = $ 18 / Ton

5.1.2 ALTERNATIVE 2: COLD BOX - AMINE CURED URETHANE BOND

1) Data Required for Cost of New Sand

Casting Core Weight = 1.4 Kgs
Sand Mold Weight = 7.7 Kgs
Core Scrap Rate = 15%
Casting Scrap Rate = 25 %
Finishing and Cleaning Scrap Rate = 3 %
Sand Mold Losses = 5 %
Purchasing Cost of New Sand including Transportation = $ 30 / Ton
Percentage of Reclaimed Sand to Total Sand Used for Making Cores = 90 %
Percentage of Reclaimed Sand to Total Sand Used for Making Molds = 90 %

2) Data Required for Capital Cost of Reclaimed Sand
Casting Core Weight = 1.4 Kgs
Sand Mold Weight = 7.7 Kgs
Core Scrap Rate = 15 %
Casting Scrap Rate = 25 %
Finishing and Cleaning Scrap Rate = 3 %
Sand Mold Losses = 5 %
Initial Cost of Reclamation Equipment = $ 1,000,000
Percentage of Reclaimed Sand to Total Sand Used for Making Cores = 90 %
Percentage of Reclaimed Sand to Total Sand Used for Making Molds = 90 %
Life of Equipment = 20 Years
Interest Rate = 6 %
Throughput of Reclamation Equipment = 50222 Tons / Year
Sand Lost during Reclamation due to Loss in properties = 5 %
3) Data Required for Energy Cost of Mold Making

Cost of Energy per KWH (Average) = 7 Cents
No of equipment required for Mold Sand Preparation = 1
Time per Mold per Equipment = 8.33 Sec / Mold
Power of respective Equipment = 750 KWatts

4) Data Required for Energy Cost of Pouring

Cost of Energy per KWH (Average) = 7 Cents
Specific Heat of Metal = 963 J / Kg.K
Latent Heat of Fusion = 389 KJ / Kg
Sand To Metal Ratio = 2

5) Data Required for Cost of Disposal

Casting Core Weight = 1.4 Kgs
Sand Mold Weight = 7.7 Kgs
Core Scrap Rate = 15%
Casting Scrap Rate = 25 %
Finishing and Cleaning Scrap Rate = 3%
Sand Mold Losses = 5 %
Percentage of Reclaimed Sand to Total Sand Used for Making Cores = 90 %
Percentage of Reclaimed Sand to Total Sand Used for Making Molds = 90 %
Cost of Disposal = $18 / Ton
5.1.3 **ANALYTIC HIERARCHY PROCESS INPUTS**

<table>
<thead>
<tr>
<th></th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCNS</td>
<td>1</td>
<td>1/5</td>
<td>5</td>
<td>1/9</td>
</tr>
<tr>
<td>TCRS</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>1/9</td>
</tr>
<tr>
<td>TCPE</td>
<td>1/5</td>
<td>1/6</td>
<td>1</td>
<td>1/9</td>
</tr>
<tr>
<td>CD</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE 5.1:** Analytic Process Hierarchy Inputs

(Refer to Section 3.13.1 for explanation of terms)

5.2 **INTERMEDIATE PROCESS RESULTS FROM SOFTWARE**

All types of costs are calculated. When subcosts are present, as in reclaimed sand costs and energy costs, they are added up to one figure which is used for subsequent calculations.

5.2.1 **ALTERNATIVE 1 RESULTS**

Cost of New Sand

\[ \text{Cost of New Sand} = 2.3484 \text{ } \$ \text{ / Cast} \]

Cost of Reclaimed Sand (Capital Costs)

\[ \text{Cost of Reclaimed Sand (Capital Costs)} = 0.00575 \text{ } \$ \text{ / Cast} \]

Cost of Process Energy (Mold Making)

\[ \text{Cost of Process Energy (Mold Making)} = 0.15006 \text{ } \$ \text{ / Cast} \]

Cost of Process Energy (Pouring)

\[ \text{Cost of Process Energy (Pouring)} = 0.001395 \text{ } \$ \text{ / Cast} \]

Cost of Disposal

\[ \text{Cost of Disposal} = 1.409 \text{ } \$ \text{ / Cast} \]
5.2.2 ALTERNATIVE 2 RESULTS

Cost of New Sand = .04022 $ / Cast
Cost of Reclaimed Sand (Capital Costs) = .00416 $ / Cast
Cost of Process Energy (Mold Making) = .12148 $ / Cast
Cost of Process Energy (Pouring) = .00698 $ / Cast
Cost of Disposal = .02413 $ / Cast

The results of these calculations are used as inputs to the Criterion Function Matrix.

5.3 RESULTS FROM SOFTWARE

The Criterion Function Matrix uses cost figures from the process results, in conjunction with the weightages determined from the Analytic Hierarchy Process to perform all necessary calculations.

5.3.1 CRITERION FUNCTION DECISION MATRIX - CALCULATIONS

<table>
<thead>
<tr>
<th>Criterion Variable - &gt;</th>
<th>TCNS</th>
<th>TCRS</th>
<th>TCPE</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Weight - &gt;</td>
<td>0.010631047</td>
<td>0.198604222</td>
<td>0.00404832</td>
<td>0.65971639</td>
</tr>
<tr>
<td>ALTERNATIVE 1</td>
<td>2.34842 0.10163 0.00575 0.19860 0.15145 0.04004 1.40905 0.65971</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.34842 0.99999 0.00575 0.99999 0.15145 1.0 1.40905 1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALTERNATIVE 2</td>
<td>0.04021 0.00174 0.00415 0.14346 0.12045 0.03396 0.02412 0.01129</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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TABLE 5.2: Criterion Function Decision Matrix - Calculations

The Highlighted boxes have the weighted normalised values of the respective criterion for that alternative. These values are added up to establish the Criterion Function for the specific alternative.

<table>
<thead>
<tr>
<th>CRITERION FUNCTION RESULTS</th>
<th>OPTION RANKING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATIVE 1</td>
<td>1</td>
</tr>
<tr>
<td>ALTERNATIVE 2</td>
<td>.190472</td>
</tr>
</tbody>
</table>

TABLE 5.3: Criterion Function Decision Matrix - Results

The Alternative with the lower Criterion Function value is judged the better alternative and the alternatives are ranked accordingly. Alternative 2 is the better alternative with respect to cost of new sand, capital costs of reclaimed sand, process energy costs of mold making and pouring, and cost of disposal.
5.4 OBSERVATIONS ON RESULTS

In the example considered above, two alternatives - the Green Sand Clay Water Bond and the Coldbox Method with Amine Cured Urethane Bond - were compared. Costs of New Sand, Capital Costs of Reclaimed Sand, Costs of Process Energy and Cost of Disposal were chosen as criteria for comparison between the two alternatives. From Intermediate results in Section 5.2.1 and 5.2.2, it is seen that Alternative 2 favours over Alternative 1 in terms of lesser Cost of new sand, Cost of reclaimed sand, cost of Process Energy and Cost of Disposal. After taking the Criterion Function Decision matrix and AHP calculations into consideration, it is seen in TABLE 5.3 that the Coldbox Method with Amine Cured Urethane Bond (Alternative 2) is better over the Green Sand Clay Water Bond (Alternative 1), and should be chosen as the better technology.

The following are the screens as obtained after running the software.

[Table and figure showing the decision matrix for direct economic costs]

FIG 5.1: Criterion Function Decision Matrix - Calculations
FIG 5.2: Criterion Function Decision Matrix - Results

Thus the Framework and its accompanying software would help us choose between alternatives based on a number of criteria, as desired by the user.
CHAPTER VI

DISCUSSION

The cost of new sand, cost of reclaimed sand, cost of energy for mold making, cost of energy for pouring and cost of disposal were the criteria chosen based on the availability of data. Alternative 2 scores over Alternative 1 in terms of lower cost of new sand, lower cost of reclaimed sand, lower cost of Process Energy and lower cost of disposal. After taking the Criterion Function Decision matrix and AHP calculations into consideration, it is seen that the Coldbox Method with Amine Cured Urethane Bond (Alternative 2) is better over the Green Sand Clay Water Bond (Alternative 1), and should be chosen as the better technology.

In 1991, the AFS Plant Engineering Committee made a Sand Reclamation Cost Savings Worksheet. Cost Savings were a function of the cost of new sand replaced by reclaimed sand, cost of waste hauling and landfiling spent sand and cost of hauling and landfiling reclamation waste product (Statler, 1991). Creese and Atluri (1995) investigated the effect of scrap rates upon profits and costs. The sand costs considered were core and molding sand costs. Core sand was assumed to have no reuse and was disposed off. Molding sand was recycled. The total cost of sand was modelled as the sum of new sand costs, recycled molding sand costs and landfill costs. The above literature review revealed that in all costing attempts so far, there was no concern about the effects of reclamation on the environment - the quantity of emissions, quality of emissions and the cost of cleaning them. Hence a cost structure needed to be developed, which looked at the Life Cycle Cost of a process before adopting it. But the results of LCA are difficult to analyse unless put in some concrete scale. Portney
(1994) advocated the use of Price Index in a market economy to summarize PLCA information to end users. Price could fluctuate easily with any change in the underline production technology. But for this, price needs to be a perfect reflection of the true cost to society of a product for it to be a successful index. With existing levels of knowledge, the price system does not yet fully reflect all the environmental consequences associated with processes and products. Hence, there is need for a normalised scale that looks at the life cycle cost of sand, its environmental costs and effects for decision making. The framework outlined in this thesis, attempts to provide a common normalised ground on which alternative technologies and options may be compared on the basis of not only simple, direct economic costs, but also environmental costs and environmental effects. The Criterion Function Decision Matrix (CFDM) and the Analytic Hierarchy Process (AHP) have been chosen for decision making on the basis of Literature Review. The efficiency of AHP in establishing subjective weightages has been well established by past practice (Refer Chapter 2). The CFDM was chosen due to its established robustness in literature. Also the data normally available in the industry could be easily formatted to suit this approach. However, it is necessary to examine the efficacy of other methods in the future.

Costs, in this Framework have been related to the sand casting process, but some of the equations can be directly applied to other processes, while others need modification.

The ultimate objective of any industry would be to minimise costs and maximise its profits. To many, sand disposal is still a better and cheaper option to sand reclamation. But the question is, for how long? Foundries generate a significant amount of waste sand from their operations. The increase in dumping and new sand replacement costs make the reuse rate of sand largely an economic exercise. The present new sand cost in North America is $23 - $30 per delivered ton (Personal Communication,
Mr. Michael W. Swartzlander, Director-Marketing, Consulting & Technical Services, Ashland Chemical Ltd. Japan has significantly higher new sand costs at $100 per delivered ton. Disposal costs, here, are $10 - $18 per delivered ton while dumping of sand in Japan would cost $50 - $100 per delivered ton. Though it can be said that costs in North America are relatively low, taking the example of Japan, the combined effects of stricter licensing controls, waste reclassification, and a levy could see the purchasing and disposal costs of foundry sand increasing sharply over the next ten to fifteen years. Also, diminishing land resource would encourage the use of alternative technologies to landfill. The only way to find the best alternative for a foundry would be to cost out the whole system rather than its individual parts. This is what LCA helps to do. The best alternative would be one that is the cheapest in the long run, though it may call for initial investments. The alternatives of Disposing of Sand Versus Reclamation in its totality should be considered for decision making. Industries in North America will have to adhere to ISO 14000 standards which is being to be implemented by 1999. This calls for mandatory environmental impact analysis for all processes in all manufacturing industries. The impact of such standards on the foundry industry will be quite significant. The framework designed here caters to this need with respect to sand.
CHAPTER VII

CONCLUDING REMARKS

In this thesis, a Framework for decision making in the foundry industry on the lines of Life Cycle Assessment has been presented. The framework attempts to provide a common normalised ground on which alternative technologies and options may be compared on the basis of economic costs and environmental effects. The framework estimates the total life cycle costs of sand in the foundry. The part of the Life Cycle of Sand inside the Foundry has been considered for analysis. Total life cycle costs are made up of two sub costs - economic costs and environmental costs. Individual cost components that make up these sub costs are calculated and added up. This cost structure along with Environmental Effects and the Material Useful Life is then used to compare processes in a Criterion Function Decision Matrix. Weights of the Criterion Variables are decided using the Analytical Hierarchy Process. The alternative with the minimum Criterion Function is judged to be the optimal choice.

LCA is being seen today as one of the best ways for industries to look at their environmental problems. Foundries, with their problems of pollution need to look at their products and processes in a new light.
Some of the work that needs to be done further in this direction are:

1) This Framework suggests parameters that need to be looked at while making any decision. Most of the suggested parameters have been touched upon, but other alternative methods of evaluating the parameters on a more efficient manner needs to be investigated.

2) The environmental effects of soil, water and air pollution needs to be modelled.

3) Open Loop Recycling should be considered as a viable alternative to reclamation. Alternative uses of waste sand should be explored with their economic and environmental costs.

4) The framework should be extended to include the entire life cycle of sand.

5) Casts which have more than one core will have to be considered.

6) Alternative equations need to be built to cater to the varied situations available in industry to make the framework more exhaustive.

7) Other Decision Making methods need to be investigated in future and their efficiency examined in relation to the ones used in this study.


36. Personal Communication, Mr. Michael W. Swartzlander, Director-Marketing, Consulting & Technical Services, Ashland Chemical Ltd, Foundry Products Division, Columbus, Ohio.

37. Personal Communication, Criterion Function Approach, Dr. A. W. Gynp, Dr. R. Stager, University of Windsor, Windsor, 1996.


APPENDIX - 1

FLOW CHART
1.3 COST TREE STRUCTURE

Selection

Environmental Effects
  - Land
  - Air
    - Water

Environmental Costs
  - Cost of Cleaning Water
    - Cost of Cleaning Land
      - Capital Costs
      - Maintenance Costs
      - Labour Costs
      - Chemical Costs
      - Energy Costs
      - Capital Costs
      - Maintenance Costs
      - Labour Costs
      - Chemical Costs
      - Energy Costs

  - Cost of Cleaning Air
    - Cost of New Sand
    - Cost of Reclaimed Sand

Costs
  - Economic Costs
    - Cost of Process Energy
    - Cost of Reclamation Energy
    - Cost of Disposal
    - Cost of Energy For Mold Sand Preparation
    - Cost of Energy For Mold Making
    - Cost of Energy For Casting Shakeout
    - Cost of Energy For Core Sand Preparation
    - Cost of Energy For Core Making
    - Cost of Energy For Pouring
## The Criterion Function Decision Matrix

### Table

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### Economic Costs

- Cost of New Sand
- Cost of Reclaimed Sand
- Cost of Process Efficiency
- Cost of Disposal

### Notes

- W = weight assigned to each criterion.
### C.F. MATRIX CONTD.....

<table>
<thead>
<tr>
<th>Cost of cleaning Water</th>
<th>Cost of cleaning Land</th>
<th>Cost of cleaning Air</th>
<th>Water Pollution</th>
<th>Land Pollution</th>
<th>Air Pollution</th>
<th>Material Useful Life</th>
<th>Criterion Function Results</th>
<th>Option Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wccw =</td>
<td>Wcl =</td>
<td>Wca =</td>
<td>Wwp =</td>
<td>Wlp =</td>
<td>Wep =</td>
<td>Wm =</td>
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APPENDIX - 2

SOURCE CODE
MENU FORM CONTROLLING FLOW OF PROGRAM

unit Mainform;
var
Menuform: TMenuform;
enerperKgsand,TCW,TMW : Real;
altsel,csland,cswater, selm, noofsel: Integer;
place : array[1..12] of real;

procedure TMenuform.FormShow(Sender: TObject);
begin
if alt>=Noofalt then
begin
noofsel:=0;
if Sel_TCNS=1 then
begin
place[1]:=1:noofsel:=noofsel+1;
end
else place[1]:=0;
if (Sel_CAPR=1) or (Sel_MR =1) or (Sel_LR=1) or (Sel_CCR=1) then
begin
place[2]:=1:noofsel:=noofsel+1;
end
else place[2]:=0;
if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) then
begin
place[3]:=1:noofsel:=noofsel+1;
end
else place[3]:=0;
if Sel_TCRE=1 then
begin
place[4]:=1:noofsel:=noofsel+1;
end
else place[4]:=0;
if Sel_CD=1 then
begin
place[5]:=1;
noofsel:=noofsel+1;
end
else place[5]:=0;
if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1)
or (Sel_WTR_CCR=1) then begin
place[6]:=1:noofsel:=noofsel+1;
end
else place[6]:=0;
if (Sel_LAND_ENER=1) or (Sel_LAND_CAPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1)
or (Sel_LAND_CCR=1) then
begin
place[7]:=1:noofsel:=noofsel+1;
end
else place[7]:=0;
if (Sel_AIR_ENER=1) or (Sel_AIR_CAPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1)

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or (Sel_AIR_CCR=1) then
  begin
  place[8]:=1; noofsel:=noofsel+1;
  end
else place[8]:=0;
if noofsel > 1 then AHP1.Enabled:=True;CriterionFunction1.Enabled:=True;
end;
if (Sel_TCNS=1) or (Sel_CAPR=1) or (Sel_MR=1) or (Sel_LR=1) or (Sel_CCR=1)
or (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) or (Sel_TCRE=1) or (Sel_CD=1) or (Sel_CCR=1)
  then
  begin
  Costs2.Enabled:=True; DirectCosts1.Enabled:=True;
  end;
if (Sel_TCRE = 1) or (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1)
or (Sel_CP=1) or (Sel_CCS=1) then
begin
GeneralData1.Enabled:=True;
end;
if Sel_TCNS = 1 then
begin
  CoreSandPreparation1.Enabled:=True; CoreMaking1.Enabled:=True; MoldSandPreparation1.Enabled:=True;
end;
if Sel_CCSP=1 then
begin
  Core1.Enabled:=True; CoreMaking1.Enabled:=True;
if (CCW<>0) and (CoreSR<>0) and (SR<>0) and (FSR<>0) then
begin
  CoreSandPreparation1.Enabled:=True; Energy1.Enabled:=True;
end;
end;
if Sel_CMSP=1 then
begin
if (SR<>0) and (FSR<>0) and (SMW<>0) then
begin
end;
end;
if Sel_CCM=1 then
begin
Core1.Enabled:=True; CoreMaking1.Enabled:=True; Energy1.Enabled:=True;
end;
if Sel_CMM=1 then
begin
end;
if Sel_CP=1 then
begin
Cast1.Enabled:=True; Pouring1.Enabled:=True; Energy1.Enabled:=True;
end;
if Sel_CCS=1 then

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begin
if (SR <> 0) and (FSR <> 0) then
begin
Cast1.Enabled := True; CastingShout1.Enabled := True; Energy1.Enabled := True;
end;
end;
if Sel_CAPR = 1 then
begin
GeneralData1.Enabled := True; Core1.Enabled := True; CoreSandPreparation1.Enabled := True; Mold1.Enabled := True;
MoldSandPreparation1.Enabled := True; CoreMaking1.Enabled := True; Reclamation1.Enabled := True;
ReclaimedSand1.Enabled := True;
end;
if Sel_MR = 1 then
begin
Reclamation1.Enabled := True; ReclaimedSand1.Enabled := True; GeneralData1.Enabled := True; Core1.Enabled := True;
CoreSandPreparation1.Enabled := True; Mold1.Enabled := True; MoldSandPreparation1.Enabled := True;
CoreMaking1.Enabled := True;
end;
if Sel_LR = 1 then
begin
GeneralData1.Enabled := True; Core1.Enabled := True; CoreSandPreparation1.Enabled := True; Mold1.Enabled := True;
MoldSandPreparation1.Enabled := True; CoreMaking1.Enabled := True; Reclamation1.Enabled := True;
ReclaimedSand1.Enabled := True;
end;
if Sel_CCR = 1 then
begin
GeneralData1.Enabled := True; Core1.Enabled := True; CoreSandPreparation1.Enabled := True; Mold1.Enabled := True;
MoldSandPreparation1.Enabled := True; CoreMaking1.Enabled := True; Reclamation1.Enabled := True;
ReclaimedSand1.Enabled := True;
end;
if Sel_TCRE = 1 then
begin
Reclamation1.Enabled := True; ReclamationEnergy1.Enabled := True;
end;
if Sel_CD = 1 then
begin
GeneralData1.Enabled := True; Disposal1.Enabled := True; Core1.Enabled := True;
CoreSandPreparation1.Enabled := True; Mold1.Enabled := True; MoldSandPreparation1.Enabled := True;
CoreMaking1.Enabled := True;
end;
if (Sel_AIR_ENER = 1) or (Sel_AIR_CAPR = 1) or (Sel_AIR_MR = 1) or (Sel_AIR_LR = 1) or (Sel_AIR_CCR = 1) then
begin
Air3.Enabled := True; Cleaning1.Enabled := True; GeneralData1.Enabled := True; Air1.Enabled := True;
EnvironmentalCosts1.Enabled := True; Costs2.Enabled := True;
end;
if (Sel_LAND_ENER = 1) or (Sel_LAND_CAPR = 1) or (Sel_LAND_MR = 1) or (Sel_LAND_LR = 1) or (Sel_LAND_CCR = 1) then
begin
EnvironmentalCosts1.Enabled := True; Costs2.Enabled := True; Core1.Enabled := True;
CoreSandPreparation1.Enabled := True; Mold1.Enabled := True; MoldSandPreparation1.Enabled := True;
end;
CoreMaking1.Enabled:=True;
end;
if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1) or (Sel_WTR_CCR=1) then
begin
EnvironmentalCosts1.Enabled:=True; Costs2.Enabled:=True;
end;
end;

procedure TMenuform.Alternative1Click(Sender: TObject);
begin
alt:=1;ECSP:=0;EMSP:=0;ECM:=0;EMM:=0;EP:=0;ECS:=0;Sel_TCNS := 0;Sel_CAPR := 0;Sel_MR := 0;
Sel_LR := 0;Sel_CCSP := 0;Sel_CMS := 0;Sel_CC := 0;Sel_CA := 0;Sel_CS := 0;
Sel_TCRE := 0;Sel_CD := 0;countairener:=0;countaircapr:=0;countairmr:=0;countairccr:=0;
countwtrener:=0;countwtrcapr:=0;countwtrmr:=0;countwtrccr:=0;countlandener:=0;
countlandenr:=0;countlandmr:=0;countlandccr:=0;countcap:=0;countmr:=0;
countcr:=0;countccr:=0;countcsp:=0;countcsm:=0;countmm:=0;countcp:=0;countcs:=0;
counttcr:=0;counttcr:=0;MessageDlg('Alternative 1 Selected', mtInformation,[mbOk], 0);
Alternative2.Enabled:=True; Alternative1.Enabled:=False;
end;

procedure TMenuform.Alternative2Click(Sender: TObject);
begin
if alt >= Noofalt then exit;
alt:=2;ECSP:=0;EMSP:=0;ECM:=0;EMM:=0;EP:=0;ECS:=0;
MessageDlg('Alternative 2 Selected', mtConfirmation,[mbOk], 0);
Alternative3.Enabled:=True; Alternative2.Enabled:=False;
end;

procedure TMenuform.Alternative3Click(Sender: TObject);
begin
if alt >= Noofalt then exit;
alt:=3;ECSP:=0;EMSP:=0;ECM:=0;EMM:=0;EP:=0;ECS:=0;
MessageDlg('Alternative 3 Selected', mtConfirmation,[mbOk], 0);
Alternative4.Enabled:=True; Alternative3.Enabled:=False;
end;

procedure TMenuform.Alternative4Click(Sender: TObject);
begin
if alt >= Noofalt then exit;
alt:=4;ECSP:=0;EMSP:=0;ECM:=0;EMM:=0;EP:=0;ECS:=0;
MessageDlg('Alternative 4 Selected', mtConfirmation,[mbOk], 0);
Alternative5.Enabled:=True; Alternative4.Enabled:=False;
end;

procedure TMenuform.Alternative5Click(Sender: TObject);
begin
if alt >= Noofalt then exit;
alt:=5;ECSP:=0;EMSP:=0;ECM:=0;EMM:=0;EP:=0;ECS:=0;
MessageDlg('Alternative 5 Selected', mtConfirmation,[mbOk], 0);
Alternative5.Enabled:=False;
end;
end.

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PERFORMS AHP CALCULATIONS
unit Ahppcm;

var
ahppcm, Tahnppcm;
norprwscmpmatx, prwscmpmatx: array[1..12,1..12] of real;
weightsunvec, coltotal, rowaver, weightmatrix : array[1..12] of real;

procedure Tahnppcm.FormShow(Sender: TObject);
var
i: Integer;
begin
MessageDlg('Please fill only one side of the diagonal.', mtInformation,[mbOk], 0);
PCMatrixt.DataFrame:=PCMatrixt DataFrame.Counter:=1;
PCMatrixt.DataFrame.Cells[0,0]:='Criterion Variables';
if Sel_TCNNS=1 then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if (Sel_CAPR=1) or (Sel_MR =1) or (Sel_LR=1) or (Sel_CCR=1) then
PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if Sel_TCRE=1 then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if Sel_CD=1 then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if (Sel_WTR_ENER=1) or (Sel_WTR_CPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1)
   or (Sel_WTR_CCR=1) then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if (Sel_LAND_ENER=1) or (Sel_LAND_CPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1)
   or (Sel_LAND_CCR=1) then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
if (Sel_AIR_ENER=1) or (Sel_AIR_CPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1)
   or (Sel_AIR_CCR=1) then PCMatrixt.DataFrame.Counter:=PCMatrixt.DataFrame.Counter+1;
i:=1;
if Sel_TCNNS=1 then
begin
PCMatrixt.DataFrame.Cells[0,i]:='Cost of New Sand':i:=i+1;
end;
if (Sel_CAPR=1) or (Sel_MR =1) or (Sel_LR=1) or (Sel_CCR=1) then
begin
PCMatrixt.DataFrame.Cells[0,i]:='Cost of Reclaimed Sand':i:=i+1;
end;
if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) then
begin
PCMatrixt.DataFrame.Cells[0,i]:='Cost of Process Energy':i:=i+1;
end;
if Sel_TCRE=1 then
begin
PCMatrixt.DataFrame.Cells[0,i]:='Cost of Reclamation Energy':i:=i+1;
end;
if Sel_CD=1 then
begin
PCMatrixt.DataFrame.Cells[0,i]:='Cost of Disposal':i:=i+1;
end;
end;
if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1) or (Sel_WTR_CCR=1) then begin
  PMatrix.Cells[0,i] := 'Cost of Cleaning Water'; i := i + 1;
end;

if (Sel_LAND_ENER=1) or (Sel_LAND_CAPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1) or (Sel_LAND_CCR=1) then begin
  PMatrix.Cells[0,i] := 'Cost of Cleaning Land'; i := i + 1;
end;

if (Sel_AIR_ENER=1) or (Sel_AIR_CAPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1) or (Sel_AIR_CCR=1) then begin
  PMatrix.Cells[0,i] := 'Cost of Cleaning Air'; i := i + 1;
end;

if selmul=1 then begin
  PMatrix.Cells[0,12] := 'Material Useful Life';
  i := 1;
end;

if Sel_TCNS=1 then begin
  PMatrix.Cells[i,0] := 'Cost of New Sand'; i := i + 1;
end;

if (Sel_CAPR=1) or (Sel_MR=1) or (Sel_LR=1) or (Sel_CCR=1) then begin
  PMatrix.Cells[i,0] := 'Cost of Reclaimed Sand'; i := i + 1;
end;

if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1) or (Sel_CP=1) or (Sel_CCS=1) then begin
  PMatrix.Cells[i,0] := 'Cost of Process Energy'; i := i + 1;
end;

if Sel_TCRE=1 then begin
  PMatrix.Cells[i,0] := 'Cost of Reclamation Energy'; i := i + 1;
end;

if Sel_CD=1 then begin
  PMatrix.Cells[i,0] := 'Cost of Disposal'; i := i + 1;
end;

if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1) or (Sel_WTR_CCR=1) then begin
  PMatrix.Cells[i,0] := 'Cost of Cleaning Water'; i := i + 1;
end;

if (Sel_LAND_ENER=1) or (Sel_LAND_CAPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1) or (Sel_LAND_CCR=1) then begin
  PMatrix.Cells[i,0] := 'Cost of Cleaning Land'; i := i + 1;
end;
if (Sel_AIR_ENER=1) or (Sel_AIR_CAPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1)
or (Sel_AIR_CCR=1) then
begin
  PCMMatrix.Cells[1,0] := 'Cost of Cleaning Air';  i := i + 1;
end;
if selmul=1 then
begin
  PCMMatrix.Cells[1,0] := 'Material Useful Life'; i := i + 1;
end;
end;

procedure Tahpcompn.0KClick(Sender: TObject);
var
  sum, CR, n, RI, CI, lambda : real;
i, j, Button: integer;
begin
  { n is no of criterion variables }
  if (PCMMatrix.RowCount-1=1) then RI:=0; if (PCMMatrix.RowCount-1=2) then RI:=0;
  if (PCMMatrix.RowCount-1=3) then RI:=0.58; if (PCMMatrix.RowCount-1=4) then RI:=0.90;
  if (PCMMatrix.RowCount-1=5) then RI:=1.12; if (PCMMatrix.RowCount-1=6) then RI:=1.24;
  if (PCMMatrix.RowCount-1=7) then RI:=1.32; if (PCMMatrix.RowCount-1=8) then RI:=1.41;
  if (PCMMatrix.RowCount-1=9) then RI:=1.45; if (PCMMatrix.RowCount-1=10) then RI:=1.49;
  if (PCMMatrix.RowCount-1=11) then RI:=1.51; if (PCMMatrix.RowCount-1=12) then RI:=1.48;
  if (PCMMatrix.RowCount-1=13) then RI:=1.56; if (PCMMatrix.RowCount-1=14) then RI:=1.57;
  if (PCMMatrix.RowCount-1=15) then RI:=1.59;
  n:=PCMMatrix.RowCount-1;
  {for i:=0 to PCMMatrix.RowCount do
  if (PCMMatrix.Cells[0,i]<>") then n:=n+1; }
  for j:=1 to PCMMatrix.ColCount-1 do
  for i:=1 to PCMMatrix.RowCount-1 do
  begin
    if (PCMMatrix.Cells[j,i]<>")
    then
      prwscmpmatx[j,i] := StrToFloat(PCMMatrix.Cells[j,i])
      {Pairwise Comparison Matrix}
      else prwscmpmatx[j,i] := 0;
    end;
  for j:=1 to PCMMatrix.ColCount-1 do
  for i:=1 to PCMMatrix.RowCount-1 do
  begin
    if (PCMMatrix.Cells[j,i]=") then
      prwscmpmatx[j,i] := 1/prwscmpmatx[j,i]  {Filling reciprocals}
    else
      prwscmpmatx[j,i] := 1/prwscmpmatx[j,i];
  end;
  for j:=1 to PCMMatrix.ColCount-1 do
  begin
    for i:=1 to PCMMatrix.RowCount-1 do
    begin
      coltotal[j] := coltotal[j] + prwscmpmatx[j,i];
    end;
  end;
end;
for j:= 1 to PCMMatrix.ColCount-1 do {Normalised Pairwise Comparison Matrix}
for i:=1 to PCMMatrix.RowCount-1 do norprwscmpmatx[i, j]:=prwscmpmatx[i, j]/coltotal[j];
for i:=1 to PCMMatrix.RowCount-1 do {Normalised Pairwise Comparison Matrix with row aver}
begin
for j:=1 to PCMMatrix.ColCount-1 do
rowaver[i]:=rowaver[i] + norprwscmpmatx[j, i];
rowaver[i]:=rowaver[i]/n;
end;
i:=1;
for j:=1 to 12 do
begin
if place[j]=1 then
begin
weightmatrix[j]:=rowaver[i];
i:=i+1;
end;
end;
end;
for j:=1 to PCMMatrix.ColCount-1 do {Weighted Sum Vector}
for i:=1 to PCMMatrix.RowCount-1 do
weightsumvec[i]:=weightsumvec[i] + rowaver[i]*prwscmpmatx[j, i];
for i:=1 to PCMMatrix.RowCount-1 do
rowaver[i]:=weightsumvec[i]/rowaver[i];
for i:=1 to PCMMatrix.RowCount-1 do
sum:=sum+rowaver[i]; {Eigen vector}
lambda := sum/n;
{CI:=(lambda - Noofalt)/(Noofalt-1); } {Consistency Index}
Cl:=(lambda - n)/(n-1); {Consistency Index}
if (RI > 0) then CR:=CI/RI {Consistency Ratio}
else
begin
Close;
Menuform.Show;
end;
If (CR<= 0.1) then
begin
if MessageDlg('Pairwise Comparisons have to be revisited! Revisit now?', mtInformation, [mbYes, mbNo], 0) = mrYes then
begin
for j:=1 to PCMMatrix.ColCount do
for i:=1 to PCMMatrix.RowCount do
begin
PCMMatrix.Cells[j, i]:="";
end;
PCMMatrix.Cells[0, 0]:='Criterion Variables'; i:=1;
if Sel_TCNS=1 then
begin
PCMMatrix.Cells[0, i]:='Cost of New Sand'; i:=i+1;
end;
if (Sel_CAPR=1) or (Sel_MR =1) or (Sel_LR=1) or (Sel_CCR=1) then
begin
PCMMatrix.Cells[0, i]:='Cost of Reclaimed Sand'; i:=i+1;
end;
end;
end;
end;
end;
end;
end;
end;
end.
end;
end.
end.
end.
end;
if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) then
begin
PCMatrix.Cells[0,i]:='Cost of Process Energy'; i:=i+1;
end;
if Sel_TCRE=1 then
begin
PCMatrix.Cells[0,i]:='Cost of Reclamiation Energy'; i:=i+1;
end;
if Sel_CD=1 then
begin
PCMatrix.Cells[0,i]:='Cost of Disposal'; i:=i+1;
end;
if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1)
or (Sel_WTR_CCR=1) then
begin
PCMatrix.Cells[0,i]:='Cost of Cleaning Water'; i:=i+1;
end;
if (Sel_LAND_ENER=1) or (Sel_LAND_CAPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1)
or (Sel_LAND_CCR=1) then
begin
PCMatrix.Cells[0,i]:='Cost of Cleaning Land'; i:=i+1;
end;
if (Sel_AIR_ENER=1) or (Sel_AIR_CAPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1)
or (Sel_AIR_CCR=1) then
begin
PCMatrix.Cells[0,i]:='Cost of Cleaning Air'; i:=i+1;
end;
if selmul=1 then
begin
PCMatrix.Cells[0,12]:='Material Useful Life';
end;
i:=1;
if Sel_TCNS=1 then
begin
PCMatrix.Cells[i,0]:='Cost of New Sand'; i:=i+1;
end;
if (Sel_CAPR=1) or (Sel_MR =1) or (Sel_LR=1) or (Sel_CCR=1) then
begin
PCMatrix.Cells[i,0]:='Cost of Reclaimed Sand'; i:=i+1;
end;
if (Sel_CCSP=1) or (Sel_CMSP=1) or (Sel_CCM=1) or (Sel_CMM=1) or (Sel_CP=1) or
(Sel_CCS=1) then
begin
PCMatrix.Cells[i,0]:='Cost of Process Energy'; i:=i+1;
end;
if Sel_TCRE=1 then
begin
PCMatrix.Cells[i,0]:='Cost of Reclamiation Energy'; i:=i+1;
end;

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if Sel_CD=1 then
  begin
    PCMMatrix.Cells[i,0]:='Cost of Disposal'; i:=i+1;
  end;
if (Sel_WTR_ENER=1) or (Sel_WTR_CAPR=1) or (Sel_WTR_MR=1) or (Sel_WTR_LR=1)
  or (Sel_WTR_CCR=1) then
  begin
    PCMMatrix.Cells[i,0]:='Cost of Cleaning Water'; i:=i+1;
  end;
if (Sel_LAND_ENER=1) or (Sel_LAND_CAPR=1) or (Sel_LAND_MR=1) or (Sel_LAND_LR=1)
  or (Sel_LAND_CCR=1) then
  begin
    PCMMatrix.Cells[i,0]:='Cost of Cleaning Land'; i:=i+1;
  end;
if (Sel_AIR_ENER=1) or (Sel_AIR_CAPR=1) or (Sel_AIR_MR=1) or (Sel_AIR_LR=1)
  or (Sel_AIR_CCR=1) then
  begin
    PCMMatrix.Cells[i,0]:='Cost of Cleaning Air'; i:=i+1;
  end;
if selmul=1 then
  begin
    PCMMatrix.Cells[i,0]:='Material Useful Life'; i:=i+1;
  end;
  PCMMatrix.Cells[5,5]:=1';PCMMatrix.Cells[6,6]:=1';PCMMatrix.Cells[7,7]:=1';PCMMatrix.Cells[8,8]:=1';
  end
{end of if with message}
else
  begin
    Close;Menuform.Show;
  end;
{end of if with CR}
else
  begin
    Close;Menuform.Show;
  end;
end;
end.

CALCULATES COST OF CLEANING AIR
unit Cair:

var
  Costair: TCostair;
  TCC_AIR:array[1..10] of real;

procedure TCostair.FormShow(Sender: TObject);
var
  AC,CC,TCCS,CAPC,MC,LC,TCCE,php :real;
begin
  if Sel_AIR_CAPR=1 then

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begin
AC:=PC*(intrate*exp(NC*(ln(1+intrate))))/(exp(NC*(ln(1+intrate)))-1);
CAPC:= AC*(TPC*365*1000); {Dollars/Ton}
end

if Sel_AIR_CCR=1 then
begin
CCC:=0;
ed
end

if Sel_AIR_MR=1 then
begin
MC:=MCC*(TPC*365*1000);{dollars/ton}
ed
end

if Sel_AIR_LR=1 then
begin
LC:=CMH*60*CLC/(TPC*1000);{dollars/ton}
ed
end

if Sel_AIR_ENER=1 then
begin
TCCE:=(Eairen*CKWH)/(36*100000);{dollars/ton}
ed
end

TCCE:=0;

CC:=CAPC+CCC+MC+LC+TCCE;{dollars/ton}
IndexUSERate:=binderpercent*(CW+MW);preamblearch:=firstnamearch;
while (preamblearch<>NIL) do
begin
preamblearch^.hap:=preamblearch^.emissfactor*IndexUSERate;phap:=phap+preamblearch^.hap;
preamblearch:=preamblearch^.next;
ed;

TCC_AIR[alt]:=CC*phap; {unit cost * total input emissions that have to be cleaned}
end.
End.

CALCULATES COST OF DISPOSAL
unit Cdisp;

var
  Costdisposal: TCostdisposal;
  CD : array [1..5] of real;

procedure TCostdisposal.FormShow(Sender: TObject);
var
ASD:real;
temp:string;
begin
if (CCW=0) or (coreSR=0) or (SR=0) or (FSR=0) or (SMW=0) or (SML=0)
  then MessageDlg('Something is 0 ', mtConfirmation, mbYesNoCancel, 0)
  else
    begin
      TCW := CCW * (1/(1-coreSR)) * (1/(1-SR)) * (1/(1-FSR)); {coreSR from Core Making}
      TMW := SMW * (1/(1-SML)) * (1/(1-SR)) * (1/(1-FSR)); {SML from Mold Sand Prep}
    end;
ASD:=(TMW+TCW)-(RSM_RATIO*TMW+RSC_RATIO*TCW); {In Tons}
Edit1.Text:=FloatToStr(ASD);CD[alt]:=ASD*CLF; {S/Cast}
Edit2.Text:=FloatToStr(CD[alt]);
end;
end.

CALCULATES COST OF NEW SAND
unit Cnisd;

var
  Costnewsand: TCostnewsand;
  TCNS:array[1..5] of real;

procedure TCostnewsand.FormShow(Sender: TObject);
var
  NWSAND:real;
begin
  TCW := CCW * (1/(1-coreSR)) * (1/(1-SR)) * (1/(1-FSR)); {coreSR from Core Making}
  TMW := SMW * (1/(1-SML)) * (1/(1-SR)) * (1/(1-FSR)); {SML from Mold Sand Prep}
  NWSAND:=TCW*(1-RSC_RATIO)+TMW*(1-RSM_RATIO);
  Edit1.Text:=FloatToStrF(NWSAND,ffFixed,8,10);
  TCNS[alt]:=CNS*(TCW*(1-RSC_RATIO)+TMW*(1-RSM_RATIO));
  Edit2.Text:=FloatToStrF(TCNS[alt],ffFixed,8,10); {in dollars/ton}
end;

CALCULATES COST OF RECLAIMED SAND
unit Crsd;

var
  Costreccsand: TCostreccsand;
  TCRS: array[1..5] of real;

procedure TCostreccsand.FormShow(Sender: TObject);
var
  temp:string;
  AR,CRS,CAPR,MR,LR:real;
begin
  if Sel_CAPR=1 then
begin
AR:=PR*(intrate*exp(NR*(ln(1+intrate))))/(exp(NR*(ln(1+intrate)))-1);
CAPR:= AR/(TPR*365); {Dollars/Ton}
end.

Calc1.Text:=FloatToStrF(CAPR,ffFixed,8,10);

end
else
CAPR:=0;
if Sel_CCR=1 then
begin
Calc2.Text:=FloatToStrF(CCR,ffFixed,8,10);
end
else
CCR:=0;
if Sel_MR=1 then
begin
MR:=MCR/(TPR*365*(1-FSLO6));Calc3.Text:=FloatToStrF(MR,ffFixed,8,10);
end
else
MR:=0;
if Sel_LR=1 then
begin
LR:=RMH*60*RLC/(TPR*(1-FSLO6));Calc4.Text:=FloatToStrF(LR,ffFixed,8,10);
end
else
LR:=0;
CRS:=CAPR+CCR+MR+LR;Calc5.Text:=FloatToStrF(CRS,ffFixed,8,10);
if (CCW=0) or (coreSR=0) or (SR=0) or (FSR=0) or (SMW=0) or (SML=0)
   then MessageDlg('Something is 0',mtConfirmation,mbYesNoCancel,0)
   else
begin
TCW := CCW * (1/(1-coreSR)) * (1/(1-SR)) * (1/(1-FSR)); {coreSR from Core Making}
TMW := SMW * (1/(1-SML)) * (1/(1-SR)) * (1/(1-FSR));{SML from Mold Sand Prep}
end;
TCR[alt]:=CRS*(TCW*RSC_RATIO + TMW*RSM_RATIO)/(1-FSLO6);
Calc7.Text:=FloatToStrF(TCR[alt],ffFixed,8,10);
end;
end.

CALCULATES COST OF PROCESS ENERGY

unit Procen;

var
Procenergy : TProcenergy;
TCE : array[1..5] of real;

procedure TProcenergy.FormShow(Sender: TObject);
var
TCSP,TMSP,TCM,TMM,TP,TCS:array[1..5] of real;
ttemp:real;
begin
if (Sel_CCSP=1) and (ECSP=0) then

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begin
if MessageDlg('Have you filled the Data for Core Sand Preparation?',
  mtInformation, [mbYes, mbNo], 0) = mrNo then begin
  MessageDlg('Please enter Core Sand Preparation Information', mtInformation,
    [mbOk], 0); Exit; Close; MenuForm.Show;
end;
end;
Edit1.Text:=FloatToStrF(ECSP, ffFixed, 8, 10);
if (Sel_CMSp=1) and (EMSP=0) then
if MessageDlg('Have you filled the Data for Mold Sand Preparation?',
  mtInformation, [mbYes, mbNo], 0) = mrNo then begin
  MessageDlg('Please enter Mold Sand Preparation Information', mtInformation,
    [mbOk], 0); Exit; Close; MenuForm.Show;
end;
end;
Edit2.Text:=FloatToStrF(EMSP, ffFixed, 8, 10);
if (Sel_CCp=1) and (ECM=0) then
if MessageDlg('Have you filled the Data for Core Making?',
  mtInformation, [mbYes, mbNo], 0) = mrNo then begin
  MessageDlg('Please enter Core Making Information', mtInformation,
    [mbOk], 0); Exit; Close; MenuForm.Show;
end;
end;
Edit3.Text:=FloatToStrF(ECM, ffFixed, 8, 10);
if (Sel_CP=1) and (EP=0) then
if MessageDlg('Have you filled the Data for Pouring?',
  mtInformation, [mbYes, mbNo], 0) = mrNo then begin
  MessageDlg('Please enter Pouring Information', mtInformation,
    [mbOk], 0); Exit; Close; MenuForm.Show;
end;
end;
Edit4.Text:=FloatToStrF(EP, ffFixed, 8, 10);
if (Sel_CCS=1) and (ECS=0) then
if MessageDlg('Have you filled the Data for Casting Shakeout?',
  mtInformation, [mbYes, mbNo], 0) = mrNo then begin
  MessageDlg('Please enter Casting Shakeout Information', mtInformation,
    [mbOk], 0); Exit; Close; MenuForm.Show;
end;
end;
Edit5.Text:=FloatToStrF(ECSP*CKWH/(36*10000));
Edit6.Text:=FloatToStrF(TCSP[alt]*ttemp);
Edit7.Text:=FloatToStrF(TCSP[alt]*ttemp);
Edit8.Text:=FloatToStrF(TCSP[alt]*ttemp);
COSTS OF RECLAMATION ENERGY

unit Recen;

var
  Recenergy: TRecenergy;
  TRec: array[1..10] of real;

procedure TRecenergy.FormShow(Sender: TObject);
begin
  Edit1.Text:=FloatToStrF(ERec,ffFixed,8,10); TRec[alt]:=CKWH*ERec/(36*100000);
  Edit2.Text:=FloatToStrF(TRec[alt],ffFixed,8,10);
end;

CALCULATES COST OF CLEANING WATER/LAND

unit Cwtrland;

var
  Costwtrland: TCostwtrland;
  TCC_LAND: array[1..10] of real;
  TCC_WTR: array[1..10] of real;

procedure TCostwtrland.FormShow(Sender: TObject);
begin
  ASD, AC, CC, TCCS, CAPC, MC, LC, TCCE : real;
  if cstrwater=1 then begin
    GroupBox1.Caption:='COSTING WATER RESULTS';
    Label2.Caption:='Cost per Water Treated per Day';
    Label3.Caption:='Cost of Cleaning Water per Cast (in Dollars / Cast)';
    if Sel_WTR_CAPR=1 then begin
      AC:=PCWTR*(inratewtr*exp(NCWTR*(ln(1+inratewtr)))/(exp(NCWTR*(ln(1+inratewtr)))-1));
      CAPC:= AC/(TCPWTR*365*1000); {Dollars/Ton}
      Edit1.Text:=FloatToStrF(CAPC,ffFixed,8,10);
    end
    else
      CAPC:=0;
    if Sel_WTR_CCR=1 then begin
      AC:=PCCWTR*(inratewtr*exp(NCWTR*(ln(1+inratewtr)))/(exp(NCWTR*(ln(1+inratewtr)))-1));
Edit2.Text:=FloatToStrF(CCCWTR,ffFixed,8,10);
end
else
CCCWTR:=0;
if Sel_WTR_MR=1 then
begin
MC:=MCCWTR/(TPCWTR*365*1000);Edit3.Text:=FloatToStrF(MC,ffFixed,8,10);
end
else
MC:=0;
if Sel_WTR_LR=1 then
begin
LC:=CMHWTR*60*CLCWTR/(TPCWTR*1000);Edit4.Text:=FloatToStrF(LC,ffFixed,8,10);
end
else
LC:=0;
if Sel_WTR_ENER=1 then
begin
TCCE:=(EWTR*CKWH)/(36*100000);Edit6.Text:=FloatToStrF(TCCE,ffFixed,8,10);
end
else
TCCE:=0;
CC:=CAPC+CCCWTR+MC+LC+TCCE;Edit5.Text:=FloatToStrF(CC,ffFixed,8,10);
TCC_WTR[alt]=CC*(TPCWTR*365)/casts_yr; {converting casts/yr to days/cast}
Edit7.Text:=FloatToStrF(TCC_WTR[alt],ffFixed,8,10);cstwater:=0;
end;

{LAND}
if cstland=1 then
begin
GroupBox1.Caption:=‘CLEANING LAND RESULTS’;
Label2.Caption:=‘Cost per Kg Soil Treated per Day’;
Label3.Caption:=‘Cost of Cleaning Soil per Cast (in Dollars / Cast)’;
if Sel_LAND_CAPR=1 then
begin
AC:=PCLND*(inratelnd*exp(NCLND*(ln(1+inratelnd))))/(exp(NCLND*(ln(1+inratelnd)))-1);
CAPC:=AC/(TPCLND*365*1000); {Dollars/Ton}
Edit1.Text:=FloatToStrF(CAPC,ffFixed,8,10);
end
else
CAPC:=0;
if Sel_LAND_CCR=1 then
begin
Edit2.Text:=FloatToStrF(CCCLND,ffFixed,8,10);
end
else
CCCLND:=0;
if Sel_LAND_MR=1 then
begin
MC:=MCCLND/(TPCLND*365*1000);Edit3.Text:=FloatToStrF(MC,ffFixed,8,10);
end
else
  MC:=0;
if Sel_LAND_LR=1 then
  begin
    LC:=CMHLND*60*CLCLND/(TPCLND*1000);Edit4.Text:=FloatToStrF(LC,ffFixed,8,10);
  end
else
  LC:=0;
if Sel_LAND_ENER=1 then
  begin
    TCCE:=(ELAND*CKWH)/(36*100000);Edit6.Text:=FloatToStrF(TCCE,ffFixed,8,10);
  end
else
  TCCE:=0;
CC:=CAPC+CCLNDA+MC+LC+TCCE;Edit5.Text:=FloatToStrF(CC,ffFixed,8,10);
if (CCW=0) or (coreSR=0) or(SR=0) or(FSR=0) or(SMW=0) or(SML=0)
  then MessageDlg('Something is 0',mtConfirmation,mbYesNoCancel,0)
else
  begin
    TCW := CCW * (1/(1-coreSR)) * (1/(1-SR)) * (1/(1-FSR)); \{coreSR from Core Making\}
    TMW := SMW * (1/(1-SML)) * (1/(1-SM)); \{SML from Mold Sand Prep\}
  end;
ASD:=(TMW+TCW)-(RSM_RATIO*TMW+RSC_RATIO*TCW); \{In Tons\}
TCC_LAND[alt]:=CC*ASD;Edit7.Text:=FloatToStrF(TCC_LAND[alt],ffFixed,8,10);estland:=0;
end;
end;

**CRITERION FUNCTION CALCULATIONS**

unit Cfdm;

var
critfuncdirect: Tcritfuncdirect;
sumdircost:array[1..5] of real;

procedure Tcritfuncdirect.FormShow(Sender: TObject);
var
str,temp1 :String;
cntalt,i,k,j,col1,col2 :Integer;
temp,maxm,row : real;
begin
  if noofsel=1 then
  begin
    weightmatrix[1]:=1;weightmatrix[2]:=1;weightmatrix[3]:=1;weightmatrix[4]:=1;weightmatrix[5]:=1;
    end;
  StringGrid1.RowCount:=Noofalt*2;
  if (Noofalt=2) then
    begin
      Alt2.Visible:=True;
    end;
  if (Noofalt=3) then
    begin

Alt2. Visible:=True; Alt3. Visible:=True;
end;
if (Noofalt=4) then
begin
end;
if (Noofalt=5) then
begin
end;
{fill first box}
str:='Weight = ' + FloatToStr(weightmatrix[1]);
Button3.Caption:= str; {Cost of New Sand}
str:='Weight = ' + FloatToStr(weightmatrix[2]);
Button4.Caption:= str; {Cost of Reclaimed Sand}
str:='Weight = ' + FloatToStr(weightmatrix[3]);
Button5.Caption:= str; {Cost of Process Energy}
str:='Weight = ' + FloatToStr(weightmatrix[4]);
Button6.Caption:= str; {Cost of Reclamation Energy}
str:='Weight = ' + FloatToStr(weightmatrix[5]);
Button14.Caption:= str; {Cost of Disposal}
for i:=0 to 10 do
for j:=0 to StringGrid1.RowCount do
StringGrid1.Cells[i,j]:=0;
for i:=1 to 5 do
begin {i hold the value of alt}
coll:=2*i-2; col2:=2*i-1;
j:=0; cntalt:=0;
while (j < StringGrid1.RowCount) do
begin
if cntalt < Noofalt then cntalt:=cntalt+1;
if (i=1) and (TCNS[cntalt]<=0) then
StringGrid1.Cells[coll,j]:=FloatToStr(TCNS[cntalt],ffFixed,8,10); {fill total cost new in all}
if (i=2) and (TCRS[cntalt] <= 0) then
StringGrid1.Cells[coll,j]:=FloatToStr(TCRS[cntalt],ffFixed,8,10); {fill total cost new in all}
if (i=3) and (TCE[cntalt] <= 0) then
StringGrid1.Cells[coll,j]:=FloatToStr(TCE[cntalt],ffFixed,8,10); {fill total cost new in all}
if (i=4) and (Trec[cntalt] <= 0) then
StringGrid1.Cells[coll,j]:=FloatToStr(Trec[cntalt],ffFixed,8,10); {fill total cost new in all}
if (i=5) and (CD[cntalt] <= 0) then
StringGrid1.Cells[coll,j]:=FloatToStr(CD[cntalt],ffFixed,8,10); {fill total cost new in all}
j:=j+2;
end;
maxm:=StrToFloat(StringGrid1.Cells[coll,0]); {to get absolute max value of crit var}
j:=0;
while (j < StringGrid1.RowCount) do
begin
temp:=StrToFloat(StringGrid1.Cells[coll,j]); {to find max abs value}
if temp < 0 then temp := temp * temp + temp;
if (maxm < temp) then maxm := temp;
j:=j+2;
end;
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j:=1;
while (j <= StringGrid1.RowCount) do  {fill in max values}
begin
StringGrid1.Cells[col1,j]:= FloatToStrF(maxm,ffFixed,8,10);j:=j+2;
end;
j:=0;
while (j < StringGrid1.RowCount) do  {fill in box 3}
begin
if StringGrid1.Cells[col1,j] <> '0' then
begin
StringGrid1.Cells[col2,j+1]:=FloatToStr(StrToFloat(StringGrid1.Cells[col1,j])/maxm);j:=j+2;
end
else
begin
StringGrid1.Cells[col2,j+1]:=‘0’;j:=j+2;
end;
end;  {fill in box 4}
j:=0;
k:=1;
while (j<StringGrid1.RowCount) and (k<=NoofAlt) do
begin
StringGrid1.Cells[col2,j]:=FloatToStr(StrToFloat(StringGrid1.Cells[col2,j+1]) *weightmatrix[i]);
sumdircost[k]:=sumdircost[k]+(StrToFloat(StringGrid1.Cells[col2,j]));j:=j+2;k:=k+1;
end;
end;
end;
Nandini Saha was born in Calcutta, India on the 18th of December, 1971. She graduated from High School in 1990. She received the Degree of M.Sc (Tech) from the Birla Institute of Technology and Science, Pilani, India. She has been studying towards a M. A. Sc. in Industrial and Manufacturing Systems Engineering at the University of Windsor since September, 1994.