International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

IMPLEMENTATION OF ANALYTIC HIERARCHY PROCESS (AHP) FOR ENVIRONMENTAL PERFORMANCE IN MANUFACTURING OF CASTLE NUT- A CASE STUDY

Prabhkiran Kaur
Mechanical Engineering Department, I.K. Gujral Punjab Technical University, Punjab, India.

ABSTRACT
In many industrial engineering applications environmental performance decision is based on the evaluation of several alternatives in terms of number of criteria. This problem may become a very difficult one when the criteria are expressed in different units or the pertinent data are difficult to be quantified. The Analytic Hierarchy Process (AHP) is an effective approach in dealing with this kind of decision problems. In this paper AHP method is used in environment performance evaluation for the processes involved in the production of bolt with castle nut. The most effective step is identified to be take care to improve environment.

KEYWORDS: Multi-Criteria Decision-Making, Analytic Hierarchy Process, Pairwise Comparisons, Castle nut.

1. INTRODUCTION
Over the time, sustainability has augmented as an important issue among the manufacturing sector and environmental activities. The accelerating environmental awareness of people, firms, and government has aided driving force for manufacturers to emphasis on the environmental performance of their processes. To take care of clean environment and for its improvement at first an investigation of processes of production should be on priority. The effect of manufacturing processes on environment should be assessed by fixing metrics for environmental performance. After considering these metrics and evaluating environmental performance for all the processes in a production plan, a decision must be analyzed for the overall environmental performance and categorize deeds to be implemented. This decision is based on huge sets of data related with different environmental metrics and processes in production of product, which some time becomes difficult to handle. For the easy of handling this multidimensional data, it is reduced via different data reduction methods.

Numerous methods have been exploited to assess the environmentally focused metrics of production processes, varying from experimental studies to development of mechanistic models [1-7]. Behm et al. [8] and Chan et al. [9] investigated experiments on foam casting and shielded metal arc welding and recognized process settings which reduced airborne particulate. Munoz et al. [10] studied a model for waste streams for machining processes. In this modeling individual models where prepared and investigated for different processes like tool wear, metal working fluid (MWF) loss, solid waste (chips), and energy consumption. Inspired by the environmental control through suitability of manufacturing sector, there are many generic strategies which involve assessing environmental performance of manufacturing operations. Shuangbing Huang et. al. [11] the model communicates the outcomes of the assessment with an integrated goal rating and three parameters. Tentatively, evaluation of an opencast limestone mine was applied. The results showed that the sequences of indices were compatible with the mine history and expert professional experience, and better revealed the impact of geo-hazards risk. For further development, different assessment criteria such as possible geo-hazards, geological state of infrastructure, and hydrogeological state were given priority. Praveen Goyal et. al. [12] the review shows market value, environmental management and policy, research and growth, pollution reduction, corporate governance and investor responsibility based on the hierarchical model built in this report, which have been found to be the most relevant practices for improving corporate sustainability efficiency. Sachin Kumar Mangla et. al. [13] this research

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

also conducts a sensitivity analysis to determine the priority stability of the barriers concentrated in the given SCP implementation. This work constitutes the most significant hurdle for implementing SCP programs effectively. S. A. A. Shah et. al. [14] fuzzy Analytical Hierarchical Process (FAHP) was used to measure barrier and sub-barrier weights and rankings. The results revealed that the political and regulatory barrier category ranks highest among the major categories, while the overall barrier ranking showed that the sub-barrier to political instability is more significant than the rest of the twenty sub-barrier categories. Guanjie He et. al. [15] this study combined the analytic hierarchy process, variable fuzzy set, and an index system to overcome the limitations of traditional evaluation methods and the problem in which the obtained evaluation level cannot be located accurately. An integrated variable fuzzy evaluation model was proposed to evaluate the social and environmental impact of dam breaks. The findings of the analysis showed that the proposed system features detailed algorithms and a mechanism of scientific evaluation.

The AHP strategies give methodical tactics for clarifying important environmental influences and improve chances for the manufacturing production and their processes. In the present study an attempt has been made to study the environmental impact assessment to identify the most effecting process in manufacturing of bolt with castle nut. The study emphasizes to make it more efficient, flexible and productivity oriented as far as possible using the principle of logistic and information technology.

Structure of AHP for decision making

AHP leads to one decision instead of giving many correct decisions, this makes easy for people to handle complex decisions. Thomas L. Saaty introduced AHP in the 1970s on the bases of human mindset and mathematics. Thus, for problem formulation AHP gives inclusive and balanced framework to represent and quantify its elements. These elements are related to overall goals and provide alternative solutions. In different sectors like government, corporate, manufacturing, medical and education this is applied throughout the world in respective decision-making circumstances. Some of the researcher's sets four level with hierarchical system. First level gives the overall goal or concentrates on decision, second level describes factors or parameters for the decision, third level divides system in to sub parts and fourth level provides the options for decision. The ranking or priority of process is done by assigning a number from an established scale which takes care of the reputation of the conditions. A matrix is generated in which pair-wise comparisons of these characteristics delivers the expressive calculation.

Implementation of AHP

First, the decision makers need to break down complex multiple criteria decision problems into its component parts of which every possible attribute are arranged into multiple hierarchical levels. After that, the decision makers must compare each cluster in the same level in a pairwise fashion based on their own experience and knowledge. For instance, every two criteria in the second level are compared at each time with respect to the goal, whereas every two attributes of the same criteria in the third level are compared at a time with respect to the corresponding criterion.

- Create hierarchies' tree.
- Pair-wise comparison.
- Weight matrix for pair-wise comparison, to value proportional.
- To value absolute.
- Calculation of weight (normalization and determination of priority)

Proposed steps of environmental impact assessment using AHP

i. Define the overall objective.
ii. Define the structured hierarchy consisting of attributes (criteria for the supplier selection for a given product) and alternatives.
iii. Determination of the priority weights of the attributes using pair-wise comparison matrix and its consistency ratio.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

iv. Determination of priority weights of alternatives with respect to attributes (various alternatives bids with respect to the individual criteria for selection) and consistency ratio for each pair-wise comparison matrix.

v. 'Enumeration of overall priority weights for all alternatives and consistency ratio for entire hierarchy'".

2. DECISION MATRIX

When the chain of command has been organized, the subsequent stage is to decide the needs of components at each dimension ('component' here means each individual from the progressive system). An arrangement of examination frameworks of all components in a dimension of the chain of importance as for a component of the quickly more elevated amount is built in order to organize and convert singular similar judgments into proportion scale estimations. The inclinations are evaluated by utilizing a nine-point scale. The significance of each scale estimation is clarified in Table 1.1. The combine insightful examinations are given regarding the amount more component A is essential than component B. As the AHP approach is an emotional procedure, data and the need weights of components might be acquired from a leader of the organization utilizing direct addressing or a survey strategy.

Table 1 The fundamental scale of absolute numbers. Source, Satty (2008)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment 'lightly favour one activity over another
5	Essential or strong important	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is favoured very strongly over another; it' dominance demonstrated in practice
9	Absolute importance	Tile evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	intermediate values between the two adjacent judgment	When compromise is needed
Reciprocal of above non-zero	If activity I has one of the above non-zero numbers assigned to it when compared with activity j. then has the reciprocal value when compared with J	A reasonable assumption"

Steps applied in synthesis process

Synthesis of priorities for all the criteria and measurement of consistency ratio (CR). Prioritizing of small scale, medium scale, and large-scale industries as against all the criteria of supplier selection separately. Synthesis of overall priority matrix of small scale, medium scale and large-scale industries.

The match shrewd examinations of the criteria of provider determination issue produce a network of relative rankings for each dimension of the chain of command. The quantity of frameworks relies upon the number of components at each dimension. The quantity of components at each dimension chooses the request of each grid. Of the following larger amount. All things considered, grids are created, eigenvectors or the relative weights (the

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

level of relative significance among the components) and the most extreme Eigen-esteem (λ max) for every lattice are computed. The λ max esteem is a critical approving parameter in AHP. It is utilized for ascertaining the consistency proportion CR of the assessed vector with the end goal to approve whether the combine astute correlation network gives a totally predictable assessment. The consistency proportion is ascertained according to the accompanying advances: -

Step 1 Ascertain the Eigenvector or the relative weights and λ max for every network of request m

Step 2 The consistency list for every framework of request n by the formulae:

$$CI = (\lambda\ max - m)/ (m-1)$$

Step 3 The consistency ratio is then calculated using the formulae: CR=CI/RCI.

- CI-Consistency index
- CR - Consistency ratio
- RCI = Random consistency index
- M=Number of elements

3. CASE STUDY

The objective of the study has been basically to current literature related to environmental impact assessment on manufacturing process and identifies the opportunities to introduce the information technology tools to make it productive by reducing its impact. A live case study is undertaken to study the environmental impact on manufacturing process using analytical hierarchy process (AHP) approach. The criteria's taken are RC-raw material consumption, SC-secondary material consumption, MWF-metal working fluid, EC-energy consumption, AW-airborne emission, LW-liquid waste, SW-solid waste. The detail of the product manufactured and whose study done is as

- Product manufactured - A bolt with castle nut
- Material Used-Plain Carbon Steel (C-45)
- Surface Treatment: Hardened, Zinc Plating (Yellow)
- The operation through which this castle nut and bolt are made is
- Cutting and rough drilling
- Facing
- Threading
- Face Milling
- Slot milling
- Fine-hole Process

For the conduct of AHP I/O diagram are used to identify critical inventory items. A process inventory is performed for each operation in the process plan. The environmental impacts of the inventories are quantified to evaluate the environmental performance of the process plan. Normalization of data to put the inventory measure on equal footing and making them dimensionless. Form impact matrix AHP is employed to establish weight for various criteria of interest. These weights are multiplied by the elements in the impact matrix to provide an environmental measure of performance of criterion and the entire process plan and finally improvement opportunities can be identified. The data has been collected from the manufacturing Industry as given in Table 2.

Table 2. Complete data collected from the manufacturing industry

Process/ criterion	RC (gm.)	SC (gm.)	MWF (litre)	EC (kwh)	AW (ppm)	LW (litre)	SW (gm.)
Cutting	179	0.514	0.05	0.6	4.16	0.02	71
Facing	149	0.19	0.04	0.96	3.26	0.01	32
Threading	140	0.119	0.03	0.96	1.7	0.01	7
Face Milling	120	0.167	0.02	0.12	0.76	0.01	20
Slot Milling	118	0.167	0.01	0.12	0.7	0.01	2
Fine Hole Process	106	0.643	0.06	0.6	1.2	0.03	12

4. RESULT AND DISCUSSION

Evaluation of Problem using AHP Method

After assigning weightage, we normalize the matrix by dividing it with their column sum. And then we check the consistency index of the matrix. If it is within the permissible limit, then it is ok. And if it is not within the permissible limit then again, we have to assign the weightage to the process and again check the consistency index and keep repeating the process till the consistency index is within the permissible limit.

1-**Preference on the basis of raw material consumption w.r.t process (Normalized)**

On normalizing weightage shown in Table 3a on the basics of raw material consumption the maximum eigen value is 6.35294 with CI of 0.070587 and CR 0.056469 which is less than 0.1. The values of normalizing are shown in Table 3b. So, the judgement is consistent with RCI=1.25 when m=6. Here it is seen that the consistency index is within the permissible limit for m=6 it is 0.0564 this show that the assigned weight is right.

Table 3a Weightage for raw material consumption

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole process
Cutting	1	3	5	7	7	9
Facing	1/3	1	3	5	5	7
Threading	1/5	1/3	1	3	3	5
Face milling	1/7	1/5	1/3	1	1	3
Slot milling	1/7	1/5	1/3	1	1	5
Fine hole process	1/9	1/7	1/5	1/3	1/5	1
	2	47/8	97/8	171/3	171/5	30

Table 3b Normalizing of weightage for raw material

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining	sum	Wi
Cutting	0.518	0.615	0.506	0.403	0.407	0.300	2.750	0.46
Facing	0.172	0.205	0.304	0.288	0.290	0.233	1.494	0.25
Threading	0.103	0.068	0.101	0.173	0.174	0.166	0.787	0.13
Face milling	0.074	0.041	0.033	0.057	0.058	0.100	0.364	0.06
Slot milling	0.074	0.041	0.033	0.057	0.058	0.166	0.431	0.07
Fine hole machining	0.057	0.029	0.020	0.019	0.011	0.033	0.171	0.03

2-Preferences on the basis of secondary consumption w.r.t machining process

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Table 4a and Table 4b Shows the weightage and its normalizing for secondary consumption w.r.t machining process. The maximum eigen value is 6.330888 with CI of 0.061776 and CR 0.0494208 which is less than 0.1. So, the judgement is consistent with RCI=1.25 when m=6. Here it is seen that the consistency index is within the permissible limit for m=6 it is 0.0494208 this show that the assigned weight is right.

Table 4a Weightage for secondary consumption

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining
Cutting	1	7	8	5	5	½
Facing	1/7	1	3	2	2	1/7
Threading	1/8	1/3	1	1/3	1/3	1/7
Face milling	1/5	½	3	1	1	1/7
Slot milling	1/5	½	3	1	1	1/7
Fine hole machining	2	7	7	7	7	1

Table 4b Normalizing of weightage for secondary

Process	Cutting	Facing	Threading	Face Milling	Slot Milling	Fine Hole Machining	Sum	W_i
Cutting	0.272	0.428	0.320	0.306	0.306	0.241	1.874	0.31
Facing	0.038	0.061	0.120	0.122	0.122	0.069	0.534	0.09
Threading	0.034	0.020	0.040	0.020	0.020	0.069	0.204	0.03
Face Milling	0.054	0.030	0.120	0.061	0.061	0.069	0.396	0.07
Slot Milling	0.054	0.030	0.120	0.061	0.061	0.069	0.396	0.07
Fine Hole Machining	0.545	0.428	0.280	0.428	0.428	0.482	0.593	0.43

3-Preferences on the basis of energy consumption w.r.t machining process

Table 5a and Table 5b Shows the weightage and its normalizing for energy consumption w.r.t machining process. The maximum eigen value is 6.28176 with CI of 0.056352 and CR 0.0450816 which is less than 0.1and shows that assigned weight for energy consumption are right.

Table 5a Weightage for energy consumption

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining
Cutting	1	1/5	1/5	3	3	1
Facing	5	1	1	5	5	2
Threading	5	1	1	5	5	3
Face milling	1/3	1/5	1/5	1	1	1/5
Slot milling	1/3	1/5	1/5	1	1	1/5
Fine hole machining	1	2	3	5	5	1

Table 5b Normalizing of weightage for energy

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining	Sum	Wi
Cutting	0.078	0.043	0.035	0.150	0.150	0.135	0.593	0.098
Facing	0.394	0.217	0.178	0.250	0.250	0.270	1.561	0.260
Threading	0.394	0.217	0.178	0.250	0.250	0.405	1.696	0.282
Face milling	0.026	0.043	0.035	0.050	0.050	0.027	0.232	0.038
Slot milling	0.026	0.043	0.035	0.050	0.050	0.02	0.232	0.038
Fine hole machining	0.078	0.434	0.535	0.250	0.250	0.1351	1.684	0.280

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

4-Preferences on the basis of air born emission w.r.t machining process

Table 6a Weightage for air born emission

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining
Cutting	1	3	5	7	8	6
Facing	1/3	1	4	7	7	5
Threading	1/5	¼	1	3	3	1
Face milling	1/7	1/7	1/3	1	1	1/3
Slot milling	1/8	1/7	1/3	1	1	1/3
Fine hole machining	1/6	1/5	1	3	3	1

Table 6b Normalizing of air born emission

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining	Sum	Wi
Cutting	0.508	0.633	0.428	0.318	0.347	0.439	2.675	0.445
Facing	0.169	0.211	0.342	0.318	0.304	0.365	1.711	0.285
Threading	0.101	0.052	0.085	0.136	0.130	0.073	0.580	0.096
Face milling	0.072	0.030	0.028	0.045	0.043	0.024	0.244	0.040
Slot milling	0.063	0.030	0.028	0.045	0.043	0.024	0.235	0.039
Fine hole machining	0.084	0.042	0.085	0.136	0.130	0.073	0.552	0.092

In case of air born emission, the weightage considered are shown in Table 6a and the correspondent normalizing values are shown in Table 6b. The maximum eigen value for air born emission is 6.2319 with CI of 0.04638 and CR 0.037104 which is well under the limit of 0.1. So, for the permissible limit m=6 the assigned weight is right.

5-Preferences on the basis of liquid waste emission w.r.t machining process

In Table 7a and Table 7b the weightage and normalization for liquid waste emission w.r.t machining process are shown. The maximum eigen value for liquid waste emission is 6.06625 with CI of 0.0132507 and CR 0.0106 which is less than 0.1. So, the judgement is consistent with RCI=1.25 when m=6 leading to the right choice of weight.

Table 7a Weightage for liquid waste emission

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining
Cutting	1	5	5	5	5	1/3
Facing	1/5	1	1	1	1	1/7
Threading	1/5	1	1	1	1	1/7
Face milling	1/5	1	1	1	1	1/7
Slot milling	1/5	1	1	1	1	1/7
Fine hole machining	3	7	7	7	7	1

Table 7b Normalizing of liquid waste emission

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining	Sum	Wi
Cutting	0.208	0.312	0.312	0.312	0.312	0.715	1.633	0.272
Facing	0.041	0.062	0.062	0.062	0.062	0.075	0.366	0.061
Threading	0.041	0.062	0.062	0.062	0.062	0.075	0.366	0.061
Face milling	0.041	0.062	0.062	0.062	0.062	0.075	0.366	0.061
Slot milling	0.041	0.062	0.062	0.062	0.062	0.075	0.366	0.061
Fine hole machining	0.625	0.437	0.437	0.437	0.437	0.525	2.900	0.483

6-Preferences on the basis of solid waste emission w.r.t machining process

Table 7a and Table 7b Shows the weightage and its normalizing for solid waste emission w.r.t machining process. The maximum eigen value is 6.38264 with CI of 0.076528 and CR 0.0612224 which is less than 0.1. So, the judgement is consistent with RCI=1.25 when m=6. Here it is seen that the consistency index is within the permissible limit and the assigned weight is right.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Table 7a Weightage for solid waste emission

Process	Cutting	Facing	Threading	Face milling	Slot milling	Fine hole machining
Cutting	1	3	9	7	9	8
Facing	1/3	1	5	4	5	3
Threading	1/9	1/5	1	¼	3	½
Face milling	1/7	¼	4	1	4	2
Slot milling	1/9	1/5	1/3	¼	1	1/3
Fine hole machining	1/8	1/3	2	½	3	1

Table 7b Normalizing of solid waste emission

Process	Cutting	Facing	Thread ing	Face milling	Slot milling	Fine hole machining	Sum	Wi
Cutting	0.548	0.602	0.421	0.538	0.360	0.539	3.010	0.501
Facing	0.182	0.200	0.234	0.307	0.200	0.202	1.327	0.221
Threading	0.060	0.040	0.046	0.019	0.120	0.033	0.320	0.053
Face milling	0.078	0.050	0.187	0.076	0.160	0.134	0.687	0.114
Slot milling	0.060	0.040	0.015	0.019	0.040	0.022	0.198	0.033
Fine hole machining	0.068	0.066	0.093	0.038	0.120	0.067	0.455	0.075

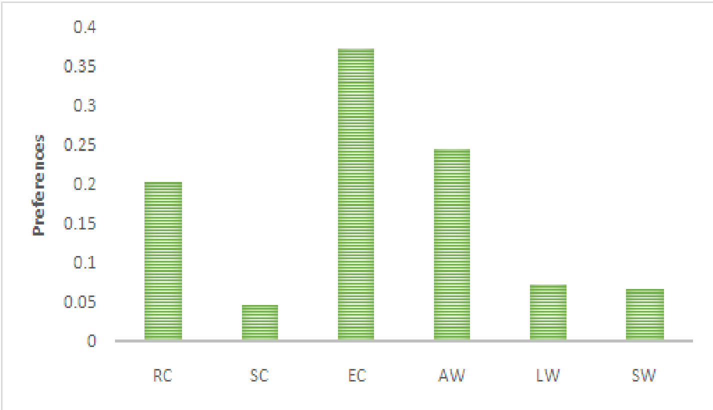

Figure 1 Preference of individual on the basis of criterion

Figure 1 shows the highest preference is for the energy consumption and the lowest preference is for the secondary material consumption. So, energy consumption affects environment more than any other criteria.

Table 8 Matrices multiplication of M1 & M2

M1							M2		SCORE
0.4585	0.3124	0.0988	0.4459	0.2722	0.5016		0.2012		0.30418
0.2490	0.0890	0.2601	0.2853	0.0611	0.2213		0.0461		0.23926
0.1312	0.0340	0.2826	0.0966	0.0611	0.0534		0.3722		0.16452
0.0607	0.0660	0.0387	0.0407	0.0611	0.1146		0.2433		0.05143
0.0718	0.0660	0.0387	0.0392	0.0611	0.0330		0.0717		0.04787
0.0285	0.4322	0.2807	0.0921	0.4833	0.0758		0.0653		0.19215

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Comparison of machining process by means of AHP

The score for all the six criterion is shown in Table 8 and same can be clearer from Figure 1. From the comparison of machining process and the method applied, it can be seen that out of 6 machining process the score for RC (0.30418) is highest for cutting as compare to all other operation. This indicate that from an environmental perspective, attention should be devoted to improving cutting operation. likewise, the score for LW was the smallest across all criterial

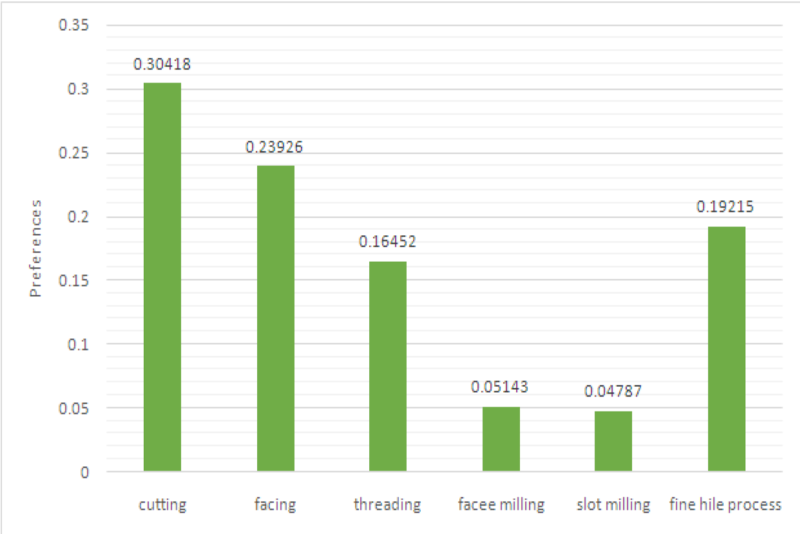

Figure 2 Comparison of process on environmental impact

5. CONCLUSIONS

An efficient approach using AHP has been used for environmental impact for manufacturing process of Castle nut and bolts. The results show that the model has the capability that the model could facilitate decision making. The approach could help in reducing time consuming efforts in assessing the environmental impact for the manufacturing process.

- The score for Cutting is highest, this indicate that from an environmental perspective, attention should be devoted to improving this operation and the lowest score is for slot milling of all the operation
- The score for secondary material consumption is minimum and the impact is largely due to one criterion this suggests that attention should be focused.
- These observations and the analysis are discussed with the valve plant engineers, and a considerable number of suggestions are to focus on reducing the liquid waste emission and followed by solid waste emission.

REFERENCES

[1] Triantaphyllou, E. and Mann, S.H. (1995) Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges. International Journal of Industrial Engineering: Applications and Practice, 2, 35-44.
[2] Goh, Chon-Huat. (1997). Analytic Hierarchy Process for Robot Selection. Journal of Manufacturing Systems - J MANUF SYST. 16. 381-386. 10.1016/S02
[3] Kaplan, Robert & A. Atkinson, Anthony. (1983). Advanced Management Accounting. The Journal of the Operational Research Society. 34. 10.2307/2581114.
[4] Yahya S, B Kingsman B. Journal of the Operational Research Society, 1999, 50, 9.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[5] Das S, Islam R & Chattopadhyay, A.B. (1997). A simple approach for on-line tool wear monitoring using the analytic hierarchy process. Proceedings of The Institution of Mechanical Engineers Part B-journal of Engineering Manufacture - PROC INST MECH ENG B-J ENG MA. 211. 19-27.

[6] Saaty, T.L. (2008) 'Decision making with the analytic hierarchy process', Int. J. Services Sciences, Vol. 1, No. 1, pp.83–98.

[7] Kumar, Sanjay & Neeraj, Parashar & Haleem, Abid. (2009). Analytical Hierarchy Process Applied to Vendor Selection Problem: Small Scale, Medium Scale and Large Scale Industries. Business Intelligence Journal. 2.

[8] Behm S.U., Gunter K. L., Sutherland J.W (2003), An Investigation into the effect of process parameter settings on air emission characteristics in the lost foam casting process, AFS Transactions, 2003, Paper #03-031.

[9] Chan W, Gunter KL, Sutherland JW (2002), An experimental study of the fume particulate produced by the shielded metal arc welding process. Transactions of NAMRI/SME 30:581-588.

[10] Munoz, A. A., & Sheng, P. (1995). An analytical approach for determining the environmental impact of machining processes. Journal of Materials Processing Technology, 53(3), 736-758.

[11] Shuangbing Huang, Xiao Li and Yanxin Wang (2012), "A new model of geo-environmental impact assessment of mining: a multiple-criteria assessment method integrating Fuzzy-AHP with fuzzy synthetic ranking Environmental Earth Sciences", 66, 275–284.

[12] Praveen Goyal, (2015) Identification and prioritization of corporate sustainability practices using analytical hierarchy process, Journal of Modelling in Management ISSN: 1746-5664.

[13] Sachin Kumar Mangla, (2017) Prioritizing the barriers to achieve sustainable consumption and production trends in supply chains using fuzzy Analytical Hierarchy Process, Journal of Cleaner Production, 151, 509-525.

[14] S. A. A. Sha, (2019) Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process, Journal of Cleaner Production Volume 235, Pages 1037-1050.

[15] Guanjie He, Junrui Chai, (2020), Coupled Model of Variable Fuzzy Sets and the Analytic Hierarchy Process and its Application to the Social and Environmental Impact Evaluation of Dam Breaks Water Resources Management, 34, 2677–2697.