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Evaluation and selection of material handling equipment in iron and steel industry using analytic hierarchy process

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1. Abstract: The paper presents the analytic hierarchy process (AHP) as a   potential decision making method for use in the selection of the most suitable material handling (MH) system in an iron and steel industry. In this study, AHP is used in assessing the various material transportation systems employed in a steel manufacturing industry and to decide the best equipment to be used.Information on the use of AHP in evaluating MH equipment is provided and an AHP model is proposed to guide the management of an iron and steel Industry, i.e., JSW Steel Ltd. Most important factors while selecting material transportation equipment and their relative influence on the objective of decision-making model are found. A total of seven decision criteria and five different alternatives are considered for this purpose. Each alternative is evaluated in terms of the decision criteria and the relative importance (or weight) of each criterion is estimated. From the obtained pairwise comparison matrices, the best
 alternative is chosen.This paper provides a good insight into a decision-making model to guide managers for assessing the various material transportation equipment that are commonly employed in a steel manufacturing plant.

2. Introduction

The Analytic Hierarchy Process(AHP) is a multi-criteria decision approach[1].The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain.Instead of endorsing a "right" choice, the AHP helps decision makers find one that best suits their goal and their understanding of the issue. It provides a comprehensive and rational framework for structuring a decision problem, for representing, measuring and quantifying its elements, for relating those elements to overall objectives, and for assessing alternative solutions.

It uses a multi-level hierarchical structure of objectives, criteria, sub criteria and alternatives.The appropriate data is derived by using a set of pairwise correlations.These comparisons are used to obtain the weights of significance of the choice criteria and the relative performance measures of the alternatives in terms of each individual decision

criteria.If the comparisons are not perfectly consistent,then it provides a mechanism for improving consistency.

Typical applications where AHP has been used are in:
- Prioritizing factors and requirements that impact software development and productivity,
- Choosing among several strategies for improving safety features in motor vehicles,
- Estimating cost and scheduling options for material requirements planning(MRP),
- Evaluating the quality of research or investment proposals.

Some of the industrial engineering applications of the AHP include its use in integrated manufacturing[2], in the evaluation of technology investment decisions[3], in flexible manufacturing systems[4], layout design[5], and also in other engineering problems[6]. A number of criticisms have been launched at AHP over the years.It is said that in order to elicit the weights of the criteria by means of a ratio scale, the method asks decision-makers meaningless questions[7].It is pointed out that this method can suffer from rank reversal[8,9].

The objective of this paper is to introduce the application of AHP in the evaluation and selection of Material Handling Equipment in an Iron and Steel industry.The various factors used for evaluation are installation cost,maintenance and operation cost,speed of movement,capacity,operator requirement, installation space required and ease of operation.Using these criteria,pairwise comparison matrices are developed to select the best material handling equipment from the available alternatives.Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion.These comparisons are quantified by using a scale.Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance,or weight,of the previous choices.The scale proposed by Saaty is depicted in Table 1.

Table 1.Scale of Relative Importance (according to Saaty(1980))

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 Slightly favor one activity Over another
5	Essential or strong importance	Experience and judgment Strongly favor one activity Over another.
7	Demonstrated importance	An activity is strongly Favored and its dominance Demonstrated in practice
9	Absolute importance	The evidence favoring one Activity over another is of Highest possible importance
2,4,6,8	Intermediate values between two adjacent judgments.	When compromise is needed.

Material handling equipment selection is an important function in the design of a material handling system, and thus, a crucial step for facilities planning[10]. Using proper material handling equipment can enhance the production process, provide effective utilization of manpower, increase production, and improve system flexibility. The importance of material handling equipment selection cannot be overlooked. However, with the wide range of material handling equipment available today, determination of the best equipment alternative for a given production scenario is not an easy task.This problem can be solved by using the AHP technique

3. Methodology

Five alternative material handling systems,i.e,conveyor,industrial truck, automated guided vehicle(AGV),rail and crane need to be evaluated in terms of the six decision criteria:installation cost,operation and maintenance cost,speed of movement, volume capacity, operator requirement, space occupied and ease of operation.This can be done by following the standard procedure of AHP as described below:

1.Developing the pair-wise comparison matrix for each criteria.
2.Synthesizing the pair-wise comparison matrix.
3.Obtaining the random consistency index (RCI) from table
4.Calculating the priority vector for each criterion.
5.Calculating λ_{max} using the consistency index value CI
6.Calculating the consistency ratio CR
7.Checking the consistency of the pair-wise comparison matrix to check whether the decision-maker's comparisons are consistent or not.

By following the AHP procedure described above,the hierarchy of the problem can be developed as shown in Fig 1.

Fig 1.Hierarchy of the MH Equipment problem
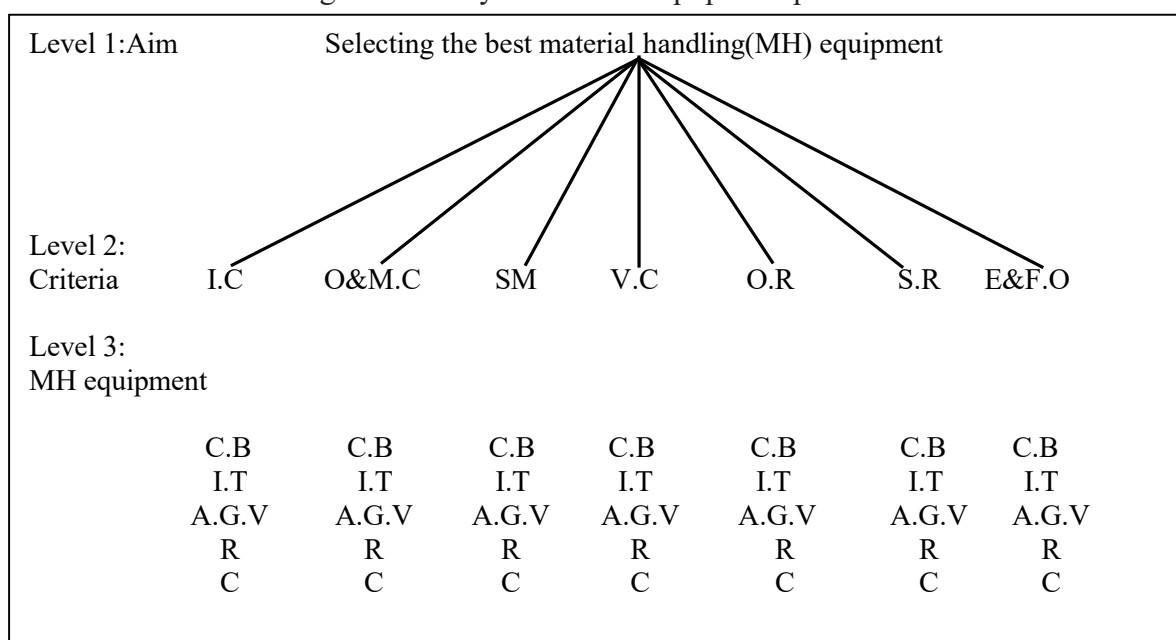
I.C=Installation Cost   O&M.C=Operation and Maintenance Cost
S.M=Speed of Movement   V.C=Volume Capacity
O.R=Operator Requirement   S.R=Space Requirement
E.O=Ease and Flexibility of Operation

R=Rail
C.B=Conveyor Belt   I.T=Industrial Truck
A.G.V=Automated Guided Vehicle   C=Crane

Table 2. RCI values for different values of n:

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Firstly,considering the installation cost of each material handling equipment,the pairwise comparison matrix is developed as shown below in Table 3:

Table 3. Pair-wise comparison matrix for installation cost:

I.C	CB	IT	AGV	R	CR
CB	1.0000	0.3333	5.0000	0.5000	3.0000
IT	3.0000	1.0000	7.0000	2.0000	6.0000
AGV	0.2000	0.1429	1.0000	0.2000	0.3333
R	2.0000	0.5000	5.0000	1.0000	4.0000
CR	0.3300	0.1667	3.0000	0.2500	1.0000

Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its column total. The priority vector in Table 4 can be obtained by finding the row averages.For example,the priority of conveyor with respect to the criterion 'installation cost' can be obtained by dividing the sum of the rows (0.1531+0.1555+0.2380+0.1265+0.2093) by the number of equipment (columns),i.e, 5,in order to obtain the value 0.1765.

The priority vector for installation cost, indicated in Table 4, is given below.

$$\begin{pmatrix} 0.1765 \\ 0.4369 \\ 0.0438 \\ 0.2620 \\ 0.0808 \end{pmatrix}$$

Table 4. Synthesized matrix for installation cost

I.C	C	IT	AGV	R	OC		Priority Vector
C	0.1531	0.1556	0.2381	0.1266	0.2093		0.1765
IT	0.4594	0.4667	0.3333	0.5063	0.4186		0.4369
AGV	0.0306	0.0667	0.0476	0.0506	0.0233		0.0438
R	0.3063	0.2333	0.2381	0.2532	0.2791		0.2620
OC	0.0505	0.0778	0.1429	0.0633	0.0698		0.0808

Now, estimating the consistency ratio is as follows:

$$0.1765 \begin{bmatrix} 1 \\ 3 \\ 0.2 \\ 2 \\ 0.33 \end{bmatrix} + 0.4369 \begin{bmatrix} 0.33 \\ 1 \\ 0.14 \\ 0.5 \\ 0.16 \end{bmatrix} + 0.0438 \begin{bmatrix} 5 \\ 7 \\ 1 \\ 5 \\ 3 \end{bmatrix} + 0.2620 \begin{bmatrix} 0.5 \\ 2 \\ 0.2 \\ 1 \\ 0.25 \end{bmatrix} + 0.0808 \begin{bmatrix} 3 \\ 6 \\ 0.33 \\ 4 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.9144 \\ 2.2818 \\ 0.2208 \\ 1.3756 \\ 0.4086 \end{bmatrix}$$

Dividing all the elements of the weighted sum matrices by their respective priority vector element, we obtain:

$$\frac{0.9144}{0.1765} = 5.1802, \quad \frac{2.2818}{0.4369} = 5.2231,$$

$$\frac{0.2208}{0.0438} = 5.0461, \quad \frac{1.3756}{0.2620} = 5.2509$$

$$\frac{0.4086}{0.0808} = 5.0551$$

To obtain λ_{max}, we compute the average of these values, i.e:

$$\lambda_{max} =$$

$$\frac{5.1802 + 5.2231 + 5.0461 + 5.2509 + 5.0551}{5}$$

$$= 5.1511.$$

Now, we compute the consistency index, CI, as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.1511 - 5}{5 - 1} = 0.0337$$

Selecting the suitable value of random consistency ratio, RI, for a matrix size of 5 using Table 2 , we obtain RI = 1.12. We then compute the consistency ratio, CR, as follows:

$$CR = \frac{CI}{RI} = \frac{0.0337}{1.12} = 0.0245.$$

As the value of CR is less than 0.1, the judgments are acceptable. The same procedure can be followed for all the decision alternatives. In addition to this, we also use the same pair-wise comparison procedure to set priorities for all the seven criteria in terms of significance of each in contributing to the overall objective. Table 11 shows the pair-wise comparison matrix and priority vector for the seven criteria.

For the criteria of Maintenance and Operation cost, priority vector is in Table 5,

Table 5.Pair-wise comparison matrix for operation cost

0. C	C	IT	AGV	R	OC	Prioriy Vector
C	1.0000	6.0000	3.0000	7.0000	2.0000	0.4397
IT	0.1667	1.0000	0.3333	1.0000	0.2500	0.0626
AGV	0.3333	3.0000	1.0000	3.0000	0.3333	0.1501
R	0.1429	1.0000	0.3333	1.0000	0.2000	0.0577
OC	0.5000	4.0000	3.0000	5.0000	1.0000	0.2899

λ_{max}=5.0811,CI= 0.0203, CR = 0.0181 < 0.1(Accept)

Table 6.Pair-wise comparison matrix for speed of movement

S.M	C	IT	AGV	R	OC	Priority Vector
C	1.0000	0.3333	7.0000	3.0000	5.0000	0.2642
IT	3.0000	1.0000	9.0000	5.0000	7.0000	0.5077
AGV	0.1429	0.1111	1.0000	0.2500	0.5000	0.0385
R	0.3333	0.2000	4.0000	1.0000	3.0000	0.1287
OC	0.2000	0.1429	2.0000	0.3333	1.0000	0.0610

λ_{max} =5.1629,CI =0.0407,CR = 0.0364 < 0.1(Accept)

Considering the capacity in Table 7, i.e ,the volume of material different equipment can hold,

Table 7. Pair-wise comparison matrix for capacity

Ca	C	IT	AGV	R	OC	Priority Vector
C	1.0000	0.5000	5.0000	0.2500	2.0000	0.1468
IT	2.0000	1.0000	6.0000	0.3333	4.0000	0.2429
AGV	0.2000	0.1667	1.0000	0.1250	0.2500	0.0375
R	4.0000	3.0000	8.0000	1.0000	5.0000	0.4790
OC	0.5000	0.2500	4.0000	0.2000	1.0000	0.0938

λ_{max}=5.2045,CI =0.0511, CR = 0.0457 < 0.1(Accept)

Table 8. Pair-wise comparison matrix for operator requirement

O.R	C	IT	AGV	R	OC	Priority Vector
C	1.0000	4.0000	0.3333	7.0000	3.0000	0.2754
IT	0.2500	1.0000	0.2000	2.0000	0.3333	0.0739
AGV	3.0000	5.0000	1.0000	7.0000	4.0000	0.4672
R	0.1429	0.5000	0.1429	1.0000	0.3333	0.0460
OC	0.3333	3.0000	0.2500	3.0000	1.0000	0.1376

λ_{max}=5.2063,CI = 0.0516, CR = 0.0461 <0.1(Accept)

Taking into account the space required for different equipment, as shown in Table 9,

Table 9. Pair-wise comparison matrix for space occupied

S.R	C	IT	AGV	R	OC	Priority Vector
C	1.0000	0.3333	0.2000	4.0000	2.0000	0.1324
IT	3.0000	1.0000	0.3333	5.0000	3.0000	0.2430
AGV	5.0000	3.0000	1.0000	7.0000	5.0000	0.4931
R	0.2500	0.2000	0.1429	1.0000	0.5000	0.0478
OC	0.5000	0.3333	0.2000	2.0000	1.0000	0.0837

λ_{max} =5.1758, CI =0.0439, CR =0.0392 < 0.1(Accept)

Considering the criteria of ease and flexibility of operation,as shown in Table 10,

Table 10. Pair-wise comparison matrix for ease of operation

E.O	C	IT	AGV	R	OC	Priority Vector
C	1.0000	0.2500	0.2000	0.5000	2.0000	0.0856
IT	4.0000	1.0000	0.5000	3.0000	5.0000	0.2967
AGV	5.0000	2.0000	1.0000	4.0000	5.0000	0.4343
R	2.0000	0.3333	0.2500	1.0000	2.0000	0.1218
OC	0.5000	0.2000	0.2000	0.5000	1.0000	0.0616

λ_{max} =5.1095, CI =0.0273, CR =0.0244 < 0.1(Accept)

Priority vector for comparison matrix of decision criterion is shown in Table 11,

Table 11. Pair-wise comparison matrix of various criterion:

	IC	O&M.C	S.M	V.C	O.R	S.R	E.O	Priority Vector
IC	1.0000	3.0000	5.0000	2.0000	9.0000	6.0000	7.0000	0.3584
O&M.C	0.3333	1.0000	3.0000	0.5000	5.0000	3.0000	4.0000	0.1571
S.M	0.2000	0.3333	1.0000	0.3333	5.0000	3.0000	4.0000	0.1082
V.C	0.5000	2.0000	3.0000	1.0000	7.0000	5.0000	6.0000	0.2388
O.R	0.1111	0.2000	0.2000	0.1429	1.0000	0.3333	0.5000	0.0272
S.R	0.1667	0.3333	0.3333	0.2000	3.0000	1.0000	3.0000	0.0646
E.O	0.1429	0.2500	0.2500	0.1667	2.0000	0.3333	1.0000	0.0387

λ_{max} = 7.3623, CI = 0.0603, CR = 0.0457 < 0.1(Accept)

The overall priority for various alternatives is computed as shown in Table 12.

Table 12. Priority matrix for MH EQUIPMENT selection:

	I.C (0.3584)	O&M.C (0.1571)	S.M (0.1082)	V.C (0.2388)	O.R (0.0272)	S.R (0.064)	E.O (0.0387)	Overall priority vector
C	0.1765	0.4397	0.2642	0.1468	0.2754	0.1324	0.0856	0.2814
IT	0.4369	0.0626	0.5077	0.2429	0.0739	0.2430	0.2967	0.2981
AGV	0.0438	0.1501	0.0385	0.0375	0.4672	0.4931	0.4343	0.1383
R	0.2620	0.0577	0.1287	0.4790	0.0460	0.0478	0.1218	0.2400
OC	0.0808	0.2899	0.0610	0.0938	0.1376	0.0837	0.0616	0.1146

The overall priority for various alternatives is computed as shown in Table 12.

For ex,the overall priority of conveyor is given as = 0.3584(0.1765) + 0.1571(0.4397) + 0.1082(0.2642) + 0.2388(0.1468) + 0.0272(0.2754) + 0.064(0.1324) + 0.0387(0.0856) = 0.2814.

4. Conclusion:
The selection of Material Handling equipment involves complex decision making problems that require discerning abilities and methods to generate sound decisions. This paper has presented the AHP as a decision-making tool that allows the consideration of multiple criteria. The actual process of conducting this analysis has helped us prioritize the criteria in a manner that otherwise might not have been possible. Bounded rationality and limited cognitive processes make it impossible for the decision maker to consider all the factors involved in a complex decision making activity. Without decision support methodologies such as AHP, managers might base their decisions on only a subset of important criteria while not understanding their relative importance and interactions. As several criteria are involved in this problems, AHP is considered superior to other decision making approaches. Material transportation equipment selection is an important factor in the design of MH systems, and thus turns out to be a crucial facet in facilities planning.

When applying the AHP method in the field of MH equipment associated with an Iron and Steel Industry i.e, JSW Steel Ltd. , the most suitable alternative was found to be an Industrial Truck. According to the selected criteria, it was also found that a Conveyor System is the next best alternative and an Overhead Crane was evaluated to the the least suitable option.

Even though we have examined an Iron and Steel Industry, this approach can be applied to any manufacturing firm where a best alternative has to chosen against multiple criteria.

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