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MATERIAL HANDLING SYSTEM DESIGN FOR INCINERATION OF WASTE MATERIALS IN CEMENT KILN

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Abstract

Present research work focuses on the selection of material handling system for cement industry, using two multi criteria decision making (MCDM) approaches, Analytical Hierarchy Process (AHP) and **T**echnique for Order Performance by Similarity to Ideal Solution (TOPSIS). For this purpose, a systematically designed questionnaire are sent to a group of experts, and on the basis of their responses, selection of different forms of wastes and their handling systems was made.

Keywords: Material handling equipment, Multi criteria decision making (MCDM), Cement, Analytical Hierarchy Process (AHP), **T**echnique for Order Performance by Similarity to Ideal Solution (TOPSIS).

1. Introduction

Soufi et al. (2021) reported that mastering the material handling system in manufacturing is a crucial issue. According to Mafokwane et al. (2019), material handling is one of the most essential aspects within manufacturing processes and or industries. Transportation equipment used in manufacturing industries varies from pallet jack to forklift trucks and or cranes. Material handling equipment are mechanical equipment used for the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal**.** According to Kamble and Patil (2019), a material handling system should be chosen in such away so that to reduce manufacturing cost and avoid interruption and damage. On the other side right selection and planning of material handling improves productivity, efficiency and profit of a company.

Goswami and Behera (2021) reported that material handling equipment selection is a rapidly increasing multi-criteria decision-making issue with a plethora of factors affecting the selection process. The proper selection of material handling equipment is a crucial issue for industrial organization's efficiency and productivity in the global market. The selection of the most suitable material handling equipment for a specific engineering application is a costly as well as time-consuming process in which many candidate alternatives available on the market are considered as preliminary choices.

Considering all these aspects, the present research work is focused on the selection of material handling equipment for a cement industry. The main objective of present research work is to find out the best form of wastes as well as their material handling systems. For this purpose, a

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well known approach multi criteria decision making has been employed, and two famous multi criteria decision making techniques AHP and TOPSIS are used.

1.1 Objectives of Research

Following points represent objectives of proposed research work:

a) **Selection of forms for different types of wastes;**

For all types of wastes, selection of most appropriate form is necessary.

b) **Selection of most suitable design of material handling systems for different types of wastes**

Selection of material handling system is necessary for different types of wastes.

2. Literature Review

Present section is devoted to scenario of research, and contributions of research in the field of material handling, the details of which are presented in upcoming sub-sections.

2.1 Scenario of Research in the Field of Material Handling

Figure 2.1 shows the radar graph showing the research publications in last five years, in the field of material handling equipment selection.

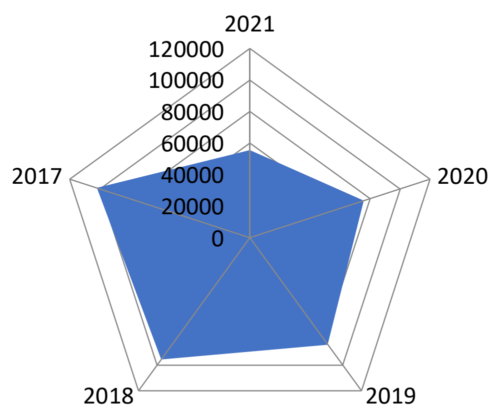

Figure 2.1: Radar Graph of research publications on the topic Material Handling Equipment Selection (www.scholar.google.com)

Figure 2.2 shows the radar graph showing the research publications in last five years, in the field of material handling system design.

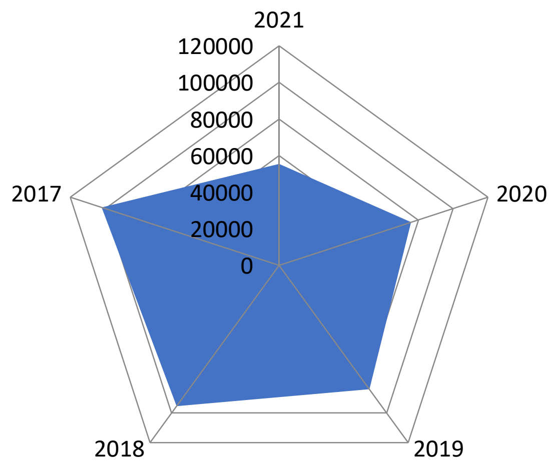

Figure 2.2: Radar Graph of research publications on the topic Material Handling System Design (www.scholar.google.com)

From above two figures, one can realize the importance of material handling in present scenario and going on research activities on material handling all around the world.

2.2 Contributions of Researchers in the Field of Material Handling and Material Handling System Design

Following are the summaries of contributions of researchers in the field of material handling and material handling system design.

- **Amjath et al. (2022)**

This study considers determining the optimal size of a homogeneous fleet of trucks to be outsourced (or subcontracted) from a third-party logistics provider to be used daily to cyclically transport different types of raw materials from designated storage yards to intermediate buffer locations to be fed as inputs to a production facility for processing.

- **Schumacher et al. (2022)**

This paper investigates the impact of material handling flexibility, equipment flexibility, and operation flexibility on the economic design of material handling systems.

- **Ngo et al. (2022)**

In this paper, non-vibration control strategies, such as the linear motion profile (LMP), symmetric motion curve (SMC), and asymmetric motion curve (ASMC), based on the phases of motion profiles, are investigated for a lifting type of carrier.

- **Madhankumar et al. (2021)**

The main idea of this proposed work is to reduce manual human effort for transporting processed cotton between different process stages. The main objective of the project is to design and model an autonomous mobile robot for material handling in the textile industry.

- **Mafokwane and Kallon (2021)**

This research document covers the selection of materials and components to be used in the manufacture and assembly of the new system.

- **Almosnino & Cappelletto (2021)**

The researchers presented a practical method for minimizing low-back cumulative loading that leverages digital human modeling capabilities and optimization using an evolutionary algorithm.

- **Gaur & Ronge (2020)**

Determining the criteria of Material Handling equipment selection is a primary and important step in the material handling equipment selection.

- **Farayibi et al.(2020)**

In this paper, the development of an automated mechanical lift for material handling purposes in a manufacturing environment was carried out and reported.

- **Sharotry et al. (2020)**

This research presents a digital twin concept and prototype to represent human operators in the material handling industry.

- **Hellmann et al. (2019)**

Motivated by a real-world material handling system selection problem, this paper proposes a framework that allows for quantifying safety and incorporating it in multi-criteria decision-making processes that involve both quantitative and qualitative measures.

- **Kadam et al. (2018)**

Material handling equipment is the media of transportation of material from one location to another in a commercial space.

- **Garudkar et al. (2018)**

This paper includes the design of belt conveyor system where the moving roller of the conveyor is powered by a pneumatic cylinder. Pneumatic cylinder will starts reciprocating and by using rack and pinion mechanism the reciprocating motion converts into the rotary motion.

- **Termiz and Calis (2017)**

According to researchers selecting proper construction equipment is a challenging task in the construction industry due to the broad array of available equipment in the market and a large number of criteria required to be taken into account during decision making.

2.3 Gaps in the Research

Following points represent gaps in the research work:

a) There is very limited research which focuses on reduction of fossil fuel consumption;
b) There is very limited research which focuses on material handling of industrial waste of cement industry; and
c) There is also very limited research available which focuses on waste reduction in cement industry.

3. Solution Methodology

Present section focuses on the different research techniques used in the research work, the details of which are presented in upcoming sub-sections. Figure 3.1 represents the solution methodology adopted to solve the research problem.

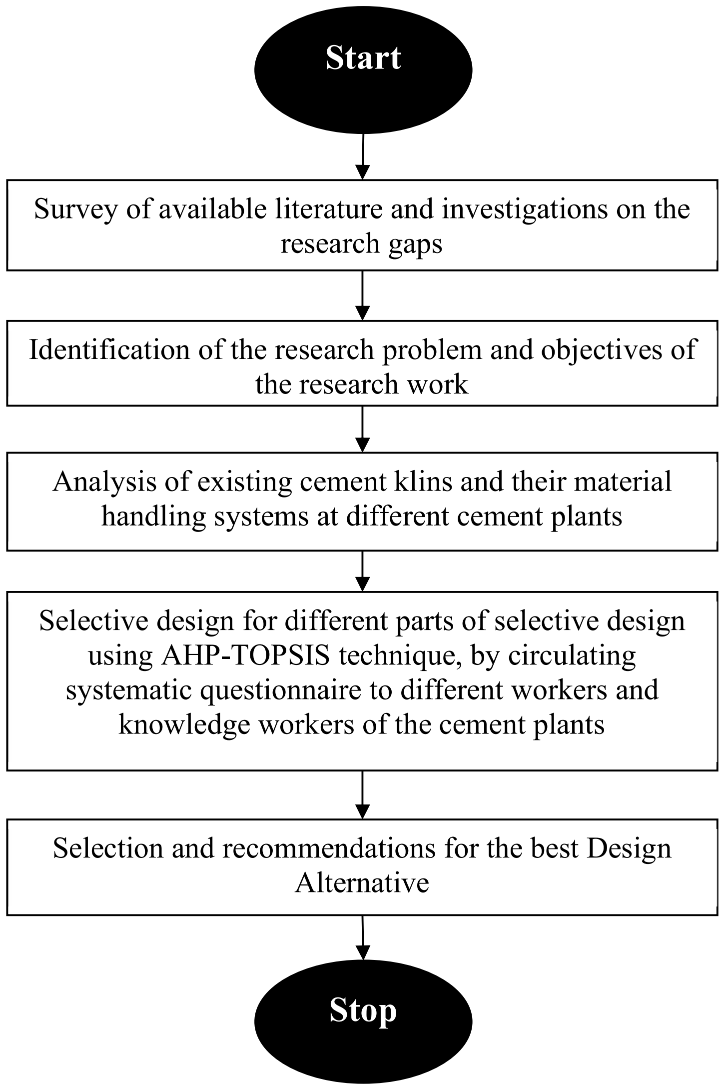

Figure 3.1: Flow Chart for Solution Methodology

3.1 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a systematic method for assisting researchers in making complex judgments. Instead of prescribing a correct option, the AHP assists in making one. It was created in the 1970s by Thomas L. Saaty and has since been extensively explored and enhanced. It is based on mathematics and human psychology. The AHP provides a complete and rational framework for constructing a problem, expressing and measuring its aspects, linking them to broader goals, and assessing alternate solutions. It is widely used in a variety of decision-making scenarios around the world, including administration, business, industry, healthcare, and education (Saaty, 1980).

3.1.1 General Procedure of AHP

The methodology of AHP can be explained in following steps (Saaty, 1980):

Step 1:

The issue is broken down into a hierarchy of goals, criteria, sub-criteria (if any), and alternatives (Holder, 1991).

Figure 3.2 shows an example of a hierarchical structure.

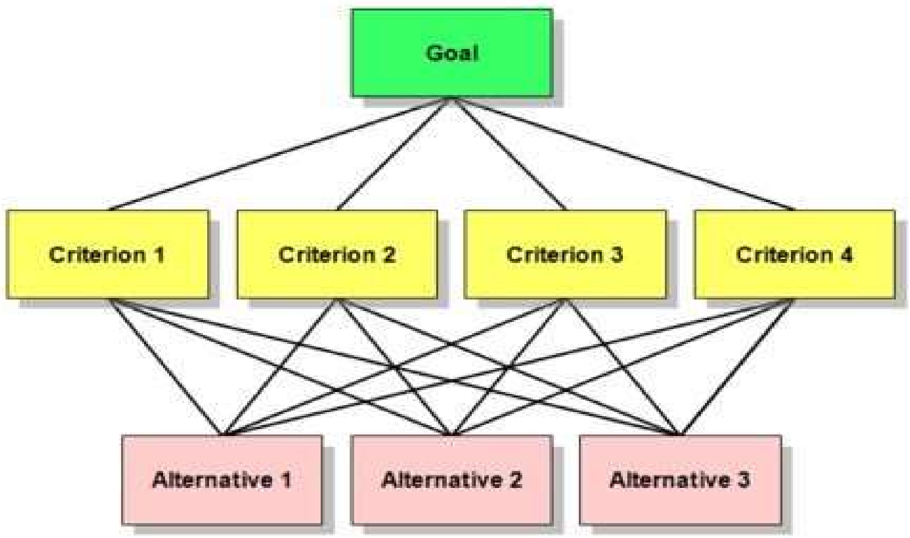

Figure 3.2: A hierarchy for Analytical Hierarchy Process (Saaty, 1980)

Step 2: Data is collected from experts or decision-makers who correspond to the hierarchical structure in order to compare alternatives pair-wise on a qualitative scale. Data is collected from experts or decision-makers who correspond to the hierarchical structure in order to compare alternatives pair-wise on a qualitative scale, as shown in Table 3.1below.

Table 3.1: Pair wise Comparison Scale (Holder, 1991)

S. No	Intensity of Importance	Definition	Explanation
1.	**1**	**Equal importance**	Two elements contribute equally to the objective
2.	**3**	**Moderate importance**	Experience and judgment slightly favor one

			element over another
3.	**5**	**Strong importance**	Experience and judgment strongly favor one element over another
4.	**7**	**Very strong importance**	One element is favored very strongly over another; its dominance is demonstrated in practice
5.	**9**	**Extreme importance**	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6 and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc., can be used for elements that are very close in importance.			

Step 3: The preceding step's pairwise comparisons of various criteria are grouped into a squared matrix. The diagonal elements of the matrix are assigned a value of one. If the value of element (I, j) is greater than 1, the criterion in the ith row is considered better than the criterion in the jth column; otherwise, the criterion in the jth column is considered better. The (j, i) element of the matrix becomes the (I, j) element's reciprocal.

Step 4: The comparison matrix's primary eigenvalue and related normalized eigenvector reveal the relative importance of the various criteria being compared. Weights of alternatives can also be computed using the same method.

Step 5: The consistency index can be used to assess the consistency of outcomes (CI). If the consistency index falls below a certain threshold, the results of comparisons may be re-evaluated. The following equation can be used to compute the consistency index.

$$CI = (\lambda\text{max} - n)/ (n - 1) \quad (3.1)$$

where, λ_{max} is the maximum eigen-value of the judgment matrix. This CI can be compared with random consistency index (RI). The ratio derived, CI/RI, is termed the *consistency ratio*, CR. Value of CR should be less than 0.1. With the help of Table 4.4 value of RI may be identified.

Table 3.2: Values of Random Consistency Index (RI)

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency Index (R.I.)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Step 6: AHP can assist in making a judgment on the best alternative design. Local weights of alternatives are multiplied by the weights of the criterion and summed to produce global ratings for this purpose.

3.2 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Among numerous MCDM methods developed to solve real-world decision problems, Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) continues to work satisfactorily in diverse application areas. Hwang and Yoon (1981) originally proposed TOPSIS to help in selecting the best alternative with a finite number of criteria. As a well-known classical MCDM method, TOPSIS has received much interest from researchers and practitioners. TOPSIS is a widely accepted multi criteria decision making technique due to its sound logic, simultaneously consideration of the ideal and the anti-ideal solutions, and easily programmable computation procedure. This technique is based on the concept that the ideal alternative has the best level for all attributes, whereas the negative ideal alternative is the one with all of the worst attribute values. The basic principle of TOPSIS lies within the fact that chosen alternative should have the shortest distance from the ideal solution and the longest distance from the negative ideal solution. This method considers three types of attributes or criteria:

a) Benefit attributes/criteria (qualitative in nature);
b) Benefit attributes (quantitative in nature); and
c) Cost attributes or criteria.

In TOPSIS, two artificial alternatives are hypothesized:

1. Ideal alternative: the one which has the best level for all attributes considered; and
2. Negative ideal alternative: the one which has the worst attribute values.

3.2.1 General procedure of TOPSIS

Following is the stepwise procedure for implementing TOPSIS (Yoon & Hwang, 1995):

Step 1: Construct Normalized Decision Matrix.

This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria. Normalize scores or data as follows:

$$r_{ij} = \frac{f_{ij}}{\sum_{j=1}^{J} f_{ij}^2} \quad (3.2)$$

where j = 1,2,3,……….. J, i = 1, 2, 3 …n

Step 2: Construct the weighted normalized decision matrix.
Assume we have a set of weights for each criteria w_j for j = 1…n.
Multiply each element (column-wise) of the normalized decision matrix by its weight.
The weighted normalized value can be calculated as:

$$V_{ij} = \left(w_{ij} \times r_{ij} \right) \quad (3.3)$$

Where w_i is the weight of the i_{th} attribute or criterion, and it is calculated by AHP method.

$$w_i = 1 \quad (3.4)$$

Step 3: Determination of ideal as well as negative- ideal solutions
Ideal solution:

$$A^* = \left(v_1^*, v_2^*, \ldots\ldots\ldots\ldots\ldots v_i^* \right) = \left((max\, v_{iji} \;\; / i \in I') \times (min\, v_{ij} \,/\, j \in I'')_j \right) \quad (3.5)$$

Negative- Ideal Solution:

$$A^- = \left(v_1^-, v_2^-, \ldots\ldots\ldots\ldots\ldots v_i^- \right) = \left((min\, v_{iji} \;\; / i \in I') . (max\, v_{ij} \,/\, j \in I'')_j \right) \quad (3.6)$$

Step 4: Investigate the separation measures, with the help of n dimensional Distance.

The separation of each option from the ideal solution is given as:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (\mathrm{vij} - \mathrm{vi}*)^2} \quad (3.7)$$

where j = 1, 2, 3……….j

Similarly, the separation of each alternative from negative ideal solution is given as:

$$D_j^- = \sqrt{\sum_{i=1}^{n} (\mathrm{vij} - \mathrm{vi}-)^2}; \quad (3.8)$$

where j = 1, 2, 3..j

Step 5: Find the relative closeness to the ideal solution
The relative closeness of the alternative a_j can be investigated as follows:

$$CC^*_j = \frac{Dj-}{Dj* + Dj-} \quad (3.9)$$

Step 6: Preference order ranking.

4. Problem Formulation and Solution

Present section focuses on the details of problem formulation and solution, the details of which are presented in upcoming sub-sections.

4.1 Problem Formulation

From the survey of available literature, and research gaps, the following problem was formulated:

Material Handling System Design for Incineration of Waste Materials in Cement Kiln

As there are different types of waste materials used in cement kiln in almost all forms of the matter (solid, liquid and gas), and in different forms (wet, dry, powder, pallets, etc), the research problem was solved using multi criteria decision making (MCDM) approach, which lead to selective design of different segments of material handling systems. In present research work, the focus was made on the selection of proper form of different types of wastes and their handling equipment/systems.

4.2 Solution of the Problem

Following procedure was adopted as the solution of above mentioned problem.

a) First of all different types of solid wastes were investigated using literature review and experts opinion, as shown below.

Table 4.1: Different types of solid wastes used in Cement Kilns along with their Forms

S. No	Name of Solid Waste	Forms in which they are used
1.	Old Tires	• Dropping to midway a slot along wet kiln • Rolling to upper end of preheater • Chopping and injecting to precalciner combustion chamber
2.	Green Waste	• Wet • Dried • Cube • Powder
3.	Sewage Sludge	• Wet • Dried • Powder
4.	Refuse-Derived Fuel	• Wet • Pallet • Powder
5.	Chemical and other hazardous waste	• Mixture burning • Burning of Separated constituents, individually • Mixture burning with cartelizes
6.	Plastic Residues	• Mixture burning • Burning of Separated constituents, individually • Burning in the form of small balls

b) In the next step of the research work, criteria for different types wastes were investigated, with the help of experts opinion, as follows:

Table 4.2: Criteria of Evaluation for Different types of Wastes

S. No	Type of Waste	Criteria
1.	Old Tires	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment
2.	Green Waste	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment
3.	Sewage Sludge	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment
4.	Refuse-Derived Fuel	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment
5.	Chemical and other hazardous waste	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment
6.	Plastic Residues	• Quality of Combustion • Safety to Workers • Cost involved • Loss to the environment

c) In the next step, best alternatives were selected using two MCDM approaches, namely, AHP and TOPSIS. For this purpose, weights of criteria were investigated using AHP, and scores of the alternatives were investigated using TOPSIS. As all criteria of all the wastes were same, their priorities were calculated only once. For this purpose, a systematically designed questionnaire, based on pairwise comparison scale, was sent to the group of experts, the their responses were presented in the tabular form, as shown in pairwise comparison matrix, presented in Table 4.3.

Table 4.3: Pairwise Comparison Matrix

From/To	Quality of Combustion	Safety to Workers	Cost Involved	Loss to the Environment
Quality of Combustion	1	1/3	2	1/4
Safety to Workers	3	1	2	1
Cost Involved	1/2	1/2	1	1/4
Loss to the Environment	4	1	4	1

d) In the next step, priorities of criteria were calculated as shown in Table 4.4. The values of priorities of criteria calculated from a SAAS entitled http://www.isc.senshu-u.ac.jp/.

Table 4.4: Priorities of Criteria

S. No	Criteria	Priority
1.	Quality of Combustion	0.138
2.	Safety to Workers	0.334
3.	Cost Involved	0.110
4.	Loss to the Environment	0.40
CR = CI/RI = 0.047/**0.90= 0.0522 < 1**		

Figure 4.1 shows the contributions of criteria to the goal.

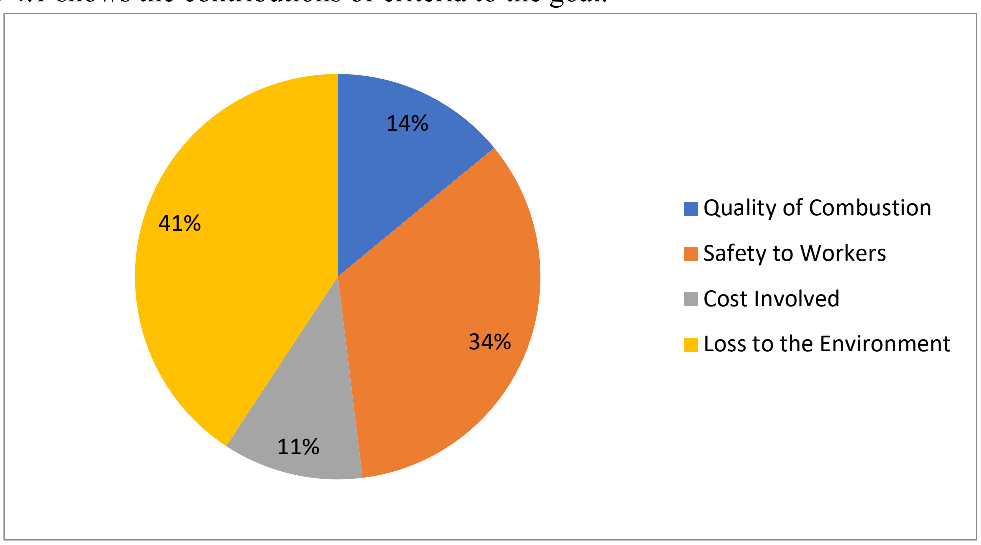

Figure 4.1: Contributions of Criteria towards the Goal for All Wastes

In next step, scores of different materials were investigated using TOPSIS approach. For this purpose priorities of criteria were the priorities obtained from AHP. Figure 4.2 shows the AHP-TOPSIS model used to get the scores of alternatives.

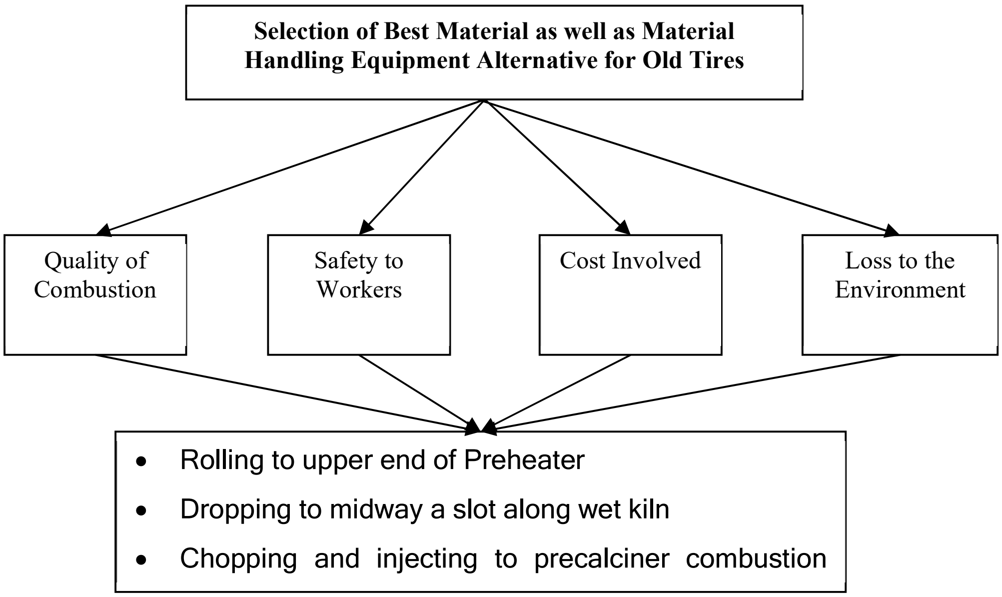

Figure 4.2: AHP-TOPSIS Model for Ranking of Alternatives for Old Tires

Following are the details of procedure used to find the scores of materials (as well as handling systems) for waste tires. Table 4.5 shows the characteristics of criteria, used in the analysis.

Table 4.5: Characteristics of Criteria

S. No	Criteria	Priority	Type
1.	Quality of Combustion	0.138	Positive
2.	Safety to Workers	0.334	Positive
3.	Cost Involved	0.110	Negative
4.	Loss to the Environment	0.40	Negative

Table 4.6 shows the shows the decision matrix, obtained as the result of responses obtained from a group of respondents, in the form of 5-Point Likert Scale questionnaire.

Table 4.6: Decision Matrix

S. No	Alternatives	Criteria			
		Quality of Combustion	Safety to Workers	Cost Involved	Loss to the Environment
1.	Dropping to midway a slot along wet kiln	2	3	1	4

2.	Rolling to upper end of preheater	3	3	2	5
3.	Chopping and injecting to precalciner combustion chamber	5	4	2	5

In next step, the normalized decision matrix was created, as follows.

Table 4.7: Normalized Decision Matrix

S. No	Alternatives	Criteria			
		Quality of Combustion	**Safety to Workers**	**Cost Involved**	**Loss to the Environment**
1.	Dropping to midway a slot along wet kiln	0.324	0.514	0.333	0.492
2.	Rolling to upper end of preheater	0.487	0.514	0.667	0.615
3.	Chopping and injecting to precalciner combustion chamber	0.811	0.686	0.667	0.615

In the next step, the weighted normalized matrix was constructed as follows.

Table 4.8: The Weighted Normalized Matrix

S. No	Alternatives	Criteria			
		Quality of Combustion	**Safety to Workers**	**Cost Involved**	**Loss to the Environment**
1.	Dropping to midway a slot along wet kiln	0.045	0.172	0.037	0.197
2.	Rolling to upper end of preheater	0.067	0.172	0.073	0.246
3.	Chopping and injecting to precalciner combustion chamber	0.112	0.229	0.073	0.246

In the next step, positive and negative solutions for different criteria were investigated, as follows.

Table 4.9: Positive and Negative Solutions for Criteria

S. No	Criteria	Positive Ideal Solution	Negative Ideal solution
1.	Quality of Combustion	0.112	0.045
2.	Safety to Workers	0.229	0.172
3.	Cost Involved	0.037	0.073
4.	Loss to the\n Environment	0.197	0.246

In the next step, distance of alternatives from positive and negative ideal solutions, was calculated.

Table 4.10: Distance of Alternatives from Positive and Negative Solutions

S. No	Alternatives	Distance from Positive Ideal Solution	Distance from Negative Ideal Solution
1.	Dropping to midway a slot along wet kiln	0.088	0.061
2.	Rolling to upper end of preheater	0.095	0.022
3.	Chopping and injecting to precalciner combustion chamber	0.061	0.088

Table 4.11 shows the relative closeness degree of each alternative to the ideal solution and their rankings.

Table 4.11: C_i Value and Ranking for Old Tires

S. No	Alternatives	Ci	Rank
1.	Dropping to midway a slot along wet kiln	0.41	2
2.	Rolling to upper end of preheater	0.19	3
3.	Chopping and injecting to precalciner combustion chamber	0.59	1

In the similar manner, rankings of different types of wastes' forms were also investigated, as follows.

Table 4.12: C_i Value and Ranking for Green Waste

S. No	Alternatives	Ci	Rank
1.	Wet	0	4
2.	Dried	0.321	3
3.	Cube	0.757	1
4.	Powder	0.404	2

Table 4.13: C_i Value and Ranking for Sewage Sludge

S. No	Alternatives	Ci	Rank
1.	Wet	0	3
2.	Dried	1	1
3.	Powder	0.633	2

Table 4.14: C_i Value and Ranking for Refuse-Derived Fuel

S. No	Alternatives	Ci	Rank
1.	Wet	0.456	3
2.	Pallet	0.544	2
3.	Powder	0.65	1

Table 4.15: C_i Value and Ranking for Chemical and Other Hazardous Waste

S. No	Alternatives	Ci	Rank
1.	Mixture burning	0.238	3
2.	Burning of Separated constituents, individually	0.34	2
3.	Mixture burning with cartelizes	0.762	1

Table 4.16: C_i Value and Ranking for Plastic Residues

S. No	Alternatives	Ci	Rank
1.	Mixture burning	0.228	3
2.	Burning of Separated constituents, individually	0.645	2
3.	Burning in the form of small balls	0.772	1

e) In next step, material handling systems/equipment was selected for different types of wastes. For this purpose, with the help of experts' opinion, following alternatives were investigated for different forms of wastes.

Table 4.17: Investigated Alternatives for Different types of Wastes

S. No	Type of Waste	Form	Material Handling Alternatives
1.	Old Tires	Chips	• Conveyor Delivery • Excavator Delivery • Sprayer Delivery • Manual delivery
2.	Green Waste	Cube	• Conveyor Delivery • Excavator Delivery • Manual Delivery
3.	Sewage Sludge	Dried Bulk	• Conveyor Delivery • Excavator Delivery • Manual Delivery
4.	Refuse-Derived Fuel	Powder	• Conveyor Delivery • Sprayer Delivery • Manual Delivery
5.	Chemical and other Hazardous Waste	Dried bulk	• Conveyor delivery • Excavator delivery • Manual delivery
6.	Plastic Residues	Small Balls	• Conveyor delivery • Excavator delivery • Sprayer delivery • Manual delivery

f) For this purpose, again with the help of expert opinion and survey of available literature, a list of criteria was finalized, as presented in Table 4.18.

Table 4.18: List of Criteria for Different types of Wastes

S. No	Criteria
1.	Overall cost of equipment
2.	Quality of handling
3.	Life of medium
4.	Safety of workers
5.	Time consumed in handling wastes

g) With the help of above information, a systematically designed questionnaire was created and sent to a group of experts of the industry, for the purpose of prioritization of criteria. From the responses obtained from questionnaire, following pairwise comparison matrix was obtained.

Table 4.19: Pairwise Comparison Matrix

From/To	Overall cost of equipment	Quality of handling	Life of medium	Safety of workers	Time consumed in handling wastes
Overall cost of equipment	1	1/3	1/2	1/5	1/2
Quality of handling	3	1	3	1/2	1
Life of medium	2	1/3	1	1/2	1/2
Safety of workers	5	2	2	1	2
Time consumed in handling wastes	2	1	2	1/2	1

h) In the next step, priorities of criteria were calculated as shown in Table 4.20. The values of priorities of criteria calculated from a SAAS entitled http://www.isc.senshu-u.ac.jp/.

Table 4.20: Priorities of Criteria

S. No	Criteria	Priority
1.	Overall cost of equipment	0.076
2.	Quality of handling	0.24
3.	Life of medium	0.124
4.	Safety of workers	0.36
5.	Time consumed in handling wastes	0.2
CR = CI/RI = 0.031 **/1.12= 0.028 < 1**		

Figure 4.8 shows the contributions of criteria to the goal.

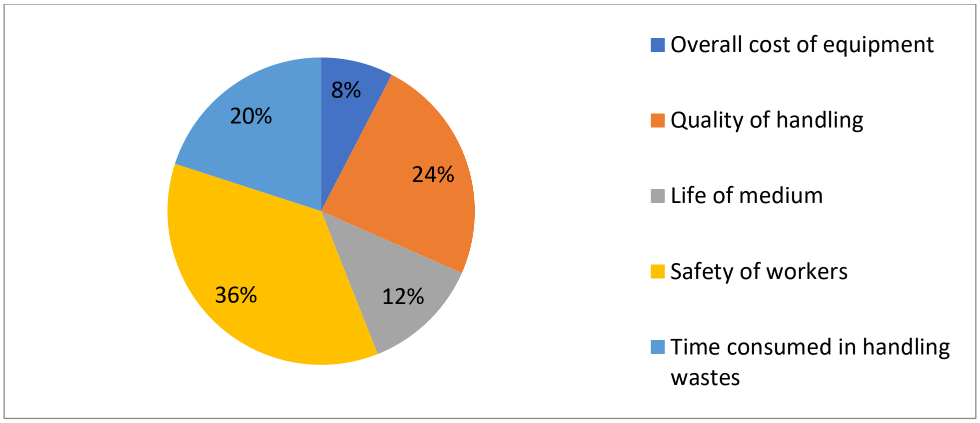

Figure 4.8: Contributions of Criteria towards the Goal for All Wastes

In next step, with the help of AHP-TOPSIS model, scores of different material handling equipment were investigated. Following are the details of hierarchies, decision matrices and rankings for different material handling equipment for different forms of materials.

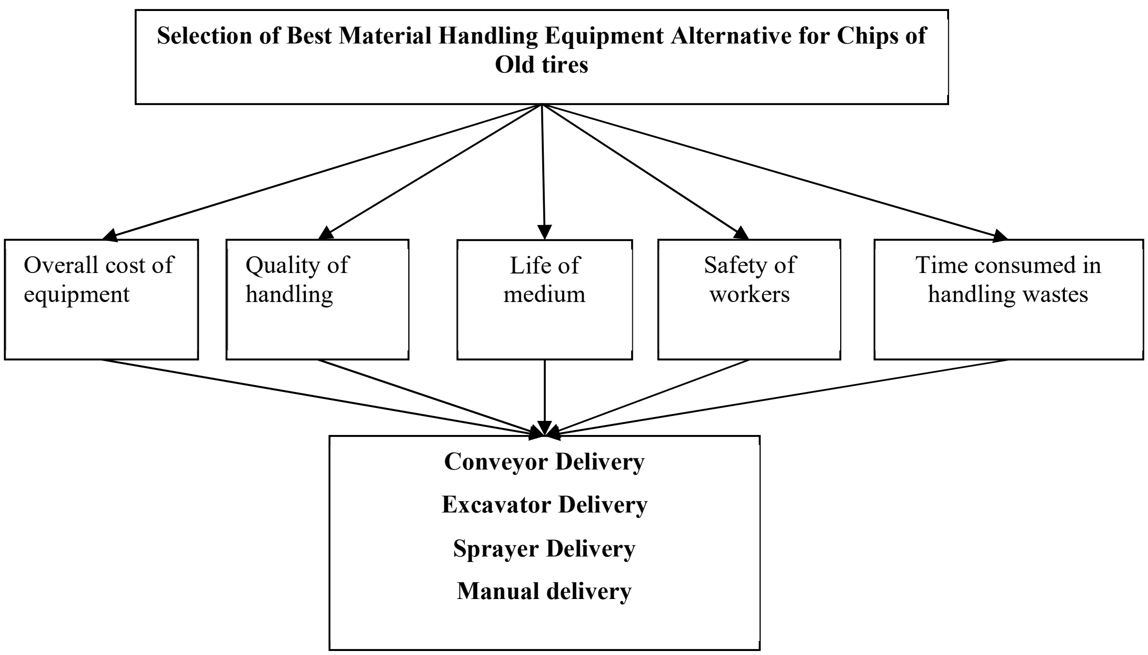

Figure 4.9: AHP-TOPSIS Model for Ranking of Alternatives for Chips of Old Tires

Table 4.21: Decision Matrix for Chips of Old Tires

S. No	Alternatives	Criteria				
		Overall cost of equipment	Quality of handling	Life of medium	Safety of workers	Time consumed in handling wastes
1.	Conveyor Delivery	4	4	5	5	4
2.	Excavator Delivery	2	3	3	5	3
3.	Sprayer Delivery	4	5	5	5	5
4.	Manual Delivery	2	1	1	1	2

Table 4.22: Ci Value and Ranking for Chips for Old Tires

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.751	1
2.	Excavator Delivery	0.706	3
3.	Sprayer Delivery	0.723	2
4.	Manual Delivery	0.277	4

In the similar manner, rankings of different material handling equipment were obtained, the details of which are presented as follows.

Table 4.23: C_i Value and Ranking for Cubes of Green Waste

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.676	1
2.	Excavator Delivery	0.661	2
3.	Manual Delivery	0.339	3

Table 4.24: C_i Value and Ranking for Dried Bulk of Sewage Sludge

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.661	2
2.	Excavator Delivery	0.676	1
3.	Manual Delivery	0.339	3

Table 4.25: C_i Value and Ranking for Powder of Refuse-Derived Fuel

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.632	2
2.	Sprayer Delivery	0.681	1

3.	Manual Delivery	0.368	3

Table 4.26: C_i Value and Ranking for Dried Bulk of Chemical and Other Hazardous Waste

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.655	2
2.	Excavator Delivery	0.679	1
3.	Manual Delivery	0.345	3

Table 4.27: C_i Value and Ranking for Small Balls of Plastic Residues

S. No	Alternatives	Ci	Rank
1.	Conveyor Delivery	0.619	2
2.	Excavator Delivery	0.605	3
3.	Sprayer Delivery	0.687	1
4.	Manual Delivery	0.3064	0.3064

5. Results and Discussion

Present section focuses on results obtained and discussion made about the research work, the details of which are presented in upcoming sub-sections.

5.1 Results

Table 5.1 and Table 5.2 represent the results of the research work, and indicate the top rankings.

Table 5.1: Results of the Research for best forms for Different Materials

S. No	Type of Waste	First Selection	Second Selection
1.	Old Tires	Chips	Dropping
2.	Green Waste	Cube	Powder
3.	Sewage Sludge	Dried Bulk	Powder
4.	Refuse-Derived Fuel	Powder	Pallet
5.	Chemical and Hazardous Waste	Dried Bulk	Burning of separated constituents, individually
6.	Plastic Residues	Small Balls	Burning of Separated constituents, individually

Table 5.2: Results of the Research for Material Handling Equipment for Different Forms of Materials

S. No	Type of Waste	Form	First Selection	Second Selection
1.	Old Tires	Chips	Conveyor Delivery	Sprayer Delivery
2.	Green Waste	Cube	Conveyor Delivery	Excavator Delivery
3.	Sewage Sludge	Dried Bulk	Excavator Delivery	Conveyor Delivery
4.	Refuse-Derived Fuel	Powder	Sprayer Delivery	Conveyor Delivery
5.	Chemical and Hazardous Waste	Dried Bulk	Excavator Delivery	Conveyor Delivery
6.	Plastic Residues	Small Balls	Sprayer Delivery	Conveyor Deliver

5.2 Discussion

Table 5.1 the details of rankings obtained scored by different forms of materials for the waste material, old tires. Results shows the alternative, chopping and injecting to precalciner combustion chamber scores rank 1 by obtaining the Ci value of 0.59. In the similar manner, the alternative, dropping to midway a slot along wet kiln obtains the Ci value of 0.41 and scores the rank 2. Proceeding in the similar manner, it may also be found that the alternative, rolling to the upper end of preheater obtains Ci value of 0.19 and scores the rank 3. This is because, according to the experts, the acitivies, dropping to midway a slot along with kiln as well as rolling to upper end of preheater, needed more complicated material handling system as well as human interactions, respectively, due to which these alternatives scored ranks 2 and 3.

Results also show the rankings for different forms of materials for the waste category, green waste. For this category, 4 types of forms of waste, wet, dried, cube, and powder, were evaluated. According to the results, the alternative, cube, showed the Ci value of 0.757 and scored the rank 1. In the similar manner, the alternative, powder showed the Ci value of 0.404 and scored rank 2, alternative dried bulk waste alternative scored the Ci value of 0.321 and scored rank 3, and finally, the option wet bulk showed the ci value of 0 and scored the rank 4. According to the experts, the cubes are economic as well as easy to make, among all other alternatives, due to which such type of ranking appeared.

The results also show the Ci values scored by different forms of materials as well as their rankings, for the waste material, sewage sludge. As per the results, the alternative, dried , scores the Ci value of 1 and also secures rank 1, whereas the alternatives powder scores the Ci value of 0.633 and scores rank 2, and the alternative wet, scored Ci value of 0 and obtained the rank 3. The reason behind the type of ranking was least cost of manufacturing as well as efficient burning along with the most regular delivery.

Results also show the scores of different forms of materials for the waste category, reuse-derived fuel. For this category, the three alternative forms of materials were, wet, pallets, as well as powder. According to the results, the alternative, powder obtains the Ci value of 0.65 and scores the rank 1. In the similar manner, alternatives, pallets and wet, obtain the Ci values of 0.544 and 0.456 and score ranks 2 and 3. Reasons behind such type of rankings were again the cost involved, as well as the efficient performance of the alternative in the kiln.

Results also showed rankings of different forms of materials for the alternative, chemical and other hazardous waste, for which the alternatives were mixture burning, burning of separated constituents, individually and mixture burning with catalyzers. The results showed that the alternative mixture burning with catalyzers obtained the Ci value of 0.762 and scored rank 1, whereas the alternatives, burning the separated constituents, individually and mixture burning scored the Ci values of 0.34 andd 0.238 and obtained the ranks 2 and 3, respectively. The reasons for such type of rankings were the cost involved as well as efficient burning.

Table 5.1 also show the rankings of alternatives for the waste category, plastic residues. There results shown that the alternative, burning in the form of small balls obtained the Ci value of 0.772 and scored rank 1, whereas the alternatives, burning of separated constituents, individually and mixture burning scored the Ci values of 0.645 and 0.228 and obtained the ranks 2 and 3, respectively. The reasons for such type of rankings were found to be the cost involved as well as efficient burning.

Table 5.2 shows the material handling equipment for material handling equipment for the type, chips, for the material category, old tires. There were 4 alternatives, conveyor delivery, excavator delivery, sprayer delivery as well as manual delivery, out of which the alternative, conveyor delivery obtained the Ci value of 0.751 and secured the rank 1, alternative sprayer delivery obtained the Ci value of 0.723 and secured the rank 2, the alternative excavator delivery obtained the ci value of 0.706 and scored the rank 3, while the alternative, manual delivery obtained the Ci value of 0.277 and secured the rank 4. According to the experts, all these rankings were primarily based on the criteria, safety of workers, cost of equipment as well as quality of handling.

Table 5.2 also provided the rankings of material handling equipment for the material form, cubes for the waste category, green waste. There were 3 alternatives, conveyor delivery, excavator delivery, and manual delivery, out of which the alternative , conveyor delivery scored the Ci value of 0.676 and obtained the rank 1; alternative excavator delivery scored the Ci value of 0.661 and scored the rank 2, whereas, the alternative manual delivery, scored the

Ci value of 0.339 and obtained rank 3. The governing criteria for such type of rankings were overall cost of equipment and safety of workers.

Proceeding further, the Table 5.2 also provides the rankings of alternatives for the waste form, dried bulk for the waste category, sewage sludge. There were 3 alternatives, conveyor delivery, and excavator delivery as well as manual delivery, out of which, the alternative excavator delivery, obtained the Ci value of 0.676 and scored rank 1; alternative, conveyor delivery scored the Ci value of 0.661 and obtained rank 2, and alternative manual delivery score the Ci value of 0.339 and obtained rank 3. The governing criteria for these rankings were found to be the safety of workers as well as the cost involved.

The Table 5.2 also shows the results of rankings scored by different alternatives for the material handling system for Powder form of material for the waste fuel category, refuse-derived fuel. In this case, the investigated alternatives were conveyor delivery, sprayer delivery and manual delivery. Results of the research work showed that the alternative sprayer delivery obtained the Ci value of 0.681 and score the rank 1, whereas, the alternatives, conveyor delivery and manual delivery, scored the Ci values of 0.632 and 0.368 and obtained the rankings, 2 and 3, respectively. The responsible factors for such type of rankings were, cost of the equipment, time consumed in handling waste as well as the safety of workers.

The Table 5.2 also show the rankings of material handling equipment for the material category, dried bulk for the waste category chemical and other hazardous waste. For this form of material, the alternative, excavator delivery scored the Ci value of 0.679 and obtained rank 1, whereas the alternatives, conveyor deliver, and manual delivery received the Ci values of 0.655 and 0.345 and obtained ranks 2, and 3, respectively. The governing criteria for such a type of rankings were overall cost of equipment, safety of workers and time consumed in handling waste.

Finally the results for the rankings of alternate material handling equipment for the waste form, small balls, for the waste category, plastic waste, were investigated. There were 4 alternatives, conveyor delivery, excavator delivery, sprayer delivery and manual delivery, out of which the alternative sprayer delivery scored the maximum value of Ci (0.687) and obtained the rank 1. Proceeding in the similar manner, the alternatives, conveyor delivery, excavator delivery, and manual delivery, obtained the Ci values of 0.619, 0.605 and 0.306, and received the rankings, 2, 3 and 4, respectively. The responsible factors for such type of rankings were safety of workers and quality of handling.

6. Conclusion, Limitations and Future Scope of the Research

Present section portrays the conclusion, limitations and future scope of the research, the details of which are presented in upcoming sub-sections.

6.1 Conclusion

Present research work was based on the design of material handling equipment for incineration of waste materials used in cement kiln, under which solid wastes were targeted. For this purpose, selective design approach was used, under which, with the help of experts' opinion, different forms of materials and material handling equipment for different classes of materials investigated, and ranked on the basis of different criteria, with the help of a well known multi criteria decision making approach AHP-TOPSIS model. Following are the results of the research work:

a) The best form for the waste category, old tires is chips and the best material handling equipment is conveyor delivery;
b) The best form for the waste category, green waste is cubes and the best material handling equipment is conveyor delivery;
c) The best form for the waste category, sewage sludge is dried bulk and the best material handling equipment is excavator delivery;
d) The best form for the waste category, refuse-derived fuel is powder and the best material handling equipment is sprayer delivery;
e) The best form for the waste category, chemical and hazardous waste is dried bulk and the best material equipment is excavator delivery; and
f) The best form for the waste category plastic residues is small balls and the best material equipment is sprayer delivery.

6.2 Limitations and Future Scope of Research

The Following points represent the limitations of the research work:

a) The research work is limited to general classes of waste materials;
b) The research work is also limited to general classes of material handling equipment/systems; and
c) The research work is also limited to a particular type of algorithm, used for the obtainment of solution of the research problem.

The following points represent the future scope of the research work:

a) An extensive research consisting of a detailed classification of materials may also be initiated;
b) A wider research including a broader set of material handling equipment/systems may also be called upon; and
c) A broader research involving a greater set of solution techniques may also be initiated.

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