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Optimization of Material Handling System through Material Handling Equipment Selection

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***Abstract* —In today's competitive world, it is very difficult and complex task to select one alternative from different sets of alternatives especially when the data are vague and inexact. This paper focuses on the application of one of multi-criteria decision making tools called the Analytical Hierarchy Process (AHP) for the selection of material handling equipment at a local industry in order to optimize the material handling system. Questionnaires were developed and distributed among experts, employees and workers working in the industry. Measure of central tendency (Mean) calculated from the data was used as an input for pair-wise exchange matrix. The selection was subject to four criteria with each having three sub-criteria. The overall results showed that AGV's are more significant for material handling in a pharmaceutical industry as compared to forklift and conveyor belt.**

***Keywords* — Analytical Hierarchy Process, Manufacturing, Material Handling system, Productivity.**

I. INTRODUCTION

The configuration of production equipment and departments and the design and arrangement of a proper material handling system is referred to as the facility planning. The design and arrangement of material handling system could be more important problem in spite of the fact that the first attempt is an important issue in facilities planning. These two issues have been simultaneously investigated by researchers [1-3]. New manufacturing paradigms e.g. lean and agile manufacturing have been occurred on the other hand in order to internationalized a product and have a quick response to market demands with reduced prices. Reducing costs and sale price and ultimately increasing profitability are one of the major concerns of a manufacturing company in order to stay in such a competitive environment [4]. Material handling cost is one of the principle costs that need to be reduced. One of the basic goals of a manufacturing company is to choose an efficient and effective material handling system that can result in the efficient utilization of workforce, reduced fuel costs, production time and prices and increased profitability and productivity of the plant. Material handling activities and equipment can account for 55% of all plant space, 25% of the number of workforce, 87% of the total production time, and 15-70% of the total manufacturing cost [5]. There are some important factors that influence the selection of a proper material handling equipment such as system flexibility, effective and efficient use of labor, enhanced productivity, and reduced lead times and costs [6]. A plant's operating cost can be primarily reduced by 15-3-% through the use of an efficient material handling equipment [7].

The process of material handling involves different functions such as the movement and storage in a manufacturing plant or a warehouse, the control and protection of raw materials, products and finished goods during the process of cleaning, preparation, manufacturing, distribution, consumption and disposal related to their packaging. Different studies have focused on methods,

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mechanical equipment, systems and related controls that are used to achieve these functions. A wide range of material handling equipment is available now a days such as industrial trucks, fork lifts, conveyor belts, automated guided vehicle's (AGV's), trolleys etc. for achieving the different functions related to material handling system. Material handling equipment are classified into main groups of conveyors, industrial trucks, cranes, AGV's, industrial robots, automated storage and retrieval systems (AS/RS) in the literature.

II. Literature Review

In recent times many researches have been carried out to solve the problem of MHE selection. A rule-based expert system was developed for material handling equipment selection called (MATHES) by Fisher et al. [8] which select appropriate type of equipment for intra-factory material handling system. A rule base is developed that relate the move characteristics to the appropriate equipment type while a certainty factor associated with each equipment type is calculated for ordering the list of selected equipment. A knowledge based expert system [9] is developed for designing repetitive manual material handling tasks by using the software package personal consultant and three structures such as frames, parameters and rules are used to control and organize information. A prototype expert system for the selection of industrial truck-type and an expert consultant for within plant transportation equipment are suggested respectively in studies [10, 11]. There are several approaches in the literature that are comprised of more than one performance evaluation measure and are termed as multi-attribute or multi-criteria decision making approaches which can account for both financial and non-financial impacts. Some of these methods include Analytical network process (ANP) [12], scoring models [13], utility models [14], analytical hierarchy process (AHP) [15], outranking methods [16] and TOPSIS [17]. Several axiomatic design (AD) [18] based methods have also been developed by various researchers that enable the decision maker to evaluate both quantitative and qualitative criteria simultaneously. Axiomatic design theory and principles has been pioneered by [19] while AD principles have been implemented on software design by [20]. Suh et al. [21] have used the principles in quality systems design and general system design [22] while [23] have provided a manufacturing system design based on AD principles. AD principles have also been employed in the design of a flexible manufacturing systems [24]. In order to improve the performance of manufacturing cells, a knowledge-based decision support system have also been proposed using the independence axiom of AD [25]. Based on AD principles, a road map has also been provided by [26] for transforming traditional production system of process layout to cellular layout. Multi-attribute AD and AHP approaches have been employed for the selection of a proper transportation company under determined criteria such as time, cost, loss/damage, documentation ability and flexibility [27]. All these researches have shown the applicability and advantages of axiomatic design (AD) in solving many industrial problems. Ioannou et al. [3] has presented a hybrid methodology that includes an integer programming formulation for the design of concurrent layout and material handling system. Analytical hierarchical process (AHP) [28], AHP-preference ranking organization method for enrichment evaluation (PROMETHEE) [4] and analytical network process (ANP)-PROMETHEE [29] approaches have been adopted for solving the problem of material handling equipment selection.

III. An Overview Of Multi-Criteria Decision Making (MCDM) Techniques

The process of determining the best alternative from a set of all possible alternatives related to different criteria is known as the multi-criteria decision making (MCDM) problem. One of the significant advantage of these techniques is that both quantitative and qualitative criteria could be consider by these techniques [30].

In a more general categorization, the MCDM techniques are divided into two branches as multi-objective decision making (MODM) and multi-attribute decision making (MADM). A small number of predetermined alternatives are included in MADM problem which are evaluated with respect to a set of attributes. Evaluations and weights are precise and crisp in classical MADM (CMADM) while decision making process accommodates with uncertainty and doubt in real world. Therefore, it is named as fuzzy MADM (FMADM) when integrated with fuzzy data to deal the uncertainty. A fuzzy MADM (FMADM) is developed by [31] in order to resolve the imprecision and vagueness occurs when weighting criteria and evaluating alternatives related to those criteria. One of the necessary and difficult works in MADM problem is weighting criteria as it differs and based on experts point of views in different decision making areas. Several procedures have been developed in recent past in order to attain the weighting criteria such as pair-wise comparison methods that includes AHP [32] or digital logic method [33], direct weighting approaches [34] such as the entropy analysis approach [35], Delphi approach [36], and synthetic value of fuzzy judgment method [37].

Analytical hierarchy process is the simplest and most popular approach in comparison to all these methods that has been applied in the literature.

IV. Analytic Hierarchy Process (AHP)

Partovi et al [38] described the analytical hierarchical process (AHP) that was first introduced by Thomas L. Saaty as the decision–making tool that deals with the unstructured, complex and multi-attribute decision. Nydick et al. [39] define the AHP as the methodology which rank the alternatives based on the judgment of decision maker related to the importance of the criteria and the extent to which each alternative met these criteria. AHP is a multi-criteria decision making tool that involves both quantitative and qualitative criteria and quantifies the relative weights on ratio scale for a given set of criteria. It allows decision maker for both financial and non-financial measures to be considered and trade-offs among them to be addressed. It ranks the decision alternatives by integrating the different measures in to a single overall score. The two features that differentiate AHP from other MCDM tools is that it provides a comprehensive structure to combine intuitive rational and irrational values and the ability to judge the consistency during the decision making process. In the recent past AHP has gained much more focus and has been applied to many problems such as projects selection [40], vendor rating [41], investment appraisals [42-44], weapon system evaluation [45], contractor selection [46], and supplier assessment [47].

V. Problem Statement

Company Y is a pharmaceutical company situated in the industrial estate area Hayatabad, Peshawar, Pakistan. The company is currently using trolleys as an equipment to handle the different types of materials used in pharmaceutical products. However, the company is facing problems while using this type of material handling equipment such as more time taken by a worker to move the trolley, injuries caused due to movement through large distances, reduced worker efficiency due to excessive movement of materials etc. Therefore; the company has decided to change the type of material handling equipment in order to eliminate or at the very least overcome these problems.

VI. Research Methodology

First hand data related to equipment selection regarding pharmaceutical industry in Pakistan is not available. Therefore a comprehensive questionnaire was developed to obtain the data from different pharmaceutical industries in Peshawar. The questionnaire was distributed with 120 well known Engineers and Managers working in the pharmaceuticals industry. Feedback of a total of 80 questionnaires were received which were then statistically analyzed by measures of central tendency (Mean). The mean was selected to be used for the development of pair wise matrix. The data was subjected to a decision making tool, analytic hierarchy process (AHP) for selecting an optimal material handling equipment for pharmaceutical industry. Figure 2 shows hierarchical structure used for solving this problem via AHP. In this structure, the AHP is divided into four levels, represented by zero level (Goal), first level (Criteria), second level (Sub-criteria), and third level (Alternatives).

The different criteria, technical, monetary, operational, and strategic are assumed to have an equal importance for equipment selection, so will have the same effect with an Eigen value of 0.25 an will cancel the effect of each other. The hierarchical structure given in Figure 2 can be divided into four sub-structures on basis of technical, monetary, operational, and strategic criteria as an objective. These four structures will be analyzed one by one through the AHP. The valid questionnaires were analyzed to model the data on basis of requirements as an input for pairwise comparison of sub-criteria. The step by step procedure of AHP on technical criteria will be discussed; and results of monetary, operational, and strategic criteria can be obtained in the same way.

Initial matrix related to the data obtained from questionnaire subjected to measure of central tendency (mean) is shown in Table 1.

Table 1 Calculated means for sub-criteria of technical criteria

S.No.	Sub-criteria	Mean
1	Convenience	4
2	Maintainability	4
3	Safety Required	2

The calculated means were used to develop the pair-wise matrix as shown in Table 2a. The normalized matrix is obtained by dividing each element of a column of pair wise comparison matrix by its sum as given in Table 2b and the priority matrix is generated by taking the averages of all elements of row in normalized matrix as given in Table 2c.

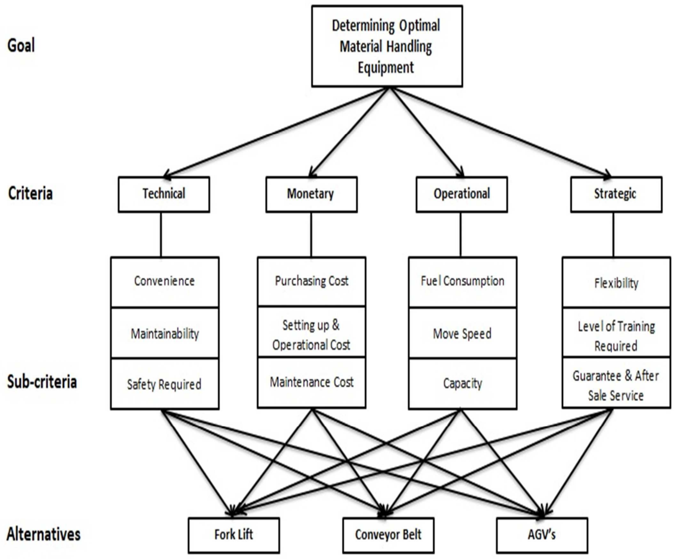

Figure 2 Hierarchical structure of equipment selection

Table 2 The develop the pair-wise matrix using calculated means

	Con.	Mty.	SR
Con.	1	1	2
Mty.	1	1	2
SR	0.5	0.5	1

2a. Pair-wise comparison matrix

→

	Con.	Mty.	SR
Con.	0.4	0.4	0.4
Mty.	0.4	0.4	0.4
SR	0.2	0.2	0.2

2b. Normalized matrix

→

Criteria	Eigen Values	Rank
Con.	0.4	1
Mty.	0.4	2
SR	0.2	3

2c. Priority matrix

To make sure that the weights given to the sub-criteria were consistent or not, the consistency ratio of a pair-wise matrix is used. For a given comparison matrix, CR=0.00 < 0.1, so given input data is consistent. Now in order to find the best equipment (forklift, conveyor belt, or AGV's) for material handling with respect to sub-criteria i.e. convenience, maintainability, and safety required, the input matrices and priority matrices are given in Table 3, 4 and 5 respectively.

Table 3 Pair-wise comparison and Priority matrixes on the basis of Convenience.

	FL	CB	AGV's
FL	1.00	0.75	0.60
CB	1.33	1.00	0.80
AGV's	1.67	1.25	1.00

→

	Eigen Values	Rank
FL	0.25	3
CB	0.33	2
AGV's	0.42	1

Table 3 shows that AGV's are more suitable for material handling on the basis of convenience (0.42) while conveyor belt and forklifts are 0.33 and 0.25 significant respectively.

Table 4 Pair-wise comparison and Priority matrixes on the basis of Maintainability.

	FL	CB	AGV's
FL	1	1.333	0.8
CB	0.75	1	0.6
AGV's	1.25	1.667	1

→

	Eigen Values	Rank
FL	0.33	2
CB	0.25	3
AGV's	0.42	1

Table 4 shows that on the basis of maintainability, AGV's are more suitable having score of 0.42 as compared to conveyor belt (0.25) and forklift (0.33).

Table 5 Pair-wise comparison and Priority matrixes on the basis of Safety required.

	FL	CB	AGV's
FL	1	0.5	0.333
CB	2	1	0.667
AGV's	3	1.5	1

→

	Eigen Values	Rank
FL	0.17	3
CB	0.33	2
AGV's	0.50	1

Table 5 shows that on the basis of safety required, again AGV's are more suitable having score of 0.50 as compared to conveyor belt (0.33) and forklift (0.17).

The overall priority matrix for alternatives is obtained by multiplying the Table 3,4, and 5 with the priority matrix of sub-criteria as in Table 2c.

Table 6 Priority matrix for alternatives on the basis of Technical criteria.

	Eigen Values		
FL	0.25	0.33	0.17
CB	0.33	0.25	0.33
AGV's	0.42	0.42	0.50

X

Criteria	Eigen Values
Convenience	0.4
Maintainability	0.4
Safety required	0.2

=

Alternatives	
Fork Lift	0.27
Conveyor Belt	0.30
AGV's	0.43

Table 6 illustrates that AGV's are 43% suitable for handling materials on the basis of technical criteria while there is only 30% and 27% positive impact of conveyor belt and forklift respectively on material handling.

Similarly when same process of AHP is applied on the monetary criteria considering purchasing cost, maintenance cost, and setting up & operational cost as sub-criteria to find the best alternative in the form of forklift, conveyor belt and AGV's, the overall priority matrix obtained is given in Table 7 below as;

Table 7 Priority matrix for alternatives on the basis of Monetary criteria.

	Eigen Values		
FL	0.50	0.17	0.33
CB	0.33	0.33	0.17
AGV's	0.17	0.50	0.50

X

Criteria	Eigen Values
Purchasing Cost	0.17
Setting Up & Operational Cost	0.33
Maintenance Cost	0.50

=

Alternatives	
Fork Lift	0.31
Conveyor Belt	0.25
AGV's	0.44

Table 7 presents the comparison in a way that the AGV's has more positive impact i.e. 44% on material handling as compared to the conveyor belt with 25% and forklift in terms of purchasing cost, setting up and operational cost, and maintenance cost.

In the same manner the AHP process when applied to operational criteria with fuel consumption, move speed, and capacity as sub-criteria and strategic criteria with flexibility, level of training, and guarantee & after sales service as sub-criteria, the priority matrixes obtained are given in Table 8 and 9 respectively as;

Table 8 Priority matrix for alternatives on the basis of operational criteria

	Eigen Values		
FL	0.14	0.25	0.38
CB	0.29	0.42	0.31
AGV's	0.57	0.33	0.31

X

Criteria	Eigen Values
Fuel Consumption	0.13
Move Speed	0.37
Capacity	0.50

=

Alternatives	
Fork Lift	0.31
Conveyor Belt	0.34
AGV's	0.35

Table 8 shows that on the basis of operational criteria, the AGV's are 35% suitable for material handling while conveyor belt and forklift are 34% and 31% significant respectively.

Table 9 Priority matrix for alternatives on the basis of strategic criteria

	Eigen Values		
FL	0.33	0.33	0.33
CB	0.22	0.50	0.22
AGV's	0.44	0.17	0.44

X

Criteria	Eigen Values
Flexibility	0.18
Level of Training	0.35
Guarantee & after Sale Service	0.47

=

Alternatives	
Fork Lift	0.33
Conveyor Belt	0.31
AGV's	0.36

Table 9 shows that on the basis of strategic criteria, the AGV's are 36% suitable for material handling while conveyor belt and forklift are 31% and 33% significant respectively.

VII. Results And Discussion

After analysis of technical, monetary, operational and strategic criteria individually, the overall priority of three alternatives forklift, conveyor belt, and AGV's are presented in Table 10. In the given Table 10, column 2 lists four criteria with 12 sub-criteria in column 3 followed by the Eigen values of FL, CB and AGV's in column 4, 5 and 6 respectively. The Eigen values of all sub-criteria come from the priority matrix of each sub-criterion as given in Table 6, 7, 8 and 9 respectively against FL, CB and AGV's for selection. When Table 10 is analyzed, it is clear that the sub-criteria "fuel consumption" an operational criteria having highest value of 0.57 while the alternative is AGV's as compared to conveyor belt and forklift with 0.29 and 0.14 respectively that is because AGV's can be operated on small electric charge motor while conveyor belt and forklift have a high consumption of electricity and fuel respectively. Furthermore; the alternative AGV's also have a large value of 0.50 each in terms of "setting up and operational cost" and "maintenance cost". The reason is that AGV's can be maintained for a long time and it could be easily set up and operated. The overall results shows that the alternative AGV's have a very positive impact (40%) related to all criteria and sub-criteria as compared to the other two alternatives i.e. conveyor belt (31%) and forklift (29%). So, it is clear that automated guided vehicles are more suitable for handling material in a pharmaceutical industry.

Table 10 Criteria, sub-criteria and Eigen values for three alternatives.

S.No.	Criteria	Sub Criteria	Alternatives		
			Fork Lift	Conveyor Belt	AGV's
1	Technical	Convenience	0.25	0.33	0.42
		Maintainability	0.33	0.25	0.42
		Safety required	0.17	0.33	0.50
2	Monetary	Purchasing cost	0.50	0.33	0.17
		Setting up & Operational cost	0.17	0.33	0.50
		Maintenance cost	0.33	0.17	0.50
3	Operational	Fuel consumption	0.14	0.29	0.57
		Move speed	0.25	0.42	0.33
		Capacity	0.38	0.31	0.31
4	Strategic	Flexibility	0.33	0.22	0.44
		Level of training required	0.33	0.50	0.17
		Guarantee and after sale service	0.33	0.22	0.44
		Total	3.53	3.70	4.77
		Average	0.29	0.31	0.40
		Rank	3	2	1

VIII. CONCLUSION

In this paper, AHP technique was successfully applied for selecting the optimal material handling equipment out of three alternatives i.e. forklift, conveyor belt, and automated guided vehicles (AGV's). The selection was based on four criteria with each having three sub-criteria and a total of 12 criteria for all alternatives. The preliminary results show that the alternative AGV's have a very positive impact (40%) related to all criteria and sub-criteria as compared to the other two alternatives i.e. conveyor belt (31%) and forklift (29%). So, it is clear that automated guided vehicles (AGV's) are more suitable for handling material in a pharmaceutical industry.

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