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A literature review on MHE selection problem: levels, contexts, and approaches

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This paper presents a review on selection problem of material handling equipment (MHE) and general equipment used in industry area. The issue on MHE is widely paid attention since MHE has contribution on material, good and product accomplishment. Few methods and softwares have been proposed and developed to select the most appropriate MHE for a complex selection problem. Today's high diverisity of MHE categories and types influence the generation of many possible choices which leads to the complexity. In this paper, a further discussion in terms of MHE and equipment including three major points namely level of selection, the context of selection problem and the approaches are served to highlight the complex MHE selection according to the number of possible choices provided, to analyse the consideration for the problem context, and to reveal the superior method for complex MHE selection. Forty-two papers collected from the past study are presented asscociating each point of the discussion.

Keywords: MHE selection; technical feasibility; economic feasibility; MCDM; knowledge-base; optimisation

1. Introduction

Material, product or good will always flow within and/or across the facility such as a plant, warehouse, between buildings, a transportation or distribution spot in order to complete the function of its availability in that facility. The material flow is related to the movement for handling the material itself which can be done by using human power or mechanical equipment and can be time consuming, expensive and troublesome. Since material handling equipment (MHE) is used, the considerations certainly lead to the decision-making for the proper selection. The equipment must be worth for the material handling operations since material handling essentially uses resources such as labour, time and space. In general practice, material handling operation accounts for 25% of all employees, 55% of all factory space and 87% of production time (Tompkins 1996).

Due to that factor, selection of MHE should be conducted carefully and comprehensively. Past studies are concerned with MHE selection by taking an effort to find the best alternative of MHE. Some of the studies select the best MHE through evaluation under multiple criteria. According to the record of past studies on MHE selection, the MHE selection problems have been rapidly generated and more sophisticated. The area where MHE performed, use of method, and generation of possible alternatives presented by past studies shows the diversity.

This paper presents a review of MHE selection problem which classifies the study in terms of level of selection, purpose and approach. Forty-two papers related to MHE selection problem have been collected from any international journal, article and thesis. It is discussed in the following order to review the classification in each context.

2. Literature review

Lashgari et al. (2012) attempted to incorporate analytic approach for selecting MHE. In their study, fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was applied to derive alternative priority based on the multi-criteria. The combination of fuzzy Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) is used to determine the weight of sub-criteria. The combination of fuzzy AHP and fuzzy ANP is applied due to consisting of dependency among the sub-criterion related to the cost criteria. Based on the depth comprehension, the weight of sub-criteria cannot be determined by using fuzzy AHP which is not able to delve into neither inner-dependency nor outer-dependency among the sub-criterion whereas ANP is fully effective to deal with that.

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Table 1. The distribution of paper in terms of diversity of MHE selection problems according to the level of selection.

Authors		Level of selection: High	Intermediate	Low	Description
(1)	Onut, Kara, and Mert (2009)		✓		Select the most appropriate category of MHE e.g. industrial truck, conveyor, rail system crane, AGV, and fixed crane
(2)	Tuzkaya et al. (2010)		✓		Select the most appropriate type of MHE
(3)	Chakraborty and Banik (2006)	✓			Select the most appropriate MHE among the category e.g. conveyor, industrial truck, crane and hoist, and auxiliary equipment (general purpose selection problem)
(4)	Lashgari et al. (2012)		✓		Select the most appropriate type of loading equipment e.g. back hoe loader, wheel loader, dragline, hydraulic shovel, cable shovel
(5)	Karande and Chakraborty (2013)		✓		Select the most appropriate type of conveyor
(6)	Chamzini-Y and Shariati (2013)	✓			Select the most appropriate category of MHE e.g. truck, conveyor, and hoist
(7)	Valli and Jeyasehar (2012)			✓	Select the most appropriate equipment model for construction project
(8)	Mousavi et al. (2013)		✓		Select the most appropriate type of conveyor
(9)	L'Eglise et al. (2000)		✓		Select the most appropriate MHE for assembly line
(10)	Lawrence and Blessing (2013)		✓		Select the most appropriate type of conveyor
(11)	Sawant, Mohite, and Patil (2011)			✓	Select the most appropriate model of AGV
(12)	Maniya and Bhatt (2011)		✓		Select the most appropriate type of AGV
(13)	Fonseca, Uppal, and Greene (2004)		✓		Assist selection of the most appropriate type of conveyor
(14)	Fisher, Farber, and Kay (1988)		✓		Assist selection of the most appropriate type of MHE among categories
(15)	Kulak, Satoglu, and Durmusoglu (2004)		✓		Assist selection of the most appropriate MHE type among the categories e.g. truck (Handcart, tier platform truck, hand lift truck, etc.), conveyor (Belt conveyor, roller conveyor, chute conveyor, etc.), AGV (Manual load/unload AGV, low-lift AGV, etc.), type of cranes, type of storage system, type of robot
(16)	Kulak (2005)		✓		Assist selection of the most appropriate MHE type among the categories
(17)	Park (1996)		✓		Assist selection of the most appropriate MHE type among the categories including transport equipment and storage equipment e.g. pipe, conveyor, industrial truck, bulk storage system, rack system AS/RS, etc.
(18)	Matson, Mellichamph, and Swaminathan (1992)		✓		Assist selection of the most appropriate type of transport equipment
(19)	Hosni (1989)		✓		Assist selection of the most appropriate MHE type among the categories
(20)	Chu, Egbelu, and Wu (1995)		✓		Assist the selection of MHE equipment type among categories
(21)	Rubinovitz and Karni (1994)		✓		Assist the selection of the most appropriate MHE type among categories
(22)	Malmborg et al. (1987)		✓		Assist the selection of the most appropriate industrial truck type
(23)	Welgama and Gibson (1995)		✓		Assist the selection of the most appropriate MHE type among the categories
(24)	Burt (2008)		✓		Alternative selection for multi-operations, finding the most appropriate type of truck and loader fleet for surface mining operations
(25)	Zhang, Huang, and Zhu (2013)		✓		Unspecified
(26)	Rai, Kameshwaran, and Tiwari (2002)	–	–	–	Select the most appropriate machine-tool for multi-operation in FMS (the equipment is unspecified)
(27)	Paulo, Lashkari, and Dutta (2002)		✓		Alternative selection for multi-operations, select the most appropriate type among the categories e.g. light-load robot, heavy-load robot, powered hand truck, forklift truck, roller bed belt conveyor, AVG,AS/RS, etc.
(28)	Sujono and Lashkari (2007)		✓		Alternative selection for multi-operations, select the most appropriate type among the categories e.g. light-load robot, heavy-load robot, powered hand truck, forklift truck, roller bed belt conveyor, AVG,AS/RS, etc.

(*Continued*)

Table 1. (*Continued*).

Authors	Level of selection High	Intermediate	Low	Description
(29) Hassan, Hogg, and Smith (1985)		✓		Finding the most appropriate type of transport equipment (the equipment is unspecified)
(30) Webster and Reed (1971)		✓		Finding the most appropriate type of transport equipment among category e.g. rider fork truck, powered conveyor, walkie lift truck, portable crane
(31) Mahdavi, Shirazi, and Sahebjamnia (2011)	✓			Finding the most appropriate category of transport equipment for multi-operations e.g. conveyor, AGV and truck
(32) Bard and Feo (1991)	–	–	–	Unspecified
(33) Haidar and Naoum (1996)		✓		Finding the most appropriate type of equipment among categories in opencast mining e.g. scrapers, truck, backhoe, front end loaders, electric shovels, hydraulic excavator
(34) Braglia, Gabbrielli, and Miconi (2001)		✓		Alternative selection for multi-operations, select the most appropriate type among the categories in manufacturing cell
(35) Yilmaz and Dağdeviren (2011)	–	–	–	Select an appropriate MHE (the equipment is unspecified)
(36) Momani and Ahmed (2011)		✓		Select an appropriate type of MHE within transport equipment category
(37) Mirhosseyni, Hamid, and Webb (2009)		✓		Select the most appropriate MHE type among the categories e.g. industrial truck, floor conveyor, overhead conveyor, AGV, cranes, manual
(38) Chan, Ip, and Lau (2001)		✓		Assist the selection of the most appropriate MHE type among the categories e.g. type of conveyor, overhead conveyor, industrial truck, industrial robot, AGV, crane, storage/retrieval system
(39) Hadi-Vencheh and Mohamadghasemi (2014)		✓		Select the most appropriate conveyor type
(40) Ahmed and Lam (2014)		✓		Select the most appropriate type of MHE within category
(41) Naoum and Haidar (2000)		✓		Select the most appropriate type of excavating and haulage equipment
(42) Ghazikalayeh et al. (2013)		✓		Select the most appropriate type of equipment for drilling, loading and haulage category

The integration approach of Multi-criteria Decision Making (MCDM) such as fuzzy ANP and fuzzy TOPSIS is also used to solve the material handling selection problem. A study established by Onut, Kara, and Mert (2009) applied it for selecting MHE in the steel construction industry. Fuzzy ANP is performed to determine the criteria weight and use the weight to assess the alternative which is established by using fuzzy TOPSIS. Similarly, fuzzy ANP and fuzzy TOPIS also have been used to select the most appropriate equipment in open-pit metal mine (Ghazikalayeh et al. 2013). The selection is intended to find the best type of equipment from the combination of three equipment categories. Alternative is evaluated by using 28 attributes. Fuzzy ANP was also proposed to MHE selection problem and integrated to fuzzy Preference Ranking Organisation method for Enrichment Evaluation (PROMETHEE) (Tuzkaya et al. 2010). The importance weight of evaluation criteria affecting MHE selection are derived by fuzzy ANP. The final rank of alternatives is constructed based on the fuzzy PROMETHEE procedures.

Karande and Chakraborty (2013) and Lawrence and Blessing (2013) used weighted utility additive theory for MHE selection. The selection is based on the multi-criteria. AHP is performed to solve the material handling selection problem (Chakraborty and Banik 2006). An integrated fuzzy AHP–fuzzy TOPSIS is adopted by Chamzini-Y and Shariati (2013) for material handling selection problem. The problem deals with the selection of best MHE for the case study in surface mine. In order to consider the criteria evaluation, fuzzy AHP is used to obtain the weight of criteria and then integrated to the fuzzy TOPSIS to tackle the final selection. Mousavi et al. (2013) proposed fuzzy grey group compromise ranking method for MHE selection. The proposed method combines grey concept and compromise ranking methods known as VIKOR to obtain a compromise solution and to determine the best alternative in order to solve complex decision problems. Hadi-Vencheh and Mohamadghasemi (2014) proposed fuzzy VIKOR to solve MHE selection problem. In addition, the preliminary procedure to determine the weight of criteria and sub-criteria through voting approach is used. Next, fuzzy weighted average is applied to aggregate the single fuzzy weights of each alternative related to sub-criteria under each criterion. The final decision is made by using VIKOR and the comparison was performed with fuzzy TOPSIS.

Sawant, Mohite, and Patil (2011) proposed a selection of automated guided vehicle (AGV) by using preference selection index (PSI) and TOPSIS with entropy weight method. The illustration procedure is applied for selecting model of AGV in medium-size company enterprise among 16 possible choices of AGV model based on 9 evaluation attributes. Maniya and Bhatt (2011) used integration of AHP and modified grey analysis (M-GRA) for selecting the most appropriate type of AGV. AHP method is used to assign the relative importance between AGV selection attributes and M-GRA method is applied to determine AGV selection utility index.

Valli and Jeyasehar (2012) presented a comparative study of equipment selection for construction project using AHP and GA (genetic algorithm). The problem is addressed to select the most appropriate model of equipment in each different type consisting of 10 types and 42 models of equipment. L'Eglise et al. (2000) proposed MHE selection for paced assembly line by using PROMETHEE II. The use of method allowed a two-level selection involving generic equipment and a further refinement yielding the actual type of equipment to be used.

Several expert systems have been developed and adopted to assist the MHE selection problem such as EMHES, MAHSES and MHE Selection Expert System (MATHES). Malmborg et al. (1987) developed a prototype expert system for industrial truck type selection incorporating 47 type of industrial truck and including 17 attributes. Fisher, Farber, and Kay (1988) developed expert system for MHE selection called MATHES incorporating 16 possible alternatives.

Chu, Egbelu, and Wu (1995) introduced ADVISOR (A computer-aided MHE selection system) to help finding the most appropriate MHE among 77 of the most common equipment types used in material handling operations including transport, positioning, unit formal ion and storage. Two evaluation stages are generated in the selection process to meet the physical specifications feasibility and economic feasibility. First stage aims to find the feasible alternatives according to physical requirement defined by users. The final decision is made through second stage which assesses alternatives listed in the previous stage according to present worth (PW), equivalent uniform annual cost, return on investment and payback period (PP) methods.

Matson, Mellichamph, and Swaminathan (1992) developed expert consultant for in-plant transportation equipment (EXCITE) for MHE selection incorporating 35 equipment types and 28 attributes which are classified into material, move and method. Park (1996) presented an intelligent knowledge-based expert system known as intelligent consultant system for MHE selection and evaluation (ICMESE) for selection and evaluation of MHE suitable for movement and storage of materials in a manufacturing facility. Alternative evaluation is established according to AHP method addressed to 50 equipment types and 29 attributes.

Kulak, Satoglu, and Durmusoglu (2004), in the paper entitled 'multi-attribute MHE selection using information axiom', developed a decision support system (DSS) applying fuzzy multi-attribute decision making. The evaluation and selection of MHE are made by using fuzzy information axiom approach. DSS based on information axiom was also presented by Kulak (2005) for fuzzy multi-attribute selection of MHE (FUMAHES).

Expert system is also proposed to conveyor selection (Fonseca, Uppal, and Greene 2004). Possible choices are evaluated through scoring system by using weighted evaluation method and the expected value criterion for decision-making under risk. Hosni (1989) developed MHES (MHE selection) covering 30 types of equipment and 11 attributes including cost, area, material type, material weight and move characteristics and frequency. Rubinovitz and Karni (1994) presented selection of material handling and transfer equipment type using expert system. The specification of equipment is created in the form of a questionnaire and offering attributes and their possible values which are figured on the interface design.

Burt (2008) in her thesis related to the MHE selection developed an optimisation model for MHE selection in surface mining. A mixed integer linear programming (MILP) was formulated by considering several conditions such as single- and multi-period mining schedule, single- and multi-location and utilised cost-based equipment selection.

Zhang, Huang, and Zhu (2013) presented a research regarding the design of large ship material handling system. The analysis of material handling system for large ship and selection of the MHE were discussed further. Selection of the MHE was made based on the optimisation model in view of the two supply ways (shore-to-ship supply and ship-to-ship supply). The optimisation model was constructed as multi-objective and multi-constraint optimisation problem. Webster and Reed (1971) proposed a material handling system selection model according to integer linear programming (ILP). The model is intended to solve selection and assignment of MHE for minimising total cost of material handling. Like the problem presented by Webster and Reed (1971), Hassan, Hogg, and Smith (1985) also presented a selection and assignment of MHE by using optimisation. An integer programming is compiled to minimise total operating cost and investment cost.

A fuzzy goal programming model was applied to solve the machine tool selection and operation allocation problems in a flexible manufacturing system (Rai, Kameshwaran, and Tiwari 2002). The objective functions are addressed to minimise total cost of machining operation, material handling and set up. Genetic algorithm was also applied to get through the procedure of optimisation from fuzzy goal programming in order to obtain the final optimal solution. Bard and Feo (1991) proposed an algorithm for manufacturing equipment selection problem which is constructed into nonlinear cost minimisation. The decision is to determine the number of each machine type to purchase. The nonlinear integer programming is solved through transforming into MILP.

Paulo, Lashkari, and Dutta (2002) also come up with machine tool selection and operation allocation problems in a flexible manufacturing system by using optimisation model. The objective is to select an optimal group of materials handling equipment to be assigned to a cell. Sujono and Lashkari (2007) in a study entitled 'a multi-objective model of operation allocation and material handling system selection in FMS design' proposed integer programming model for selecting machines, assigning operations of part types to the selected machines and assigning MHE to transport the parts from machine to machine. The integer programming model is compiled for satisfying the two objectives that are minimisation of costs of operations, material handling, machine setups and maximisation of the part-equipment compatibility. Mahdavi, Shirazi, and Sahebjamnia (2011) developed an optimisation method namely a chaotic ant swarm simulation-based optimisation (CAS^{2}O) for controlling operation allocation and MHE selection in FMS. The objectives are to minimise total cost including operation, machine setup and material handling cost and to minimise the number of used machines. Haidar and Naoum (1996) presented a study regarding MHE selection in opencast mining. The optimisation model aims to seek the best equipment which minimises the total cost of operations. The model is solved by using genetic algorithm.

Braglia, Gabbrielli, and Miconi (2001) proposed a hybrid approach by using AHP and ILP to deal with material handling device selection in cellular manufacturing particularly. The problem involves several cells in manufacturing line. The integration is emerged to incorporate the investment decision. The overall weight of each alternative derived from AHP is applied to the ILP. It aims to achieve the maximum goodness of the material handling device selection. The results suggested that each cell is to be served by different material handling device which is the most appropriate one.

Integration of expert systems and MCDM approach was developed by Chan, Ip, and Lau (2001). The expert systems packaged called MHESA (MHE selection advisor) was built from three modules that they are database systems for MHE, a knowledge-based expert system for assisting MHE selection, and the third module performs the selection process of MHE by using AHP method which represents the integration of the expert system and MCDM approach.

Mirhosseyni, Hamid, and Webb (2009) proposed a hybrid method for MHE selection and assignment by using integrated fuzzy knowledge-based expert system and genetic algorithm. The selection process is conducted through two phases. First phase done according to fuzzy knowledge-based expert system aims to sort the feasible alternative and generate the most appropriate MHE types. Second phase, a genetic algorithm completes the optimum solution of the feasible alternatives in the previous phase.

Yilmaz and Dağdeviren (2011) proposed a combined approach for equipment selection using integrated fuzzy PROMETHEE and zero–one goal programming (ZOGP). Fuzzy PROMETHEE II is used to identify the best alternative and the accurate ranking of alternatives with respect to the evaluation criteria. The net flows as the result of fuzzy PROMETHEE II are defuzzied with Yager index. To integrate with ZOGP, the net flows are constructed into the goal function which is to minimise adjunct normalised net flow value and other goals which are to minimise cost, weight and volume are also constructed and solved simultaneously. Finally, the best alternative is derived based on the ZOGP satisfying four goals.

Momani and Ahmed (2011) proposed hybrid method for MHE selection by utilising Monte Carlo simulation combined with AHP. The element of pairwise comparison matrix constructed according to AHP is generally deterministic but in this study, it is generated from random variable instead which is probabilistic by using Monte Carlo simulation. The number of replications is generated for each pairwise comparison matrix. Alternative weight is determined by entering the result of simulation to AHP procedure. Ahmed and Lam (2014) also combined Monte Carlo simulation for multi-criteria MHE selection problem. Monte Carlo is combined with MAUT (multi-attribute utility technique) to capture the uncertainty associated with a single point estimate of the decision-maker's preferred judgement in evaluating the performance of alternative since it is defined as a random variable with a triangular distribution.

Chan, Ip, and Lau (2001) developed an expert system consultant for MHE selection called MHESA (MHE selection advisor) for the movement and storage in a manufacturing system. AHP is used to choose the best alternative. Welgama and Gibson (1995) also developed expert system combined with optimisation method for selection of material transport system. Appropriate possible alternatives are filtered based on the compatibility of tasks and technologies. Final decision to deal with the best alternative is derived based on ILP. Naoum and Haidar (2000) proposed a hybrid method for excavating and haulage equipment in opencast mining by using expert system and optimisation via genetic algorithm. The final selection is executed based on the minimisation of total operation cost.

3. Levels of MHE selection

Alternatives selection of MHE can be done by considering the one satisfying the requirements. But, evaluating the one satisfying the requirement would take the time and effort when the requirements are broken down into many criteria and generating the alternatives in high number will increase the complexity. Depending on which level of MHE is focused related to the MHE categories, types and models, MHE selection can be classified into three levels:

(1) High level: MHE selection problem is focused on seeking a suitable MHE among the categories, e.g. conveyors, cranes, industrial trucks, positioning equipment, etc.
(2) Intermediate level: MHE selection problem is focused on seeking a suitable type of MHE within a category, e.g. selecting the best alternatives of among conveyors category (chute or wheel or roller).
(3) Low level: MHE selection problem is focused on seeking a suitable model of MHE within a type, e.g. selecting the best alternatives of among hand pallet truck types in terms of dimension (Model PTH 50 27–48 or PTH 50 20–48 or PTH 50 20–36).

Selecting MHE as a low-level problem would be tougher because it can bring the result in too many possible alternatives. Capturing MHE selection problem from a high level does not narrow the number of possible alternatives enough. Whereas selecting MHE from intermediate level reduces the possible alternatives to be chosen from 15 to 50 possible types of MHE.

According to the levels of selection, the papers discussed in the literature review are classified in Table 1. It shows that among 42 papers, only 2 papers discuss low-level selection, 3 papers deal with high-level selection, and 34 papers mainly discuss MHE selection for intermediate level. For intermediate level selection, it is found that the focus of alternative selection indicates the distinction. Finally, in this review we divide the intermediate level into two different categories which are:

(1) Within-groups alternative selection: In this category, we focus on selecting a particular MHE type among categories within various types (e.g. the first evaluation suggests that industrial truck is the appropriate equipment category to perform the material transport, and then final decision will come up with the most appropriate type of industrial such as e-counterbalanced truck). The complexity of alternative selection is confronted by diversity of equipment categories and types.
(2) Specific-group alternative selection: The selection consideration is based on the most appropriate type of MHE if only initially a particular category of MHE is determined and specified (given a category of MHE to find the most appropriate type). For example, finding the most appropriate industrial truck type among IC-counterbalanced truck, E-counterbalanced truck, narrow aisle truck and E-pallet truck since the category is specified in the beginning of problem description. Unlike within-groups alternative selection, the alternative selection in specific-group category is less complex because it is only confronted by diversity of equipment type under given specific equipment category.

Such paper (3), (14), (15), (16), (17), (18), (19),(20), (21), (23), (30), (31), (33), (34), (37), (38), (40) and (42) attempting to seek the most appropriate type of equipment among categories, the papers are included in within-groups alternative selection. Specific-group alternative selection can be seen on the paper (1), (4), (5), (8), (9), (10), (11),(12), (13), (22), (36), (39) and (41) whose possible alternatives are focused on a particular type of equipment. Whereas, other papers in group of intermediate level such paper (2), (24), (25), (26), (29), (32) and (35) are not possible to be identified in which category of intermediate level problem is focused on, because the alternative is not mentioned explicitly in the paper.

Including the provided 50 equipment types, Park (1996) presented a list of MHE with 7 categories of move equipment and 4 categories of storage equipment. If being compared with other papers in this literature, it becomes a notable MHE selection incorporating a wide variety of alternative and of course, with the high number of possible alternative will lead to the more complexity (Karande and Chakraborty 2013). Malmborg et al. (1987) generated 47 possible alternatives in terms of industrial truck type. Fisher, Farber, and Kay (1988) provided 16 possible alternatives of general MHE equipment type among categories. Matson, Mellichamph, and Swaminathan (1992) elaborated 35 equipment types as possible choices for MHE selection.

4. Context of MHE selection problem

Experiencing the problem in terms of MHE or equipment selection, commonly we are confronted by the question of how to select the most appropriate one. The pre-determined condition related to the essential information and consideration to the problem should be clearly identified. It would be the base-line or input of defining and capturing the problem we focus on. The decision-maker as the owner of the problem or representative of the problem execution plays a

Table 2. Classification of paper according to the context of MHE selection problem.

Authors	Problem type			Problem objective	Problem content
	Multi-criteria	Multi-objective	Single-objective		
(1) Onut, Kara, and Mert (2009)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(2) Tuzkaya et al. (2010)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(3) Chakraborty and Banik (2006)	✓			Selection	MHE selection based on multi-criteria
(4) Lashgari et al. (2012)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(5) Karande and Chakraborty (2013)	✓			Selection	MHE selection based on multi-criteria
(6) Chamzini-Y and Shariati (2013)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(7) Valli and Jeyasehar (2012)	✓			Selection	MHE selection: a comparative study
(8) Mousavi et al. (2013)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(9) L'Eglise et al. (2000)	✓			Selection	MHE selection based on multi-criteria
(10) Lawrence and Blessing (2013)	✓			Selection	MHE selection based on multi-criteria
(11) Sawant, Mohite, and Patil (2011)	✓			Selection	MHE selection based on multi-criteria
(12) Maniya and Bhatt (2011)	✓			Selection	MHE selection based on multi-criteria
(13) Fonseca, Uppal, and Greene (2004)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(14) Fisher, Farber, and Kay (1988)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(15) Kulak, Satoglu, and Durmusoglu (2004)	✓			Selection	MHE selection based on multi-criteria and knowledge base under fuzzy environment
(16) Kulak (2005)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(17) Park (1996)	✓			Selection	MHE selection based on multi-criteria
(18) Matson, Mellichamph, and Swaminathan (1992)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(19) Hosni (1989)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(20) Chu, Egbelu, and Wu (1995)	✓			Selection	MHE selection based on multi-criteria and knowledge base
(21) Rubinovitz and Karni (1994)	✓			Selection	MHE selection problem under multi-criteria
(22) Malmborg et al. (1987)	✓			Selection	MHE selection problem under multi-criteria
(23) Welgama and Gibson (1995)	✓		✓	Selection	MHE selection is based on multi-criteria and an objective (investment and operation cost minimisation) with constraints
(24) Burt (2008)			✓	Selection and Assignment	MHE selection for cost minimisation with constraints
(25) Zhang, Huang, and Zhu (2013)		✓		Selection and Determination Number of equipment	Multi-problems: MHE selection (for cost minimisation and fitness maximisation with constraints) and determination of number of MHE (for load carrying maximisation)

(*Continued*)

Table 2. (*Continued*).

Authors	Problem type			Problem objective	Problem content
	Multi-criteria	Multi-objective	Single-objective		
(26) Rai, Kameshwaran, and Tiwari (2002)		✓		Selection and Assignment	Multi-problems: machine-tool selection and operation allocation in FMS
(27) Paulo, Lashkari, and Dutta (2002)		✓		Selection and Assignment	Multi-problems: operation allocation (cost minimisation) and MHE selection (maximisation of MHE ability)
(28) Sujono and Lashkari (2007)		✓		Selection and Assignment	A multi-objective problem operation allocation and MHE selection (cost minimisation and maximisation of MHE ability)
(29) Hassan, Hogg, and Smith (1985)			✓	Selection and Assignment	MHE selection and assignment with an objective for minimising operation and investment cost
(30) Webster and Reed (1971)			✓	Selection	MHE selection with an objective to minimise the total cost of material handling
(31) Mahdavi, Shirazi, and Sahebjamnia (2011)		✓		Selection and Assignment	MHE selection and operation allocation with two objectives (minimising the machine operation, material handling and machine setup costs, and maximising the machine utilisation)
(32) Bard and Feo (1991)			✓	Selection	Equipment selection with an objective to minimise total discounted cost of machines
(33) Haidar and Naoum (1996)			✓	Selection	Equipment selection with an objective to minimise total cost of operation
(34) Braglia, Gabbrielli, and Miconi (2001)	✓		✓	Selection and Assignment	MHE selection based on multi-criteria and an objective
(35) Yilmaz and Dağdeviren (2011)	✓	✓		Selection	MHE selection based on multi-criteria and multi-objective
(36) Momani and Ahmed (2011)	✓			Selection	MHE selection based on multi-criteria
(37) Mirhosseyni, Hamid, and Webb (2009)	✓		✓	Selection	MHE selection based on multi-criteria under fuzzy environment and objectives
(38) Chan, Ip, and Lau (2001)	✓			Selection	MHE selection based on multi-criteria
(39) Hadi-Vencheh and Mohamadghasemi (2014)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment
(40) Ahmed and Lam (2014)	✓			Selection	MHE selection based on multi-criteria
(41) Naoum and Haidar (2000)	✓		✓	Selection	MHE selection based on multi-criteria and an objective (cost minimisation)
(42) Ghazikalayeh et al. (2013)	✓			Selection	MHE selection based on multi-criteria under fuzzy environment

major contribution to decide the approach of decision-making. Therefore, to deal with the context of MHE selection problem, capturing the problem under provided information and existing condition in the selection consideration will be the basis for determining problem definition. The problem regarding MHE or equipment selection can be classified into three contexts as shown in Table 2 which refers to the 42 papers. The depth-explanation is prepared in the following.

4.1 *Multi-criteria (Multi-attribute) selection problem*

The MHE selection is defined as multi-criteria problem if the alternatives are assessed under criteria. In this context, information and condition as the basis of compiling the criteria and evaluation are measured based on the intuition, opinion, knowledge and expertise of the decision-maker. Such MHE selection problem presented by Chakraborty and Banik (2006) consider three criteria (material, move, method) involving 11 sub-criteria for alternative evaluation. Among papers (1)–(23) and (34)–(42) dealing with multi-criteria selection problem, paper (17) presented by Park (1996) becomes a remarkable multi-criteria problem so far because it covers 49 attributes (criteria) for alternative evaluation.

4.2 *Multi-objective selection problem*

According to this context, alternative is selected based on more than one objective. Multi-objective selection problem requires that all objectives must be achieved without sacrificing another objective. The information and condition which are quantifiable are constructed into objective functions and constraints which generally follow the rule of mathematical model. The selection of MHE may consider the one which satisfies the whole objective in terms of cost minimisation and fitness maximisation (Zhang, Huang, and Zhu 2013) or in terms of minimisation of machine operation, material handling and machine setup costs, and maximisation of machine utilisation (Mahdavi, Shirazi, and Sahebjamnia 2011).

4.3 *Single-objective selection problem*

Slightly similar to multi-objective selection problem which use mathematical model to evaluate alternatives, MHE selection is decided based on an objective. All papers which define the problem into single-objective selection problem (24, 29, 30, 32 and 33) rely on the final decision addressed to the cost minimisation except paper (34) proposed by Braglia, Gabbrielli, and Miconi (2001). Braglia, Gabbrielli, and Miconi (2001) used a different consideration to express the most appropriate MHE. Instead of cost consideration, they consider all feasibility aspects presented by maximisation of global goodness (fitness) of MHE. The aspects are derived based on the result of alternatives evaluation under multi-criteria which consist of not only cost consideration but also benefits (advantages) and compatibility.

Regardless of concentrated context of MHE selection problem mentioned above, exclusively we would like to highlight the multi-context problem. Multi-context problem can be found in the papers represented by Welgama and Gibson (1995), Yilmaz and Dağdeviren (2011) and Mirhosseyni, Hamid, and Webb (2009). Basically, their study considers both criteria and objective dealing with qualitative and quantitative aspects in order to achieve technical feasibility and economic feasibility. Welgama and Gibson (1995) at initial selection process filtered the compatible possible alternative in accordance with technical feasibility. Then, the compatible alternatives are evaluated with respect to the economic feasibility. To measure the economic feasibility, the considerations are based on the objectives which are cost minimisation and utilisation maximisation. Yilmaz and Dağdeviren (2011) incorporated the integration of criteria and objectives by using systematic procedure. In the first phase, alternatives are evaluated under multi-criteria. Then, the alternative weight is obtained and translated into an objective function. Finally, technical feasibility and economic feasibility are measured simultaneously based on the minimum weight, cost and volume. Mirhosseyni, Hamid, and Webb (2009) also in the first phase applied initial procedure to filter appropriate possible alternatives with respect to the evaluation criteria. And then, in the second phase final decision is made simultaneously to select the most appropriate type of MHE which is qualified for minimisation of cost, appropriateness factors and varieties.

5. MHE selection approaches

There is a correspondence between the context of MHE selection problem and the approach of solution. Each context leads to the particular approach which appropriates for solving the problem. According to the studies, there are four major approaches which can be used to solve MHE or equipment selection problem. It is summarised in Table 3 and explained in the following.

5.1 *MCDM approach*

MHE selection problem can properly adopt MCDM approach when the problem is defined as the context of multi-criteria selection problem. MCDM approach relies on the alternative assessment under evaluation criteria. Some of often used methods included in MCDM approach which attract researchers for MHE selection are AHP, ANP, TOPSIS and PROMETHEE. Nevertheless, there are still many more MCDM methods focused on another topic which are not captured in this literature review. In today's more sophisticated decision-making, the ambiguity, vagueness, uncertainty and subjectivity of information and opinion are tackled by utilising fuzzy logic on the assessment and evaluation. Fuzzy logic has been fully paid attention by the researchers and becomes a substantive unity in MCDM. Such paper (1), (2), (4), (6), (8) incorporate decision-making under fuzzy environment by using fuzzy logic which is expressed into TFN (triangular fuzzy number).

Table 3. MHE selection approaches.

Authors	MHE selection approach				Methods/Tools
	MCDM	Artificial intelligence	Optimisation	Hybrid	
(1) Onut, Kara, and Mert (2009)	✓				Fuzzy ANP, Fuzzy TOPSIS
(2) Tuzkaya et al. (2010)	✓				Fuzzy ANP, Fuzzy PROMETHEE
(3) Chakraborty and Banik (2006)	✓				AHP
(4) Lashgari et al. (2012)	✓				Fuzzy AHP, Fuzzy ANP, Fuzzy TOPSIS
(5) Karande and Chakraborty (2013)	✓				WUTA
(6) Chamzini-Y and Shariati (2013)	✓				Fuzzy AHP, Fuzzy TOPSIS
(7) Valli and Jeyasehar (2012)	✓	✓			A comparative study of AHP and GA
(8) Mousavi et al. (2013)	✓				Fuzzy grey group compromise ranking method
(9) L'Eglise et al. (2000)	✓				PROMETHEE II
(10) Lawrence and Blessing (2013)	✓				WUTA
(11) Sawant, Mohite, and Patil (2011)	✓				PSI, TOPSIS
(12) Maniya and Bhatt (2011)	✓				AHP, M-GRA
(13) Fonseca, Uppal, and Greene (2004)		✓			Weighted evaluation method (Expert system)
(14) Fisher, Farber, and Kay (1988)		✓			MATHES (expert systems)
(15) Kulak, Satoglu, and Durmusoglu (2004)		✓			MHAD (DSS)
(16) Kulak (2005)		✓			FUMAHES (DSS)
(17) Park (1996)				✓	ICMESE (expert system and AHP)
(18) Matson, Mellichamph, and Swaminathan (1992)		✓			EXICTE
(19) Hosni (1989)		✓			MHES
(20) Chu, Egbelu, and Wu (1995)		✓			ADVISOR
(21) Rubinovitz and Karni (1994)		✓			Expert systems
(22) Malmborg et al. (1987)		✓			Expert systems
(23) Welgama and Gibson (1995)				✓	Expert system and optimisation model
(24) Burt (2008)			✓		MILP
(25) Zhang, Huang, and Zhu (2013)			✓		Multi-objective optimisation model
(26) Rai, Kameshwaran, and Tiwari (2002)			✓		Fuzzy goal programming via GA
(27) Paulo, Lashkari, and Dutta (2002)			✓		0–1 integer programming
(28) Sujono and Lashkari (2007)			✓		0–1 integer programming via e-constraint
29) Hassan, Hogg, and Smith (1985)			✓		Integer programming
(30) Webster and Reed (1971)			✓		Integer programming
(31) Mahdavi, Shirazi, and Sahebjamnia (2011)			✓		MOMILP via Chaotic ant swarm simulation based optimisation (CAS^2O)
(32) Bard and Feo (1991)			✓		MILP
(33) Haidar and Naoum (1996)			✓		Optimisation model via GA
(34) Braglia, Gabbrielli, and Miconi (2001)				✓	AHP and ILP
(35) Yilmaz and Dağdeviren (2011)				✓	Fuzzy PROMETHEE and ZOGP
(36) Momani and Ahmed (2011)				✓	AHP and Monte Carlo Simulation
(37) Mirhosseyni, Hamid, and Webb (2009)				✓	Expert systems and GA
(38) Chan, Ip, and Lau (2001)				✓	MHESA (Expert systems and AHP)

(*Continued*)

Table 3. (*Continued*).

Authors	MHE selection approach: MCDM	Artificial intelligence	Optimisation	Hybrid	Methods/Tools
(39) Hadi-Vencheh and Mohamadghasemi (2014)	✓				Fuzzy weighted average, Fuzzy VIKOR
(40) Ahmed and Lam (2014)				✓	MAUT and Monte Carlo simulation
(41) Naoum and Haidar (2000)				✓	Expert system and GA
(42) Ghazikalayeh et al. (2013)	✓				Fuzzy ANP, Fuzzy TOPSIS

5.2 *Artificial intelligent approach*

In this paper, artificial intelligent approach is interpreted as computerised technique which consults selection problem by using knowledge base and simulates the intelligence of experts. The most common methods of artificial intelligent for assisting problem solving of MHE or equipment selection are expert system and DSS. Expert system is more applicable for complex system because of its superiority as an efficient programme in capturing the human expertise (Welgama and Gibson 1995). The technology development in terms of software package has highly contributed to the model of expert system and decision support method. Until the year 2005, there have been several software packages consulting MHE or equipment selection. In this paper, Table 4 is prepared in order to discuss the more attention on artificial intelligent approach by exploring the software package which has been developed for consulting MHE or equipment selection.

5.3 *Optimisation approach*

This approach aims to achieve optimal solution corresponding to goal or objective for either single-objective or multi-objective selection problem within any existence of boundaries or limit in accordance with the mathematical model. Optimisation approach is able to be used when the information and condition of the system can be quantified

Table 4. The software package of intelligence systems for MHE selection.

No	Software package	Year	Developer
1	SEMH (Selection of Equipment for Material Handling)	1984	Hatem Nasr
2	Prototype expert system for industrial truck type selection	1987	C. J. Malmborg, M. H. Agee Simons and J. V. Choudhary
3	MATHES (Material Handling Equipment Selection Expert System)	1988	E. L. Fisher, J. B. Farber and M. G. Kay
4	MAHDE	1988	P. Gabbert and D. Brown
5	MHES (Material Handling Equipment Selection)	1989	Y. A. Hosni
6	MATHES II (Material Handling Equipment Selection Expert System II)	1990	W. L. Honng
7	EXCITE (Expert Consultant for in Plant Transportation Equipment)	1990	S. R. Swaminathan, J. O. Matson and J. M. Mellichamp
8	EMHES (Expert System for Material Handling Equipment Selection)	1992	F. Attia, Hosny and Ramu
9	MHESVES (Material-Handling Equipment Selection via An Expert System)	1992	J. H. Bookbinder and D. Gervais
10	Prototype Expert Systems For AGV Selection	1992	J. T. Luxhoj, S. Hellman, S. R. Lee and J. Perdek
11	ADVISOR (A computer-aided material handling equipment selection system)	1995	H. K. Chu, P. J. Egbelu and C. T. Wu
12	ICMESE (Intelligent Consultant System for Material Handling Equipment)	1996	Y. B. Park
13	MAHSES (Material Handling Selection Expert System)	1997	K. S. Kim and J. K. Eom
14	MHESA	2001	F. T. S. Chan, R. W. L. Ip and H. Lau
15	MHAD	2004	O. Kulak and C. Kahraman
16	Prototype expert system for industrial conveyor selection	2004	D. J. Fonseca, G. Uppal, and T. J. Greene
17	FUMAHES	2005	O. Kulak
18	DESIGNER (web-based integrated material handling system)	2005	C. Cho and P. J. Egbelu

and measured well. Several branches of integer programming are widely applied for MHE or equipment selection such as ILP (Hassan, Hogg, and Smith 1985; Webster and Reed Jr. 1971), MILP (Bard and Feo 1991; Burt 2008), multi-objective mixed integer linear programming (MOMILP) (Mahdavi, Shirazi, and Sahebjamnia 2011; Zhang, Huang, and Zhu 2013), 0–1 integer programming (Paulo, Lashkari, and Dutta 2002; Sujono and Lashkari 2007). Moreover, another optimisation approach as well as goal programming has been also applied (Rai, Kameshwaran, and Tiwari 2002).

5.4 *Hybrid approach*

Hybrid approach combines two different approaches such as artificial intelligent approach and optimisation approach (Mirhosseyni, Hamid, and Webb 2009; Welgama and Gibson 1995), artificial intelligence approach and MCDM approach (Chan, Ip, and Lau 2001; Park 1996), MCDM approach and optimisation approach (Braglia, Gabbrielli, and Miconi 2001; Yilmaz and Dağdeviren 2011) or with another approach (which is not defined in this literature) (Ahmed and Lam 2014; Momani and Ahmed 2011). By viewing the problem at multi-context, hybrid approach intends to incorporate both criteria and objective as well for a comprehensive decision-making. Hybrid approach can enhance the inferiority of particular method which may lead to the improper decision if it stands alone. Among 42 papers, only few papers are concerned with hybrid approach. It might be triggered (particularly for MHE or equipment selection) by the complexity of capturing the problem, complexity on the calculation procedure of the combined method, and difficulty in integrating both approaches.

6. Conclusion

MHE selection needs an effort since the problem becomes more complex. All aspects are really focused for throughout selection process. Principally, the selection process is supposed to respect the technical feasibility and economic feasibility. In this paper, a review of MHE selection problem from 42 papers which is discussed in each session including level of selection, context of selection and selection approach shows the diversity. Most of the researchers define MHE or equipment selection based on multi-criteria problem. To deal with it, MCDM approach and intelligence approach are proposed to find the solution which generally relies on the knowledge and human expert. While, the solution of a single-objective and multi-objective problem are obtained by using optimisation approach since the aspects are measured objectively. Among four major approaches, artificial intelligence as well as expert system is superior in providing more possible alternatives in terms of number of MHE category and type for assisting multi-criteria problem. It is enormously useful for particularly within-group MHE selection problem because the problem always brings unknown consideration in current situation dealing with equipment category and it is also applicable most likely for specific-group MHE selection problem since variety of equipment is usually wide. The ultimate expert system application on MHE selection can be distinguished in accordance with its ability in providing the generation of a wide variety of equipment and attribute evaluation and guiding systematically DM in order to seek the best-fit MHE efficiently. Moreover, it contributes numerously to the ease of decision support. So far, there have been 50 equipment types covered at most. The number may increase as the innovation of MHE technology grows rapidly. The use of MHE in today’s technology will compel any forthcoming developed expert system software package to provide up-to-date equipment. But, not many of the expert systems incorporate economic feasibility with objective measurement. It would result in nonoptimal solution for cost consideration.

In this review, most of the high-level selection problems under multi-criteria whose number of alternative is small applied MCDM approach. It becomes reasonable since MCDM approach is very effective to tackle few alternatives under human’s judgement. The special issue on MHE selection and assignment problem or determination equipment number always needs explicit decision to decide which equipment should perform material handling operation *i*. The literature proofs that optimisation is the sole solution to solve the assignment problem in the view of its effectiveness in searching the feasible alternative by using 0–1 integer variable.

The hybrid approach associating optimisation integration for MHE selection should be more concerned and developed because in view of the superiority in translating and measuring the aspect particularly cost consideration quantitatively and objectively. For future research work, it is necessary to be suggested that the combination of optimisation and another method will be a superior approach if the integration can incorporate simultaneously both the technical feasibility and economic feasibility. As we know that based on the papers reviewed dealing with optimisation approach, generally it only reveals cost consideration.

To conclude the review, it can be declared that there is a link in MHE problem since it is captured in accordance with focus of levels, context and approach.

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