A Decision-Making Framework using a Preference Selection Index Method for Automated Guided Vehicle Selection Problem

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ABSTRACT
Automated guided vehicle selection, a key concern in manufacturing environment is a complex, difficult task and requires extensive technical knowledge with systematic analysis. It is invaluable to justify the selected equipment before actual implementation of the same. This paper presents a logical procedure to select automated guided vehicle in manufacturing environment for a given application. The procedure is based on preference selection index (PSI) and TOPSIS with entropy weights method. An automated guided vehicle selection index is proposed that evaluates and ranks automated guided vehicle for the given application. We demonstrate the effectiveness and feasibility of methods with an illustration.

Keywords
PSI, TOPSIS, Automated guided vehicle

1. INTRODUCTION
Automated guided vehicles (AGVs) are among the fastest growing classes of equipment in the material handling industry. They are battery-powered, unmanned vehicles with programming capabilities for path selection and positioning. They are capable of responding readily to frequently changing transport patterns and they can be integrated into fully automated intelligent control systems. These features make AGVs a viable alternative to other material handling methods, especially in flexible environments where the variety of products processed results in fluctuating transport requirements.

The decision to invest in AGVs and other advanced manufacturing technology has been an issue in the practitioner and academic literature for over two decades. An effective justification process requires the consideration of many quantitative and qualitative attributes. AGV selection attribute is defined as a factor that influences the selection of an automated guided vehicle for a given application. These attributes include: costs involved, floor space requirements, maximum load capacity, maximum travel speed, maximum lift height, minimum turning radius, travel patterns, programming flexibility, labor requirements, expansion flexibility, ease of operation, maintenance aspects, payback period, reconfiguration time, company policy, etc.

In the past very few researches had been reported for selection of AGV using multi attribute decision-making methods except [1]. A multi attribute analysis is a popular tool to select best alternative for given applications and the methods are simple additive weighted (SAW) method, weighted product method (WPM),technique for order preference by similarity to ideal solution (TOPSIS), Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method, analytical hierarchy process (AHP), graph theory and matrix representation approach (GTMA), etc [2, 3, 4].

To help address the issue of effective evaluation and justification of material handling equipments, various mathematical and systems modeling approaches have been proposed. Park [5] proposed an intelligent consultant system for material handling equipment selection, including 50 equipment types and 29 attributes, i.e., move attributes, material characteristics, operation requirements and area constraints. Fisher et al. [6] introduced MATHES, the material handling equipment selection expert systems, for the selection of material handling equipment from 16 possible choices. MATHES incorporated 172 rules dealing with path, volume of flow, sizes of unit, and distance between departments as parameters. MATHES-II had been provided with the same procedure as MATHES. However, MATHES-II had a larger working scope and greater consultation functions. Chan et al. [7] described the development of an intelligent material handling equipment selection system called material handling equipment selection advisor (MHESA). In addition to above approaches Fonseca et al. [8] developed expert decision support systems for the selection of material handling equipments. One of the successful applications of experts systems was SEMH, selection of equipment for material handling. SEMH searches its knowledge base to recommend the degree of mechanization, and the type of material handling equipment to be used, based on various characteristics, i.e., type, weight, size, etc. Kulak et al. [9] developed a decision support system called FUMAHES-fuzzy multi-attribute material handling equipment selection. FUMAHES consists of a database, a rule-based system, and multi-attribute decision-making modules. In other application, Chakraborthy et al. [10] focused on the application of the AHP technique in selecting the optimal material handling equipment for a specific material handling equipment type. The relative importance of each criterion, sub criterion and sub-sub criteria was measured using pair-wise comparison matrices, and the overall ranking of each alternative equipment was then determined.

There are several limitations of existing expert systems for material handling equipment selection. Most of them are incomplete prototypes that consider only a limited number of equipment types and attributes. Another limitation of existing material handling selection systems is the lack of flexibility in dealing with selection attributes such as economic and strategic. However, there is a need for a simple, systematic and logical scientific method or mathematical tool to guide user organizations in taking a proper decision. To the best of our knowledge, no-one has implemented a PSI method for selection of AGV for a given application. The objectives of this paper are to illustrate the PSI method for AGV selection using an example and compare the results with TOPSIS method.

2. PSI PROCEDURE

The steps of PSI procedure can be expressed as follows [11]:
Step 1: Identify the goal; find out all possible alternatives, selection attribute and its measures for the given application.

Step 2: Construct a decision matrix. Assume there m alternatives (AGVs) A_i (i = 1, 2 . . . , m) to be evaluated against n selection attributes C_j (j = 1, 2 . . . , n). The decision matrix D = x_{ij}, i = 1, 2. . , m; j = 1, 2. . . , n as shown below represents the utility ratings of alternative A_i with respect to selection attribute C_j.

$$D=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad (1)$$

Step 3: The process of transforming attributes value into a range of 0-1 is called normalization and it is required in multi attribute decision making methods to transform performance rating with different data measurement unit in a decision matrix into a compatible unit. The normalized decision matrix is constructed using Eq.(2) and (3). If the expectancy is the larger-the-better (i.e. profit), then the original attribute performance can be normalized as follows:

$$R_{ij}=\frac{x_{ij}}{x_j^{\max}} \qquad (2)$$

If the expectancy is the-smaller-the-better (i.e. cost), then the original attribute performance can be normalized as follows:

$$R_{ij}=\frac{x_j^{\min}}{x_{ij}} \qquad (3)$$

where x_{ij} is the attribute measures (i = 1, 2, 3, ... , N and j = 1, 2, 3, . . . , M)

Step 4: Compute preference variation value (PV_j). In this step, preference variation value (PV_j) or each attribute is determined with concept of sample variance analogy using following equation:

$$PV_j=\sum_{i=1}^{n}[R_{ij}-\overline{R}_{ij}]^2 \qquad (4)$$

where R_j is the mean of normalized value of attribute j and

$$\overline{R}_j=\frac{1}{N}\sum_{i=1}^{n}R_{ij}$$

Step 5: Determine overall preference value (Ψ_j). In this step, the overall preference value (Ψ_j) is determined for each attribute. To get the overall preference value, it is required to find deviation (Φ_j) in preference value (PV_j) and the deviation in preference value for each attribute is determined using the following equation:

$$\phi_j=1-PV_j \qquad (5)$$

and overall preference value (Ψ_j) is determined using following equation:

$$\psi_j=\frac{\phi_j}{\sum_{j=1}^{m}R_{ij}} \qquad (6)$$

The total overall preference value of all the attributes should be one, i.e. $\sum\phi_j=1$.

Step 6: Obtain preference selection index (I_i). Now, compute the preference selection index (I_i) for each alternative using following equation:

$$I_i=\sum_{j=1}^{m}(R_{ij}\times\psi_j) \qquad (7)$$

Step 7: After calculation of the preference selection index (I_i), alternatives are ranked according to descending or ascending order to facilitate the managerial interpretation of the results, i.e. an alternative is ranked/selected first whose preference selection index (I_i) is highest and an alternative is ranked/selected last whose preference selection index (I_i) is the lowest and so on.

3. TOPSIS PROCEDURE

The TOPSIS (technique for order performance by similarity to ideal solution) was first developed by Hwang & Yoon [2]. According to this technique, the best alternative would be the one that is nearest to the positive-ideal solution and farthest from the negative ideal solution. The positive ideal solution is a solution that maximizes the benefit attribute and minimizes the cost attribute, whereas the negative ideal solution maximizes the cost attribute and minimizes the benefit attribute. In short, the positive-ideal solution is composed of all best values attainable from the attribute, whereas the negative ideal solution consists of all worst values attainable from the attribute.
The calculation processes of the method are as following:
Step 1: Establish the normalized performance matrix: The purpose of normalizing the performance matrix is to unify the unit of matrix entries. Assume the original performance matrix is

$$x=(x_{ij}) \qquad \forall i,j \qquad (8)$$

where x_{ij} is the performance of alternative i to attribute j.

Step2: Create the weighted normalized performance matrix.
TOPSIS defines the weighted normalized performance matrix as:

$$V = (V_{ij}) \quad \forall i, j$$
$$V_{ij} = w_{ij} \times r_{ij} \quad \forall i, j \tag{9}$$

where w_j is the weight of attribute j.

Step3: Determine the ideal solution and negative ideal solution The ideal solution is computed based on the following equations:

$$A^{+} = \left\{(\max V_{ij} \,/\, j \in J), (\min V_{ij} \,/\, j \in J'), i = 1,2,....,m\right\} \tag{10a}$$

$$A \;\; = \left\{(\min V_{ij} \,/\, j), (\min V_{ij} \,/\, j \in J'), i = 1,2,....,m\right\} \tag{10b}$$

Where j = {j = 1, 2,…, n/ j belongs to benefit attribute}; j = {j = 1, 2,… n/j belongs to cost attribute}:

Step4: Calculate the distance between idea solution and negative ideal solution for each alternative:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} (Vij - V_j^{+})^2} \quad i = 1,2,......,m \tag{11}$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} (Vij - V_j^{-})^2} \quad i = 1,2,......,m \tag{12}$$

Step5: Calculate the relative closeness to the ideal solution of each alternative

$$C_i^{+} = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \qquad i = 1,2,......,m \tag{13}$$

where $0 \le c_i^{*} \le 1$ that is, an alternative i is closer to A_i^{*} as C_i^{*} approaches to 1.

Step6: Rank the preference order. A set of alternatives can be preference ranked according to the descending order of C_i^{*} .

4. ILLUSTRATIVE EXAMPLE

An industry problem is selected to demonstrate and validate the PSI method for evaluation of AGV for a given industrial application. The selected company is a medium sized manufacturing enterprise, which is located in Maharashtra, India. The company is an automated manufacturing company dealing with an enormous volume and varieties of products and supplies it to oil refineries. The company wants to purchase a few AGVs to improve on the productivity by reducing its work in process inventory and to replace its old material handling equipment. The decision of which AGV to select is very complex because AGV performance is specified by many parameter for which there are no industry standards. There are more than 114 AGVs from 76 companies worldwide available in market. Above mentioned industry has supplied information about the requirement from material handling equipment which is given below.

1. Load to be carried is greater than 3628 kg.
2. Maximum lift height is 150 mm.
3. Battery capacity has to be more than 200 amp-hr.
4. Budgetary provisions is less than $20,000.

Among nineteen attributes available with system, we have considered for this analysis nine attributes and sixteen feasible AGV models. Among nine attributes, four attributes viz., length(L), Width(W), Height(H) of AGV, maximum load capacity (MLC), maximum travel speed (MS), Battery capacity (B), maximum lift height (LH), Lift speed (LS) attributes are beneficial attributes, i.e. higher values are desired and position accuracy(P)is non-beneficial attributes, i.e. lower values are desired.

Table 1. AGV system selection attributes data

AGVs	L	W	H	MLC	MS	B	P	LH	LS
HK40/O	2.03	0.91	1.52	3628.74	91.44	345.00	6.35	6.10	45.00
F150	2.64	1.77	2.26	3628.74	67.05	345.00	9.53	1.83	17.50
P330	2.98	1.49	2.46	3628.74	60.96	560.00	9.53	1.83	16.50
P325	4.63	1.85	2.54	18143.69	60.96	240.00	9.53	1.83	11.00
C530	0.98	1.57	0.46	18143.69	45.72	300.00	12.70	1.83	12.00
DT-40	1.28	0.91	1.60	3628.74	60.96	345.00	25.40	1.83	12.00
DT-60	1.66	2.45	1.37	3628.74	60.96	345.00	25.40	1.83	12.00
RLV/N	2.79	2.03	1.68	6096.28	119.80	300.00	6.35	3.00	30.00
AD100	4.04	3.56	3.25	11339.81	54.86	300.00	12.70	1.83	12.00
AD130	3.68	3.05	2.67	11339.81	54.86	300.00	12.70	1.83	12.00
T-20	2.92	1.73	1.78	4535.92	41.15	350.00	6.35	1.83	12.00
T-40	4.53	2.44	2.49	9071.85	30.48	350.00	6.35	1.83	12.00
T-60	5.08	2.79	2.62	13607.77	24.39	350.00	6.35	1.83	12.00
T-100	5.84	3.20	3.30	22679.62	18.29	350.00	6.35	1.83	12.00

UV-200	3.89	3.40	4.62	9071.85	45.72	345.00	9.53	1.53	6.00
UV-600	5.59	4.88	5.84	27215.54	15.24	345.00	9.53	1.53	2.50

Table 2. AGV selection index values

AGVs	PSI	TOPSIS	Average of Methods
HK40/O	0.685	0.524	0.605
F150	0.448	0.743	0.595
P330	0.565	0.752	0.659
P325	0.324	0.605	0.464
C530	0.461	0.647	0.554
DT-40	0.428	0.724	0.576
DT-60	0.476	0.717	0.596
RLV/N	0.549	0.589	0.569
AD100	0.418	0.663	0.541
AD130	0.409	0.684	0.547
T-20	0.405	0.824	0.615
T-40	0.394	0.746	0.570
T-60	0.385	0.677	0.531
T-100	0.364	0.545	0.454
UV-200	0.432	0.702	0.567
UV-600	0.355	0.505	0.430

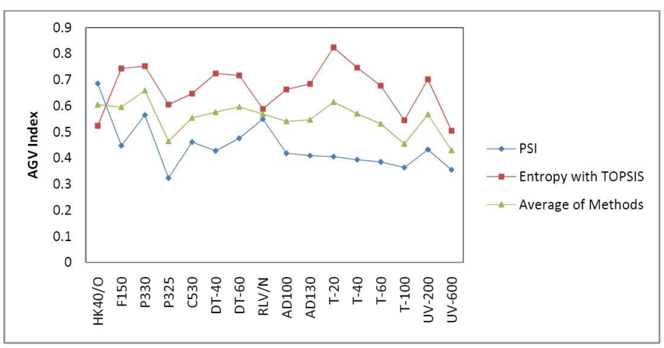

Figure 1. AGV index comparison using PSI/ Entropy with TOPSIS and average of two methods

The next step is to represent all the information available of attributes in the form of a decision matrix as shown in eq 1. The data given in table 1 are represented as matrix D_{16x9}. But the matrix is not shown here as it is nothing but the repetition of data given in Table 1. Next the procedure given in section 2 is followed to calculate the values of preference selection index (I_i) similarly procedure given in section 3 is used for TOPSIS method. AGVs are ranked according to descending order to facilitate the managerial interpretation of the results. The results obtained are presented using the PSI and compare with TOPSIS method with entropy weight approach as shown in Table 2. The AGV selection index is calculated for sixteen AGV models, which are used to rank the AGVs. The AGVs are arranged in the descending order of their selection index for TOPSIS method.

From Fig. 1, it can be seen that the match between the PSI, TOPSIS and Average of two methods is good. The top two ranked AGV for PSI is HK40/O and P330, for TOPSIS is T20 and P330, and average of two methods gives P330 as first and T20 second ranked AGV. From the above values it is understood that the AGV designated as P330 and T20 are the right choice for the given industrial application under above methods. We need further scrutiny with respect to there attribute data, so that best AGV can be selected. The proposed approach in the present work ranks the alternatives in a single model. The proposed AGV selection procedure using a PSI, TOPSIS with entropy and average of two methods is a relatively easy and simple approach and can be used for any type of decision making situations. These methodologies avoid the approach of relative importance of attributes to rank the alternatives.

5. CONCLUSIONS

A PSI methodology based on MADM methods was suggested for the selection of AGV for a given application. These are general methods and are applicable to any type of material handling system. Unlike conventional methods which adopt only one of the assessment attribute, the proposed method considers the entire attribute simultaneously and gives the correct and complete evaluation of the AGV to be selected. The proposed AGV selection index evaluates and ranks AGVs for the given application. The methodology developed also helps in not just selecting the best AGV, but it can be used for any number of quantitative and qualitative AGV selection attributes simultaneously and offers a more objective and simple AGV selection approach. Further, the PSI results are compared with TOPSIS with entropy and average of two methods and decision regarding best AGV can be made. The methods considered are relatively simple and can be used for any type of decision making situations. It may also be worthwhile to incorporate all other multi attribute decision methods to validate the results.

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