A UNIFIED DECISION FRAMEWORK FOR INVENTORY CLASSIFICATION THROUGH GRAPH THEORY

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ABSTRACT

Conventionally, a traditional ABC analysis based on a single criterion of annual consumption cost is employed in industry to facilitate classification of inventory items. However, other criteria may be important in inventory classification such as lead time, item criticality, storage cost, etc. Hence, for situations like this many multiple criteria decision-making methods are available and the Analytic Hierarchy Process (AHP) is a popular one. The present article demonstrates a new approach by integrating Graph Theory (GT) and the Analytic Hierarchy Process (AHP) as a decision analysis tool for multi-criteria inventory classification. In this paper, 47 disposable items used in a respiratory therapy unit of a hospital were considered for a case study. Output of this hybrid method shows more precise results than that of either traditional ABC or the AHP classification methods. As the proposed decision analysis tool is a simple, logical, systematic and consistent method, it may be recommended for application in diverse industries handling multi-criteria inventory classification systems.

Keywords: ABC classification; graph theory; Analytic Hierarchy Process; inventory classification; graph theory-AHP integration; hybrid system

1. Introduction

Inventories are resources of any kind that have an economic value. Appropriate inventory control is necessary because efficiency and cost of its operation are generally largely

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affected by both its excess and shortage. Inventory control is thus essential to determine the item(s) to indent (i.e., to order) along with its quantity, time to indent and the optimum stock to maintain so that purchasing and storage costs are reduced to a minimum (Mallick, Dutta, & Das, 2012).Hence, the planning and control of inventory attract substantial attention from the management in an organization.

In a large organization, the inventory that must be maintained consists of a great variety of items. Statistics reveal that just a handful of items account for the bulk of the annual expenditure on materials. These few items, called ‘A’ items, therefore hold the key to the business. The other items, known as ‘B’ and ‘C’ items, are large in number, however their contribution is less. Traditional ABC analysis is performed based on the consumption values of inventory items. Consumption values are arranged in descending order. Cumulative consumption values are then converted corresponding to cumulative percentages. A, B and C classifications are then made based on the cumulative percentage figures. To classify the inventories, the break point percentages can be chosen by the management depending on the number of items that can be effectively managed under each category (Flores, Olson, & Dorai, 1992).

A number of researchers have questioned the focus on the consumption value as a single criterion. There are many instances when other criteria, other than the annual consumption value, may be significant in deciding the importance of an inventory item (Cohen & Ernst, 1988). In these cases, multiple criteria decision-making methods are helpful.

A few investigators have worked on multi-criteria inventory classification. Flores and Whybark introduced a multi-criteria inventory classification in 1986 and 1987 (Flores & Whybark, 1986, 1987). Though it included several criteria, e.g. obsolescence, lead times, substitutability, reparability, criticality and commonality, this approach became increasingly complicated if more than two criteria were considered to classify inventory items. Flores et al. (1992) applied the Analytic Hierarchy Process (AHP) for multiple criteria inventory classification.

Guvenir & Erel (1998) applied Genetic Algorithm (GA) to solve the problem of multiple criteria inventory classification. Their proposed method called Genetic Algorithm for Multi-Criteria Inventory Classification (GAMIC) is within the framework of the AHP to deal with multi-criteria ABC analysis. On the other hand, Braglia et al. (2004) used the AHP models to solve various multi-attribute decision problems at different levels of the decision tree. They identified the best control strategy for the spare stocks by defining the inventory policy matrix linking different classes of spare parts with the possible inventory management policies.

Ramanathan (2006) proposed a weighted linear optimisation model for multiple criteria ABC (MCABC) inventory classification. The performance score of each item was obtained using a Data Envelopment Analysis (DEA). The defect of his model was that an item with a high value in an unimportant criterion was inappropriately classified under class A. This drawback was rectified by Zhou & Fan (2007) who incorporated balancing features for multi-criteria inventory classification (MCIC) by using most favourable and least favourable scores for each item. In another work, Bhattacharya et al. (2007)

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presented a distance-based multi-criteria consensus framework utilizing the concepts of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) model. The technique took into account various conflicting criteria having different units of measurement, which were then ranked in categories A, B and C using TOPSIS.

Cakir & Canbolat (2008) presented an inventory classification system based on FAHP, integrating the fuzzy concept with real inventory data and designed a decision support system. Torabi et al. (2012) applied a modified version of a common weight DEA-like model to ABC inventory classification in those cases where both quantitative and qualitative criteria existed, while Kabir & Hasin (2013) developed a multi-criteria inventory classification model through integration of Fuzzy Analytic Hierarchy Process (FAHP) and artificial neural network approach. Soylu & Akyol (2014) incorporated the preferences of the decision maker into the Multi-criteria inventory classification decision-making process in terms of reference items into each class.

In a recent work, a new method of Evaluation based on Distance from Average Solution (EDAS) was introduced for multi-criteria inventory classification (MCIC) problems (Ghorabaee, 2015). A comparative analysis (involving seven sets of criteria weights and Spearman's correlation coefficient) was also put forward to show the validity and stability of the proposed method in problems related to MCDM. Liu et al. (2016) mentioned the necessity of considering the non- compensation in the multiple criteria ABC analysis. The authors proposed a new classification approach based on the outranking model to cope with such a problem. Mallick et al. (2016) presented a multi-criteria inventory classification system by MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) method for hospital inventory management.

None of the multiple criteria decision-making methods mentioned above is foolproof and a single multi-criteria decision-making method doesn't exist that can be applied to all decision problems with equal efficiency. Therefore, there is a need for a simple, systematic, logical and consistent method or tool to guide decision makers in making an optimal selection. Hence, a methodology was developed by integrating Graph Theory (GT) and the Analytic Hierarchy Process (AHP) for multi-criteria inventory classification to solve a typical hospital inventory management problem. The outcome of the present application of this hybrid method was also compared with certain previous researchers dealing with same problem.

2. The proposed methodology

Graph theory is a logical and systematic approach that originated from combinatorial mathematics. The graph theory consists of the digraph representation, the matrix representation and the permanent function representation. The digraph is the visual representation of the variables and their interdependencies. The matrix converts the digraph into mathematical form and the permanent function is a mathematical representation that helps to determine the numerical index (Faisal, Banwet, & Shankar, 2007).Various researchers have addressed the application of the graph theory approach to engineering systems in a significant number of papers.

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Rao (2007) in his book has demonstrated how this methodology could be effectively used for decision making in various situations in the manufacturing environment. The graph theory and matrix approach (GTMA) method has been employed to total quality management evaluation of an industry (Grover, Agrawal, & Khan, 2004), contractor ranking (Darvish, Yasaei, & Saeedi, 2009), non-traditional machining processes selection (Chakladar, Das, & Chakraborty, 2009), equipment selection (Paramasivam, Senthil, & Rajam Ramasamy, 2011), and assessing the vulnerability of supply chains (Wagner & Neshat, 2010).

The Analytic Hierarchy Process (AHP) developed by Saaty (1980) has been successfully applied to multi-criteria inventory classification by Flores et al. (1992).The AHP has been used in a variety of business decision-making settings. A significant feature of the AHP is the consistency check of relative importance of the attributes. In view of this advantage, for multi-criteria inventory classification, a methodology combining graph theory and the AHP method is proposed. The AHP is applied for determination of the relative weights of the selected attributes and graph theory is applied for evaluation and ranking of the alternatives. This hybrid approach is similar to the one reported by Rao and Parnichkun (2009), Singh and Rao (2011) and Lanjewar et al. (2016).

The proposed hybrid method is a simple, fast, logical, systematic and consistent method, that may be recommended for use as a decision making method for multi-criteria inventory classification. However, it can be used for any type of decision making situation. It enables more critical analysis than the common multi-attribute decision making methods since any number of quantitative and qualitative attributes can be considered. In the permanent procedure, even a small variation in the attribute leads to a significant difference in the overall performance value making it convenient to rank the alternatives in a descending order with a clear difference in the overall performance value. Moreover, the proposed procedure using the graphical representation not only enables the analysis of the alternatives, but also facilitates visualization of various criteria along with their interrelations.

The steps for the proposed methodology are presented below after Rao (2007), Chakladar et al. (2009), and Darvish et al. (2009).

Step1- Identify the inventory attributes or criterion for decision matrix.

Step 2- Generate the decision matrix using raw inventory data.

A typical multi-criteria decision making problem can be precisely presented with a decision matrix showing the performance of different alternatives with respect to various attributes or criteria as given in Equation1.

$$D = \left[x_{ij}\right]_{i=1,\dots,m,\ \ j=1,\dots,n} \qquad (1)$$

Where x_{ij} is the performance measure of i^{th} alternative on j^{th} criteria, m is the number of alternatives; n is the number of criteria. Information stored in a decision matrix is generally incommensurable, wherein performance ratings *w.r.t.* different criteria are

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expressed after considering different units of measure. Therefore, it is desirable to transform data into comparable values, using the normalization procedure of Step 3.

Step 3- Normalize the matrix calculation.

The normalized values of a criterion assigned to the alternatives are calculated using the following formula:

$$\frac{F_i - F_{min}}{F_{max} - F_{min}}$$

where, F_i is the i^{th} value of the factor, F_{max} is the maximum value of the factor, and F_{min} is the minimum value of the factor under transformation (Flores et al.,1992). There are also some other methods of normalizing which incorporate negative values into the AHP system (Millet & Schoner, 2005).

Step 4- Construct the relative importance matrix

A relative importance matrix (Equation 2) is constructed using a pair-wise comparison scale of absolute numbers from 1 to 9 as proposed by Saaty (1980). An element when self-compared is assigned a value of 1. Assuming that there are N number of criteria in a decision-making problem, the pair-wise comparison of i^{th} criterion with respect to the j^{th} one yields a square matrix, where a_{ij} = 1 when i = j and $a_{ji} = 1/a_{ij}$ (a_{ij} is the comparative importance of i^{th} criterion with respect to j^{th} one).

$$M = [a_{ij}] = \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{21} & a_{22} \dots & a_{2n} \\ \vdots & & \vdots \\ a_{i1} & a_{i2} \dots & a_{nn} \end{bmatrix} \quad (2)$$

Step 5- Digraph model of the inventory attributes showing their interdependencies.

A digraph consists of a set of nodes N= {n_i} (i=1, 2, M) and a set of directed edges E= {e_{ij}}. A node n_i represents i^{th} selection criterion/attribute and edges represent the relative importance among the attributes. The total of nodes, M, is equal to the number of selection criteria considered. If a node i has relative importance over another node j in the selection process, a directed edge or arrow is drawn from node i to node j (e_{ij}). If j is having relative importance over i, then a directed edge or arrow is drawn from node j to node i(e_{ji}). The digraph depicts the graphical representation of the interdependence between various decision attributes taken two at a time and their relative importance for quick visual perception.

Step 6- Develop other square matrix based on the digraph

As the number of nodes and their interrelations increase, the digraph becomes complex. To address this problem, the digraph is usually represented in a matrix form. Matrix representation of a digraph gives one-to-one representation, taking all the attributes (A_i) and their relative importance (a_{ij}) into account. The matrix B for a digraph can be represented as Equation 3:

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$$B = \begin{bmatrix} A_i & a_{12} & a_{13} & \cdots & \cdots & a_{1M} \\ a_{21} & A_2 & a_{23} & \cdots & \cdots & a_{2M} \\ a_{31} & a_{32} & A_3 & \cdots & \cdots & a_{3M} \\ \vdots & \vdots & & & & \vdots \\ \vdots & \vdots & & & & \vdots \\ a_{M1} & a_{M2} & a_{M3} & \cdots & \cdots & A_M \end{bmatrix} \ldots \qquad (3)$$

where A_i is the value of the i^{th} attribute represented by node n_i and a_{ij} is the relative importance of the i^{th} attribute over the j^{th} one represented by the edge e_{ij}.

Step 7- Calculate the overall performance value using matrix method.

The overall performance value of each inventory item can be found by calculating the permanent function value of matrix B, i.e. per (B) (Rao, 2007). The permanent of a matrix was introduced by Cauchy in 1812. At that time, while developing the theory of determinants, he also defined a certain subclass of symmetric function that later was named permanent by Muir. In the expression for the permanent of the matrix, as no negative sign appears, no information is lost. This permanent function is the determinant of a matrix, considering all the terms as positive.

Step 8- Rank the inventory items based on overall performance value.

In this step, all inventory items are ranked according to their overall performance value arranged in descending order.

3. Illustrative example

The hybrid system, i.e. integrated graph theory and the Analytic Hierarchy Process, is applied in this paper for classifying inventory items using the data referred to in Flores et al. (1992) corresponding to hospital inventory management. Flores applied the Multiple Criteria ABC analysis method based on the Analytic Hierarchy Process (AHP) using data obtained from a traditional ABC inventory classification presented by Reid (1987)

Now, in order to demonstrate and validate the proposed procedure, the multi-criteria inventory classification integrating Graph Theory (GT) and the Analytic Hierarchy Process and the various steps of the methodology, given in Section 2, are described below:

Step 1- Four attributes are identified for the Multiple Criteria ABC analysis: (1) Average Unit Cost (AUC); (2) Annual Dollar Usage (ADU); (3) Critical Factor (CF): 1, 0.50, or 0.01 being assigned to each of the 47 disposable items, where values imply very critical, moderately critical, and non-critical respectively; (4) Lead Time (LT) (weeks) being the time that it takes to receive a replenishment order after it is placed, ranging from 1 to 7 weeks.

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Step 2- Generation of decision matrix using raw inventory data based on the 47 disposable items referred to as S1 through S47 are taken from Flores et al.(1992) (Table 1).

Table 1
Decision and normalised matrix

Item	Decision Matrix					Normalised Matrix			
	AUD ($)	ADU ($)	CF	LT		AUD ($)	ADU ($)	CF	LT
S1	49.92	5840.64	1	2		0.21866	1.00000	1.00000	0.16667
S2	210	5670.00	1	5		1.00000	0.97066	1.00000	0.66667
S3	23.76	5037.12	1	4		0.09098	0.86183	1.00000	0.50000
S4	27.73	4769.56	0.01	1		0.11036	0.81582	0.00000	0.00000
S5	57.98	3478.80	0.5	3		0.25800	0.59385	0.49495	0.33333
S6	31.24	2936.67	0.5	3		0.12749	0.50063	0.49495	0.33333
S7	28.2	2820.00	0.5	3		0.11265	0.48057	0.49495	0.33333
S8	55	2640.00	0.01	4		0.24346	0.44961	0.00000	0.50000
S9	73.44	2423.52	1	6		0.33346	0.41239	1.00000	0.83333
S10	160.5	2407.50	0.5	4		0.75840	0.40963	0.49495	0.50000
S11	5.12	1075.20	1	2		0.00000	0.18053	1.00000	0.16667
S12	20.87	1043.50	0.5	5		0.07687	0.17508	0.49495	0.66667
S13	86.5	1038.00	1	7		0.39721	0.17413	1.00000	1.00000
S14	110.4	883.20	0.5	5		0.51386	0.14751	0.49495	0.66667
S15	71.2	854.40	1	3		0.32253	0.14256	1.00000	0.33333
S16	45	810.00	0.5	3		0.19465	0.13492	0.49495	0.33333
S17	14.66	703.68	0.5	4		0.04656	0.11664	0.49495	0.50000
S18	49.5	594.00	0.5	6		0.21661	0.09778	0.49495	0.83333
S19	47.5	570.00	0.5	5		0.20685	0.09365	0.49495	0.66667
S20	58.45	467.60	0.5	4		0.26030	0.07604	0.49495	0.50000
S21	24.4	463.60	1	4		0.09410	0.07536	1.00000	0.50000
S22	65	455.00	0.5	4		0.29227	0.07388	0.49495	0.50000
S23	86.5	432.50	1	4		0.39721	0.07001	1.00000	0.50000
S24	33.2	398.40	1	3		0.13706	0.06415	1.00000	0.33333
S25	37.05	370.50	0.01	1		0.15585	0.05935	0.00000	0.00000
S26	33.84	338.40	0.01	3		0.14018	0.05383	0.00000	0.33333
S27	84.03	336.12	0.01	1		0.38515	0.05344	0.00000	0.00000
S28	78.4	313.60	0.01	6		0.35767	0.04956	0.00000	0.83333
S29	134.34	268.68	0.01	7		0.63071	0.04184	0.00000	1.00000
S30	56	224.00	0.01	1		0.24834	0.03415	0.00000	0.00000

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S31	72	216.00	0.5	5		0.32643	0.03278	0.49495	0.66667
S32	53.02	212.08	1	2		0.23380	0.03211	1.00000	0.16667
S33	49.48	197.92	0.01	5		0.21652	0.02967	0.00000	0.66667
S34	7.07	190.89	0.01	7		0.00952	0.02846	0.00000	1.00000
S35	60.6	181.80	0.01	3		0.27079	0.02690	0.00000	0.33333
S36	40.82	163.28	1	3		0.17425	0.02371	1.00000	0.33333
S37	30	150.00	0.01	5		0.12144	0.02143	0.00000	0.66667
S38	67.4	134.80	0.5	3		0.30398	0.01882	0.49495	0.33333
S39	59.6	119.20	0.01	5		0.26591	0.01613	0.00000	0.66667
S40	51.68	103.36	0.01	6		0.22725	0.01341	0.00000	0.83333
S41	19.8	79.20	0.01	2		0.07165	0.00925	0.00000	0.16667
S42	37.7	75.40	0.01	2		0.15902	0.00860	0.00000	0.16667
S43	29.89	59.78	0.01	5		0.12090	0.00592	0.00000	0.66667
S44	48.3	48.30	0.01	3		0.21076	0.00394	0.00000	0.33333
S45	34.4	34.40	0.01	7		0.14291	0.00155	0.00000	1.00000
S46	28.8	28.80	0.01	3		0.11558	0.00059	0.00000	0.33333
S47	8.46	25.38	0.01	5		0.01630	0.00000	0.00000	0.66667

Step 3- The quantitative values of the inventory attributes, which are given in Table 1, are normalized. It is to be noted that all four criteria considered in this study are positively related to the importance level of inventory items (Ramanathan, 2006).

Step 4- Relative importance relation matrix (A1) as shown in Table 2 and weight (W_i) of each attribute for the above-mentioned criteria is kept the same as in Flores et al. (1992).

Table2
Relative Importance Relation Matrix

Relative Importance Relation Matrix (A1)				
	AUC	ADU	CF	LT
AUC	1	1	1/8	¼
ADU	1	1	1/3	1/6
CF	8	3	1	1
LT	4	6	1	1

The weight (W_i) of each attribute is taken as: W_{AUC}: 0.07872; W_{ADU}: 0.09161; W_{CF}: 0.41969; and W_{LT}: 0.40999 after Flores et al. (1992).

Step 5- Digraph model of the inventory attributes showing their interdependencies is shown in Figure 1. As explained, the nodes in the digraph represent criteria. The interactions among criteria are represented by edges.

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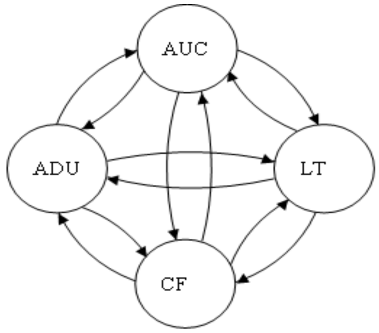

Figure1. Digraph model of the inventory attributes

Step 6- The attributes matrix for the above digraph is prepared as Equation 4.

$$
B = \begin{array}{c} \\ AUC \\ ADU \\ CF \\ LT \end{array}
\begin{array}{c} \text{Attribute AUC ADU CF LT} \\ \begin{bmatrix} A_1 & 1 & 1/8 & 1/4 \\ 1 & A_2 & 1/3 & 1/6 \\ 8 & 3 & A_3 & 1 \\ 4 & 6 & 1 & A_4 \end{bmatrix} \end{array} \tag{4}
$$

Step 7- The characteristic permanent function for Overall Performance Value can be written as Equation 5 (Rao, 2007):

$$
\begin{aligned}
\mathrm{per}(B) = \prod_{i=1}^{4} A_i &+ \sum_{i=1}^{3}\sum_{j=i+1}^{4}\sum_{k=1}^{3}\sum_{l=k+1}^{4}(a_{ij}a_{ji})A_kA_l \\
&+ \sum_{i=1}^{2}\sum_{j=i+1}^{3}\sum_{k=j+1}^{4}\sum_{l=1}^{4}(a_{ij}a_{jk}a_{ki} + a_{ik}a_{kj}a_{ji})A_l \\
&+ \Big[\sum_{i=1}^{1}\sum_{j=i+1}^{4}\sum_{k=i+1}^{3}\sum_{l=j+2}^{4}(a_{ij}a_{ji})(a_{kl}a_{lk}) \\
&+ \sum_{i=1}^{1}\sum_{j=i+1}^{3}\sum_{k=i+1}^{4}\sum_{l=j+1}^{4}(a_{ij}a_{jk}a_{kl}a_{li} + a_{il}a_{lk}a_{kj}a_{ji})\Big]
\end{aligned} \tag{5}
$$

Overall performance value is calculated using the values of A_i's and a_{ij}'s for each inventory item. A_i's are obtained from the normalized decision matrix and a_{ij}'s are obtained from relative importance matrix (Table 2).

Step 8- According to graph theory and matrix method, classification of inventory items based on the overall performance value arranged in descending order are shown in Table 3.

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In order to obtain comparison, the same distribution of 10 class A, 14 class B and 23 class C items was maintained. Inventory items with an overall performance value of 17.20748099 and above were classified as class A items, those with scores of 15.50751142 and below were classified as class C items, while those with scores between 17.20748099 and 15.50751142 were classified as class B items.

The ABC classification using proposed method as shown in Table 3 is compared with the result of traditional ABC and the AHP classification methods as reported in Flores et al. (2002).

Table 3
A comparison of ABC classification

A comparison of ABC classification as determined by:									
Item	Reid (1987) using only a single criterion.			Flores et al. (1992) using AHP for multiple criteria inventory classification.			This paper using the hybrid system i.e. integrated graph theory and AHP for multiple criteria inventory classification.		
	Annual Dollar Usage	Rank	ABC	AHP (Weighted Score)	Rank	ABC	Overall performance value	Rank	ABC
S1	5840.64	1	A	0.59684	7	A	18.98048509	5	A
S2	5670	2	A	0.86066	2	A	26.10663828	1	A
S3	5037.12	3	A	0.71080	4	A	19.5330094	4	A
S4	4769.56	4	A	0.08342	42	C	13.82213779	37	C
S5	3478.8	5	A	0.41910	24	B	16.68158993	11	B
S6	2936.67	6	A	0.40029	26	C	15.83281893	16	B
S7	2820	7	A	0.39728	27	C	15.70537438	19	B
S8	2640	8	A	0.26535	37	C	15.1261434	25	C
S9	2423.52	9	A	0.82538	3	A	20.43548102	2	A
S10	2407.5	10	A	0.50995	13	B	18.72709566	6	A
S11	1075.2	11	B	0.50456	17	B	14.91889907	27	C
S12	1043.5	12	B	0.50314	18	B	15.78723561	17	B
S13	1038	13	B	0.87690	1	A	20.33433735	3	A
S14	883.2	14	B	0.53502	12	B	17.36928478	8	A
S15	854.4	15	B	0.59480	8	A	16.77468681	10	A
S16	810	16	B	0.37207	29	C	14.79540034	29	C
S17	703.68	17	B	0.42707	22	B	14.8344986	28	C
S18	594	18	B	0.57539	9	A	16.66968694	12	B
S19	570	19	B	0.50592	16	B	15.97287062	15	B

S20	467.6	20	B	0.44018	21	B	15.45752996	22	B
S21	463.6	21	B	0.63900	6	A	16.29263253	13	B
S22	455	22	B	0.44250	20	B	15.56395933	21	B
S23	432.5	23	B	0.66237	5	A	17.51474999	7	A
S24	398.4	24	B	0.57302	10	A	15.71356327	18	B
S25	370.5	25	C	0.01771	47	C	11.96390314	47	C
S26	338.4	26	C	0.15263	40	C	12.98776323	41	C
S27	336.12	27	C	0.03521	45	C	12.53370856	43	C
S28	313.6	28	C	0.37435	28	C	15.32649641	23	B
S29	268.68	29	C	0.46347	19	B	16.83859629	9	A
S30	224	30	C	0.02268	46	C	12.13135833	46	C
S31	216	31	C	0.50975	14	B	16.17631119	14	B
S32	212.08	32	C	0.50937	15	B	15.24071987	24	B
S33	197.92	33	C	0.29309	33	C	14.23044817	34	C
S34	190.89	34	C	0.41335	25	C	14.59149575	32	C
S35	181.8	35	C	0.16044	38	C	13.28125951	39	C
S36	163.28	36	C	0.57224	11	B	15.69489064	20	B
S37	150	37	C	0.28485	34	C	13.89944772	35	C
S38	134.8	38	C	0.37004	30	C	14.7489373	31	C
S39	119.2	39	C	0.29574	32	C	14.34183744	33	C
S40	103.36	40	C	0.36078	31	C	14.75658732	30	C
S41	79.2	41	C	0.07482	44	C	12.14000067	45	C
S42	75.4	42	C	0.08164	43	C	12.37195808	44	C
S43	59.78	43	C	0.28339	35	C	13.84673594	36	C
S44	48.3	44	C	0.15362	39	C	13.0396684	40	C
S45	34.4	45	C	0.42138	23	B	14.96412365	26	C
S46	28.8	46	C	0.14582	41	C	12.75973946	42	C
S47	25.38	47	C	0.27461	36	C	13.49604159	38	C

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Table 4
A comparison of Annual dollar Usage percentage of class A, B and C type of items for integrated Graph theory-AHP,traditional ABC and the AHP

Class of items	% of items each category	Annual Dollar usage percentage		
		Integrated Graph theory-AHP (Proposed method for multiple criteria inventory classification.)	Traditional ABC (Reid (1987) using only a single criterion.)	Flores et al. (1992) using AHP for multiple criteria inventory classification
A	21	54	74	43
B	30	23	19	30
C	49	23	7	27

Comparative analysis of Annual Dollar Usage percentage of A, B and C type of items of three types of ABC analyses is shown in Table 4.

Table 4 illustrates that 54% of the Annual Dollar Usage for 21% of item (A type) was obtained by the proposed method. In accordance with the traditional ABC by Reid (1987),where only one criteria has been considered, 30% of item (B type) accounts for 19% of Annual Dollar Usage. In consonance with Flores et al. (1992), 49% of items (type C) are responsible for the 27% Annual Dollar Usage.

Therefore, it can be stated that for any organization, both inventory cost-control as well as multi-criteria decision making can be done more effectively by applying the proposed method from a materials management point of view. The suggested hybrid method envisages the proper controlling of materials (47 items) in comparison to the other two methods.

4. Conclusions

In the present investigation, the combination of graph theory and the Analytic Hierarchy Process was applied for multi-criteria inventory classification. It may be noted that, as per the author's purview, this kind of hybrid system has not been used earlier to classify inventory items.

A case study on a hospital inventory management system for 47 disposable items used in a respiratory therapy unit was considered. The results obtained using the proposed method were found to be more precise than that of solely the AHP classification method.

Hence, this hybrid method being a simple, fast, logical, systematic and consistent method, may be recommended for use as a decision making method for multi-criteria inventory classification. It can also be used for any type of decision-making situation. It enables more critical analysis than the common multi-attribute decision making methods since any number of quantitative and qualitative attributes can be considered. In the

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permanent procedure, even a small variation in the attribute leads to a significant difference in the overall performance value making it convenient to rank the alternatives in a descending order with clear difference in the overall performance value. Moreover, the proposed procedure using the graphical representation not only enables the analysis of the alternatives, but also facilitates visualization of various criteria along with their interrelations. The suggested hybrid method envisages the proper controlling of materials in comparison with traditional ABC and the AHP methods. The present paper considers the decision taken under certainty, which is otherwise often highly uncertain and risky for the decision-makers. Therefore, this hybrid method may elevate applicability considering uncertainty and vagueness in attribute values.

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