MANAGEMENT OF MULTICRITERIA INVENTORY CLASSIFICATION

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Abstract—The most common method that materials managers use for classifying inventory items for planning and control purposes is the annual-dollar-usage ranking method (ABC classification). Recently, it has been suggested that multiple criteria ABC classification can provide a more comprehensive managerial approach, allowing consideration of other criteria such as lead time and criticality. This paper proposes the use of the Analytic Hierarchy Process (AHP) to reduce these multiple criteria to a univariate and consistent measure to consider multiple inventory management objectives.

INTRODUCTION

The traditional method of classifying inventory items using annual dollar usage as the only criterion may be inappropriate under some circumstances. A problem in using this criterion to rank inventory items may arise because the method may over-emphasize the importance of those items that have high annual cost but are not as important to the production/service operation of the firm. At the same time, focusing only upon a measurable cost may under-emphasize low annual cost items that are important. Therefore, use of annual dollar usage only, in some cases, may lead the firm to mismanage its inventory assets.

Classification of items using the inventory investment criterion exclusively can sometimes create problems for an organization. Consider a company that has a product that is still in an evolutionary mode. That is, the design and market response is not yet stable. An item could be classified, say, as a B item considering its cost and expected annual usage. Since the design is not stable, it may very well happen that the component may not form part of the final design. Because of this factor, a company may end up with a large inventory of an obsolete part. If it is classified as an A item, then management will be paying closer and more detailed attention to the inventory level of this component and thus decrease the probability of large obsolete inventories.

In another example [1], a company had items that were classified as C. These components had a long lead time because they were imported from Japan. The long time span, which was prolonged by the rather lengthy Mexican custom procedures made these items critical, as they were delaying the completion of some production units. If classified, using lead time as the criterion, they would have been an A item.

Depending upon the nature and type of the firm, the number of criteria that should be used to manage the inventory, and the relative impact of each, may vary. For example, in the constantly changing environment of high-tech industry, obsolescence of inventory items may be a more appropriate classification factor. A firm holding high-value (dollar value in total), but obsolete, inventory may incur financial losses. In the health sector, hospitals must hold an inventory of essential drugs and life saving equipment based on how critical the items are to the needs of...
the patients and the strength of the competition. Here, criticality of the items may be more important than cost.

The firm is faced with the problem of how to classify, analyze, and rank inventory items when more than one criterion is used. After this, the items should be grouped (like an ABC classification) to better reflect inventory management objectives. Cohen and Ernst [2] suggest a multicriteria classification and some stock control policies. Those authors describe an approach that uses clustering as a way to combine groups of items, and they state that the method provides an improvement over the typical ABC method. Previously, Flores and Whybark [1,3] described advantages, such as reduction of investment and lead time from using multiple criteria ABC analysis. They did not propose a specific methodology to integrate the utilization of several criteria and only suggested a mechanical way to reduce the classification to an ABC grouping. This paper extends their results and suggests the use of the Analytic Hierarchy Process (AHP) to integrate the use of several criteria and rank inventory items.

The first section briefly outlines past research on multiple criteria ABC classification, and the second section briefly outlines the salient features of AHP. The proposed methodology is discussed in the third section. Section 4 illustrates the use of the proposed methodology with a numerical example. The results of the example are discussed in detail and the main differences between the classic univariate ABC classification and AHP with a multivariate ABC classification are described.

MULTIPLE CRITERIA ABC CLASSIFICATION

Zimmerman [4] noted that most firms use the annual dollar usage ranking of inventory items in its application of the ABC principle. For instance, under the annual dollar usage system of ABC classification inventory items could be partitioned as follows:

<table>
<thead>
<tr>
<th>CLASS</th>
<th>% OF TOTAL ITEMS PURCHASED</th>
<th>% OF TOTAL PURCHASE ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ITEMS</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>B ITEMS</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>C ITEMS</td>
<td>70</td>
<td>10</td>
</tr>
</tbody>
</table>

This is commonly known as the 80-20 rule, although these percentages may vary from firm to firm. As described by Leenders et al. [5], this system of classification is very useful and powerful as it allows management to focus attention on the areas of highest payoff. However, annual dollar usage may not be the only criterion to be considered.

Flores and Whybark [1] recommended consideration of one or more other criteria, such as lead time, criticality, commonality, obsolescence, substitutability, or reparability. The number of categories under any system of classification need not be limited to three (A, B, and C). Flores and Whybark [3] noted that additional categories could help in the analysis of inventory policy. The firm can create super categories, subcategories, or lower categories based upon its established inventory management policies, systems, and control methods. In fact, in some cases categories such as 'AB,' 'AC,' 'BA,' 'BC,' 'CA,' and 'CB' can and possibly should be created.

Depending upon the type of industry, and whether the engineering, purchasing, maintenance, or manufacturing part of the organization is concerned, the number of criteria for ABC classification could vary. Flores and Whybark [1,3] proposed the use of a joint criteria matrix when considering two criteria for classification. In one case, they stated that under the new multiple criteria savings in investment and reductions of lead time were obtained. An example of joint criteria matrix is displayed in Figure 1.

In this joint-matrix, X's represent inventory items that are positioned in the diagonal cells and are classified as 'AA' or 'BB' or 'CC' items; and *'s represent items that are positioned in the off-diagonal cells.

It can be seen from this example that a two criteria, three-tiered joint matrix may require nine different policies to deal with inventory items in the nine cells. Although it is possible to establish nine different policies, it would be a more difficult process to implement and manage
The problem, though, would soon become unmanageable if say, three or more, criteria are utilized. The policy that may be adopted by managers for reclassification depends on the approach of the firm towards inventory management. If more than two criteria are deemed necessary for classifying inventory items, the joint matrix becomes at least three-dimensional and no longer easy to analyze, synthesize, or use. A reclassification of the items into three groups would permit the firm to establish only three instead of nine different policies. Managers are accustomed to working with ABC inventory classifications (e.g., three groups). If the reclassification could be made, this would make for an easier managerial task. The issue to resolve, however, is: on what grounds can the reclassification be made?

The next section will outline a method that can generate a rational, fair, and consistent measure that can help the materials manager reclassify inventory items under multiple criteria.

THE ANALYTIC HIERARCHY PROCESS

Saaty [6-8] developed AHP to aid decision maker(s) with a finite set of alternatives to combine multiple objectives. AHP breaks down a complex, unstructured situation into basic elements. The process arranges these elements in a hierarchy of nodes with branches, and translates subjective judgments on the relative importance of each element into numerical values based on a pairwise comparison/judgment scale. Finally, AHP synthesizes these judgments to provide a quantitative measure of value, as presented by Saaty [7]. All criteria of importance can be considered. However, as the human mind can analyze only a limited number of criteria simultaneously, Saaty has suggested restricting the number of criteria to be considered at one time to seven.

AHP is well known, but for clarity is summarized in simple form. AHP can be explained in three steps. First, the decision maker identifies all criteria of importance to the specific decision. Second, these criteria are arranged in a hierarchy of one or more levels. If some criteria are naturally grouped together, they can be made subelements of an overall concept. There are limits as to the number of factors in a node. Some software, such as EXPERT CHOICE [9], will not accept more than seven factors at one node, forcing decision makers to group concepts if more than seven criteria are present. Third, a series of pairwise comparisons are conducted at each node of the hierarchy, converting the decision maker(s) subjective judgment into a set of weights of relative importance. The resulting set of weights can then be synthesized to provide a formula reflecting the combination of all hierarchical elements.

An inventory management example might include criteria such as average unit cost, annual dollar usage, criticality, and lead time. The implementation of the methodology will reduce the four criteria, using a linear combination of the variables, to a single variable here named UTILITY. The definition of the variables can continue at lower levels. For instance, it could be assumed that criticality can consist of the impact upon integrated operations (quantitative or qualitative), the possible scarcity of supply, and existence (or not) of substitutes.

The hierarchy requires pairwise comparison wherever subelements are found. In this case, UTILITY and CRITICALITY both have subelements. We follow the convention of Saaty [7], and conduct pairwise comparisons starting from the top of the hierarchy, and work down. We note, however, that there is a position that greater accuracy of preference is obtained by conducting the pairwise comparisons from the bottom first, and working up in the hierarchy. In our example, the first pairwise comparison would involve the subelements of UTILITY. A pairwise comparison...
matrix has the feature that the main diagonal consists of 1s (each factor is equally as important as itself), and all off-diagonal elements are reciprocal to the corresponding symmetric element. This means that only the upper half of the matrix needs to be evaluated. For each pair of factors, the decision maker(s) evaluate the relative importance of the base factor to the other factor. Saaty [8] provided the following scale:

<table>
<thead>
<tr>
<th>Scale</th>
<th>Relative Importance</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Both factors contribute equally</td>
</tr>
<tr>
<td>3</td>
<td>Weak preference</td>
<td>The base factor is slightly more important than the second factor</td>
</tr>
<tr>
<td>5</td>
<td>Essential preference</td>
<td>Base factor strongly preferred</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrable preference</td>
<td>Definite preference for base factor</td>
</tr>
<tr>
<td>9</td>
<td>Absolute preference</td>
<td>Base factor preferred at highest possible level</td>
</tr>
</tbody>
</table>

Important values 2, 4, 6, 8 can be used as intermediate values on this scale. If the base factor (row) is less important than the other factor being considered (column), reciprocals of the above ratings can be used. The pairwise comparison could result in the following values:

<table>
<thead>
<tr>
<th></th>
<th>AVG UNIT COST</th>
<th>ANNUAL DOLLAR USAGE</th>
<th>CRITICALITY</th>
<th>LEAD TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG UNIT COST</td>
<td>1</td>
<td>1</td>
<td>1/8</td>
<td>1/4</td>
</tr>
<tr>
<td>ANNUAL DOLLAR USAGE</td>
<td>1</td>
<td>1</td>
<td>1/3</td>
<td>1/6</td>
</tr>
<tr>
<td>CRITICALITY</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>LEAD TIME</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

These comparisons indicate that AVG UNIT COST is considered roughly equivalent in importance to ANNUAL DOLLAR USAGE, much less important than CRITICALITY, and LEAD TIME’s relative importance to AVG UNIT COST is between ‘weakly more important’ and ‘essentially more important’ (see classification above). ANNUAL DOLLAR USAGE is rated as slightly less important than CRITICALITY, and between ‘essentially’ and ‘demonstrably less important’ than LEAD TIME. The last comparison rates CRITICALITY as roughly equivalent in importance to LEAD TIME.

The implicit weights for this pairwise comparison matrix can be obtained by a variety of software products recently available on the market. One of these is EXPERT CHOICE, with excellent graphics and user assistance. In this paper, the authors used software written by a fellow faculty member. While alternative means of calculation of weights exist, Saaty has argued for the eigen vector of weights implied by the pairwise comparisons. In this example, the resulting weights are:

\[ 0.07872 \text{ AVG UNIT COST} + 0.09161 \text{ ANNUAL DOLLAR USAGE} + 0.41969 \text{ CRITICALITY} + 0.40999 \text{ LEAD TIME} \] (Inconsistency Index = 0.044).

The weights indicate that for this decision maker, AVG UNIT COST contributes about 8%, ANNUAL DOLLAR USAGE about 9%, CRITICALITY about 42%, and LEAD TIME about 41% to UTILITY. These values will be used in the next section. Another feature of AHP is the existence of a check on the relative consistency of the subjective evaluations. While subjective
Multicriteria inventory classification

Assessments are not expected to be totally consistent, the inconsistency index provides a measure of relative disparity. If perfectly consistent evaluations were made, this index value would be zero. Therefore, a low index is desired. Values for totally random indices are available [6] as a function of the number of factors compared.

<table>
<thead>
<tr>
<th>number of factors</th>
<th>random index</th>
<th>maximum (10% of index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.58</td>
<td>0.06</td>
</tr>
<tr>
<td>4</td>
<td>0.90</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>1.12</td>
<td>0.11</td>
</tr>
<tr>
<td>6</td>
<td>1.24</td>
<td>0.12</td>
</tr>
<tr>
<td>7</td>
<td>1.32</td>
<td>0.13</td>
</tr>
</tbody>
</table>

An inconsistency index greater than 10% of random indicates more inconsistency than is desired, and the decision maker(s) should reassess subjective comparisons. In this example, with 4 factors, the index of 0.044 is below the maximum of 0.09, so adequate consistency is assumed.

The same process is applied to the subelements of criticality.

<table>
<thead>
<tr>
<th></th>
<th>IMPACT</th>
<th>SCARCITY</th>
<th>SUBSTITUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAJOR</td>
<td>1</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>SIGNIFICANT</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>MINOR</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

For these ranks, the resulting weights are: 0.66942 IMPACT + 0.24264 SCARCITY + 0.08795 SUBSTITUTES. The inconsistency index here is 0.004, well below the maximum of 0.06 (for 3 factors), indicating adequate consistency. The last step in obtaining a set of weights is to synthesize all elements of the hierarchy. Each super-ordinate node’s weight is allocated to its subordinate elements in the proportions indicated by the eigenvector weights. In this case, CRITICALITY’s 0.41969 weight is proportionally distributed to IMPACT, SCARCITY, and SUBSTITUTES. This yields the formula:

0.07872 AVG UNIT COST + 0.09161 ANNUAL DOLLAR USAGE + 0.28095 IMPACT
+ 0.10183 SCARCITY + 0.03691 SUBSTITUTES + 0.40999 LEAD TIME; TOTAL 1.0.

This formula can now be used to evaluate inventory items, reflecting all six criteria considered. Application of AHP to weighting multiple criteria in inventory management can be viewed as a linear estimator of utility. Saaty [7] presents the method, intending ratio evaluation of each alternative as part of the hierarchy. With the large number of inventory items typically managed, it will be necessary to apply the set of weights obtained from AHP, rather than treat each alternative through pairwise comparison as proposed by Saaty. If ratio measures for each characteristic were available (such as average unit cost, annual dollar usage, and lead time), the ratio character of AHP could still be applied. However, when subjective evaluation is required, as with criticality, some absolute or relative measure is required. As the criteria may have different measurement scales, the impact of these diverse scales have to be eliminated (to avoid mixing dollars with weeks, etc.). This can be done by converting the measures of each criteria into a 0-1 scale, with 1 being the ideal characteristic and 0 the worst acceptable characteristic. Schoner and Wedley [10] discuss alternatives and ramifications.

**PROPOSED METHODOLOGY**

This paper proposes the use of AHP as a means for decision makers to custom design a formula reflecting the relative importance of each unit of an inventory item based on a weighted value of the criteria utilized. This process will integrate the effect of all the factors.
<table>
<thead>
<tr>
<th>ITEM #</th>
<th>TOTAL ANNUAL USAGE</th>
<th>AVERAGE UNIT COST ($)</th>
<th>ANNUAL DOLLAR USAGE ($)</th>
<th>CUM ANN. DOLLAR USAGE ($)</th>
<th>CUM ANN. % USAGE</th>
<th>ABC INVENTORY CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>117</td>
<td>49.92</td>
<td>5,840.64</td>
<td>5,840.64</td>
<td>11.3</td>
<td>A</td>
</tr>
<tr>
<td>S2</td>
<td>27</td>
<td>210.00</td>
<td>5,670.00</td>
<td>11,510.64</td>
<td>22.3</td>
<td>A</td>
</tr>
<tr>
<td>S3</td>
<td>212</td>
<td>23.76</td>
<td>5,037.12</td>
<td>16,547.76</td>
<td>32.0</td>
<td>A</td>
</tr>
<tr>
<td>S4</td>
<td>172</td>
<td>27.73</td>
<td>4,769.56</td>
<td>21,317.32</td>
<td>41.2</td>
<td>A</td>
</tr>
<tr>
<td>S5</td>
<td>60</td>
<td>57.98</td>
<td>3,478.80</td>
<td>24,796.12</td>
<td>48.0</td>
<td>A</td>
</tr>
<tr>
<td>S6</td>
<td>94</td>
<td>31.24</td>
<td>2,936.67</td>
<td>27,732.68</td>
<td>53.7</td>
<td>A</td>
</tr>
<tr>
<td>S7</td>
<td>100</td>
<td>28.20</td>
<td>2,820.00</td>
<td>30,552.68</td>
<td>59.1</td>
<td>A</td>
</tr>
<tr>
<td>S8</td>
<td>48</td>
<td>55.00</td>
<td>2,640.00</td>
<td>33,192.68</td>
<td>64.2</td>
<td>A</td>
</tr>
<tr>
<td>S9</td>
<td>33</td>
<td>73.44</td>
<td>2,423.52</td>
<td>35,616.20</td>
<td>68.9</td>
<td>A</td>
</tr>
<tr>
<td>S10</td>
<td>15</td>
<td>160.50</td>
<td>2,407.50</td>
<td>38,023.70</td>
<td>73.6</td>
<td>A</td>
</tr>
<tr>
<td>S11</td>
<td>210</td>
<td>5.12</td>
<td>1,075.20</td>
<td>39,098.90</td>
<td>75.6</td>
<td>B</td>
</tr>
<tr>
<td>S12</td>
<td>50</td>
<td>20.87</td>
<td>1,043.50</td>
<td>40,142.40</td>
<td>77.7</td>
<td>B</td>
</tr>
<tr>
<td>S13</td>
<td>12</td>
<td>86.50</td>
<td>1,038.00</td>
<td>41,180.40</td>
<td>79.7</td>
<td>B</td>
</tr>
<tr>
<td>S14</td>
<td>8</td>
<td>110.40</td>
<td>883.20</td>
<td>42,063.60</td>
<td>81.4</td>
<td>B</td>
</tr>
<tr>
<td>S15</td>
<td>12</td>
<td>71.20</td>
<td>854.40</td>
<td>42,918.00</td>
<td>83.0</td>
<td>B</td>
</tr>
<tr>
<td>S16</td>
<td>18</td>
<td>45.00</td>
<td>910.00</td>
<td>43,729.00</td>
<td>84.6</td>
<td>B</td>
</tr>
<tr>
<td>S17</td>
<td>48</td>
<td>14.66</td>
<td>703.68</td>
<td>44,431.68</td>
<td>86.0</td>
<td>B</td>
</tr>
<tr>
<td>S18</td>
<td>12</td>
<td>49.50</td>
<td>594.00</td>
<td>45,025.68</td>
<td>87.1</td>
<td>B</td>
</tr>
<tr>
<td>S19</td>
<td>12</td>
<td>47.50</td>
<td>570.00</td>
<td>45,595.68</td>
<td>88.2</td>
<td>B</td>
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<tr>
<td>S20</td>
<td>8</td>
<td>58.45</td>
<td>467.60</td>
<td>46,063.28</td>
<td>89.1</td>
<td>B</td>
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<tr>
<td>S21</td>
<td>19</td>
<td>24.40</td>
<td>463.60</td>
<td>46,526.88</td>
<td>90.0</td>
<td>B</td>
</tr>
<tr>
<td>S22</td>
<td>7</td>
<td>65.00</td>
<td>455.00</td>
<td>46,981.88</td>
<td>90.9</td>
<td>B</td>
</tr>
<tr>
<td>S23</td>
<td>5</td>
<td>80.50</td>
<td>432.50</td>
<td>47,414.38</td>
<td>91.7</td>
<td>B</td>
</tr>
<tr>
<td>S24</td>
<td>12</td>
<td>33.20</td>
<td>398.40</td>
<td>47,812.78</td>
<td>92.5</td>
<td>B</td>
</tr>
<tr>
<td>S25</td>
<td>10</td>
<td>37.03</td>
<td>370.30</td>
<td>48,183.28</td>
<td>93.2</td>
<td>C</td>
</tr>
<tr>
<td>S26</td>
<td>10</td>
<td>33.84</td>
<td>338.40</td>
<td>48,521.68</td>
<td>93.9</td>
<td>C</td>
</tr>
<tr>
<td>S27</td>
<td>4</td>
<td>84.03</td>
<td>336.12</td>
<td>48,857.80</td>
<td>94.5</td>
<td>C</td>
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<td>78.40</td>
<td>313.60</td>
<td>49,171.40</td>
<td>95.1</td>
<td>C</td>
</tr>
<tr>
<td>S29</td>
<td>2</td>
<td>134.34</td>
<td>268.68</td>
<td>49,440.08</td>
<td>95.7</td>
<td>C</td>
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<td>S30</td>
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<td>56.00</td>
<td>224.00</td>
<td>49,664.08</td>
<td>96.1</td>
<td>C</td>
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<td>72.00</td>
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<td>50,092.16</td>
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<td>C</td>
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<tr>
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<td>49.48</td>
<td>197.92</td>
<td>50,290.08</td>
<td>97.3</td>
<td>C</td>
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<tr>
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<td>27</td>
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<td>190.89</td>
<td>50,480.97</td>
<td>97.7</td>
<td>C</td>
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<td>163.28</td>
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<td>C</td>
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<tr>
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<td>30.00</td>
<td>150.00</td>
<td>50,976.05</td>
<td>98.6</td>
<td>C</td>
</tr>
<tr>
<td>S38</td>
<td>2</td>
<td>67.40</td>
<td>134.80</td>
<td>51,110.85</td>
<td>98.9</td>
<td>C</td>
</tr>
<tr>
<td>S39</td>
<td>2</td>
<td>59.60</td>
<td>119.20</td>
<td>51,250.05</td>
<td>99.1</td>
<td>C</td>
</tr>
<tr>
<td>S40</td>
<td>2</td>
<td>51.68</td>
<td>103.36</td>
<td>51,353.41</td>
<td>99.3</td>
<td>C</td>
</tr>
<tr>
<td>S41</td>
<td>4</td>
<td>19.80</td>
<td>79.20</td>
<td>51,412.61</td>
<td>99.5</td>
<td>C</td>
</tr>
<tr>
<td>S42</td>
<td>2</td>
<td>37.70</td>
<td>75.40</td>
<td>51,488.01</td>
<td>99.6</td>
<td>C</td>
</tr>
<tr>
<td>S43</td>
<td>2</td>
<td>29.89</td>
<td>59.78</td>
<td>51,547.79</td>
<td>99.7</td>
<td>C</td>
</tr>
<tr>
<td>S44</td>
<td>1</td>
<td>48.30</td>
<td>48.30</td>
<td>51,596.09</td>
<td>99.8</td>
<td>C</td>
</tr>
<tr>
<td>S45</td>
<td>1</td>
<td>34.40</td>
<td>34.40</td>
<td>51,630.49</td>
<td>99.9</td>
<td>C</td>
</tr>
<tr>
<td>S46</td>
<td>1</td>
<td>28.80</td>
<td>28.80</td>
<td>51,659.29</td>
<td>100.0</td>
<td>C</td>
</tr>
<tr>
<td>S47</td>
<td>3</td>
<td>8.46</td>
<td>25.38</td>
<td>51,684.67</td>
<td>100.0</td>
<td>C</td>
</tr>
</tbody>
</table>
The next step after calculating the weighted score of each inventory item is to determine a way to uniquely reclassify the items as A, B, or C items. Material managers are familiar with an ABC classification scheme. Reclassification of inventory items will enable managers to effectively and efficiently implement the established policy for inventory management.

A straightforward view of the reclassification scheme would be to take the rank ordered list of items and state that the top 10% would be the new A’s, the next 20% the B’s and the last 70% the C’s. The percentages could be chosen by the manager depending on the number of items that can be effectively managed under each category. Note that this approach can lead to separate classification for items with very close scores. Another approach would be to differentiate groups on the basis of distinctive differences in score. However, there is no guarantee that such distinctive differences will occur, and if they do exist, that the distribution of items in each group will be satisfactory.

NUMERICAL EXAMPLE AND RESULTS

The example shown in this paper is based upon data in an article by Reid [11] on hospital inventory management. In that example, Reid classified 47 disposable items used in a hospital-based respiratory therapy unit using the annual dollar usage as the sole criterion.

Classical ABC Analysis

Table 1 shows the 47 disposable items referred to as S1 through S47. The total annual usage of these items range from 1 unit to a maximum of 210 units. The average unit costs range from a low $5.12 to a high of $210.00.

Based upon the annual dollar usage, ten items, S1 to S10, have been classified as Class A items. Fourteen items, S11 to S24, have been classified as Class B items, and the remaining 23, S25 to S47, have been classified as Class C items.

<table>
<thead>
<tr>
<th>Item Class</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Items</td>
<td>10</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>% Items</td>
<td>21.3%</td>
<td>29.8%</td>
<td>48.9%</td>
</tr>
<tr>
<td>Annual Usage</td>
<td>73.6%</td>
<td>18.9%</td>
<td>7.5%</td>
</tr>
</tbody>
</table>

In hospitals, some equipment may have highly critical characteristics, requiring consideration beyond that reflected in dollar value. Further, procurement lead time for an item can have an influence on inventory management policy. The procedure presented allows for combinations of elements not directly measurable in dollars.

Reclassification

Table 2 lists items using ANNUAL DOLLAR USAGE as the ranking criterion. Table 2 also lists the measures for each of the multiple criteria: average unit cost in dollars, annual dollar usage in dollars, criticality factors, and procurement lead time in weeks.

The presentation of the hierarchy has been simplified in order to improve clarity. Only the top level of the hierarchy is used. This requires simplifying the original example by condensing the three factors that make up the overall criticality factor into one.

A criticality factor of 1, 0.50, or 0.01 was assigned to the 47 disposable items. A value of 1 would indicate a very critical item, a value of 0.50 would indicate a moderately critical item and a value of 0.01 would indicate a non-critical item. These values are shown in Table 2. In this example, criticality factors were assigned randomly. In a real situation the classification could be done by the inventory manager in conjunction with the hospital staff. The procurement lead time for an item, that is, the time it takes to receive replenishment after it has been ordered, ranges from 1 day to 7 weeks. Real data would come from the purchasing or production control department.

The top level of the hierarchy developed above is used to generate a formula considering average unit cost, annual dollar usage, criticality, and lead time. The weights are 42% for criticality, followed by lead time (41%), annual dollar usage (9.2%), and average unit cost (7.8%).
Table 2. Listing of disposable items. Multiple criteria factors.

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>AVERAGE UNIT COST ($)</th>
<th>ANNUAL DOLLAR USAGE ($)</th>
<th>CRITICAL FACTOR</th>
<th>LEAD TIME</th>
<th>WEIGHTED SCORE</th>
<th>WEIGHTED RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>49.92</td>
<td>5,840.64</td>
<td>1</td>
<td>2</td>
<td>0.59684</td>
<td>M7</td>
</tr>
<tr>
<td>S2</td>
<td>210.00</td>
<td>5,670.00</td>
<td>1</td>
<td>5</td>
<td>0.86066</td>
<td>M2</td>
</tr>
<tr>
<td>S3</td>
<td>23.76</td>
<td>5,037.12</td>
<td>1</td>
<td>4</td>
<td>0.71080</td>
<td>M4</td>
</tr>
<tr>
<td>S4</td>
<td>27.73</td>
<td>4,769.56</td>
<td>0.01</td>
<td>1</td>
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<td>M24</td>
</tr>
<tr>
<td>S5</td>
<td>57.98</td>
<td>3,478.80</td>
<td>0.5</td>
<td>3</td>
<td>0.41910</td>
<td>M24</td>
</tr>
<tr>
<td>S6</td>
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<td>3</td>
<td>0.40029</td>
<td>M26</td>
</tr>
<tr>
<td>S7</td>
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<td>2,620.00</td>
<td>0.5</td>
<td>3</td>
<td>0.39728</td>
<td>M27</td>
</tr>
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<td>0.01</td>
<td>4</td>
<td>0.26535</td>
<td>M37</td>
</tr>
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<td>6</td>
<td>0.82538</td>
<td>M3</td>
</tr>
<tr>
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<td>0.50995</td>
<td>M13</td>
</tr>
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<td>2</td>
<td>0.50456</td>
<td>M17</td>
</tr>
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<td>0.50314</td>
<td>M18</td>
</tr>
<tr>
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<td>7</td>
<td>0.87690</td>
<td>M1</td>
</tr>
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<td>883.20</td>
<td>0.5</td>
<td>5</td>
<td>0.53502</td>
<td>M12</td>
</tr>
<tr>
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<td>854.40</td>
<td>1</td>
<td>3</td>
<td>0.59480</td>
<td>M8</td>
</tr>
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<td>810.00</td>
<td>0.5</td>
<td>3</td>
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<td>M20</td>
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<td>0.57539</td>
<td>M9</td>
</tr>
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<td>0.5</td>
<td>5</td>
<td>0.50592</td>
<td>M16</td>
</tr>
<tr>
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<td>0.44618</td>
<td>M21</td>
</tr>
<tr>
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<td>1</td>
<td>4</td>
<td>0.63900</td>
<td>M6</td>
</tr>
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<td>0.02268</td>
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<td>0.50975</td>
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<td>0.50837</td>
<td>M15</td>
</tr>
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<td>5</td>
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</tr>
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<td>0.01</td>
<td>7</td>
<td>0.41335</td>
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</tr>
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<td>163.28</td>
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<td>3</td>
<td>0.57224</td>
<td>M11</td>
</tr>
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<td>150.00</td>
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<td>2</td>
<td>0.08164</td>
<td>M43</td>
</tr>
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</tr>
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<td>0.01</td>
<td>5</td>
<td>0.27461</td>
<td>M36</td>
</tr>
</tbody>
</table>
### Table 3. Listing of disposable items in descending order of weighted score.

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>AVERAGE UNIT COST ($)</th>
<th>ANNUAL DOLLAR USAGE ($)</th>
<th>CRIT FACT</th>
<th>LEAD TIME</th>
<th>WEIGHTED SCORE</th>
<th>DOLLAR CLASS</th>
<th>WEIGHTED CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 S13</td>
<td>86.50</td>
<td>1,036.00</td>
<td>1</td>
<td>7</td>
<td>0.87690</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>M2 S2</td>
<td>210.00</td>
<td>5,670.00</td>
<td>1</td>
<td>5</td>
<td>0.86066</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>M3 S9</td>
<td>73.44</td>
<td>2,423.52</td>
<td>1</td>
<td>6</td>
<td>0.82538</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>M4 S3</td>
<td>23.76</td>
<td>5,037.12</td>
<td>1</td>
<td>4</td>
<td>0.71080</td>
<td>A</td>
<td>A</td>
</tr>
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<td>4</td>
<td>0.66237</td>
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<td>A</td>
</tr>
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<td>1</td>
<td>4</td>
<td>0.63900</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
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<td>2</td>
<td>0.59684</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>M8 S15</td>
<td>71.20</td>
<td>854.40</td>
<td>1</td>
<td>3</td>
<td>0.59480</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>M9 S18</td>
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<td>594.00</td>
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<td>0.57539</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
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<td>398.40</td>
<td>1</td>
<td>3</td>
<td>0.57302</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
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<td>1</td>
<td>3</td>
<td>0.57224</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>M12 S14</td>
<td>110.40</td>
<td>883.20</td>
<td>0.5</td>
<td>5</td>
<td>0.53502</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
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<td>4</td>
<td>0.50995</td>
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<td>B</td>
</tr>
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<td>0.50975</td>
<td>C</td>
<td>B</td>
</tr>
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<td>2</td>
<td>0.50937</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
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<td>0.50592</td>
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<td>0.50456</td>
<td>B</td>
<td>B</td>
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<td>5</td>
<td>0.50314</td>
<td>B</td>
<td>B</td>
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<td>0.46347</td>
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<td>B</td>
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<td>0.44250</td>
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<td>B</td>
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<td>0.44018</td>
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<td>0.42707</td>
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<td>3</td>
<td>0.41910</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>M25 S34</td>
<td>7.07</td>
<td>190.89</td>
<td>0.01</td>
<td>7</td>
<td>0.41335</td>
<td>C</td>
<td>C</td>
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<tr>
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<td>31.24</td>
<td>2,906.67</td>
<td>0.5</td>
<td>3</td>
<td>0.40029</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
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<td>28.20</td>
<td>2,820.00</td>
<td>0.5</td>
<td>3</td>
<td>0.39728</td>
<td>A</td>
<td>C</td>
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<tr>
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<td>0.01</td>
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<td>0.37435</td>
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<td>3</td>
<td>0.37207</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>M30 S38</td>
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<td>0.5</td>
<td>3</td>
<td>0.37004</td>
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</tr>
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<td>M31 S40</td>
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<td>0.36078</td>
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<tr>
<td>M32 S39</td>
<td>59.60</td>
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<td>5</td>
<td>0.29574</td>
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<td>C</td>
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<tr>
<td>M33 S33</td>
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<td>0.29309</td>
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</tr>
<tr>
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<td>0.01</td>
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<td>0.28485</td>
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<td>C</td>
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<tr>
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<td>50.78</td>
<td>0.01</td>
<td>5</td>
<td>0.28339</td>
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<td>C</td>
</tr>
<tr>
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<td>8.46</td>
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<td>5</td>
<td>0.27461</td>
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<td>4</td>
<td>0.26535</td>
<td>A</td>
<td>C</td>
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<td>181.80</td>
<td>0.01</td>
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<td>0.16044</td>
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<td>48.30</td>
<td>0.01</td>
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<td>0.15362</td>
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<td>C</td>
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<td>28.80</td>
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<td>1</td>
<td>0.06342</td>
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<td>C</td>
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<tr>
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<td>75.40</td>
<td>0.01</td>
<td>2</td>
<td>0.08164</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>M44 S41</td>
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<td>79.20</td>
<td>0.01</td>
<td>2</td>
<td>0.07482</td>
<td>C</td>
<td>C</td>
</tr>
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<td>M45 S27</td>
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<td>0.01</td>
<td>1</td>
<td>0.03521</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>M46 S30</td>
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<td>224.00</td>
<td>0.01</td>
<td>1</td>
<td>0.02268</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>M47 S25</td>
<td>37.05</td>
<td>370.50</td>
<td>0.01</td>
<td>1</td>
<td>0.01771</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

### Multicriteria inventory classification

Table 3. Listing of disposable items in descending order of weighted score.
Table 4. Comparison of rankings. Annual dollar usage and multiple criteria.

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>TOTAL ANNUAL USAGE</th>
<th>ANNUAL DOLLAR USAGE ($)</th>
<th>ANNUAL USAGE CLASS</th>
<th>WEIGHTED SCORE</th>
<th>WEIGHTED CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>117</td>
<td>5,840.64</td>
<td>A</td>
<td>0.59684</td>
<td>A</td>
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<tr>
<td>S2</td>
<td>27</td>
<td>5,670.00</td>
<td>A</td>
<td>0.86066</td>
<td>A</td>
</tr>
<tr>
<td>S3</td>
<td>212</td>
<td>5,037.12</td>
<td>A</td>
<td>0.71080</td>
<td>A</td>
</tr>
<tr>
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<td>172</td>
<td>4,769.56</td>
<td>A</td>
<td>0.08342</td>
<td>C</td>
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<tr>
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<td>A</td>
<td>0.41910</td>
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<td>2,936.67</td>
<td>A</td>
<td>0.40029</td>
<td>C</td>
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<td>2,640.00</td>
<td>A</td>
<td>0.26535</td>
<td>C</td>
</tr>
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<td>S8</td>
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<td>2,423.52</td>
<td>A</td>
<td>0.82538</td>
<td>A</td>
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<td>2,407.50</td>
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<td>B</td>
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<td>B</td>
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<td>B</td>
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<td>A</td>
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<td>B</td>
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<td>B</td>
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<td>B</td>
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<td>0.57539</td>
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<td>B</td>
<td>0.50592</td>
<td>B</td>
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<tr>
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<td>C</td>
<td>0.01771</td>
<td>C</td>
</tr>
<tr>
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<td>10</td>
<td>338.40</td>
<td>C</td>
<td>0.15263</td>
<td>C</td>
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<tr>
<td>S27</td>
<td>4</td>
<td>336.12</td>
<td>C</td>
<td>0.03521</td>
<td>C</td>
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<tr>
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<td>4</td>
<td>313.60</td>
<td>C</td>
<td>0.37435</td>
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<td>C</td>
</tr>
<tr>
<td>S31</td>
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<tr>
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<td>S33</td>
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<td>197.92</td>
<td>C</td>
<td>0.29309</td>
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<tr>
<td>S34</td>
<td>27</td>
<td>190.89</td>
<td>C</td>
<td>0.41335</td>
<td>C</td>
</tr>
<tr>
<td>S35</td>
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<td>C</td>
<td>0.16044</td>
<td>C</td>
</tr>
<tr>
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<td>C</td>
<td>0.28485</td>
<td>C</td>
</tr>
<tr>
<td>S38</td>
<td>2</td>
<td>134.80</td>
<td>C</td>
<td>0.37004</td>
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<td>S39</td>
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<td>119.20</td>
<td>C</td>
<td>0.29574</td>
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<tr>
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</tr>
<tr>
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<td>3</td>
<td>25.38</td>
<td>C</td>
<td>0.27461</td>
<td>C</td>
</tr>
</tbody>
</table>
The values used for the criticality factor, and the ranges for lead time are considered representative. As the criteria have different units of measure, the measures have to be converted to a common 0-1 scale. The criteria such as average unit cost, annual dollar usage, and lead time were transformed using the following formula:

\[
\frac{F_i - F_{\min}}{F_{\max} - F_{\min}}
\]

where \( F_i \) is the \( i \)-th value of the factor under transformation, \( F_{\max} \) is the maximum value of the factor under transformation, and \( F_{\min} \) is the minimum value of the factor under transformation. For instance, item S1 would be evaluated in the following manner:

\[
0.07872 \left( \frac{49.92 - 5.12}{210 - 5.12} \right) + 0.00161 \left( \frac{5840.64 - 25.38}{5840.64 - 25.38} \right) + 0.41069 \left( \frac{1 - 0.01}{1 - 0.01} \right) + 0.40099 \left( \frac{2 - 1}{7 - 1} \right) = 0.59684.
\]

In Table 2 the hospital items are still listed from S1 to S47 but on the right-most column, the new classification using the composite weights have the names M1 through M47 (not in sequential order). With the weighted score as a common measure, the inventory items can be reclassified. The results are listed in Table 3.

A reasonable scenario is that, since the same items are viewed under more than one criterion, an item would not be classified the same under all criteria. For instance, item X may be classified as an A item using the first criterion. The same item may be classified as C using another criterion. The same policies can be applied as under the dollar value method, but items will be classified on a broader, more effective basis reflecting all objectives modeled.

Table 4 compares the classification of the individual items, as determined by Reid using only a single criterion for analysis, and as determined in this paper using a multiple criteria ABC classification (sorted by descending value of annual dollar usage).

Another form for viewing this would be to show both classifications:

<table>
<thead>
<tr>
<th>OLD CLASSIFICATION</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>5</td>
<td>18</td>
<td>23</td>
</tr>
</tbody>
</table>

| TOTAL              | 10 | 14 | 23 | 47    |

Observe that two items that previously were classified as A are now in category B and four in C (first row in the table above). On the other side, six items that were B are now A (first column in the table above).

The important changes and their explanations can be described as follows.

1. Of the six items that went up to A, five were classified as very critical and the other (S18) as moderately critical. The weight on criticality in the example was emphasized. S18 had a relatively long lead time. All six of these items had lead times of three weeks or greater.

2. None of the six items dropped from the A category had high criticality ratings. Only items S8 and S10 had a lead time as long as four weeks, and S10 (with a moderate criticality rating) was reclassified to the B category.

3. One item rated as B in the original classification (S16) was dropped to C. S16 had an intermediate criticality index, and a lead time of 3 weeks. Neither of these factors alone explain the reclassification, but the combination of intermediate criticality and relatively low annual dollar usage and unit cost resulted in lower classification.

4. Five C items were reclassified as B. S32 and S36 had high criticality ratings, and barely missed A reclassification. This was due to low lead times. Item S31 had an intermediate
criticality rating and relatively long lead time, but low unit cost and annual dollar usage. Items S29 and S45 had low criticality ratings, but a very long lead time, combined with higher unit costs and annual dollar usage than other C items.

These two parameters, criticality and lead time, are by far the most important ones. It should be remembered that the weight for these two criteria were 42 percent and 41 percent of the total. The impact that they can have can be dramatic as was described above.

The effect of the application of a multiple criteria ABC analysis can be summarized as follows. The modified classification reveals the impact of other criteria by changing the items in categories A, B and C. Unless these other criteria are included, the original classification may not be complete and in some cases it may be misleading.

CONCLUSIONS

The classical single criterion ABC inventory classification is simple, straightforward and practical. However, in the management of an inventory, other criteria influence its administration. Factors such as lead time, criticality, and obsolescence may sometimes be so important that they override financial concerns.

When considering multiple criteria, a major concern is not to complicate the managerial process. It is necessary to incorporate multiple criteria and still have a reasonably simple set of inventory policies. The utilization of AHP provides a way to combine these multiple criteria. AHP generates a consistent measure that can be used for reclassification of inventory items in a simple ABC structure. Once the reclassification process is made, the use of a resource limitation variable can be used to generate the new grouping.

The new reclassification reveals the results of a more complete analysis. An inventory item measured under different parameters ranks (in most cases) differently from parameter to parameter. An item may be very costly, but not as critical. Another may be very critical, but have a very short lead time. When all of these factors are synthesized into a single ranking, very likely the assignment of items to classes will be more uniform, as described by Flores and Whybark [1].

A limitation of the approach is that more managerial time is needed to develop more information for each inventory item. Reviewing thousands of items and classifying them with respect to key criteria requires management time (although much of this operation can be automated). This will create a natural constraint for the number of criteria considered.

However, use of multiple criteria ABC analysis can improve the quality and completeness of the inventory analysis. To make the results more manageable the use of AHP can be a powerful ally in supporting the policy development process.

REFERENCES