## 1 Prioritizing warehouse performance measures in contemporary supply chains

In this study, fuzzy AHP was applied to obtain more decisive judgments by weighting the performance measures in the presence of vagueness of experts’ preferences. The approach of fuzzy AHP to calculate weights of performance measures is described as follows:

1) Develop a hierarchical structure for prioritizing the performance measures. A fuzzy AHP model (Figure 3), based on the identified potential measures and associated categories, is developed and presented. With a hierarchical structure, a complicated and complex problem is converted to a hierarchical system of elements. The hierarchical structure systematically accommodates the use of expert judgment:

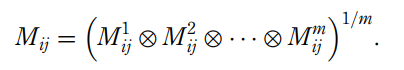
在这项研究中，模糊的AHP被应用于通过在专家偏好模糊的情况下对绩效指标进行加权来获得更果断的判断。模糊 AHP 计算性能指标权重的方法如下：

1. 制定等级结构，优先确定绩效指标的优先级。开发并提出了一个模糊的AHP模型（图3），基于已确定的潜在措施和相关类别。在分层结构下，复杂而复杂的问题被转换为元素的分层系统。等级结构系统地适应专家判断的使用：

(2) Establish a fuzzy judgment matrix (or a pairwise comparison matrix). A panel of experts was asked to make pairwise comparisons for elements and questionnaires were provided to collect information from the experts. Each expert was asked to assign linguistic terms based on his/her subjective judgment, to the pairwise comparisons by asking which one of two categories is more important and how much more important it is with respect to the preceding element. In this case, linguistic terms adopted include five different scales: equally important, moderately important, fairly important, very important (VI) and absolutely important. In decision making, each expert gave his/her preference on the categories identified in the above step (Step 1) of the procedure. In the case of pairwise comparison of categories using linguistic terms, each expert’s judgment resulted in (n−1) of comparisons for n number of categories. For the four categories identified above, there are six pairwise comparisons from each expert. The fuzzy judgment matrix reflects the relative importance of the decision categories. After recoding answers from the experts in linguistic terms, these linguistic judgments are then converted to triangular fuzzy sets:

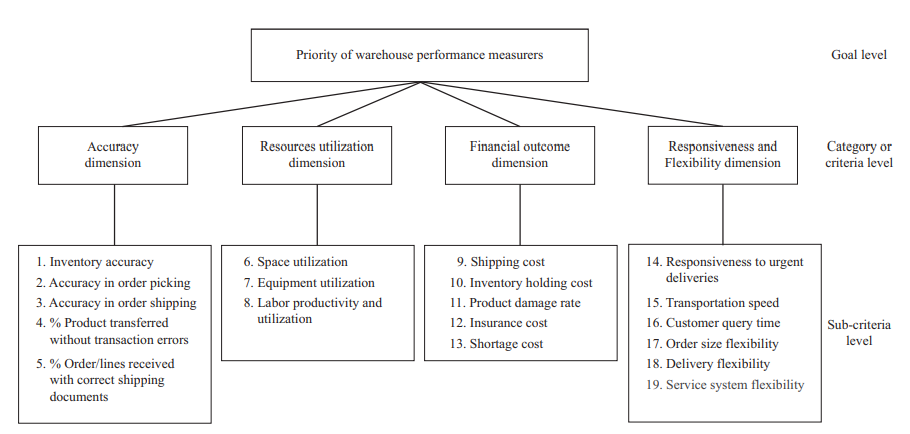
（2） 建立模糊判断矩阵（或对比矩阵）。请一个专家小组对要素进行对比，并提供问卷，以便从专家处收集信息。每位专家被要求根据主观判断来分配语言术语，通过询问哪两个类别中哪一个更重要，以及它对上述要素有多重要，从而对配对进行对比。在这种情况下，采用的语言术语包括五个不同的尺度：同样重要、中等重要、相当重要、非常重要（六）和绝对重要。在决策中，每位专家都对程序上述步骤（第 1 步）中确定的类别给予了偏好。在使用语言术语对类别进行对比的情况下，每个专家的判断导致（n−1）对n个类别的比较。对于上述四个类别，每个专家有六个对比。模糊的判断矩阵反映了决策类别的相对重要性。在用语言术语重新编码专家的回答后，这些语言判断被转换为三角模糊集：

(3) Combine the opinions from several experts by using geometric mean. The perception of each expert varies according to individual experience and knowledge. In order to get a consistent and fair outcome from several experts’ subjective judgments, the informed judgments were aggregated through the geometric mean of individual experts’ judgments. By using the geometric mean method to derive the fuzzy weight, therefore, different judgmental values can be converted to one element in the fuzzy judgment matrix. Let Mk ij represent a subjective judgment of the kth expert for the relative importance of two elements (the ith element and the jth element), then the fuzzy geometric mean Mij from m experts is shown in following equation. Fuzzy geometric mean:

使用几何均值将几位专家的意见结合起来。每个专家的看法因个人经验和知识而异。为了从几位专家的主观判断中得到一致和公正的结果，通过个别专家判断的几何平均值对知情的判断进行了汇总。因此，通过使用几何均值法来推导模糊重量，可以将不同的判断值转换为模糊判断矩阵中的一个元素。让 Mk ij 代表 kth 专家对两个元素（即元素和 jth 元素）的相对重要性的主观判断，然后 m 专家的模糊几何表示 Mij 在以下方程中显示。模糊几何表示：

(4) Repeat the calculation of the local priority weights for other categories of performance measures.重复计算其他类别绩效指标的本地优先权重

(5) Calculate the global priority weight of each element



The global priority weight of each element is calculated by multiplying its local weight with its corresponding weight along the hierarchy. Tables V–IX show the results from fuzzy AHP process from the three different groups of experts, while Table X presents the overall result. There are a variety of extensions to the fuzzy AHP approach that can increase its usefulness for managerial decision making. For prioritizing the performance measures, in this study,

6）Validate the priorities/ranks of performance categories using judgments of multiple decision makers

6）使用多个决策者的判断验证绩效类别的优先级/等级

Priorities of performance categories identified by weights from AHP (Table X) are validated by minimization of deviation between the ranking of each category by individual decisionmaker and weighted average of each category. Decision makers are selected from the group of 20 warehouse managers that participated in the study (Table IV). The following key variables and parameters were defined for the minimization of deviation using integer programming model:

The AHP, developed at the Wharton School of Business by in 1980, is one of the most powerful and flexible weighted scoring decision-making process to help people set priorities and make the best decision. AHP has been widely used to solve multi-criteria decision making in both academic research and in industrial practice.

AHP 于 1980 年在沃顿商学院开发，是最强大、最灵活的加权评分决策流程之一，旨在帮助人们确定优先事项并做出最佳决策。AHP已广泛应用于解决学术研究和工业实践中的多标准决策问题。

Fuzzy set theory was first introduced by [7] in 1965. He was motivated by observing that human reasoning can utilize concepts and knowledge that don’t have welldefined boundaries [8], Fuzzy set theory (FST) is a generalization of the ordinary set theory as shown in figure 1.

Fuzzy Logic, which was developed on the mathematical basis of the Fuzzy Collection theory founded by Professor L.A. Zadeh in 1965, argues that all-natural languages are vague, such as "red" and "old" concepts, which have no clear connotation and extension and are therefore ambiguous and ambiguous. Fuzzy theory is based on the fuzzy set, the fundamental spirit of which is to accept the fact that fuzziness phenomenon exists, and to deal with the vague and uncertain concept as its research goal, and actively quantify it closely into information that computer can handle, and does not advocate the use of complicated mathematical analysis that is model to solve the model.

[17] L.A. Zadeh, “Fuzzy sets”, Information Control, Vol. 8, No.3, pp.338–353, 1965.

AHP 于 1980 年在沃顿商学院开发，是最强大、最灵活的加权评分决策流程之一，旨在帮助人们确定优先事项并做出最佳决策。AHP已广泛应用于解决中的多标准决策问题。

层次分析法，简称AHP，是指将与[决策](https://baike.baidu.com/item/%E5%86%B3%E7%AD%96/1513)总是有关的[元素](https://baike.baidu.com/item/%E5%85%83%E7%B4%A0/9563210)分解成目标、准则、方案等层次，在此基础之上进行[定性](https://baike.baidu.com/item/%E5%AE%9A%E6%80%A7/2704301)和[定量](https://baike.baidu.com/item/%E5%AE%9A%E9%87%8F/8916396)分析的决策方法。

层次分析法是指将一个复杂的[多目标决策问题](https://baike.baidu.com/item/%E5%A4%9A%E7%9B%AE%E6%A0%87%E5%86%B3%E7%AD%96%E9%97%AE%E9%A2%98/19143718" \t "_blank)作为一个系统，将目标分解为多个目标或准则，进而分解为多指标（或准则、约束）的若干层次，通过定性指标模糊量化方法算出层次单排序（权数）和总排序，以作为目标（多指标）、多方案优化决策的系统方法。

层次分析法是将决策问题按总目标、各层子目标、评价准则直至具体的备投方案的顺序分解为不同的层次结构，然后用求解判断矩阵[特征向量](https://baike.baidu.com/item/%E7%89%B9%E5%BE%81%E5%90%91%E9%87%8F/8663983)的办法，求得每一层次的各元素对上一层次某元素的优先权重，最后再加权和的方法递阶归并各备择方案对总目标的最终权重，此最终权重最大者即为最优方案。

层次分析法的基本原理是根据问题的性质和要达到的总目标，将问题分解为不同的组成因素，并按照因素间的相互关联影响以及[隶属关系](https://baike.baidu.com/item/%E9%9A%B6%E5%B1%9E%E5%85%B3%E7%B3%BB/8924394)将因素按不同层次聚集组合，形成一个多层次的分析结构模型，从而最终使问题归结为最低层(供决策的方案、措施等)相对于最高层(总目标)的相对重要权值的确定或相对优劣次序的排定。

[层次分析法](https://wiki.mbalib.com/wiki/%E5%B1%82%E6%AC%A1%E5%88%86%E6%9E%90%E6%B3%95)最大的问题是某一层次评价指标很多时（如四个以上），其[思维](https://wiki.mbalib.com/wiki/%E6%80%9D%E7%BB%B4" \o "思维)一致性很难[保证](https://wiki.mbalib.com/wiki/%E4%BF%9D%E8%AF%81)。在这种情况下，将模糊法与[层次分析法](https://wiki.mbalib.com/wiki/%E5%B1%82%E6%AC%A1%E5%88%86%E6%9E%90%E6%B3%95)的优势结合起来形成的模糊层次分析法（FAHP），将能很好地解决这一问题。模糊层次分析法的基本思想和步骤与AHP的步骤基本一致，但仍有以下两方面的不同点：

　　（1）建立的判断矩阵不同：在AHP中是通过元素的两两比较建立判断一致矩阵；而在FAHP中通过元素两两比较建立模糊一致判断矩阵

　　（2）求矩阵中各元素的相对重要性的[权重](https://wiki.mbalib.com/wiki/%E6%9D%83%E9%87%8D" \o "权重)的方法不同

而模糊层次分析法（FAHP）改进了传统层次分析法存在的问题，提高了决策可靠性。FAHP有一种是基于模糊数，另一种是基于模糊一致性矩阵。

[The biggest problem with hierarchical analysis](https://wiki.mbalib.com/wiki/%E5%B1%82%E6%AC%A1%E5%88%86%E6%9E%90%E6%B3%95) is that when there are many evaluation indicators at a certain level (such as more than four), the [consistency](https://wiki.mbalib.com/wiki/%E6%80%9D%E7%BB%B4) of thinking is difficult to [guarantee.](https://wiki.mbalib.com/wiki/%E4%BF%9D%E8%AF%81) In this case, the fuzzy hierarchy [analysis](https://wiki.mbalib.com/wiki/%E5%B1%82%E6%AC%A1%E5%88%86%E6%9E%90%E6%B3%95) method(FAHP) formed by combining the advantages of fuzzy method with hierarchical analysis methodwill solve this problemwell. The basic ideas and steps of fuzzy hierarchical analysis are basically the same as about AHP, but there are still two differences:

(1) The judgment matrix is different: in AHP, a consistent matrix of judgment is established by two comparisons of elements, and in FAHP, a fuzzy consistent judgment matrix is established by comparing two or two elements

(2)The method of determining the [weight](https://wiki.mbalib.com/wiki/%E6%9D%83%E9%87%8D) of the relative importance of each element in the matrix is different

Fuzzy Hierarchy Analysis(FAHP)improves the problems of traditional hierarchical analysis and improves decision-making reliability. FAHP is based on fuzzy numbers one and fuzzy consistency matrix.

将决策的目标、考虑的因素（决策准则）和决策对象按它们之间的相互关系分为最高层、中间层和最低层，绘出层次结构图。

**1、 模糊互补判断矩阵的建立**

　　在模糊层次分析中,作因素间的两两比较判断时,采用一个因素比另一个因素的重要程度定量表示,则得到的模糊判断矩阵A=(a_{ij})n \times n,如果其具 有如下性质:

　　1)a_{ii}=0.5,i=1,2,\cdots,n;

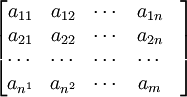
　　2)a_{ij}+a_{ji}=1,i,j=1,2, \cdots ,n;

　　则这样的判断矩阵称为模糊互补判断矩阵。为了使任意两个方案关于某准则的相对重要程度得到定量描述,通常采用如表1的0.1～0.9标度法给予数量标度。

|  |  |  |
| --- | --- | --- |
| 标度 | [定义](https://wiki.mbalib.com/wiki/%E5%AE%9A%E4%B9%89) | 说明 |
| 0.5 同等重要 | 两元素相比较, | 同等重要 |
| 0.6 稍微重要 | 两元素相比较, | 一元素比另一元素稍微重要 |
| 0.7 明显重要 | 两元素相比较, | 一元素比另一元素明显重要 |
| 0.8 重要得多 | 两元素相比较, | 一元素比另一元素重要得多 |
| 0.9 极端重要 | 两元素相比较, | 一元素比另一元素极端重要 |
| 0.1,0.2,0.3,0.4 | 反比较 | 若元素ai与元素aj相比较得到判断rii,则原素a\_i与元素ai相比较得到的判断为*rji*=1-*rij* |

*aii* = 0.5表示因素与自己相比同样重要;若a_{ij} \in [0.1,0.5),则表示因素*xj*比*xi*重要;若a_{ij} \in [0.5,0.9],则表示因素xi比xj重要。

　　依据上面的数字标度,因素*a*1,*a*2,…,an相互进行比较,则得到如下模糊互补判断矩阵

　　A= （1）

Table

Description automatically generated  
　　2、**模糊互补判断矩阵的权重公式**

　　推导出求解模糊互补判断矩阵权重的一种通用公式,该公式充分包含了模糊一致性判 断矩阵的优良特性及其判断信息,计算量小且便于计算机编程实现,为实际应用带来了极大方便。该求解模糊互补判断矩阵权重的公式如下：

W_i=\frac{\sum_{j=1}^n a_{ij}+\frac{n}{2}-1}{n(n-1)} （2）

　　3、**模糊互补判断矩阵的一致性检验方法**

　　由式(2)得到的权重值是否合理,还应该进行比 较判断的一致性检验。当偏移一致性过大时,表明此时将权向量的计算结果作为决策依据是不可靠的。推导出用模糊判断矩阵的相容性来检验其一致性原则的方法。

　　定义1:设矩阵A=(a_{ij})_{n \times n}和B=(b_{ij})_{n \times n}均为模糊判断矩阵,称

I(A,B)=\frac{1}{n^2}\sum_{j=1}^n \sum_{i=1}^n a_{ij}+b_{ij}-1 （3）

　　为A和B的相容性指标。

　　定义2:设W=(W_1,W_2, \cdots ,W_n)^T是模糊判断矩阵A的权重向量,其中\sum_{i=1}^n W_i=1,W_i \ge 0(i=1,2,\cdots ,n),令W_{ij}=W_iW_i+W_j,(P_i,j=1,2,3, \cdots ,n),则称n阶矩阵：

W \star =(W_{ij})_{n \times n} (4)

　　为判断矩阵A的特征矩阵。对于决策者的态度A,当相容性指标I(A,W) \le A时,认为判断矩阵为满意一致性的。A越小表明决策者对模糊判断矩阵的一致性要求越高,一般可取A=0.1。

　　对于实际的问题,一般都是由多个(设k=1,2, \cdots ,m)专家给出同一因素集X上的两两比较判断矩阵

A_K=(a_{ij}^{(k)})_{n \times n}(k=1,2, \cdots ,m)

　　它们均是模糊互补判断矩阵,则可分别得到权重集的集合W^{(k)}=(w_1^{(k)},w_2^{(k)}, \cdots ,w_n^{(k)}) (k=1,2, \cdots ,m)

　　则进行模糊互补判断矩阵的一致性检验,要做以下两方面的工作:

　　1)检验m个判断矩阵Ak的满意一致性:I(Ak,W^{(k)}) \le A,k=1,2, \cdots ,m

　　2)检验判断矩阵间的满意相容性:

I(A_k,A_l) \le A,k \ne l;k,l=1,2, \cdots ,m可以证明在模糊互补判断矩阵A_k(k=1,2, \cdots ,m)是一致可接受的情况下,它们的综合判断矩阵也是一致可接受的。权重向量表达式:

W=(W_1,W_2, \cdots ,W_n) (5)

　　式(5)中:W_i=\frac{1}{n} \sum_{k=1} W_i^{(k)} (i=1,2, \cdots ,n)2

　　即只要当1)和2)两条满足时,m个权重集的均值作为因素集X的权重分配向量是合理和可靠的。

We use the NP value we summarized to measure the importance of the variable, and select NP=5 as an importance level.