A MULTICRITERIA DECISION MAKING AT PORTFOLIO MANAGEMENT

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Introduction

In this paper we propose an application of the Analytic hierarchy process (AHP) to partial task at portfolio management. Any portfolio manager who works in an asset management company deals with the problem of converting his portfolio into cash. There is a need to decide, which instrument available on the market is the best one to invest in. Of course, there are specific areas e.g. law, contract, internal requirements (criteria), which make the problem difficult. This problem could be viewed as a multicriteria decision making (MCDM) problem and Analytic Hierarchy Process (AHP) seems to be a suitable method for solving it.

Apart from the classical portfolio selection based on Markowitz theory, see for example [1], there are some studies applying AHP on portfolio mix, see e.g. [10]. This paper represents an appropriate approach to e.g. a pension fund portfolio. This may be also a problem of pair-wise comparison, see e.g. [11]. Another application of AHP close to our approach can be found in [12]. In this paper we show that AHP results could be comparable to that obtained by mean-variance optimization. In fact our specific approach could be viewed as a development of the idea given in [10].

In [4] a new MCDM method is presented which, in some sense, is an extension of AHP allowing for using triangular fuzzy inputs and feedback between criteria The result of our work should answer the question if the software tool FVK created in [4] could be used as an alternative to the well known SW Expert Choice (EC) for solving our portfolio problem.

Let us start with the basic characteristics of a decision making (DM) model. Any DM model should satisfy the following characteristics:

- should be easy to compose,
- should follow an intuition (it is not always the case),
- should be flexible in all elements,
- should comply with common sense,
- should include instructions for compromise,
- should be comprehensible.

It is important that even a poor problem design into a format convenient for mathematical modelling brings useful insight into a detail of the problem. The logic of MCDM is based on the goal identification, elements incorporated and influencing the output. In the next stage we shall deal with the time horizon, scenarios and limiting factors, see [7].

Some studies on analytical thinking led to the development of such models in 1970s, see e.g. [5] and the references therein. That was the time the method for DM support called the AHP was developed. The author Thomas L. Saaty – an American professor – and his coworkers and successors found many applications for the method. For example, in everyday life (e.g. a new car purchase, a choice of carrier, and so on) or in decision making problems in society or institutions (general elections, marketing strategies, political decisions, project selection etc.) For more information, see [2] or [5,6].

Since its inception, the AHP has become one of the most widely used tools for MCDM. The procedures of the AHP involve the following steps, see [5,6]:

- Define the problem, objectives and outcomes.
- Decompose the problem into a hierarchical structure with decision elements (criteria, detailed criteria and alternatives).
- Apply the pair-wise comparison method resulting in pair-wise comparison matrices.
- Apply the principal eigenvalue method to estimate the relative weights of the decision elements.

- Check the consistency of pair-wise comparison matrices to ensure that the judgments of decision makers are consistent.
- Aggregate the relative weights of decision elements to obtain an overall rating for the alternatives.

1. Description of AHP

Here, we consider a three-level hierarchical decision system: On the first level we consider a decision goal G, on the second level, n independent evaluation criteria: $C_1, C_2,...,C_n$ are considered such that $\sum_{i=1}^{n} w(C_i)=1$, where $w(C_i)$ is a positive real number – weight, usually interpreted as a relative importance of criterion C_i subject to the goal G. On the third level, m alternatives (variants) of the decision outcomes $V_1, V_2,...,V_m$ are considered, again $\sum_{i=1}^{m} w(V_r, C_i)=1$, where $w(V_r, C_i)$ is a non negative number - weight of alternative V_r subject to the criterion C_i, $i = 1,2,...,n$. It is advantageous to put the above mentioned weights into a matrix form.

Let $\mathbf{W}_1$ be the $n\times 1$ matrix (weighing vector of the criteria), i.e. $\mathbf{W}_1 = \begin{bmatrix} w(C_i) \\ \vdots \\ w(C_n) \end{bmatrix}$, and $\mathbf{W}_3$ be $m\times n$ matrix:

$$\mathbf{W}_3 = \begin{bmatrix} w(C_1,V_1) & \cdots & w(C_n,V_1) \\ \vdots & \cdots & \vdots \\ w(C_1,V_m) & \cdots & w(C_n,V_m) \end{bmatrix}. \qquad (1)$$

The columns of this matrix are evaluations of alternatives according to the given criteria. Moreover, in matrix $\mathbf{W}_3$ the sums of columns are assumed to be equal to one (this property is called stochasticity, for more details see [5]). The following matrix product

$$\mathbf{Z} = \mathbf{W}_3\mathbf{W}_1 \qquad (2)$$

is an m×1 matrix - the resulting vector of weights of the alternatives – expressing the relative importance of the alternatives. From formula (2) we get the weights in following way

$$Z_j = \sum_{i=1}^{n} w(C_i)\, w(C_i, V_j),\ j = 1,2,...,m. \qquad (3)$$

The weights $w(C_i)$, and $w(C_i,V_j)$ will be denoted in the following text simply as w_k, we get them from the pair-wise comparison matrix. An element of pair-wise comparison matrix serves as a relative evaluation element from the given hierarchy level to a given element from the dominant level. Each pair of elements is evaluated on a specific scale, see below. A starting point for the weights calculation is a pair-wise comparison matrix $S=\{s_{ij}\}$. The value s_{ij} expresses the relative importance of elements x_i to element x_j, with respect to the superior element, in other words a ratio of w_i and w_j:

$$s_{ij} = \frac{w_i}{w_j},\ i,j = 1,2,...,m. \qquad (4)$$

As the weights w_k are not known in advance, (it is our goal to find the weights), we use for their determination an additional information about the numbers sij, from the basic scale {1, 2,...,9}, i.e.

$$s_{ij} \in \{1,2,3,4,5,6,7,8,9\}. \qquad (5)$$

It follows from (4) that pair-wise comparison matrix $\boldsymbol{S}$ is reciprocal, which means that

$$s_{ij} = \frac{1}{s_{ji}}\ . \qquad (6)$$

In AHP, the vector w_k of weights wk is calculated by a specific method based on the principal eigenvector of pair-wise comparison matrix $S=\{s_{ij}\}$. The following equation holds:

$$\boldsymbol{S}\boldsymbol{w} = \lambda_{\max}\, \boldsymbol{w}, \qquad (7)$$

where $\lambda_{\max}$ is the maximal eigenvalue of matrix $\boldsymbol{S}$.

The values (called also intensities) from 1 to 9 in the evaluation scale (5) being used in pair-wise comparisons can be interpreted qualitatively by words as follows:

Pair-wise comparison of elements x_i and x_j - number scale	Intensity of relative importance of element x_i to element x_j – word scale
1	x_i and x_j are equally important
3	x_i is more important than x_j
5	x_i is strongly more important than x_j
7	x_i is very strongly more important than x_j
9	x_i is absolutely more important than x_j

The numbers 2,4,6,8 and their reciprocals are used to facilitate a compromise between slightly different judgments. Some authors also use rational numbers to form ratios from the above scale values, see [3] or [4].

2. Application to Portfolio Management – Empirical Example

The main task of a portfolio manager is asset allocation, which is to select new assets for a new investment. Moreover, the portfolio manager has to make predictions about the price development concerning each asset class and, consequently, sell some of his positions and make new investments. The trickiest part of his work is to close some losing positions. It may happen when the loss reaches a specified value, which is not bearable for the owner of the portfolio any more. This is called realization of Stop-Losses. By the word “trickiest” we mean the effect given by cutting off any recovery possibility of the price.

Nevertheless, the main motivation for portfolio management is a possibility of its diversification. Financial instruments are divided into several categories, i.g. cash, bonds, equities and others. The prices movements at asset allocation could take different directions, or, do not have the same drift, which is reflected by correlation. There are other possible diversification styles: we distinguish credit, geographic, currency and other diversification styles depending on different characteristics of issuer, see e.g. [1].

As the need in portfolio management is to make daily decisions concerning substitution of matured instruments for some new allocations, it may be useful to apply the AHP. Here, we illustrate the application of this MCDM technique on the following practical problem.

In Tab. 1 we consider four instruments, which are available for the sale on the financial market:

Tab. 1 contains preselected instruments (bonds), considered by a portfolio manager for his investment activity. For all financial instruments we consider some characteristics – evaluation criteria. Particularly, we consider 4 evaluation criteria: Crit1 - volatility, Crit2 - rating, Crit3 - duration and Crit4 - liquidity.

Volatility is one of the most popular characteristic of the financial instrument. Sometimes it is considered as a risk. We can simply say, the more volatile price of some instrument is, the higher is the risk of loss. Some conservative models consider equity of volatility at the level of 30 %. The bonds prices have lower volatility which is given by the fact that the investment into such instrument is not risky, of course, from the point of view of volatility. A usual expected volatility level of bonds is between 0 %-10 %. Moreover, the bonds are in fact the right to get back invested money – nominal value plus the coupon, which is usually paid through the life of the bond.

Here, we use the well known historical approach for volatility calculation. First of all, we calculate the changes of asset returns by formula:

$$R_{i,t} = \frac{P_{i,t} - P_{i,t-1}}{P_{i,t-1}} = \frac{P_{i,t}}{P_{i,t-1}} - 1.$$

Next, an expected value of returns is calculated by the following formula:

$$E(R_i) = \frac{1}{N} \cdot \sum_{t=1}^{N} R_{i,t}.$$

The sample variance of returns is calculated as follows:

$$\sigma_i^2 = \frac{1}{N-1} \cdot \sum_{t=1}^{N} \left[R_{i,t} - E(R_i)\right]^2,$$

and the sample standard deviation of returns is calculated as:

$$\sigma_i = \sqrt{\sigma_i^2}$$

Tab. 1: Financial instruments

ISIN	NAME	1. volatility	2. rating	3. duration	4. liquidity
CZ0002000219	Ceskomoravska Hypotecni Banka	0,03	A	0,8491	low
XS0212596240	Deutsche Bank AG	0,05	AA	0,0381	good
XS0215579946	Tesco PLC	0,08	A	1,0991	worse
CZ0001000863	Czech Republic Govrnment Bond	0,01	A	0,4916	the best

Source: Authors

This is considered as the volatility (risk). Here, historical prices are used, however, there exist elaborated models for volatility prediction, e.g. Vasicek´s model, EWMA model or GARCH models, see [9].

The second criterion is rating of a given issuer or issue. Here, we use the rating format given by Moody's scale in a simplified form without increasing signs (+) and decreasing signs (-). The higher number of A - symbols indicates more positive information about the credit profile of issuer. On the lower levels of the scale, instead of symbols A, symbols B and C can be used, but symbols under BBB are considered as a speculative investment.

The third criterion is *duration*. The bond price function *f(x)* is approximated by the *Taylor's expansion*. The first member of this expansion is called the duration, i.e.:

$$f(x+\Delta x)=f(x)+f'(x)\cdot\Delta x.$$

The price after certain time is calculated by the help of the first member of Taylor's expansion in the following way:

$$P_1 \equiv P(y+\Delta y) = P(y) + P'(y)\cdot\Delta y$$

where y is a yield to maturity, P is a price at the beginning of time period and P_1 is a price of bond after the change of interest rates.

By modification the equitation by subtracting and dividing of the starting price P we get:

$$\frac{P_1 - P}{P} = \frac{\Delta P}{P} = \frac{1}{P}\cdot\frac{dP}{dy}\,\Delta y,$$

The right side of the equation

$$\frac{1}{P}\cdot\frac{dP}{dy} = \frac{1}{P}\cdot\sum -t\cdot CF_t\cdot(1+y)^{-t-1} = -\mathrm{MD}$$

is called the modified duration, where CF_t is expected cash flow an owner of the bond will receive till the maturity of the bond. The negative sign of MD is a reflection of the reverse relationship between the yield curve represented here by y and price of the bond.

The modified duration is expressed by the Macauloy's duration as follows:

$$D = \frac{\dfrac{dP}{P}}{\dfrac{dy}{(1+y)}} = \frac{1}{P}\cdot\sum t\cdot CF_t\cdot(1+y)^{-t},$$

and, consequently, we obtain:

$$MD = \frac{1}{1+y}\cdot D.$$

The above formulae show that the results reflect the cash flows weighted by time. The bonds, which do not pay coupons, have the duration equal to their time to maturity. Portfolio managers usually use the secondly expressed duration, which is a MD with the positive sign, because they consider this number as an average time to maturity of their portfolio. The MD is the parameter of a portfolio, which is usually requested by contract and must be watched out.

The fourth criterion is *liquidity*. Here, the empirical approach is used: In Tab. 1 the relative evaluation is carried out by pair-wise comparison.

2.1 Solving the Problem by AHP and Expert Choice

Now, we shall solve the problem by the special SW tool named Expert Choice (EC), see [13], based on the AHP theory. The original data of our problem are given in Tab. 1. For evaluating the liquidity criterion which is given in ordinal expressions as well as the other qualitative criterion rating we use pair-wise comparison on the Saaty's scale mentioned earlier in Section 2. The same is true for evaluating relative importance of all individual criteria. Tab. 2 shows the pair-wise comparison matrix of the criteria importance given by a portfolio manager.

Tab. 2: Pair-wise comparison matrix of importance of the individual criteria

Criteria	Crit 1	Crit 2	Crit 3	Crit 4	
Crit 1	1	1/3	1/2	1/2	**- volatility**
Crit 2	3	1	3	2	**- rating**
Crit 3	2	1/3	1	2	**- duration**
Crit 4	2	1/2	1/2	1	**- liquidity**

Source: Authors

Tab. 3 contains the weights of criteria calculated by the well known eigenvector method mentioned earlier, see Eq. (7). It is clear that rating and duration are the most important criteria.

Tab. 3: Relative importance of the criteria obtained by pair-wise comparison

Criteria	Weights
Volatility	0,079
Rating	0,526
Duration	0,246
Liquidity	0,149

Source: Authors

Tab. 4 shows the pair-wise comparison matrix of liquidity.

Tab. 4: Pair-wise comparison matrix of Liquidity

Zn=	Var 1	Var 2	Var 3	Var 4	
Var 1	1	1/5	1/3	1/4	**- Ceskomoravska hypotecni banka**
Var 2	5	1	2	1/2	**- Deutsche Bank AG**
Var 3	3	1/2	1	1/2	**- Tesco PLC**
Var 4	4	2	2	1	**- Czech Republic Government bond**

Source: Authors

The values of the other criteria are calculated explicitly from the original data in Tab. 1.

Tab. 5 shows the result of calculation of each variant and criterion in the final – normalized form, i.e. the sum of all numbers in each column is equal to 1.

Tab. 5: Weights of criteria and weights of variants

Variant	Volatility	Ratingt	Duration	Liquidity
V1	0,201	0,200	0,039	0,088
V2	0,121	0,400	0,864	0,197
V3	0,075	0,200	0,030	0,231
V4	0,603	0,200	0,067	0,484

Source: Authors

Tab. 6 shows the result of the final synthesis calculated as weighting average (3) using both the calculation method called the Distributive mode and the calculation method called the Ideal mode. In the Distributive mode, all values of each criterion (i.e. in each column) are normalized, i.e. divided by the sum of the values of the respective criterion, see Tab. 5, whereas in the Ideal mode, all values of each criterion (i.e. in each column) are divided by the maximal value of the respective criterion, i.e. the highest value of each criterion is then equal to 1. In the both modes the resulting ranking of the variants is identical. For more details, see [5].

Tab. 6: Final synthesis by AHP

Distributive mode	Weights	Rank	Ideal mode	Weights	Rank
V1	0,144	4	V1	0,161	4
V2	0,462	1	V2	0,416	1
V3	0,153	3	V3	0,173	3
V4	0,242	2	V4	0,250	2

Source: Authors

Summarizing the results in Tab. 6, we can see a clear dominance of variant V2 over all other variants. Variant V4, which is ranked as the second best, has significantly lower weight. The weights of V1 and V3 are very similar each other, significantly lower than V4. Consequently, the best choice from given variants is V2, hence a cash available should be invested into variant V2.

2.2 Solving the Problem by FVK

In this part we solve the same problem as in section 3.1 by an alternative method. The method AHP was published as early as in 1980s, now it is considered a "classical" methodology; on the other hand, FVK is a newly created tool enlarging application possibilities of the AHP. The abbreviation FVK is a shortcut of Fuzzy Multicriteria Method (in Czech language). Here, we compare and discuss the results obtained by both methods.

When comparing the AHP and FVK we find out some significant differences:

- In FVK the vector of weights wk is calculated from the pair-wise comparison matrix $\boldsymbol{S} = \{s_{ij}\}$ by the geometric mean as follows:

$$w_k = \frac{\left(\prod_{j=1}^{n} s_{kj}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} s_{ij}\right)^{1/n}} . \qquad (8)$$

- FVK reduces some disadvantages of the principal eigenvector method used in AHP (see [5]),
- FVK allows for reflecting criteria interdependency, which is not considered in classical AHP.
- FVK enables to use fuzzy evaluations, specifically by triangular fuzzy numbers (i.e. triangular membership functions). Hence, FVK is convenient in situations, where the decision maker has vague information for evaluation (here we will not use this feature).

All results presented below have been calculated by software tool named FVK. This SW has been created as an add-in of MS Excel 2003 within the GACR project No. 402060431, see [3].

Tab. 7 shows the criteria weights calculated by (8), they are calculated from pair-wise comparison matrix in Tab. 2. Comparing to Tab. 3 the weights in Tab. 7 are different, however, the order of the importance of the criteria is the same.

Tab. 7: Weights of criteria by FVK

Criteria	Weights
Volatility	0,119065
Rating	0,456456
Duration	0,238131
Liquidity	0,186347

Source: Authors

Tab. 8: Final synthesis by FVK

Zn=	Weights	Rank
Var 1	0,176003	3
Var 2	0,396322	1
Var 3	0,127531	4
Var 4	0,300144	2

Source: Authors

Tab. 8 shows the final weights of the variants and ranking according to FVK. Again, the best variant is V2, however, the variants on the third and the fourth place interchanged their positions.

In the AHP we assume that the decision criteria are mutually independent. In practice, it is, however, not the case. Generally, the criteria are frequently interdependent, one criterion directly or indirectly influences the other one, e.g. rating strongly influences liquidity etc. On the other hand, FVK enables also to reflect influences between the criteria, which enables a deeper analysis of convenient alternatives. The influences (interdependeces) between the criteria are evaluated also by pair-wise comparison,

The values in the pair-wise comparison matrix evaluating influences between Crit 1 and other criteria (see Tab. 9) can be interpreted as follows: Crit 2 influences Crit 1 two times (2) more than Crit 3. Crit 2 influences Crit 1 four times (4) more than Crit 4. Crit 3 influences Crit 1 three times (3) more than Crit 4, etc.

Tab. 9: Pair-wise comparison matrix (influences between volatility and other criteria)

Crit 1	Crit 2	Crit 3	Crit 4	
Crit 2	1	2	4	**- rating**
Crit 3	1/2	1	3	**- duration**
Crit 4	1/4	1/3	1	**- liquidity**

Source: Authors

In Tab. 10 influences of Crit 2 – Rating by other criteria is presented:

Tab. 10: Pair-wise comparison matrix (influences between rating and other criteria)

Crit 2	Crit 1	Crit 3	Crit 4	
Crit 1	1	2	3	**- volatility**
Crit 3	1/2	1	1	**- duration**
Crit 4	1/3	1	1	**- liquidity**

Source: Authors

In Tab. 11 influences of Crit 3 – Duration by other criteria is presented:

Tab. 11: Pair-wise comparison matrix (influences between duration and other criteria)

Crit 3	Crit 1	Crit 2	Crit 4	
Crit 1	1	1	1	- volatility
Crit 2	1	1	1	- rating
Crit 4	1	1	1	- liquidity

Source: Authors

In Tab. 12 influences of Crit 4 – Liquidity by other criteria is presented:

Tab. 12: Pair-wise comparison matrix (influences between liquidity and other criteria)

Crit 4	Crit 1	Crit 2	Crit 3	
Crit 1	1	1/2	2	- volatility
Crit 2	2	1	5	- rating
Crit 3	1/2	1/5	1	- duration

Source: Authors

In the last table - Tab. 13 - the final weights and the corresponding ranking of the variants is presented. In comparison to the previous case, the weights of the criteria are calculated by FVK, particularly by the method of geometric mean taking into account interdependences (infuences) between the criteria, see [3,4].

Tab. 13: Final evaluation of variants according FVK

Zn=	Weights	Rank
Var 1	0,192401	3
Var 2	0,371611	1
Var 3	0,111567	4
Var 4	0,324421	2

Source: Authors

When comparing the results obtained by FVK with those obtained earlier by AHP we conclude: The best variant is again Variant 2 and the second one is again Variant 4. However, Variant 1, ranked in the case of AHP as the fourth, is now located on the third place. In this particular example, from the viewpoint of the investor, who is focused on the top variants, both AHP and FVK supply equivalent results. In general, we should, however, be careful as the results obtained by these methods could be different, particularly in case of strong interdependences between criteria.

Conclusion

In this paper we tried to show that an application of MCDM methods in portfolio management may be useful. Here, we applied classical Saaty's AHP and, at the same time, the newly developed modification of AHP named FVK extending an application power of AHP as well as reducing some of its theoretical shortages.

In the AHP we assume that the decision criteria are mutually independent, however, it is usually not the case. Generally, the criteria are interdependent, one criterion either directly or indirectly influences the other one. New method, FVK, enables also to reflect influences between the criteria, which enables a deeper analysis of all convenient alternatives. The influences (interdependeces) between the criteria are evaluated also by pair-wise comparison.

When compared the results obtained by FVK with those obtained earlier by AHP in this particular application, from the viewpoint of the investor, both AHP and FVK supplied more or less equivalent results. In general, we should, however, be careful as the results obtained by these methods could differ, particularly in case of strong interdependences between criteria.

By the help of MCDM methods, the portfolio manager is able to acquire quick information (feedback) about advantages of the asset allocation into some specific product. Consequently, every specific requirement of a contract can be reflected by the applied methods. For example, liquidity evaluation could be derived from the liquidity spread. On one hand, this approach is much more dependent on input data, on the other hand, the suggested modification could increase an objectivity of the model. Further extension could be made by implementation of ex-ante volatility, see [8]. Moreover, the rating inputs taken from the external rating agencies could be derived also from the rating models developed within the project BASEL II.

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The article deals with an application of the methodology of Analytic Hierarchy process (AHP) and also its newly developed modification named FVK at portfolio management. The method AHP was published already in 1980s whereas FVK is a newly created tool enlarging application possibilities of the AHP. Both methods provide a mathematical support to human decision making process in many areas. They can be supportive for decision making in problems like buying a new car, buying a house, which could be a task for a private person, but this decision making methods could be also useful as a supportive tool for institutions. Just to give a support for solving a problem like selecting a new employee, how to lead marketing campaign or how a specific policy would influence voters. In short, both methods are based on defining decision criteria and variants in a logical hierarchy. In a process of structuralization of the problem we firstly decompose the decision problem analytically from the upper to the lowest level and then synthesis follows in evaluating the decision variants and eliciting the best one. We apply this multi-criteria methodology to the problem of a portfolio manager decision making when selecting the best possible instrument on the financial market for his use. This decision making method is useful because the portfolio manager is not able to evaluate too many parameters at the same time and objectively rank candidates. On a numerical example we demonstrate how convenient application of the above mentioned methods could show clear and objective way for finding a satisfactory solution of this problem.

Key Words: *Multi-criteria decision making; Analytic hierarchy process; Portfolio management.*

JEL Classification: *C65.*