AEROSPACE PERFORMANCE FACTOR OPTIMIZATION

Monica VLAD, Octavian Thor PLETER
University Politehnica of Bucharest, Romania
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Abstract: *This paper illustrates a possible optimization enhancement for the APF (Aerospace Performance Factor). The APF is an approach to measure safety performance. It is a tool that visually assesses safety and its evolution over time, for the purpose of aiding the decision makers to take the most effective safety measures. Given a specific situation, the optimized APF calculates the best areas where investment is effective and, in the same time, budget considerate. This is possible by using the already implemented What-if function. This function simulates what would happen to the APF index in a scenario where a certain hypothetical decision reduces a certain contributing factor. The tool works symmetrically with mitigating factors by artificially increasing the percentage. Assuming enough data is included in the APF, the optimization returns the contribution/mitigation factor/s with the best ratio between cost and effect on the APF index.*
Keywords: *APF, optimization, safety performance, what-if tool, AHP*

1. INTRODUCTION

Costs in the context of aviation safety have always been a sensitive subject. The moral question is how to put a price on the safety of passengers - there is no possible good answer.

The paradox of costs is that you should invest an infinite amount of money (or not fly at all) to bring a zero rate of incidents and accidents and in the same time to decrease infinitely the money investment to obtain profits, at the end of the day aviation is a business. But that of course is not possible.

Because it is such a delicate topic, the cost notion is not included in safety organizational tools. Nevertheless on the day to day operation of a company, money represents the main deciding actor.

The question that this paper intends to answer is whether the cost notion can be introduced successfully in a deciding tool, namely the Aerospace Performance Factor (APF).

The Aerospace Performance Factor is a tool that is able to assess the internal safety situation of a company based on the businesses' own ranking of elements.

The second version of the APF introduces another scope of the tool, one that helps in making decisions.

The cost notion will be included in the deciding part of the APF in order to assess if the money factor can bring an added value to the Aerospace Performance Factor tool.

2. DATABASE AND METHODS

2.1 The Aerospace Performance Factor (APF) and the Analytical Hierarchical Process (AHP). This paper used as a research base the Aerospace Performance Factor (APF) tool. The APF represents a large incident data base that returns the safety evolution of an organization based on its own rankings. The company establishes the ranking of different relevant elements, this way founding its mind-map. After creating a mind-map the APF has to be populated in time by events. If enough data is introduced in the APF, the tool returns a visual situation of the companies' incidents calibrated to the ranking made in the mind-map. To make the explanation simpler an example is in order. Let's suppose an airport is the organization that uses the APF. At the level of management it is established that they have 3 big categories of incidents (Technical Events; Ground Incidents, Missed Approaches), each with its own sub-category. Each of the three is given a weight/an importance at the level of management.

Because this part of the process represents a very subjective task, the method used by the APF to decide on the ranking of incidents is the Analytical Hierarchical Process, method that will be discussed in the following rows. The weights given to each category and sub-category forms the mind map of that specific organization. As mentioned, after the formation of the mind-map the APF has to be populated by events. Based on the number of events and on the weight given to each category, the APF produces an index of the companies' situation for the specific time (usually a month). Extrapolating the same process to a larger period (for example an year), the variation of this index represents the safety evolution of the organization.

One of the key aspects of the APF is the mind-map formation. This is made by using the concepts behind the Analytical Hierarchical Process. The AHP method is used in synthesizing complex decision making. Most of the important decisions require a trade-off between different goals, both of objective and subjective nature. This process offers a systematic and approachable way in which such decisions could be made. AHP builds ratio scales from paired comparisons. These ratio scales derive from the principal Eigen vectors.

The method can be split into four parts:

1. The construction of the hierarchy of the problem: selecting the overall goal, the criteria and the alternatives of the situation
2. Using judgments to develop the relative importance of each criterion in terms of its significance to the achievement of the overall goal
3. Indicate the prioritization of each decision alternative in terms of its contribution to each criterion
4. Using the AHP mathematical method, the relative importance of the criteria and the prioritization of alternatives are synthesized to obtain a relative ranking of all alternatives in terms of their overall preference

Assuming that the hierarchy of the problem has been established, the mathematical method of the AHP will be described next.

This method can also be split into four main parts:

1. Computing the vector of criteria weights. In this part judgments are used to calculate the relative importance of each criterion with respect to the overall goal. In order to achieve that, the AHP method constructs a pairwise comparison matrix A. A is a real matrix, mxm, where m represents the number of criteria. The relative importance between two criteria is measured on a 1-9 scale[1]. The interpretation of this specific scale is given in Table 2, where it is assumed that the j-th criterion is equally or more important than the k-th one. Intermediate numbers can also be given.

The following rules apply when constructing the pairwise comparison matrix:

Table 1. Matrix elements meaning

Comparison	Meaning
$a_{jk} > 1$	then j-th criterion is more important than the k-th criterion
$a_{jk} < 1$	then j-th criterion is less important than the k-th criterion
$a_{jk} = 1$ $a_{jj} = 1, \forall j$	then the two criteria have the same importance

Constraint:

$$a_{jk} * a_{kj} = 1 \tag{1}$$

If a matrix is said to be pairwise consistent then it obeys (1). A is a pairwise consistent matrix. The number of comparisons depends, of course on the number of objects to be compared. For the case of A, the total number of comparisons is:

$$\frac{m(m-1)}{2} \tag{2}$$

After building the A matrix, the normalized Eigen vector of the matrix has to be calculated.

1 Research and experience have confirmed that a nine-unit scale is a relative good basis for discriminating between two items (Lin)

The following method is an approximate calculation of the Eigen vector that works well with small matrix sizes m ≤ 3. Therefore we construct the normalized pairwise comparison matrix A_{norm}

Table 2. Score interpretation

Value of a_{jk}	Interpretation
1	j and k are equally important
3	j is slightly more important than k
5	j is more important than k
7	j is strongly more important than k
9	j is absolutely more important than k

Each element of the A_{norm} matrix has the following formula:

$$\overline{a_{jk}} = \frac{a_{jk}}{\sum_{i=1}^{m} a_k} \quad (3)$$

Finally, after the construction of the normalized matrix A, the criteria weight vector[2] is developed. Each element is built by averaging the values of each row:

$$w_j = \frac{\sum_{i=1}^{m} a_j}{m} \quad (4)$$

2. Computing the matrix of option scores. The next step in the AHP method is computing the matrix of option scores. This matrix will show the ranking of each option with respect to each criterion. In order to obtain it, another pair wise matrix must be built $B^{(j)}$. $B^{(j)}$ is a nxn matrix, where n represents the number of options under evaluation. The elements of $B^{(j)}$ will have the form:

$b_{ih}^{(j)}$ – Evaluation of the i-th option compared to the h-th option with respect to the j criterion

The construction rules of $B^{(j)}$ matrix are the same as for our first pair wise comparison matrix A.

These rules can be found in Table 1 and Table 2. $B^{(j)}$ is also a pairwise consistent matrix.

The following step in the AHP method normalizes each matrix $B^{(j)}$ (the approximate method presented divides each element by the sum of the elements in the same column, and then it averages the entries on each row). Out of each normalization, a score vector is obtained $s^{(j)}, j = 1,...,m$. Finally after obtaining all score vectors, the matrix of option scores has the following form:

$$S = [s^{(1)},...,s^{(m)}] \quad (5)$$

3. The option ranking. The results of steps one and two are combined here in the final step. The global score vector v has the following formula:

$$v = S * w \quad (6)$$

Where the i-th element of $v(v_i)$, represents the global score assigned by the AHP to the i-th option. The final step of the AHP method orders the global scores in decreasing order.

4. Checking consistency. Because of the high number of comparisons, inconsistencies may rise. A simple example of such inconsistency is shown below.

Inconsistency example: Let’s say there are three criteria to compare: A, B and C. The first judgment evaluations are as follows:
A is slightly more important than B (3) 3>1
B is slightly more important than C (3) 3>1

If C is equal or more important than A – evident inconsistency (transitivity)

If A is slightly more important than C - slight inconsistency

If A is more important than C- consistent evaluation

The AHP method incorporates a method of checking consistency of judgment. The method implies calculating the Principal Eigen value, this value is obtained from the summation of products between each element of the Eigen vector/weight matrix (w or $S^{(j)}$) and the sum of columns of the respective matrix A or $B^{(j)}$.

2 m dimensional column vector

For A:

$$\lambda_{\max} = \sum_{i=1}^{m} w_i * (\sum_{j=1}^{m} a_{ij}) \quad (7)$$

A matrix A is said to be consistent if $a_{ij}a_{jk} = a_{ik}, \forall i,j,k$. However the consistency is not forced. In the example above A doesn't have to have a score 9>1 in comparison with C. In his work Prof. Saaty proved that for consistent reciprocal matrixes the largest Eigen value is equal to the size of the comparison matrix (for A, the size is m). He also gave a measure of verifying consistency, the Consistency Index (CI).

$$CI = \frac{\lambda_{\max} - m}{m - 1} \quad (8)$$

He also introduced the Random Consistency Index by randomly generating reciprocal matrixes and calculating the CI for each of them. The two numbers the CI and RI are compared:

$$CR = \frac{CI}{RI} \quad (9)$$

If the Consistency Ratio (CR) is smaller or equal to 10 the inconsistency is accepted, otherwise the comparisons need to be reviewed.

2.2 The What-if function-this application was developed in the second version of the APF. It has the scope of simulating what would happen to the APF index if at a certain moment in time one or more contributing factors are reduced. The logic behind the reduction of a contributing factor answers the question what would have happed to the APF index if at x point in time a decision would have been made to reduce the contributing factors with y%. The application works symmetrically with mitigating factors, this time augmenting the APF index.

If a reduction with y% of a contributing factor is considered the following changes will occur:

- Incidents that have these specific contributing factors (CF) as the unique CF will fall by y%
- Incidents that have two contributing factors, out of which one is decreased with y%, will decrease with y% with a probability of 50%
- By continuing the pattern, incidents that have k contributing factors, out of which one in lowered with y%, will fall with y% with a probability of 1/k (x/k%)

As mentioned, the question that this paper intends to answer is whether such a tool can be developed further into an application that incorporates a cost input. What-if optimization
The idea is that the program should return the best investment option based on two factors: the effect of each contributing/mitigating factor on the overall APF index and the cost of such an investment.

The cost of investment will be based on expert opinion and will be introduced in the program in the following way:
"1% of reduction of Contributing Factor 1 would cost X units"

2.3 Area Calculation-Firstly the area of the overall APF index graph on a specific period of time is calculated. After that the APF area produced by the total reduction of a chosen specific contributing/mitigating factor is formed. The difference between the two will then be the denominator of the ratio.
When calculating the area, the supposition made is that there is a way in which that specific cause can be entirely nullified. This is of course not feasible; nonetheless it does not negate the validity of the search - the greatest effect on the overall APF index is the purpose of the calculation.

2.4 Introducing the Cost-Cost will be introduced in the APF without a specific unit in mind; it will be a general monetary unit and will be built-in by experts.
Cost will be thought out in this way:
"1% reduction of Contributing Factor 1 would cost X units"
By introducing the cost the nominator of our ratio will be formed. The cost will decrease the ratio as it gets bigger.

2.5 The logic of the optimization- The optimization involves maximizing the ratio between the effect (surface area) and the cost: the larger the area the bigger the ratio, the smaller the cost the bigger the ratio.

$$R_i = \frac{Area(APF_{real} - APF_{i100\%reduced})}{C_i} \quad (10)$$

$$R_{opt} = \max R_i \quad (11)$$

For each contributing/mitigating factor a ratio between area and cost will be calculated. The optimum ratio will be the maximum of all ratios.

2.6 Results- Four random modifications of the APF index are made, which represent the effect of 4 different 100% reductions of four contributing factors on the APF index. For each reduction the area beneath the function is calculated. In TABLE IV there are represented the area differences between the real APF index (first line) and the APF indexes resulted from the each of the four reductions.

Table 4. Area differences

	Mar	Apr	May	Jun	Jul
ANSP	0,33	0,24	1,16	0,79	0,46
Area	0,28	0,70	0,97	0,62	0,56
Cause 1	0,21	0,21	0,99	0,67	0,36
AreaC1	0,21	0,60	0,83	0,51	0,39
Cause 2	0,32	0,24	1,16	0,79	0,45
AreaC2	0,28	0,70	0,97	0,62	0,55
Cause 3	0,24	0,16	1,00	0,61	0,34
AreaC3	0,20	0,58	0,81	0,48	0,43
Cause 4	0,32	0,23	1,15	0,78	0,45
Area C4	0,27	0,69	0,96	0,61	0,55

For each contributing factor a cost is given, symbolizing the monetary units that would suffice to produce a 1% reduction for that factor. In TABLE V there are both the denominator and nominator of our four ratios. The next step is to calculate the ratios between them (Ri). As can be seen in TABLE V, the biggest ratio is the one associated with the first cause.

One possible way of going further is to attribute a weight to cost and one to efficiency. When making a decision sometimes a greater importance is given to the cost and sometimes costs are not as significant as immediate and efficient action. We can therefore attribute weights to the two criteria considering the specific situation.

In the example below a 70% weight is given to efficiency and 30% to cost. The change can be seen in Ri weight.

2.7 Discussion- As can be seen in Table 5 R_{opt}, corresponds to the first causal factor. This causal factor has the second best effect and the smallest price. The second biggest ratio is the one corresponding to causal factor 3, which has the greatest effect, much larger than the other three and the second expensive price. The smallest ratio corresponds to contributing factor 2 which corresponds to the smallest effect and the second cheapest price. The results are consistent with the scope of the optimization, which is to return the best possible investment considering the effect and cost.

Table 5. Ratio calculation

	C1	C2	C3	C4
Area differences	0,822	0,017	1,254	0,116
Cost	1,000	2,000	3,000	5,000
Ri	**0,822**	0,008	0,418	0,023
Ri weight	0,352	0,019	**0,975**	0,054
Cost	0,300			
Efficiency	0,700			

Table 5 also shows that if a significant importance is given to efficiency and cost, the results change. Because the most efficient causal factor reduction is what is being searched after, the results show that this happens for contributing factor 3. It has the greatest area difference and it is the second expensive. The smallest ratio corresponds again to the second contributing factor, which makes sense because it has the smallest effect on the overall APF index.

CONCLUSIONS

Cost represents one of the most important factors, if not the most important, in everyday decisions. Its inclusion gives the APF a realistic feel about how decisions are made.

The idea presented accompanied by the example shows a straight forward method of introducing cost into the APF tool.

The question that is asked is: what is the best investment option that we need to implement?

The Optimized APF returns the causal factor that has the best ratio between the effect on the APF index and the cost of a possible improvement. The added value that this brings to the APF is that it is a palpable and visual answer that can convince the management of an organization to make a change in one aspect or another.

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