A web-based approach to allocating audit resources using the Analytic Hierarchy Process

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Abstract

Internal auditing is a crucial business process, as it ensures that an organization's operations run effectively and that the organization's business documents are credible. However, as auditing is an intensive process, the resources available are usually insufficient to conduct complete audits. It is therefore necessary to allocate audit resources in such a way that the overall risk to the organization is minimised. Furthermore, because large organizations can have a large number of departments that are separated geographically, it can be difficult to obtain input from all of the applicable role-players, such as auditors that have working knowledge of the departments and whose input can help reduce the risk faced by the organisation. In this paper a web-based solution is proposed that would aid in calculating the best resource allocation strategy given an evaluation of appropriate risk factors and other issues. The proposed system is based on both qualitative and quantitative techniques described in the literature, but offers more functionality, such as providing for users that are geographically separated. The techniques implemented, as well as the methodology followed to develop the new system will be presented. A real-world application, along with comments from an industry representative, is presented to demonstrate the usefulness of the system.

Keywords

Audit Resource Allocation, Decision Support Systems, Analytic Hierarchy Process, Risk Management

1. Introduction

Any organization of sufficient size relies upon auditing. This comes as a result of the value of auditing, in that it lends credence to business documents, and aids in preventing both fraud and mismanagement (Gray & Manson 2000). However, as auditing requires a substantial amount of time and effort, most companies cannot afford to include all possible audit areas in a short- to medium term audit plan, and as such only those audit areas that pose a high or unacceptable risk to the company will be audited. As the intention of auditing is to reduce the overall risk to the company, some form of risk evaluation is normally used when selecting the areas to be audited. One of the most popular ways of conducting such an audit area risk evaluation is to identify a set of risk factors that impact the audit areas, and then assess their importance and possible influence. The risk factors used when conducting these evaluations may differ from company to company, and a difference in opinion regarding the selection of specific risk factors may have a profound impact upon the outcome of the evaluation (Van Buuren et al. 2014). Following an assessment of the risk factors, managers usually decide on which audit areas should be audited, as well as the amount of audit resources (time, money, manpower, etc.) that should be allocated to each audit area.

Owing to this resource allocation problem, a number of studies are regularly performed that attempt to address the problem in a fair and structured manner. A significant number of these studies include the use of management science techniques in order to try and construct formal resource allocation frameworks. Some of these techniques include the use of the Analytic Hierarchy Process (Awad et al. 2011; Sueyoshi et al. 2009; Kruger & Hattingh 2006; Patton et al.1983), mathematical programming techniques such as Data Envelopment Analysis and goal programming (Sueyoshi et al. 2009; Kruger & Hattingh 2006) and non-linear optimisation (Patton et al. 1983). It is also interesting to note that these techniques are very rarely applied on their own but that they are, as a rule, combined to address both qualitative and quantitative aspects of the audit resource allocation process. The literature also supports the notion that it is important to have a proper audit resource allocation strategy (Fukukawa et al. 2011; Pathak & Baldwin 2008; Von Wielligh 2008; Johnson 2006; Newman et al. 1998; Hackenbrack & Knechel 1997).

An aggravating problem to the resource allocation process may occur when a company has a significant number of geographically separated business units, each with their own management structure. The allocation process may become a complicated decision-making process as different managers, at different locations, have to reach consensus on what resources should be allocated to which audit areas. With this in mind, this paper proposes a web-based approach for allocating audit resources to different audit areas. The techniques implemented in the system are based on an existing framework (Patton et al. 1983), but will provide for an enhanced and centralised framework that can be used by geographically separated users. The main techniques implemented in the system are the Analytic Hierarchy Process (AHP) and a mathematical minimisation model – the same model as suggested in the literature (Patton et al. 1983). The new web-based system is an improvement on the techniques reported in the literature as it is an easy-to-use automated system that can be accessed from multiple locations. Furthermore, several technical enhancements, such as consensus rankings, a significant reduction in the number of pairwise comparisons and consistency checks, were also implemented. This paper will not report on these technical enhancements, but will provide a general background to the techniques implemented and the methodology followed to develop the web-based decision support system for audit resource allocations. A real-world application will also be presented to illustrate the allocation process that has been automated.

The remainder of the paper is structured as follows. In Section 2, some brief and introductory background comments on the models and techniques implemented in the system are presented. In Section 3 the focus shifts to the methodology followed to develop the system, followed by a discussion of a real-world application in Section 4. In Section 5 the results of the system's evaluation are discussed, after which the paper concludes in Section 6 with some general remarks.

2. Background

The developed Decision Support System (DSS) utilises a risk evaluation model that is based on three main aspects. First, the principle that an organization's loss function should be minimised forms the basis of the system. The loss function and its associated concepts are then evaluated using the well-known Analytic Hierarchy Process (AHP) technique, and then finally the minimisation of the loss function and final resource allocation is obtained using the Method of Lagrange Multipliers. This section will give a brief and introductory background account of the three main parts of the DSS.

2.1 The Principle of a Loss Function

Within the context of auditing and control systems, the expected loss to an organization, or to a specific area within the organization, is a function of certain risk factors, as well as the extent of auditing (Patton et al. 1983). Risk factors are not necessarily of equal importance under normal circumstances, and some risk factors may be of greater importance than others. If it is assumed that the risk factors are independent, then the expected loss in an audit area can be expressed as

$$Expected\ loss\ in\ audit\ area\ i = w_1 f_1 + w_2 f_2 + \cdots + w_n f_n, \tag{2.1}$$

where w_j indicates the weight, or importance, of risk factor f_j.

To represent the relationship between audit resources and the impact of the risk factors, a simple assumption is made: as the amount of resources to a particular audit area increases, the expected loss associated with that particular audit area decreases. This implies that the loss suffered is inversely proportional to the amount of audit resources allocated to that particular audit area. This approach, which reflects the diminishing effects of additional audit resources, can be expressed as

$$Expected\ loss\ in\ audit\ area\ i = \frac{w_1 f_1 + w_2 f_2 + \cdots + w_n f_n}{a_i} \tag{2.2}$$

where a_i represents the proportion of audit resources allocated to audit area i.

The total expected loss to an organization can then simply be stated as the sum of all losses in the different audit areas subject to a restricted amount of resources. The minimisation of the total expected loss to an organization can then be mathematically formulated as

$$\text{Minimise} \quad \frac{w_1 f_{11} + w_2 f_{21} + \ \dots + w_n f_{n1}}{a_1} + \frac{w_1 f_{12} + w_2 f_{22} + \ \dots + w_n f_{n2}}{a_2} + \ \dots \ + \frac{w_1 f_{1k} + w_2 f_{2k} + \ \dots + w_n f_{nk}}{a_k}$$

$$subject\ to \sum_{i=1}^{k} a_i \le 100 \tag{2.3}$$

where f_{ij} is audit risk factor i in audit area j, w_i is the importance weight of audit risk factor i and a_i is the amount of audit resources allocated to audit area i.

The values for f_{ij} and w_i can be obtained using the AHP (see section 2.2) and the model can be solved using the Method of Lagrange Multipliers (see section 2.3).

2.2 The Analytic Hierarchy Process (AHP)

The AHP is a qualitative method that uses pairwise comparisons to address multi-criteria problems. Such a problem is normally structured as a hierarchy with the top level representing the objective, and each of the subsequent levels representing the different criteria and alternatives respectively. Figure 1 below shows the hierarchy that was implemented in this study.

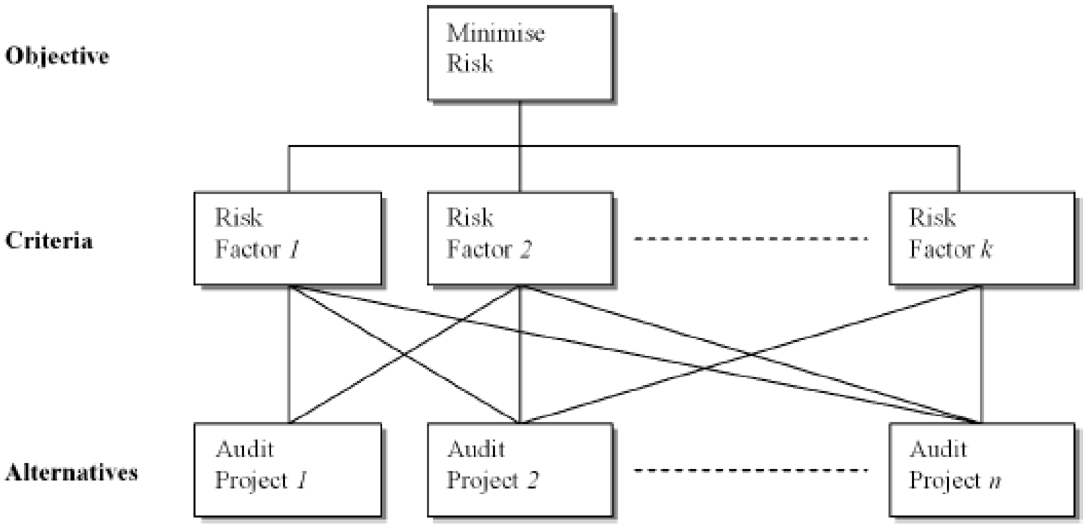

Figure 1: Analytic Hierarchy (Kruger & Hattingh 2006)

Pairwise comparisons are used as a subjective method of evaluation and involve comparing two alternatives according to a specific criterion that both alternatives have in common. These pairwise comparisons then indicate the decision-maker's preference. The preference scale chosen for this study was taken from Patton et al. (1983) and is shown in Table 1.

Risk	Numerical Value	Explanation
Equally risky	1	Two audit projects are equally risky with respect to the risk factor of interest
Slightly more risky	3	Experience and judgement indicate that one audit project is slightly more risky that the other
Strongly more risky	5	Experience and judgement indicate that one audit project is considerably more risky that the other
Demonstrably more risky	7	One audit projects is much more risky, and this risk has been demonstrated
Absolutely more risky	9	The evidence showing one audit project to be much riskier is of the highest order of affirmation
Intermediate values	2, 4, 6, 8	

Table 1: Relative risks in audit projects (Patton et al. 1983)

To ensure an acceptable degree of consistency among the pairwise comparisons, a consistency test, that is not discussed here, may be performed. Taylor (2013) can be consulted for details on how to compute the consistency of a pairwise comparison matrix. Once the required pairwise comparison matrices have been constructed a numerical measure of the relative importance of the criteria can be extracted. This is done by using simple normalized averages (Taylor 2013), or by computing the matrices' normalised eigenvalues (Patton et al. 1983).

2.3 The Method of Lagrange Multipliers

Once the risk factors, their values and their importance weights have been established, the model in (2.3) can now be solved in order to allocate audit resources to the audit areas in such

a way that the total risk (loss) is minimised - to accomplish this, the Method of Lagrange Multipliers is utilised.
While it is not feasible to provide a complete mathematical and technical account of the method in this paper, a very basic explanation of the method follows (Anton 1999).
Consider the following two-variable extremum problem with one constraint: maximise (or minimise) the function $f(x, y)$ subject to the constraint $g(x, y) = 0$. The following procedure for optimization is now followed:

- Create a Lagrange function which is composed of the function to be optimised combined with the constraint function. The function is given by:

$$F(x, y, \lambda) = f(x, y) + \lambda g(x, y) \tag{2.4}$$

  where λ is referred to as the Lagrange Multiplier.

  This function suggests that the maximum of $f(x, y)$, if it exists, occurs at a point (x_0, y_0) where the gradient vectors ∇f and ∇g are scalar multiples of one another. This can then be expressed as $\nabla f(x_0, y_0) = \lambda \nabla g(x_0, y_0)$ for some scalar λ.

- Following from multivariable calculus theory on partial derivatives and extreme values, which are not discussed here, the next step is to find the partial derivative with respect to each variable x, y and λ. The partial derivatives are given by

$$\frac{\partial F}{\partial x} = \frac{\partial f}{\partial x} - \lambda \frac{\partial g}{\partial x}, \tag{2.5}$$

$$\frac{\partial F}{\partial y} = \frac{\partial f}{\partial y} - \lambda \frac{\partial g}{\partial y}, \tag{2.6}$$

$$\frac{\partial F}{\partial \lambda} = g(x, y). \tag{2.7}$$

- Set each of the partial derivatives equal to 0 and, by using $\frac{\partial F}{\partial x} = 0$ and $\frac{\partial F}{\partial y} = 0$, proceed to solve for x and y in terms of λ. Substitute the solutions for x and y so that $\frac{\partial F}{\partial \lambda}$ is expressed in terms of λ only. Solve for λ and use this value to find the optimal values for x and y.

In the context of this study $f(x, y)$ would be the total loss function to be minimised in (2.3) while the constraint $\sum a_i \leq 100\%$ is represented by $g(x, y)$.

3. Methodology

To implement the techniques described in Section 2, and to provide a centralised method to allocate audit resources amongst geographically separated audit areas, a web-based DSS was developed. The system was developed in Visual Studio 2012, using the ASP.Net framework and the C# programming language.
The basic structure of the system conforms to four basic steps needed to determine the resource allocations, and is shown in Figure 2.

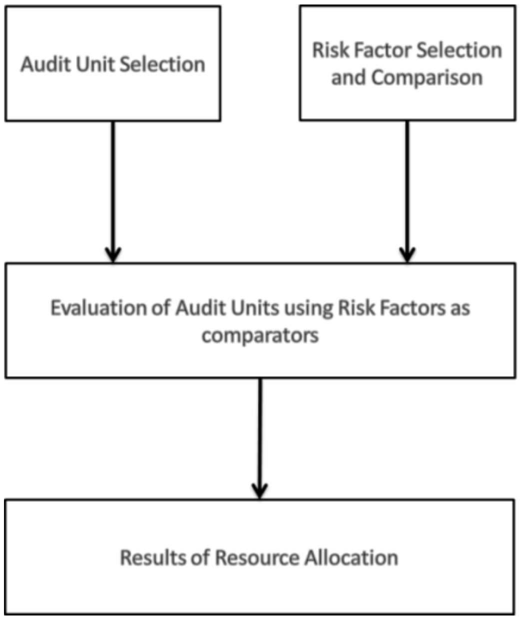

Figure 2: High level structure of the DSS

Step 1: Audit area selection

The purpose of step 1 is to define the various audit areas to which resources need to be allocated. An audit area is viewed as any separable entity within an organization that can be audited. As part of this step, a database table was created that allows for the audit areas to be treated as variables, rather than constants. This makes the DSS adaptable to the point where the system can be used to evaluate any comparable entities, rather than just audit areas.

Step 2: Risk factor selection and comparison

Once the audit areas have been chosen, the risk factors that may influence the risk associated with the audit areas have to be selected. A pre-determined list of factors, based on the literature, is displayed and the user can select from this list (Patton et al. 1983). The list is stored in an alterable database that allows for any risk factors to be used by the system. The pairwise comparisons and importance of the risk factors are calculated here using the AHP. A technique, based on a transitivity rule, is also implemented in this step in order to reduce the number of pairwise comparisons without compromising the consistency of the evaluation (Ishizaka & Lusti 2004).

Step 3: Evaluation of audit areas based on selected risk factors

This step implements a novel heuristic to determine a consensus rating (pairwise comparison) in cases where a number of different stakeholders provide the pairwise comparisons. The consensus heuristic is based on a minimisation problem where the sum of the differences between a consensus value *c* and each of the provided ratings is minimised. Finally, consistency of the pairwise comparisons are checked and if all comparisons are consistent the final overall risk for each of the audit areas are calculated based on the selected risk factors and their associated importance.

The system provides user friendly interfaces for all the different activities in steps 2 and 3 and users can follow simple on-screen instructions to complete the different calculations.

Step 4: Perform the final resource allocation

The final step in the system implements the Method of Lagrange Multipliers to determine the final resource allocations based on the risk factor values and their importance ratings. A user can simply press a button to trigger the calculation and the system will then display the request as a list containing the identified audit areas, along with the percentage resources allocated to each area.

4. Application

To illustrate the practical value of the DSS, this section presents a real-world application of the system and the implemented techniques. The next section will provide a discussion of the results and the DSS.

Real-world data was obtained from the literature (Kruger & Hattingh 2006), where the Analytic Hierarchy Process was combined with a goal programming model to allocate audit resources in a mining company. The AHP results from this study will be used here to demonstrate the newly developed DSS. It should however be noted that the final results as published in the aforementioned article cannot be compared with the results of the DSS described here. This comes as a result of the differing goals between the studies. The Kruger & Hattingh (2006) study describes a method whereby resources are allocated according to predefined risk levels, whereas the newly developed DSS is aimed at minimising the overall risk an organization might experience.

The real-world case study was based on data obtained from a mining company with operations established on multiple continents. A total of five large audit areas were evaluated using five risk factors. The exact details of the data obtained may be found in Kruger & Hattingh (2006). The application of the method as used by the DSS is described according to the steps detailed in Section 3.

Step 1: Audit area selection
As mentioned, five audit areas, of which each is categorised as an audit project within the Commercial Services area, were used. These audit areas are Strategic Spares, Service Exchange, Strategic Supplies, Stock Process and Staffing.

Step 2: Risk factor selection
The five main risk factors that were selected are Complexity of Operations, Frequency of Occurrence (where, for example, a transaction is seen as an occurrence), Financial Implications, Changes in the Area (both planned and unexpected), and External Influences (legislation, public image, etc.). It should be noted that these risk factors do not form part of the list of default risk factors as used by the DSS, and as such these risk factors were entered specifically for this exercise.

Step 3: Evaluation of audit areas based on selected risk factors
The evaluation as reported in the Kruger & Hattingh (2006) study was used as the output of step 3. This was necessitated by the fact that the original comparison matrices that were obtained were no longer available. The results for step 3 are shown in Tables 2, 3, and 4.

Projects	Complexity	Occurrence	Financial	Changes	External
Strategic Spares	0.5510	0.0337	0.4029	0.5290	0.0417
Service Exchange	0.2132	0.3272	0.0751	0.0705	0.0387
Strategic Supplies	0.0646	0.0906	0.3913	0.1185	0.2725
Stock Process	0.1415	0.5126	0.0861	0.1801	0.2353
Staffing	0.0296	0.0359	0.0446	0.1019	0.4118

Table 2: Audit project risk matrix

Table 2 details the final risks for each of the five audit projects with respect to each of the five risk factors. These results were obtained by applying the scale in Table 1 in a pairwise comparison process. Consistency tests were then performed after which the final numerical scales, as shown in Table 2, were extracted. The risk rankings for the different audit projects with respect to each individual risk factor can now directly be observed from Table 2. For example, with respect to the risk factor Complexity, the project Strategic Spares has the highest risk (0.5510) and Staffing the lowest risk (0.0296); with respect to the risk factor External, the project Staffing has the highest risk (0.4118) with Service Exchange the lowest risk (0.0387). Table 3 shows the importance scale for the risk factors which was also obtained through a pairwise comparison process. The results in Tables 2 and 3 are then combined to obtain a final overall risk for each audit project as detailed in Table 4. This combination is performed using the following composition formula.

$$Overall\, risk\ of\ audit\ project\ i = \sum_{j=1}^{n} \begin{bmatrix} Risk\ of\ audit\ project\ i \\ on\ risk\ factor\ j \end{bmatrix} \times \begin{bmatrix} Importance\ of \\ risk\ factor\ j \end{bmatrix}$$

Complexity of operations	0.5739
Frequency of occurrence	0.0527
Financial implications	0.2471
Changes in the Area	0.0420
External Influences	0.0843

Table 3: Importance scale for risk factors

Strategic Spares	0.4433
Service Exchange	0.1644
Strategic Supplies	0.1655
Stock Process	0.1569
Staffing	0.0689

Table 4: Overall risk of audit areas

Step 4: Resource Allocation

Using the results of step 3, the minimisation model as described in Section 2.1 is constructed and then solved using the Method of Lagrange Multipliers as described in Section 2.3. The final results delivered by the DSS are shown in Table 5.

Audit Area	Percentage Allocation
Strategic Spares	31%
Service Exchange	19%
Strategic Supplies	19%
Stock Process	19%
Staffing	12%

Table 5: Final resource allocation

The percentages were rounded to the nearest integer and the three projects that received 19% each of the resources are in line with the overall computed risks which were very similar for the three projects (see Table 4 in step 3). The results shown in Table 5 indicate that the audit area Strategic Spares should receive 31% of the audit resources (time, money, manpower, etc.) with Staffing receiving only 12% of the audit resources. This is once again in line with the overall risks computed in table 4.

5. Discussion

It is clear from the application presented that the DSS delivers valid results for each audit area based upon the level of risk associated with that audit area. The developed DSS and the techniques implemented provide a centralised, systematic and objective method to geographically separated users when they have to identify, assess and evaluate audit risk factors. These types of evaluations are normally carried out on an ad-hoc basis and through numerous discussions.

Other advantages of the system that were not discussed in this paper include the benefits to using a framework that can be used to justify the allocation of resources, as well as indicate the relative risk of a particular audit area. Another benefit to the use of the DSS is that it is possible to perform certain “what-if” analyses, wherein the impact of adding or removing risk factors can be calculated, their importance weights can be adjusted, etc.

To further confirm the value of the DSS as far as real-world applications are concerned, the system was demonstrated to an industry expert (from a large petrochemical company) that has experience with company audits. The remarks that were received were positive overall and he mentions that the DSS definitely addresses a current problem experienced in the industry, and that the system is flexible enough to be used in any situation where resource allocation might be used, such as with user-acceptance-testing. A further remark received was that, whilst the DSS’s purpose and use becomes intuitive after a demonstration, the interface is not intuitive enough to be used without proper training. A final remark was that, while the system clearly accounts for the size and complexity of an audit area, the system output is not explanatory enough to make the impact of these factors obvious.

In conclusion, although the techniques used in the development of the DSS were mainly based on the framework suggested by Patton et al. (1983), a number of new aspects were developed and implemented. Some of the new features include:

- The techniques were automated in a web-based system that provides a centralised and consistent manner for audit resource allocation for users from different geographic locations;
- A new consensus method, which was developed specifically for use with pairwise comparisons, was implemented;

- A technique was implemented that drastically reduced the number of pairwise comparisons needed; and
- The system presents a more structured way to justify decisions and to perform “what-if” analyses.

6. Conclusion

Internal auditing is a crucial business process that is viewed as an objective and independent assurance function that adds value and improves operations within an organisation. One of the key aspects of any internal audit department involves audit planning, which may comprise of several steps, one of which involves the selection of audit areas, and another the subsequent allocation of resources to each of those audit areas. The focus of this paper was to describe a newly developed, web-based decision support system that can be used to aid in allocating audit resources. The system implements both qualitative techniques, such as the Analytic Hierarchy Process, and quantitative techniques, such as the mathematical minimisation model, and offers additional functionality than those mentioned in the literature. A real-world application was presented to demonstrate the usability of the system, while positive comments on the system were received from an industry expert.

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