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Decision Support modeling with standard tools

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, Mag. Werner Überall, hereby declare

1. that I am the sole author of the present Master Thesis,

   "Decision Support modeling with standard tools", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, 12th November 2010 ______________________________

Date Signature

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ABSTRACT

This thesis mainly handles the Analytic Hierarchy Process and if it is applicable for managers of small to medium businesses or department managers in large enterprises. At the beginning a short introduction to decision making and its history is presented. Furthermore, some examples for simple decision-making methods are included. The third chapter provides a short history of the Analytic Hierarchy Process and some real world examples of its application. Afterwards, the basic principles of AHP are discussed and different approaches of including costs in decisions are mentioned. The main part discusses three real life examples developed together with a commercial customer for some of his current decisions. Two examples cover Information Technology Infrastructure topics, the third one handles a recruiting decision. At the end, the thesis shows up a conclusion about using the Analytic Hierarchy Process for these decisions and the opinion of the affected managers concerning this method. The goal of this thesis is to analyze this method and to show up whether it is worth to apply the Analytic Hierarchy Process for decision modeling in the real life of managers.

0 PROBLEM FORMULATION

Quite often decisions are based on any inadequate methods or even made intuitively. Based on this problem, this thesis will cover the Analytic Hierarchy Process and its possibilities to structure and analyze decision problems. AHP is said to be an easy-to-use, multi-criteria, decision-making method. This means that managers of small to medium business companies or managers of departments in bigger enterprises are able to handle it without advanced training. Besides an introduction and the principles of AHP, this thesis will cover many real world examples calculated with AHP. These examples have been discussed with department managers and in the Results section, their human choices will be compared to the ones calculated with AHP. A few examples of simple decision making methods will be mentioned too and the usability of AHP will be compared to these approaches.

1 INTRODUCTION

Currently we are living in the age of technology and decisions should get simpler, based on the huge amount of data collected and available for everyone. Retailers, credit agencies, investment companies and so on are collecting data all the time to decide how to proceed in future and to offer the right goods to the customer. Of course, this data needs to be analyzed in some way. Just a few years ago, this used to be a task for specialists in big companies, but today there are tools to get guidance for decision-making just by clicking into some computer interface. Stating that these users know where the data is coming from and the way the data is converted in this tool is up to their knowledge too, it seems quite easy to get at least directions for decisions based on numbers.

These tools are common for the main tasks of big companies like the mentioned retailers, but for their internal departments, which are not directly connected to their main business, there are no tools available for getting directions or even analyzing the available data. Austrian companies are usually small to medium-sized enterprises and most of them do not have powerful decision-support tools. During my experience in cooperation with companies like those or IT departments in bigger enterprises I have been faced with many unusual methods for decision making. Quite often these customers do not have any analytic methods for getting optimal decisions done. Sometimes there are evaluations based on questionnaires, but at the end the final decision is quite often based on some subjective opinions.

This thesis will cover a method for bringing tangible and intangible factors into a decision structure, this method is called the analytic hierarchy process (AHP). This tool seems to be a good method for analytical decision making and evaluation of priorities even though it is not necessary to be a specialist in mathematics. At the beginning, the thesis will cover a short overview concerning decision support in general and how to start the decision making process. Usually decisions are just the end of solving a bigger problem, this part will also be described briefly in the next part of this thesis. Furthermore, some possibilities for simple decision making will be mentioned. In the third chapter, a small history about AHP and some further developments will be presented. Chapter four will cover the basic methods and calculations for this decision making tool and in the main part three real world examples, developed together with a customer, will be discussed. The values for the examples had to be changed a little bit and the customer asked me to leave out his and the names of affected companies. Finally, in chapter six the results of these examples will be discussed and how the results fit to the decision done by the customer.

2 DECISION MAKING

This part of my thesis will cover some historical overview concerning decision making and an impression how decisions are handled in companies and which approaches are employed to find a decision.

2.1 History of decision making

In the middle of the last century a retired executive of a communication company and author named Chester Barnard brought the term *decision making* from public administration into business. In this context this wording replaced descriptions like *resource allocation* or *policy making*. This phrasing seems to have changed the thinking of managers about what they did and how they were handling decisions. So Barnard laid the foundation for the science of managerial decision making. Of course there were some methods for risk analysis, probability etc. in mathematics before, but the foundation of managerial decision making is not just about calculating.

The science of decision making consists of many different intellectual disciplines like mathematics, sociology, psychology, economics and political science. Besides the philosophical part, decision making has been improved by research into risk and organizational behavior, with the intention to help managers to achieve better outcomes. Sometimes even good decisions fail and so this realistic approach is not always the best one. Furthermore, decision making was improved by the availability of knowledge of risk management, partly understanding of human behavior and advances in technology.

Over the years, complex circumstances, limited time and inadequate computational power made it more and more complex for decision makers to make well-analyzed decisions, even if managers tend to make economically rational decisions. It turned out quite hard to keep confidence in decisions, therefore some theorists sought ways to achieve, if not optimal outcomes, at least acceptable ones.

Every decision contains some risks, for daily decisions they are usually kept quite small, but for corporate decisions the implications can be enormous. Even win-win situations may turn out not optimal if there was another way which has not been considered before. To make good choices, companies need to calculate and manage the associated risks. There are many tools available for managing risk, but in former times there was nothing besides hope and guessing. Today in some cases risk is still analyzed in that way. (Buchanan and O'Connel, 2006)

The first known application of probability calculations or risk calculation was in the 14^{th} century and was used for the first insurance companies to calculate the insurance rates. Calculations based on observations started in the 16^{th} century mainly based on gambling examples. The main pioneer for these calculations was Geronimo Cardano. He mainly investigated the different possibilities in the game of dice. Until mid of the 17^{th} century calculations described special solutions, but the mathematical background was not brought together to form a theory. In the 17^{th} century Pascal, Fermat and Huygens started to analyze these problems in a more sophisticated way and formed the first kind of standard theory for probability calculations. These scientists are quite often mentioned as the founders of probability theory. Huygens wrote "De ratiociniis in ludo aeae", this book stated basic knowledge for probability calculations until the beginning of the 18^{th} century. In this century Jakob Bernoulli further developed Huygens' theories and brought up the golden theorem for probability. Furthermore, he stated the possibility of application of these calculations to economical and social problems, but this work was not finished. (Kaiser and Nöbauer, 2002)

In the nineteenth century, Carl Friedrich Gauss brought up the well-known bell curve of normal distribution and Francis Galton came up with the concept of regression. But it took until World War I for risk calculations to be used in economic analyses. Frank Knight distinguished between risk and uncertainty, this means either an outcome is possible to be calculated or is not possible to be determined. Two decades later Neumann and Morgenstern brought up the fundamentals of game theory which deals with situations where decisions are influenced by unknowable variables. (Buchanan and O'Connel, 2006)

2.2 Managerial decisions today

According to some statistics many decisions in management fail. Although successful tactics are known, they are uncommonly practiced. Furthermore, decision makers feel time pressure and therefore short cuts are taken, participation is known but used quite seldom. Another reason for failure is some kind of ability to tell problems in the right way, it is better to ask people for inputs than to show them their failures.

Paul C. Nutt mentions the following process for decision making:

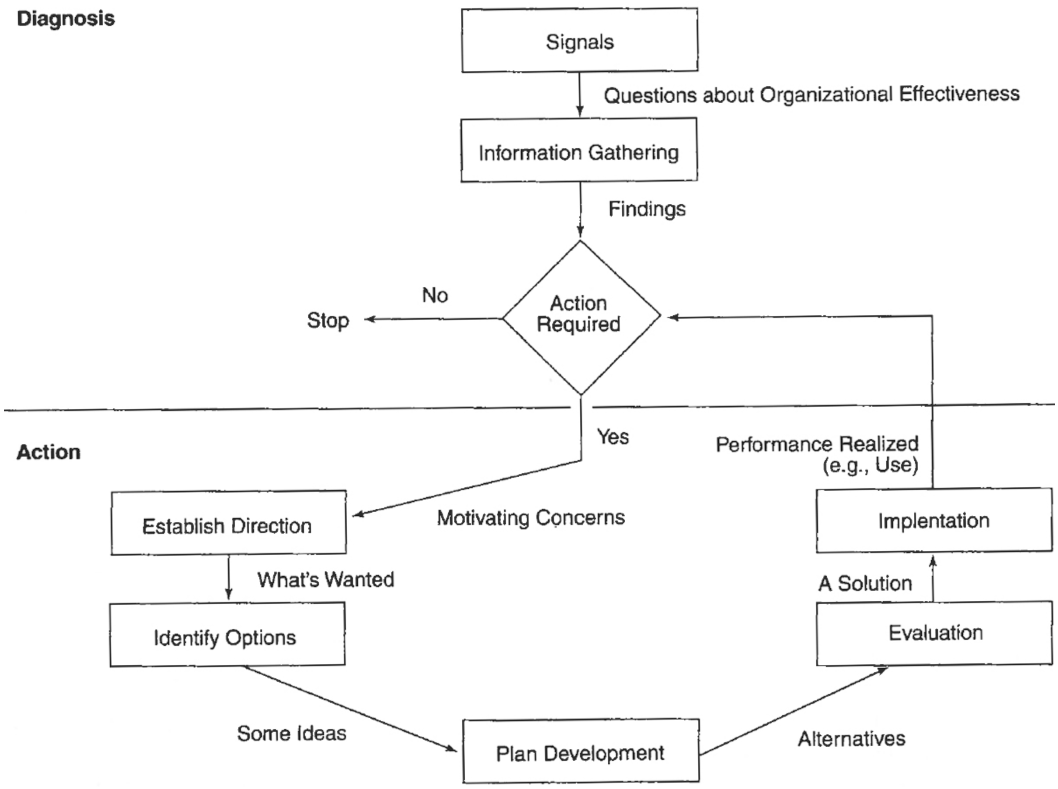

Fig. 1 decision process (Nutt, 2000)

The process starts when a signal is identified, a signal is something concerning the company and can be inside and outside. For example an inefficient operation which has to be optimized would be considered inside, a new product of a competitor is an outside signal. The second step is information gathering and if the signal turns out to be important the process is going on. Quite often managers are not following exactly the path described in this process, the main stages “establish direction”, “identify options” and “implementation” will be described in the next step. Different approaches are used in these stages and described by Nutt, in the following a short overview of these approaches will be discussed.

2.2.1 establish directions

The first method quite often used for finding a decision or solving a problem is generating ideas. Generating ideas for solving a problem is somehow difficult to handle because it can prompt managers to focus just on a single solution. This approach is quite often used if there are time constraints even if these constraints are just a kind of imagined pressure.

The second approach is called problem solving. In this case the identified problem raised by the signal, is analyzed with the hope of quickly detecting a solution that suggests a remedy. In this case it is very important not to analyze the symptoms instead of finding the root cause. In hasty situations quite often managers tend to treat just the symptoms of a problem, so the problem definition is crucial for this method.

Another approach is decision management by objective. In this case the manager is bringing up the objectives and the affected employees have to search for considerable solutions. For example the management is setting the goal to increase market share and employees have the chance to solve this problem and to achieve their goals by finding their own solutions. Managers tend to be careful with managing decisions in this way, because they could be considered indecisive. Furthermore, for very action-adhesive managers, it is hard to define the objectives and not to present their solution. The definition of these objectives has to be very clear, measurable and not too demanding, this means the objectives should be reachable by the people involved.

The fourth method for getting directions for a decision is intervening the process. For example the manager is coming up with performance ratios provided by norms or other companies, compared to the ratios of the own company. The manager has to explain where these values are coming from and to propose possible improvements. The performance gap is used by the other managers to make claims about needs and opportunities. These claims provide the direction for decision making, indicating what is wanted as an outcome. This method is mainly based on networking between the managers.

Paul C. Nutt states that the most effective methods for establishing the direction in the decision process are the least frequently used one. Intervention and setting objectives turned out as the most effective and successful ways during his evaluation. The second step in the decision making process is to identify the available options. (Nutt, 2000)

2.2.2 identify options

Quite often managers benchmark practices that are being used by respected organizations to find a solution. Sometimes practices are just copied from others, because it seems pragmatic and cuts costs. “Why reinvent the wheel” is the mentioned reason for this method. It seems logical just to copy practices, but if modifications or adoptions are necessary to fit the transported practice to the needs of the new situation it tends to get very difficult. There is the more sophisticated and successful approach of integrated benchmarking, this means different approaches are identified and the best features of the tactics get merged for the new solution. Of course this way of doing benchmarking takes more time and therefore managers tend to try it by single-benchmarking.

Searching for solutions is another method for identifying an option for the decision-making process. Usually managers use search aids, such as a request for proposal, to find solutions. It is necessary to define exactly the needs of the company in this case. If the managers are not aware of standards and functions, multiple requests can be issued to define the content and afterwards the final request is written. This method seems to work quite well if the managers are aware of available criteria.

The third method for getting the available options is design, in this case managers develop and design innovative options according to the needs. Managers tend to be reluctant to use design, because it seems quite risky to them. The main question using this method is how the design is carried out. Usually managers do not have skills for designing options, external consultants are not optimal for using the design tactic, because they have to follow the wants of their clients.

The method for decision making discussed later on in this thesis handles decisions based on the results and inputs of this phase. The next phase shows up methods for implementation of decisions, the last step in the decision-making process.

2.2.3 Implementing decisions

Similar to intervention in the “establishing direction” part of the process, it is mainly based on networking and acquiring sponsorship of other managers. This is mainly done by presenting the solution to other managers and especially expressing benefits for them. Furthermore it can be accomplished by showing how comparable organizations were able to gain benefit from this solution. Therefore a need for change is created in the minds of key people.

Another sometimes quite time-consuming but successful method is participation. In this case the manager creates task forces with key individuals as members and authority is delegated to them as well. Some managers try to avoid these methods, because it seems they give up control. It is important to think about the definition of involved people very well. When task force members are given an important assignment success is more likely. Failure of this method is usually linked to low involvement, complete participation usually leads to decisions that are adopted in almost all cases. Of course as the proportion of participants to all affected groups falls, the failure rate increases.

An often used method by managers is persuasion. External consultants are hired to identify options offered by vendors or used by competitors or to devise novel options, evaluating the benefits of the proposed solution. Combining the rational arguments and a kind of salesmanship the manager tries to sell the solution to the other managers and employees. Depending on the power of the arguments and the power of persuasion this way will lead to success or not.

Another well-known quite impersonal method is to issue a directive or edict that announces the decision. Usually this kind of implementation of a decision is done without consulting or discussing with people affected by the new solution. Managers using this method are usually relying on their power and sometimes hard communications like this can lead to positive feedback, mentioning fast decisions or quick action. In case of heavy usage of directives this could cause resistance by the employees and affected managers.

2.2.4 successful decisions

Considering the findings, Paul C. Nutt mentions some major points for making successful decisions in management. The following figure shows the results of the study of 356 decisions based on the different methods.

Stage/Tactic	*Cases*	*Percent of Decisions Studied*	*Sustained Use Rate*	*Full Use Rate*
Establish Directions				
Imposition process types				
▼ Idea	131	37	56	42
▼ Problem Solving	92	26	55	44
Discovery process types				
▼ Objectives	107	30	70	58
▼ Intervention	26	7	96	92
TOTAL	356	100	N/a	N/a
Identify options				
Imposition process types				
▼ Existing solution	223	63	55	41
Discovery process types				
▼ Benchmarking	46	13		
Single	(25)	(7)	59	59
Integrated	(21)	(6)	71	78
▼ Searching	43	12		
Single	(34)	(9)	63	51
Multiple	(9)	(3)	100	100
▼ Designing	44	12	63	53
TOTAL	356	100	N/a	N/a
Implement Decisions				
▼ Intervention (revisited)	26	7	96	92
▼ Participation	63	18	80	73
Token	(9)	(3)	70	67
Delegated	(34)	(10)	80	77
Complete	(20)	(6)	100	95
Comprehensive	(0)	(0)	0	0
▼ Persuasion	133	38	56	47
▼ Edict	132	38	53	35
TOTAL	344	100	62	50

Fig. 2 study results (Nutt, 2000)

These results are quite interesting concerning the methods mentioned above. During the study, various kinds of decisions have been analyzed and classified as successful or not according to their long-term use (sustained use) and the degree of use (full use rate) after two years. This table shows up which methods have to be considered as promising tactics and which ones are more likely to fail. Finally, in the article the combination of personal management of decision-making processes, careful problem definition, direction establishing via intervention and objectives, idea creation with clear thinking, multiple options with integrated benchmarking and use of intervention to manage social and political barriers are mentioned as a guideline for successful decisions.(Nutt, 2000)

2.3 simple decision method examples

If managers do not have any specialized software or tools for getting their decisions done, they employ simple lists or excel tables. In the following some of these simple methods will be explained shortly. Of course these examples are not intended to be complete, but the mentioned ones seem to be quite common and used by many people.

2.3.1 decision matrix

A decision matrix is a chart with the different alternatives on one axis and the important criteria on the other. These criteria are ranked for importance and each option is scored against each criterion.

Table 1 simple decision matrix

	criterion 1	criterion 2	…	criterion N
alternative 1	w_{11}	w_{11}	…	w_{1N}
alternative 2	w_{11}	w_{11}	…	w_{2N}
...	...	…	...	…
alternative M	w_{M1}	w_{M2}	…	w_{MN}
sum				
rank				
status				

This decision matrix is also the basis of the technique described later in this thesis. In this simple version it does not offer any possibility for weighting the different criteria. Furthermore, one has to be careful when filling this matrix with the respective values, because it can happen that there are different units or scales.

2.3.2 PMI technique

Plus/Minus/Interesting is a little bit more complex version of scoring the positives and negatives in a list. In the "plus" column all positive results of the decision are listed, in the "minus" all negative effects are mentioned. The column "interesting" should show up all implications and possible outcomes whether positive or negative or uncertain. In the following this method is shown for a simple example. It is about a young professional deciding about moving to a big city or not.

Table 2 PMI

Plus	Minus	Interesting
More cultural possibilities (+5)	Sell house (-6)	Better networking? (+2)
Meet friends (+4)	Pollution (-3)	Difficulties with hobbies (-4)
Easier to get a job (+6)	Less space (-3)	
	Life quality (-3)	
+15	**-15**	**-2**

After summing this up, there is a result of -2, so it seems to be not worth to move to the city for the young professional. PMI is a way of weighting the pros, cons and implications of a decision.

2.3.3. decision trees

Decision trees differ from the example above in that a sequence of possible events is charted first, but afterwards numerical values are assigned, either financial values or probabilities. There are many tools available for drawing charts like this, but the classic way of painting it on a sheet of paper is most common. Decision trees are not just used for simple decision making by painting them, they are used to graphically organize information about possible options, consequences and outcomes.

Furthermore, they are used in computing for probability calculations and data mining.

A square represents a decision, an uncertainty is shown up by a circle. The probability is shown at each branch, of course all the branches coming from one decision node must sum up to 100%. Each branch is representing a payoff too, usually this is expressed as the present value of net costs or profits. To get the final amount of money of the branch this amount is multiplied by the shown probability on this branch. At any circles along the path, the end value is multiplied by the probability of its occurring. The following figure shows an example of a simple decision tree.

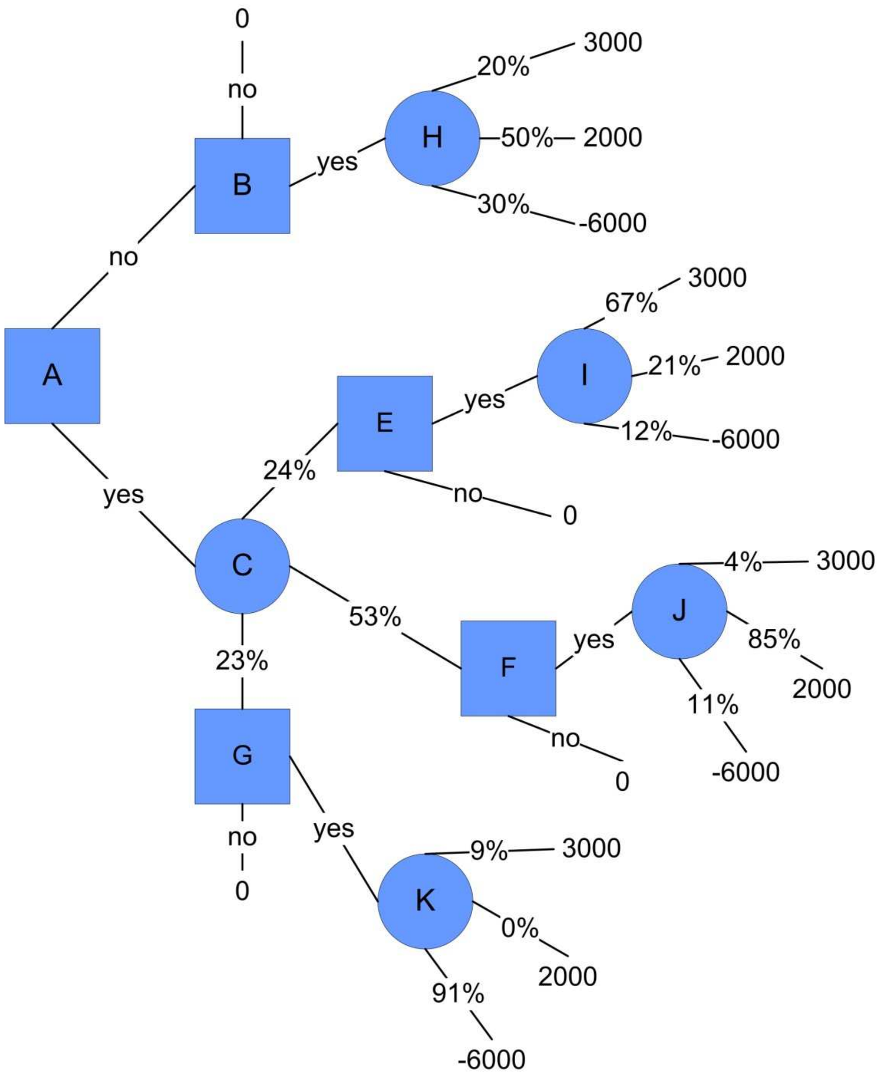

Fig. 3 decision tree

Calculating a short example of this decision tree will show how to calculate the different possibilities. For example considering Square A represents to hire a consultant or not. If this consultant is hired, the result of his work can either be E, F or G. Afterwards another decision to follow the concept or not is necessary. The other possibility is not to hire a consultant, than there is just one idea for executing this project or not. In this case the calculation for example for the amount of 3000 is 0,2 x 3000 = 600. To calculate an example for hiring a consultant the path via option F to 3000 is 0,53 x 0,04 x 3000 = 63,6. As stated above, this method is quite good for visualizing simple decisions in a clear way.

3 HISTORY AND APPLICATIONS OF AHP

This part of the thesis will cover a short overview of AHP history and some examples of application of this decision making method. Moreover, a short overview of further development will be given.

3.1 AHP history

The Analytic Hierarchy Process has been developed by Thomas L. Saaty in the late 1960's. Saaty was born in 1926 and studied mathematics in the United States and France. He was one of the first scientists handling Operations Research and started doing this during working for the Arms Control and Disarmament Agency at the U.S. Department of State. At this time he worked together with reputable economists and game and utility theorists. While teaching, he experienced some communication difficulties between scientists and lawyers, especially in priority setting and decision making. Therefore, Saaty started together with these specialists to develop a simple method for analytical decisions. So the analytic hierarchy process has been developed, based on mathematics and psychology.

Today AHP is a widely used decision tool and has already been further developed for more complex group and dynamic decision. There are not just institutional users of AHP, but many software tools for "home use" are available. An overview of well known applications of AHP and a short introduction into further developments will be provided in this chapter.

3.2 AHP applications

AHP is currently used by many companies to make decisions and is taught in many operational management courses. It is even taught during courses for quality assurance related to six sigma. Surprisingly, there are applications available for iphone and ipad for decision making based on AHP. In this part of the thesis, three examples for AHP applications will be provided, just to get an overview of the possibilities of this method. AHP is used in many different areas, for example in logistics for supply chain optimization and evaluation, in project management, forecasting software and many other economic or social fields.

3.2.1 IBM application cloud assessment

For example IBM recommends AHP to customers for evaluation of whether their application is suited for cloud computing or not. AHP is briefly explained on the mentioned website and AHP will help in this case to evaluate business value, technical fitment and risk exposure of the application.

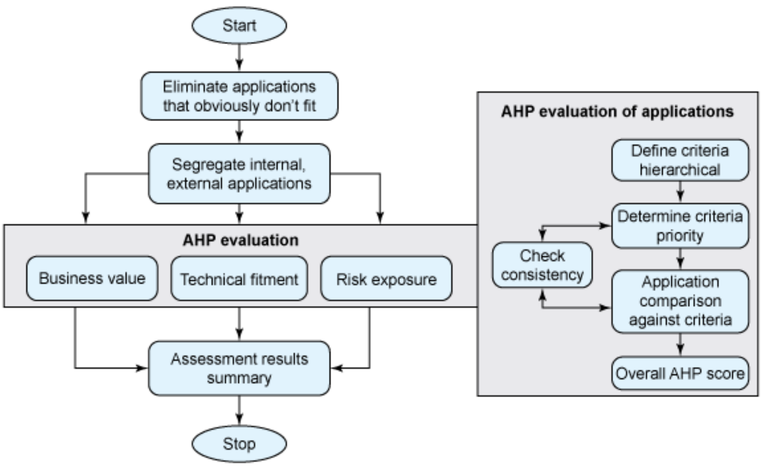

Fig. 4 IBM cloud assessment (Deb, 2010)

3.2.2 Decision Lens

Another very interesting application is a software tool based on AHP and used by many companies. The product is called Decision Lens and is based on the hierarchies of AHP. According to the website of Decision Lens Inc., this product easily allows one to structure decisions and evaluate alternatives.

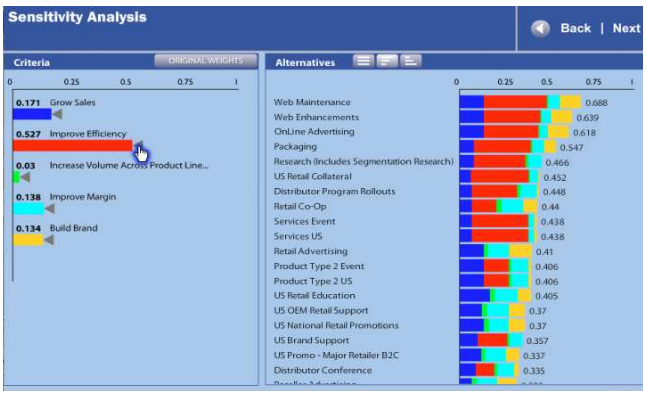

Fig. 5 user interface decision lens (Decision Lens, 2010)

There are many different examples for applications of AHP, some industries can be found on the website of Decision Lens. One more example for general project decision is the following.

3.2.3 project investment appraisal (Xinli and Jianghua, 2009)

The article of Wang Xinli and Ma Jianghua analyzes how to use AHP for making project investment decisions. The article contains an example of a property company and how the company should use an open area. After analyzing the investment factors they identified the main criteria economic efficiency, social efficiency and environment benefit.

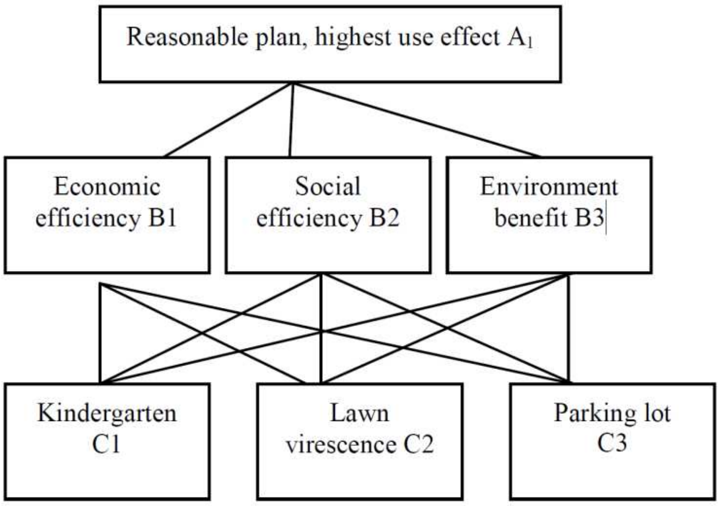

Fig. 6 project investment (Xinli and Jianghua, 2009)

This example is mentioned here, because it shows that AHP is used for high level decisions too, even if the examples later in this thesis are mainly based on choosing one alternative. Thomas L. Saaty applied AHP to numerous different businesses, starting at military applications, coming to insurances, currency forecasts and even elections. (Xinli and Jianghua, 2009)

3. 3 Development of AHP

AHP structures decisions in hierarchies, but not all problems or decisions can be structured in that way. Therefore AHP has been further developed by Saaty and other scientists to the Analytic Network Process, the main intention was to allow interaction between elements on different levels of the hierarchy. This leads to a different architecture of the process called a network.

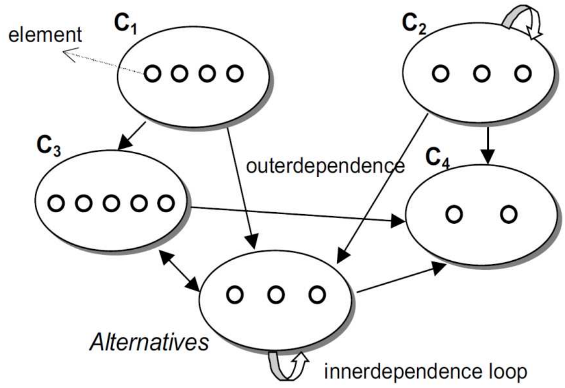

Fig. 7 feedback network example (Büyükyazici and Sucu, 2002)

In ANP it is not necessary to define levels and there are no linear relations from top to bottom. For this case the term level is replaced by the term cluster. The new possibility of considering cycles and feedback loops of course makes the analysis of problems or decision like this more complex, but ANP is able to handle these important parts, because feedback loops are quite common.

The weightings are defined as in AHP in matrices and pairwise comparison is applied to the alternatives. There is a main difference in synthesizing the values, AHP is doing this in a linear way by getting the eigenvector, whereas ANP Saaty introduced an improved supermatrix technique. A supermatrix consists of more matrices and in this way the relationships between elements in a cluster and another cluster are considered. The following figures show a supermatrix and a matrix out of this supermatrix.

$$
W = \begin{array}{cc}
 & \begin{array}{cccc} C_1 & C_2 & \cdots & C_N \\ e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{2n_2} & & e_{N1}e_{N2}\cdots e_{Nn_N} \end{array} \\
\begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \\ C_N & \begin{array}{c} e_{N1} \\ e_{N2} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} &
\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \cdots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}
\end{array}
\qquad
W_{ij} = \begin{bmatrix} W_{i1}^{(j_1)} & W_{i1}^{(j_2)} & \cdots & W_{i1}^{(jn_j)} \\ W_{i2}^{(j_1)} & W_{i2}^{(j_2)} & \cdots & W_{i2}^{(jn_j)} \\ \vdots & \vdots & & \vdots \\ W_{in_i}^{(j_1)} & W_{in_i}^{(j_2)} & \cdots & W_{in_i}^{(jn_j)} \end{bmatrix}
$$

Fig. 8 supermatrix of a network and detail of a matrix in it (Saaty, 2004)

Each scale is brought into a column in a matrix to represent the relation of elements in a cluster to an element in the same or another cluster. There is no requirement that each element influences another cluster. The arising supermatrix has to consist of priority vectors derived from the pairwise comparison matrices and has to be stochastic to produce meaningful results. The supermatrix consists of clusters and each bunch of column vectors is weighted by the priority of the corresponding cluster, with their elements displayed vertically on the left side of the matrix and horizontally at the top of the matrix. To ensure stochasticy the clusters are compared with themselves with respect to their impact on each cluster at the top. The priorities afterwards are used to weight column vector clusters on the left with respect to the clusters at the top. It is necessary to be careful when synthesizing ratio scale priority vectors in systems with feedback loops, as elements could be interacting indirectly. In case of a direct and indirect influence from one element on another, the total impact is calculated by multiplying the direct impact and the impact between the element inbetween and the target and so on. All the second order impacts can be obtained by the square of the supermatrix, third order impacts by the third power of the supermatrix. At the end the limiting power of the supermatrix has to be calculated.

There are many examples for applications of ANP too, one example to illustrate is mentioned by Saaty, the main goal is to gain market share in selling Hamburgers.

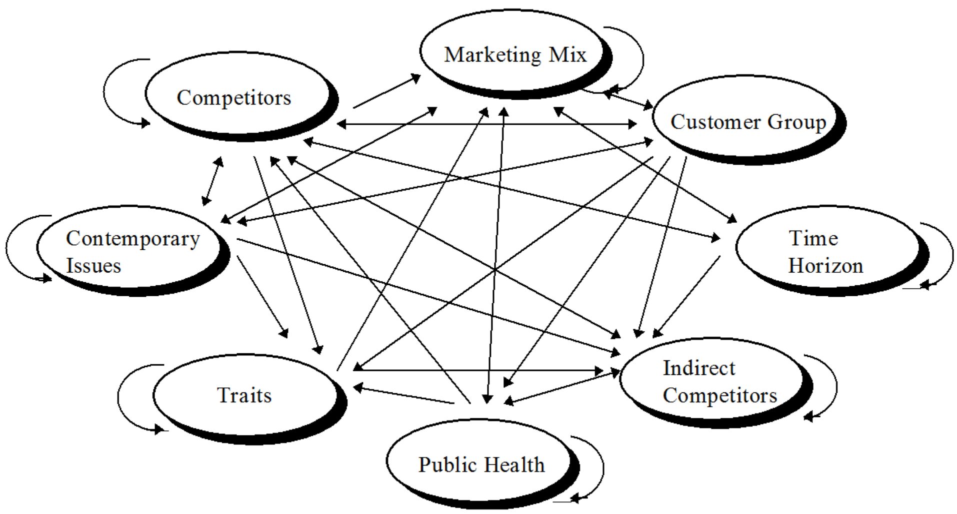

Fig. 9 network for gaining marketshare (Saaty, 2004)

For example in the cluster “competitors” the elements are McDonalds, Burger King and Wendy’s. Of course the other clusters consist of different elements too, but the example is not intended to be discussed in detail, it just shows that even complex decisions like gaining market share considering all influences can be analyzed with this method.

There is a software tool for decisions based on AHP available and can be found on www.superdecisions.com.

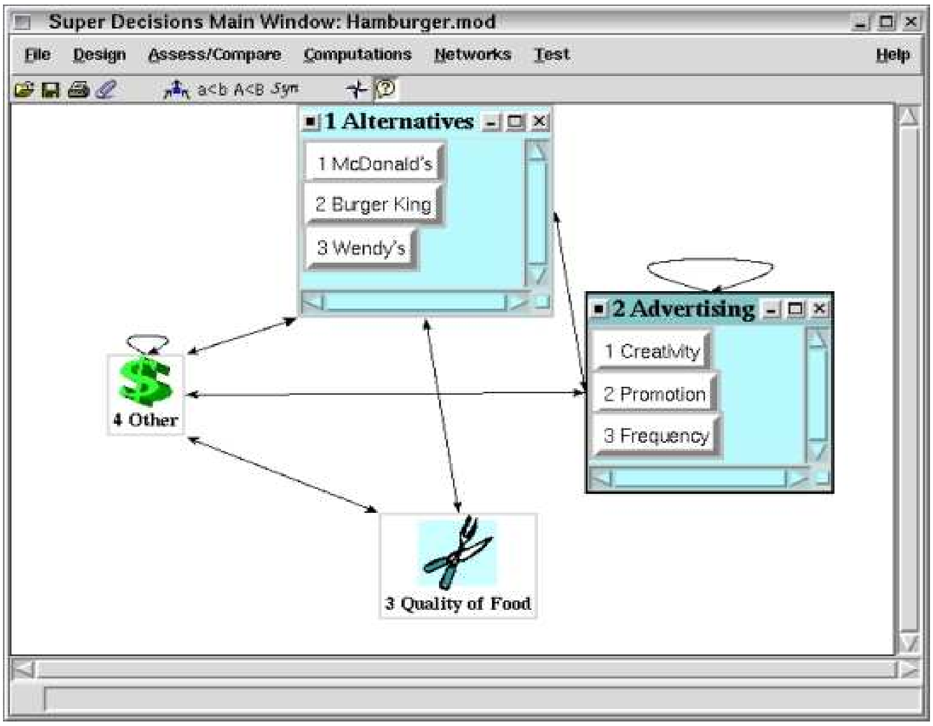

Fig. 10 screenshot "Super Decisions" (www.superdecisions.com)

4 INTRODUCTION TO THE ANALYTIC HIERARCHY PROCESS

Making multi-criteria decisions based on quantitative and qualitative information can be very complex. How is it possible to choose between different possibilities when considering both objective and subjective factors that influence the overall decision? In this chapter a brief introduction to the analytic hierarchy process, a well-known method created by Thomas L. Saaty for decision making will be provided. A short description of application of AHP and an overview of most used calculations will be discussed too.

The analytic hierarchy process (AHP) is a widely used technique for comparing a set of alternatives with respect to an overall goal (Saaty, 1980). It is widely used by decision makers to analyze and quantify complex data. AHP is relying on the ability of decision makers to decompose the main problem into a hierarchy of smaller decision problems. These sub-problems consist of different objective and subjective factors, aggregated they all influence the overall goal. The main result of using AHP is a priority vector to provide a ranking of the different alternatives. Perhaps the most important strength of AHP is that it is available to people having just basic knowledge of theory, even though it is based on complex matrix calculations. Through pairwise comparisons, AHP compares the various competing alternatives in terms of each selection criteria.

4.1 Hierarchies

AHP uses structures to represent a decision problem, designing this structure is crucial for the reliability of decisions. Accuracy of the structure is at least as important as crunching the numbers the right way.

The hierarchy represents the simplest type of dependence of one component of a system on another, furthermore it is a way to decompose complex problems. Hierarchies are structured linearly and go down from the most general to concrete and controllable parts, coming down to different alternatives.

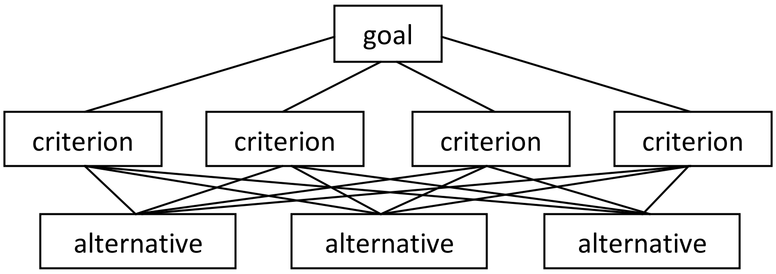

Fig. 11 AHP hierarchy

The hierarchy starts at the top by clearly stating the goal of the problem. Right beneath the goal are the primary criteria to be considered. In this Figure the goal at the top is influenced by four criteria, also called factors. These criteria are usually broken down into subcriteria, there is no limit amount of criteria or factors, the hierarchy should cover all important criteria, but it should stay manageable. At the bottom the alternatives which are connected to each criterion are listed, so all alternatives are compared with respect to all criteria.

AHP uses hierarchies, because the primarily internal dynamics of a system are not known. The main contribution of AHP is that it gives us tools to make judgments about the relative impact of variables even if intangibles like feelings have to be considered. It provides a structured view of complex problems and provides an overview starting from more important down to less important criteria. Furthermore, this structure gives the possibility to have an idea how changing priorities in upper levels affect elements in lower levels. (Saaty, 2006)

4.2 Pairwise comparison

After building the hierarchy, the first step in executing AHP after building the hierarchy is to identify all possible alternatives and to select one to start. Furthermore it is important to identify all influencing criteria from the pool for this alternative. Of course these criteria are based on some values, usually numbers are based on any units, but in decision making quite often intangible facts have to be considered too, in this case, there are dimensionless values which as well have to be taken into consideration. Therefore, it is necessary to define the relative scale, or weight, of each alternative in respect of each criterion. This task is done by using Table 3.

Table 3 The Fundamental Scale (Saaty, 2006)

Importance	Definition
1	equal Importance
3	moderate importance
5	strong importance
7	demonstrated importance
9	extreme importance
2, 4, 6, 8	Intermediate values between the adjacent judgments

This table, developed by Saaty, is the method for the decision maker to compare the criteria pairwise. The decision maker has to bring his opinion and values about different criteria into values in the matrix. This comparison has to be executed during AHP for each influencing criterion and at the end all criteria are compared and ranked.

Carrying out this scale of relative weightings, the decision maker is able to build up judgment matrices. This step is the next important one while employing AHP and evaluates the weight of each possible alternative against the others. The final matrix in this step is called "criteria judgment matrix" and shows the weight of each criterion over the other. Entries in the judgment and criteria judgment matrices are expressed according to their importance shown in the table above.

For instance, consider a judgment matrix comparing the quality of the colors Red, Green and Blue.

By default, the comparison of strength is always of an alternative appearing in the column on the left against an alternative appearing in the row on top. (Saaty, 1980)

Table 4 pairwise comparison

Like?	**Red**	**Green**	**Blue**
Red	1,00	7,00	
Green			
Blue	3,00		

1) I like Red more than Green, therefore 7 is my rating for Red/Green
2) But I like Blue even a little bit more than Red, therefore 3 is my weight for Blue/Red

It is not mandatory to enter a reciprocal value, but it is generally rational to do so. (Saaty, 1980).

Therefore the table can be filled up with the correlated values, of course for example the comparison Green/Red is 1/7 = 0,14.

Table 5 pairwise comparison - finished

Like?	Red	Green	Blue
Red	1,00	7,00	0,33
Green	0,14	1,00	0,11
Blue	3,00	9,00	1,00

Judgment matrices have to be constructed for each criterion to follow the AHP. As presented in this example, each criterion has to be weighted with competing alternatives. At the end of this task, a judgment matrix has to be created that prioritizes each criterion by comparing one against all other criteria.

4.3 Extraction of priority vectors

After creating all judgment matrices for each selection criterion as well as the criteria judgment matrix, the decision maker has to get to the next step of AHP. This step is to extract the relative weights brought by each matrix. This task is accomplished by using matrix algebra to determine the eigenvector of each judgment matrix. Mathematically speaking, the principal eigenvector of each matrix, when normalized, becomes the vector of priorities for that matrix (Saaty, 1980).

The computation of the principal eigenvector in Expert Choice takes the normalized row sums of the limiting power of a primitive matrix, this gives the desired eigenvector. Thus a short computational way to obtain this vector is to raise the matrix to powers. Fast convergence is obtained by successively squaring the matrix. The row sums are calculated and normalized. The computation is stopped when the difference between these sums in two consecutive calculations of the power is smaller than a prescribed value. (Saaty, 2006)

As we can see, this way is quite complex and not easy to compute, we will approximate values of this eigenvectors by applying an easier way:

Multiply the elements in each row and take the n^{th} root where n is the number of elements. Then normalize the column of numbers thus obtained by dividing each entry by the sum of all entries. Alternatively normalize the elements in each column of the judgment matrix and then average over each row. (Saaty, 2006)

This approximation method shown based on our example concerning the colors.

Table 6 eigenvector approximation method

Like?	**Red**	**Green**	**Blue**	**row product**	**3rd root**	**eigenvector**
Red	1,0000	7,0000	0,3333	2,3333	1,3264	0,2897
Green	0,1429	1,0000	0,1111	0,0159	0,2513	0,0549
Blue	3,0000	9,0000	1,0000	27,0000	3,0000	0,6554
					4,5777	1,00

As expected, Blue is my “most liked” color, so in terms of AHP in criterion “Like?” alternative “Blue” is the most preferred one, with the alternatives “Red” and “Green” ranked as second and third alternative.

There is another quite accurate and easy-to-calculate method to define the priority vector of a criterion. This calculation method normalizes the elements of each column and the elements in each row are summed and divided by the total number of elements in the row. This step averages the normalized columns to yield the estimated principal eigenvector. (Saaty, 1980)

Table 7 second eigenvector approximation method

	Red	**Green**	**Blue**	**row sum**	**eigenvector**
Red	0,2414	0,4118	0,2308	0,8839	0,2946
Green	0,0345	0,0588	0,0769	0,1702	0,0567
Blue	0,7241	0,5294	0,6923	1,9459	0,6486

This shows that both methods present similar results for their eigenvector. During this thesis the first mentioned method will be employed.

It is important to understand that these methods of priority vector calculation are estimates. The exact solution for a principal eigenvector is obtained by raising the matrix to arbitrarily large powers and dividing the sum of each row by the sum of the elements of the matrix. (Saaty, 1980) If there is no software available for extracting such priority vectors, what will probably be the case in a managers office, this step can be very complex. Usually exact mathematical calculation computing the eigenvector is not necessary. Each approximation method will deliver slightly different values for the priority vectors. This arises by some inconsistencies in the judgment matrix weight assignments. It is important that the judgment matrix is checked for consistency after inserting the different weights.

4.4 Consistency Evaluation

Consistency in the judgment matrix is crucial to the validity of the AHP. In the example mentioned above it was decided that the ratio between Red & Green is 7:1 and Blue & Red is 3:1, this brings Green to the least important color for me. The ratio of Green & Blue has not been mentioned, if this will be rated as 5:1 for example, this will become inconsistent, because I like Red more than Green and Blue more than Red, so it is not possible to like Green more than Blue.

A matrix or its weights are called consistent if

$$a_{ij} = a_{ik}a_{kj} \quad (1)$$

for all i, j and k. This kind of matrix exists, but usually not in case of human judgments, because we always tend to be somewhat inconsistent in weightings. Therefore we have to adjust the relation λ=n (λ is the eigenvalue) which is valid for consistent matrices to:

$$\lambda_{max} = \mathrm{n} \qquad (2)$$

together with

$$A\omega = \lambda_{max}\omega \ (3)$$

and

$$\lambda_{max} \geq n \ (4)$$

we have a way to calculate the C.I. (Consistency Index):

$$C.I. = \frac{\lambda_{max} - n}{n-1} \ (5)$$

λ_{max} is defined as the mean of the values that appear after divison of the components of Aω by the components of the eigenvector. If λ_{max} = n the judgments have turned out to be optimally consistent, but usually there is a difference and C.I. has to be calculated. After calculating C.I. the Consistency Ratio (C.R.) will show up the value for consistency. C. R. is the ratio of C.I. and Random Consistency Index (R.I.):

Table 8 Random Consistency Index (Saaty, 2006)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R.I.	0,00	0,00	0,52	0,89	1,11	1,25	1,35	1,40
n	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
R.I.	1,45	1,49	1,51	1,54	1,56	1,57	1,58	

The calculated value for C.I. has to be divided by the related number in this table to get the Consistency Ratio. “n” in the table is the dimension of the analyzed judgment matrix. According to Saaty, C.R. must not exceed the value of 0,1 (Saaty, 2006). If this value is exceeded the judgment matrix has to be reviewed and corrected.

Coming back to the example of the colors in table 4 we can calculate Aω:

Table 9 vector for consistency calculation

Aω
0,8925
0,1691
2,0187

with:

$$m_{11}*v_1 + m_{12}*v_2 + m_{13}*v_3 = A\omega_1 \qquad (6)$$

These values are divided by the values of eigenvector yielding to:

3,0803
3,0803
3,0803

The mean of these values is defined as λ_{max}. So C.I. can be calculated according to 4:

$$C.I. = \frac{\lambda_{max} - n}{\mathrm{n} - 1} = \frac{3{,}080 - 3}{2} = 0{,}04$$

Now one can calculate the Consistency Ratio, according to the table 3.6 for a matrix with three activities (n=3) the Random Consistency Index is 0,52.

$$\frac{C.I.}{R.I.} = C.R. = \frac{0{,}04}{0{,}52} = 0{,}0769$$

This value is below the maximum of 0,1 stated by Saaty, so the matrix is nearly consistent. This check for consistency has to be done for each judgment matrix and the criteria judgment matrix, to keep the accuracy of the process. If there is a C.R. higher than 0,1 in any instance, the weights have to be reviewed in this part and modified accordingly.

4.5 Ranking of alternatives

The final part of AHP starts with constructing the decision matrix, together with the priority vector of the criteria judgment matrix this determines the rank of alternatives. The entries of the decision matrix are populated with the received vectors of all criteria. Therefore the decision matrix consists of a distinct amount of columns, given by the amount of criteria. The rows are defined by the number of available alternatives. For example there are three priority vectors (a, b, c) for three criteria, weighting three alternatives A, B and C, in a decision matrix:

C_1	C_2	C_3
a_1	a_2	a_3
b_1	b_2	b_3
c_1	B_2	c_3

Furthermore, there is a priority vector for weighting the importance of all three criteria:

$$\begin{array}{c} \mathbf{V_c} \\ v_{C1} \\ v_{C2} \\ v_{C3} \end{array}$$

To obtain the ranking of all alternatives, the decision matrix is multiplied by the eigenvector of the criteria judgment matrix.

Executing this operation accomplishes weighting of each of the individual criteria priority vectors by the priority of the corresponding selection criteria. (Saaty, 1980). The way of calculating is as follows:

rank of alternative A = $a_1v_{C1}+ a_2v_{C2}+ a_3v_{C3}$

rank of alternative B = $b_1v_{C1}+ b_2v_{C2}+ b_3v_{C3}$

rank of alternative A = $c_1v_{C1}+ c_2v_{C2}+ c_3v_{C3}$

The alternative with highest rank is the most desireable.

AHP provides a mathematically manageable way of solving complex multi-criteria decision problems. Application of AHP has to be done carefully, especially in case of engineering applications. In case of very similar values in the final priority vector, criteria should be reviewed carefully. Over all AHP is a good method during decision making, but it should not be considered almighty and scrutinizing is mandatory. (Saaty, 2006)

4.6 AHP Example for buying a car

Just to illustrate the theory mentioned above a simple example for better understanding will be discussed, just any subjective values were taken. Furthermore, it is somehow difficult to express costs in AHP and some things have to be considered, this part will be covered in the example too.

The example will cover an example concerning a decision for buying a new car. As mentioned above we need to establish a hierarchy first:

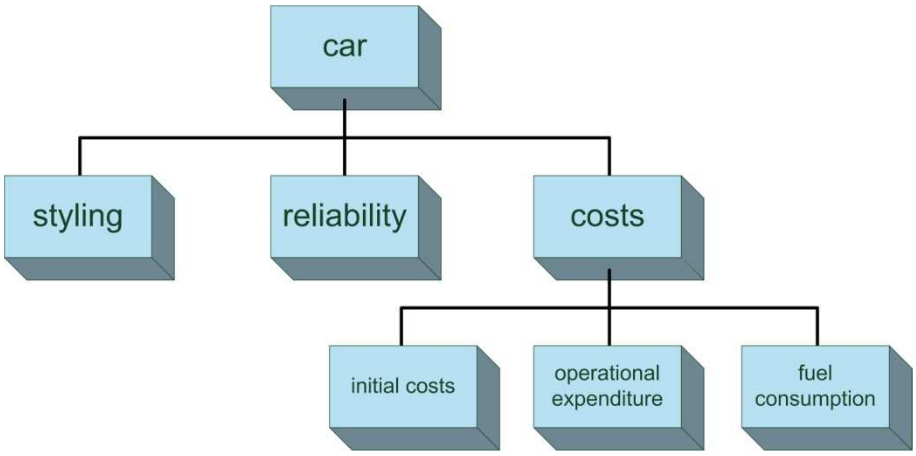

Fig. 12 hierarchy for car decision

Of course this is just an example for available criteria in this case, as described in the hierarchy a few subcriteria for costs were established. The next step in the AHP is to find the weights for the three main criteria:

Table 10 car criteria weighting

	styling	reliability	cost	priority vector	consistency
styling	1,00	0,50	3,00	0,3196	λ_{max}: 3,0183
reliability	2,00	1,00	4,00	0,5584	C.I.: 0,0091
cost	0,33	0,25	1,00	0,1220	C.R.: 0,0176

As mentioned above it is very important to check the consistency in every judgment matrix, in all further examples just C.R. will be mentioned, it has been calculated and every matrix is nearly consistent, this means C.R. is below 0,1. The next step is to determine the weight of the different car models in each criterion. First we will have a look at styling and reliability:

Table 11 pairwise comparison styling

styling	A3	Golf	Mazda 3	Astra	priority vector
A3	1,00	2,00	4,00	6,00	0,5128
Golf	0,50	1,00	2,00	4,00	0,2755
Mazda 3	0,25	0,50	1,00	2,00	0,1377
Astra	0,17	0,25	0,50	1,00	0,0740
C.R.	0,0039				

Table 12 pairwise comparison reliability

reliability	A3	Golf	Mazda 3	Astra	priority vector
A3	1,00	2,00	3,00	4,00	0,4668
Golf	0,50	1,00	2,00	3,00	0,2776
Mazda 3	0,33	0,50	1,00	2,00	0,1603
Astra	0,25	0,33	0,50	1,00	0,0953
C.R.	0,0116				

In the next steps, it is shown how costs come up in this example. Saaty mentions different approaches to include costs in decisions with AHP, first costs are listed as part of the whole hierarchy. According to Saaty there is the possibility to establish an extra hierarchy for costs additional to the one for benefits. Another alternative is just to take the normalized costs, both ways lead to a priority vector for costs which is used to create a benefit/cost ratio. The other way is to take costs into the hierarchy and bring the right scale into an eigenvector. (Saaty, 2006). This way will be calculated first, because it allows the decision maker to set a weight for costs versus other criteria, by using benefit/cost ratios it is not possible to define an importance for costs in a hierarchy. According to this way of including cost in the hierarchy it is possible to continue with the decision problem for the car as follows. First weights for different kinds of cost are defined:

Table 13 cost criteria weighting

cost	price	operational expenditure	fuel consumption	priority vector
price	1,00	3,00	2,00	0,5499
operational expenditure	0,33	1,00	1,50	0,2402
fuel consumption	0,50	0,67	1,00	0,2098
C.R.	0,0707			

Now one needs to set the real values of price, maintenance costs and fuel consumption in relation to each other, because the values need to be normalized on the one hand and we need to get a scale for costs to compare the different alternatives on the other hand. So in the next step we try to define a matrix to get the weights for each alternative concerning the price of the car. Let's assume these are the prices for the different types:

Table 14 car prices

price	
A3	30000,00
Golf	25000,00
Mazda 3	20000,00
Astra	18000,00

As mentioned above we need to get ratios between the alternatives, on the other hand we need to normalize the amounts. So one needs to fill these ratios into a judgment matrix to get the priority vector for this part of costs. For example the value in the matrix for A3 over Golf is 25000/30000 = 0,83. Of course it is possible just to take the reciprocal values of the normalized costs too. But Saaty applies this method to keep the nature of handling different priorities similar to each other, but in this case a matrix is filled with real values instead of subjective weightings. (Saaty, 2006) So this shows that the A3 is worse than the others, so the matrix can be filled up as follows:

Table 15 price weighting

	A3	Golf	Mazda 3	Astra	priority vector
A3	1,00	0,83	0,67	0,60	0,1863
Golf	1,20	1,00	0,80	0,72	0,2236
Mazda 3	1,50	1,25	1,00	0,90	0,2795
Astra	1,67	1,39	1,11	1,00	0,3106
C.R.	0,0000				

As we can see in this table we get a priority vector out of costs, the same way as we did before to get the weights for criteria by pairwise comparison. So we can follow up the same way to get importances for the missing costs.

Table 16 operating expenditure weighting

operating expenditure (3yrs)					
A3	2500,00				
Golf	2200,00				
Mazda 3	2000,00				
Astra	2200,00				
	A3	**Golf**	**Mazda 3**	**Astra**	**priority vector**
A3	1,00	0,88	0,80	1,00	0,2246
Golf	1,14	1,00	0,91	1,14	0,2553
Mazda 3	1,25	1,10	1,00	1,25	0,2808
Astra	1,00	0,88	0,80	1,00	0,2246
C.R.	0,0000				

Table 17 fuel compensation weighting

fuel consumption (per 100km)					
A3	6,00				
Golf	5,50				
Mazda 3	5,00				
Astra	6,00				
	A3	**Golf**	**Mazda 3**	**Astra**	**priority vector**
A3	1,00	0,92	0,83	1,00	0,2293
Golf	1,09	1,00	0,91	1,09	0,2501
Mazda 3	1,20	1,10	1,00	1,20	0,2751
Astra	1,00	0,92	0,83	1,00	0,2293
C.R.	0,0000				

After having all the priority vectors for each subcriterion, we just need to find the weight of each cost over the others by getting the final decision matrix for the cost hierarchy, this is done as described above.

First we need to list all the priority vectors we found for each subcriterion, afterwards their importance is evaluated by applying the priority vector for the cost hierarchy. So we get the following:

Table 18 cost ranking

	buying	opex	fuel	Priority vector	cost-ranking
A3	0,1863	0,2246	0,2293	0,5499	0,2045
Golf	0,2236	0,2553	0,2501	0,2402	0,2368
Mazda 3	0,2795	0,2808	0,2751	0,2098	0,2789
Astra	0,3106	0,2246	0,2293		0,2729

The values in “ranking” are calculated like this example for A3:

ranking A3: 0,1863 x 0,5499 + 0,2246 x 0,2402 + 0,2293 x 0,2098 = 0,2045

So we got the priority vectors for all primary criteria, this leads us to the last step in this example. We need to get the final decision matrix similar to the cost decision matrix, by taking all priority vectors and applying the main priority vector to them. In this way we get the decision for which car we decide.

Table 19 car decision matrix

	styling	reliability	cost	priority vector	ranking
A3	0,5128	0,4668	0,2045	0,3196	0,4495
Golf	0,2755	0,2776	0,2368	0,5584	0,2719
Mazda 3	0,1377	0,1603	0,2789	0,1220	0,1675
Astra	0,0740	0,0953	0,2729		0,1101

So at the end A3 is the winner of this decision, the values would be different if there is an extra hierarchy for cost and the benefit/cost. All examples will be calculated in both ways of including costs in AHP, the following shows the benefit/cost calculation for the car example.

4.6.1.benefit/cost ratio

At the beginning the hierarchy is split up as shown in this figure:

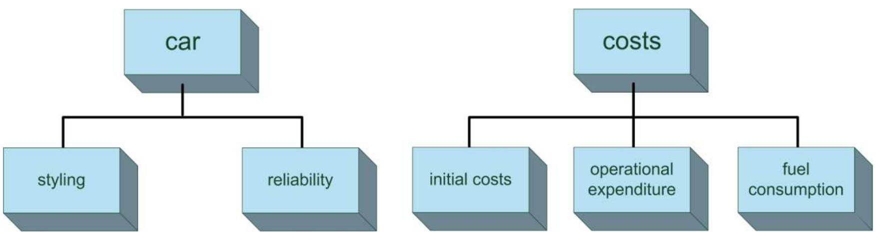

Fig. 13 car decision hierarchies for benefit/cost ratio

Applying the same weights to the remaining criteria, styling got 1/3 and reliability got 2/3. Taking the same weights as in the example above for styling and reliability the decision matrix for benefits is as follows.

Table 20 decision matrix for car benefits

	styling	**reliability**	**pv**	**Ranking**
A3	0,5128	0,4668	0,3333	0,4821
Golf	0,2755	0,2776	0,6667	0,2769
Mazda 3	0,1377	0,1603		0,1528
Astra	0,0740	0,0953		0,0882

Now we need to fill the normalized costs and the priority vector into the cost decision matrix to get the costs for each car.

Table 21 decision matrix for car costs

	buying	**opex**	**fuel**	**priority vector**	**cost-ranking**
A3	0,3226	0,2809	0,2667	0,5499	0,3008
Golf	0,2688	0,2472	0,2444	0,2402	0,2585
Mazda 3	0,2151	0,2247	0,2222	0,2098	0,2189
Astra	0,1935	0,2472	0,2667		0,2218

In the final decision matrix for the car based on the benefit/cost ratio the benefit ranking has to be divided by the cost ranking. The result of this division is normalized again and so the ranking is done by employing the benefit/cost ratio.

Table 22 car ranking with benefit/cost ratio

	benfits	**costs**		**ranking**
A3	0,4821	0,3008	1,6027	0,4252
Golf	0,2769	0,2585	1,0711	0,2842
Mazda 3	0,1528	0,2189	0,6979	0,1852
Astra	0,0882	0,2218	0,3977	0,1055

The ranking stays the same, but the values are slightly different compared to the first method, but the main difference is that costs cannot be weighted compared to benefits in this method. This means if the example with costs and benefits in one hierarchy is calculated with different weights for the main criteria, another car will win. For example if weights for the main criteria are defined as follows, Mazda 3 will get the highest ranking. Just changing the benefits slightly does not change the ranking in the benefit/cost method either, but in the following example the priority of costs has been increased significantly.

Table 23 alternative weights for main criteria

	styling	**reliability**	**cost**	**priority vector**	**consistency**
styling	1,00	1,00	0,11	0,0909	λ_{max}: 3,0000
reliability	1,00	1,00	0,11	0,0909	C.I.: 0,0000
cost	9,00	9,00	1,00	0,8182	C.R.: 0,0000

Changing the ranking by changing the priorities of main criteria is even easier if there are smaller differences in benefit weighting. Therefore for all examples in this thesis both possibilities of handling costs will be discussed for the example where costs occur.

5 DECISIONS IN INFORMATION TECHNOLOGY WITH AHP

During this chapter three examples of decisions which have been done for a commercial customer will be described. Not all customer details are mentioned in this thesis and values like costs, which are necessary during creation of AHP for these examples, are somehow changed because auf confidentially, but the relations are nearly kept as they were in the original decision. IT projects get more and more critical for customers, they are usually quite expensive, but very important too. Costs have to be kept as low as possible and efficiency is a well-known term in running a datacenter. Therefore the landscape of vendors for the different areas in IT is currently under consolidation and competition is in some fields quite hard. Trends like “cloud computing” and “XaaS” (Everything as a service) are buzzwords in IT, but most companies still see these topics as future or strategic items.

The hierarchies for the AHP examples have been discussed with the responsible department head and the values in the judgment matrices have been reviewed by him, so the values are quite near to reality. The third example will show up a recruiting process in an IT company, to have another example of applied AHP

5.1 Enterprise Storage decision

Storage is getting more and more important for companies, because the stored information is very important for them. Furthermore the amount of data is growing rapidly and therefore it comes up to a financial problem for many companies. On the other hand they have to keep their information as save as possible and it is not just a task of not losing any data, availability is a very important part too. If there are hundreds or thousands of people in a company and they are not able to work because of IT, or there are online portals for customers not available, it gets very expensive for companies. Therefore there are many things to consider during the decision for a specific vendor and his technology. The following example will show up a decision which has been done by one of the customers a few months ago. The company did not use any algorithm or even AHP to get the decision, they just relied on their classical methods by comparing features etc. by some lists. Together with the responsible people at the customer it has been tried to get this decision in AHP to have a look at the results.

5.1.1 Hierarchy

As mentioned above, the hierarchy for this decision has been discussed with the responsible department head and we came up with the following:

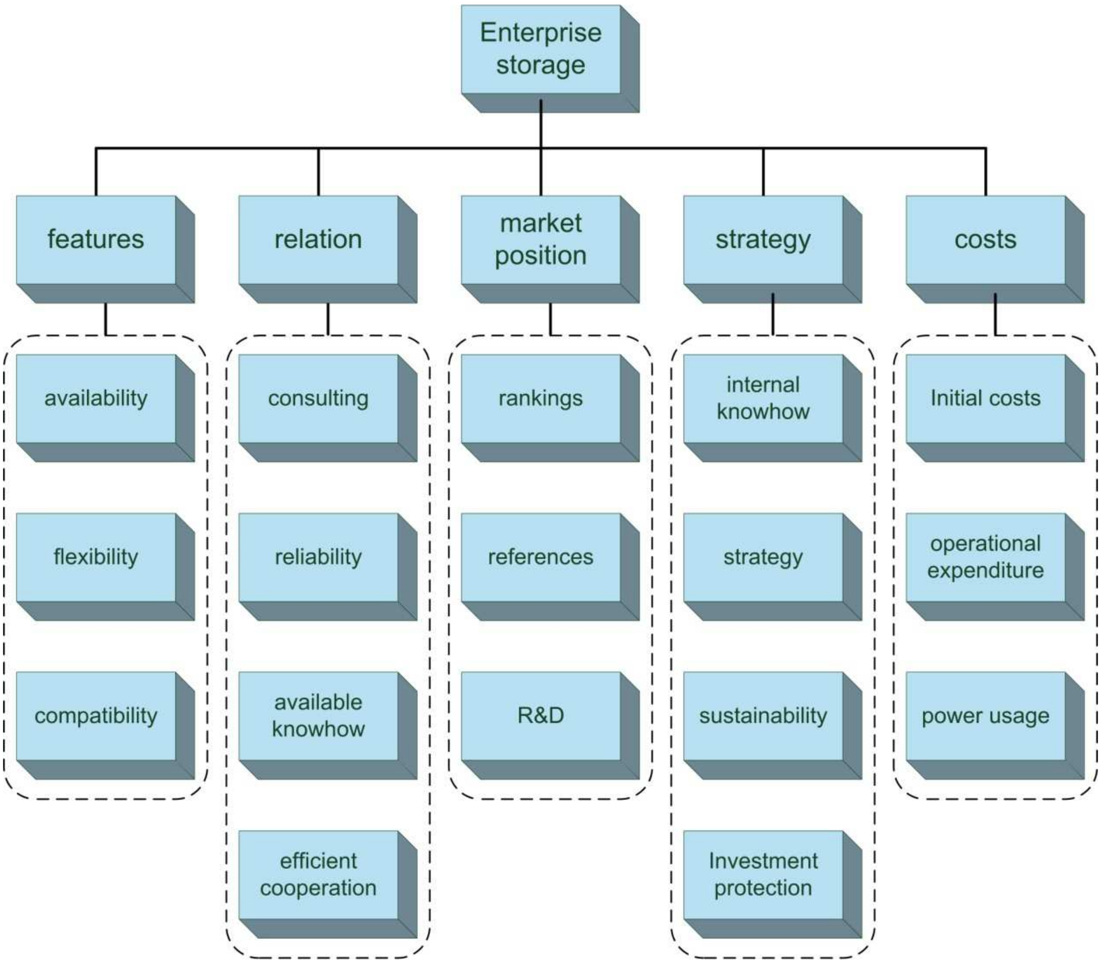

Fig. 14 storage hierarchy

As you can see in this figure we decided to build up a hierarchy consisting of five main criteria with three or four subcriteria each. Like we did in the example for the car above, it is necessary to define the importance of the five main criteria first. In case of this storage project the reason for the main criteria will be briefly explained in the following. All influencing criteria have been identified together with the department head, afterwards they were put in groups as shown in the figure. All parts of the evaluation during the project decision were considered and they tried to define the groups as they were mentioned in their internal guidelines for projects like this and as it has been presented to their management.

5.1.2 weighting main criteria

Weighting of main criteria is probably one of the most important steps during AHP. As we can see, they decided to take costs as the most important criterion, features and relation are equal and strategy and market are equal too. During definition of each subcriterion later on it will be explained why the customer put in these priorities. Similar to the car example, all criteria have been determined by pairwise comparison and costs are in the hierarchy again. They defined the priorities for the five main criteria as follows:

Table 24 storage main criteria weighting

	cost	**features**	**relation**	**strategy**	**market**	**Priority vector**
cost	1,00	2,00	2,00	3,00	3,00	0,3682
features	0,50	1,00	1,00	2,00	2,00	0,2065
relation	0,50	1,00	1,00	2,00	2,00	0,2065
strategy	0,33	0,50	0,50	1,00	1,00	0,1094
market	0,33	0,50	0,50	1,00	1,00	0,1094
C. R.	0,0030					

As already mentioned before, cost is the most important part in case of a storage decision, but of course all other criteria have to be considered too. As mentioned above, all matrices have to be checked for consistency to assure the reliability of the process. In the next step we will see how the customer decided to weight the importance of all subcriteria.

5.1.3 weighting features

As we can see in the hierarchical structure the first criterion called features consists of availability, flexibility and compatibility. Availability is mainly based on the architecture of the offered solution and its capabilities related to Business Continuity and Disaster Recovery. Flexibility means in this case the possibilities offered by the solution referred to unexpected growth and major changes in the company. Compatibility shows up the openness of the system to new technical developments and the possibility of including new systems supported for maintenance by the vendor.

So we get the matrices for the importance of each subcriterion related to others and of course matrices for evaluation of weights have to be built up. At the end we get the priorities for this criterion, listed in the last part of this table.

Table 25 weighting features

features	**availab.**	**flexib.**	**compatib.**		**priority vector**
availability	1,00	3,00	5,00		0,6370
flexibility	0,33	1,00	3,00		0,2583
compatibility	0,20	0,33	1,00		0,1047
C.R.	0,0370				
availability	**A**	**B**	**C**	**D**	**priority vector**
A	1,00	1,00	3,00	5,00	0,3937
B	1,00	1,00	3,00	5,00	0,3937
C	0,33	0,33	1,00	2,00	0,1374
D	0,20	0,20	0,50	1,00	0,0752
C.R.	0,0016				
flexibility	**A**	**B**	**C**	**D**	**priority vector**
A	1,00	3,00	5,00	1,00	0,3937
B	0,33	1,00	2,00	0,33	0,1374
C	0,20	0,50	1,00	0,20	0,0752
D	1,00	3,00	5,00	1,00	0,3937
C.R.	0,0016				
compatibility	**A**	**B**	**C**	**D**	**priority vector**
A	1,00	3,00	1,00	3,00	0,3750
B	0,33	1,00	0,33	1,00	0,1250
C	1,00	3,00	1,00	3,00	0,3750
D	0,33	1,00	0,33	1,00	0,1250
C.R.	0,0000				

features	availa.	flexib.	compatib.	pv (features)	priority
A	0,3937	0,3937	0,3750	0,6370	0,3917
B	0,3937	0,1374	0,1250	0,2583	0,2994
C	0,1374	0,0752	0,3750	0,1047	0,1462
D	0,0752	0,3937	0,1250		0,1627

This table shows up that availability is very important for the customer, in this case the customer is running his most important applications on this systems, these applications are crucial to his business. If they are offline more than a few minutes the customer is going to lose a lot of money, because the company is not able to deliver any goods in this timeframe. Flexibility is less important, but still necessary, compatibility is not that important, because strategic decisions concerning their environment have been fixed and there will not be fundamental changes in hardware or software in the next four to five years. At the end of this part vendor A got the best values in this criterion.

5.1.4 weighting relation

The main criterion relation consists of consulting, reliability, available knowhow and cooperation. Consulting implies the availability of resources with experience in projects like this. There have to be enough resources for designing the solution and to provide information for the customer to get all information which has to be considered. Reliability relates the experience in cooperation with this vendor and available knowhow describes the available technical resources to implement and maintain the solution. The last subcriterion, cooperation, focuses on efficient communication with the vendor in case of maintenance or service needs. Efficient processes and ways are of course an advantage for a vendor in this criterion. In this criterion reliability the most important for the customer, they experienced many issues in the past few years.

Table 26 weighting relation

relation	consult.	reliab.	knowh.	coop.	priority vector
consulting	1,00	0,33	1,00	3,00	0,1933
reliability	3,00	1,00	3,00	7,00	0,5447
knowhow	1,00	0,33	1,00	3,00	0,1933
cooperation	0,33	0,14	0,33	1,00	0,0686
C.R.	0,0030				

consulting	A	B	C	D	priority vector
A	1,00	3,00	1,00	5,00	0,3938
B	0,33	1,00	0,33	2,00	0,1371
C	1,00	3,00	1,00	5,00	0,3938
D	0,20	0,50	0,20	1,00	0,0753
C.R.	0,0007				

reliability	A	B	C	D	priority vector
A	1,00	1,00	3,00	5,00	0,3937
B	1,00	1,00	3,00	5,00	0,3937
C	0,33	0,33	1,00	2,00	0,1374
D	0,20	0,20	0,50	1,00	0,0752
C.R.	0,0016				

knowhow	A	B	C	D	priority vector
A	1,00	2,00	0,33	3,00	0,2188
B	0,50	1,00	0,20	1,50	0,1145
C	3,00	5,00	1,00	7,00	0,5890
D	0,33	0,67	0,14	1,00	0,0777
C.R.	0,0024				

cooperation	A	B	C	D	priority vector
A	1,00	3,00	1,00	5,00	0,3937
B	0,33	1,00	0,33	2,00	0,1374
C	1,00	3,00	1,00	5,00	0,3937
D	0,20	0,50	0,20	1,00	0,0752
C.R.	0,0016				

relation	consult.	reliab.	knowh.	coop.	pv (relation)	priority
A	0,3938	0,3937	0,2188	0,3937	0,1933	0,3599
B	0,1371	0,3937	0,1145	0,5447	0,5447	0,2725
C	0,3938	0,1374	0,5890	0,1933	0,1933	0,2919
D	0,0753	0,0752	0,0777	0,0686	0,0686	0,0757

As mentioned before reliability is the most important subcriterion for this customer, of course these values can change for a different customer, it depends on the experience the company had and how the vendor handled problems in the past. Again vendor A got the highest ranking, so vendor A already has little advantages compared to the others. The values in this area are mainly based on subjective values, of course there are numbers for available technicians etc., but the customer mentioned that these matrices are mainly based on his experience concerning the vendor in the last few years. Mainly based on external rankings and reports is the next main criterion to be weighted.

5.1.5 weighting market position

The third main criterion focuses on the position of the vendor in the market and the experience of other companies having with the respective vendor. This criterion consists of the subcriteria rankings, references and R&D. Rankings refers to reports delivered by some institutions like Gartner or IDC and shows up the position of the vendors in the Enterprise Storage market. The second subcriterion References focuses on experience of other customers with the vendor, the product and the involved people. In the R&D section the customer tried to justify the development and inventions done by the vendors and if the vendors are offering up to date technology.

Table 27 weighting market

market	**references**	**R&D**	**rankings**		**priority vector**
references	1,00	3,00	5,00		0,6370
R&D	0,33	1,00	3,00		0,2583
rankings	0,20	0,33	1,00		0,1047
C.R.	0,370				

references	**A**	**B**	**C**	**D**	**priority vector**
A	1,00	3,00	1,00	3,00	0,3750
B	0,33	1,00	0,33	1,00	0,1250
C	1,00	3,00	1,00	3,00	0,3750
D	0,33	1,00	0,33	1,00	0,1250
C.R.	0,0000				

R&D	A	B	C	D	priority vector
A	1,00	3,00	5,00	1,00	0,3937
B	0,33	1,00	2,00	0,33	0,1374
C	0,20	0,50	1,00	0,20	0,0752
D	1,00	3,00	5,00	1,00	0,3937
C.R.	0,0016				

rankings	A	B	C	D	priority vector
A	1,00	1,00	3,00	2,00	0,3512
B	1,00	1,00	3,00	2,00	0,3512
C	0,33	0,33	1,00	0,50	0,1089
D	0,50	0,50	2,00	1,00	0,1887
C.R.	0,0039				

features	references	R&D	rankings	pv (market)	priorities
A	0,3750	0,3937	0,3778	0,6370	0,3773
B	0,1250	0,1374	0,3778	0,2583	0,1519
C	0,3750	0,0752	0,0793	0,1047	0,2697
D	0,1250	0,3937	0,1887		0,2011

The market analysis brings up vendor A as the leader, in this case this was somehow expected, because in this area vendor A is the superior market leader and according to their decisions concerning their planned infrastructure this vendor shows up the best inventions. Even though this ranking has to be established, to get the relations.

5.1.6 weighting strategy

This main criterion focuses on the customer's internal strategy and plans, including knowhow, strategy, sustainability and investment protection. Internal knowhow referred to the vendors is evaluated in the first subcriterion, their strategy concerning suppliers and technology is justified in the second criterion. Sustainability is a major part of their mission so it is considered in this decision too. Investment protection covers the reusability of hardware and software and usability of the new infrastructure for additional tasks.

Table 28 weighting strategy

strategy	investment protection	strategy	sustainab.	internal knowhow	priority vector
investment protection	1,00	3,00	5,00	3,00	0,5205
strategy	0,33	1,00	3,00	1,00	0,2010
Sustainab.	0,20	0,33	1,00	0,33	0,0776
internal knowhow	0,33	1,00	3,00	1,00	0,2010
C.R.	0,0162				

investment protection	A	B	C	D	priority vector
A	1,00	3,00	3,00	1,00	0,3750
B	0,33	1,00	1,00	0,33	0,1250
C	0,33	1,00	1,00	0,33	0,1250
D	1,00	3,00	3,00	1,00	0,3750
C.R.	0,0000				

strategy	A	B	C	D	priority vector
A	1,00	3,00	1,00	5,00	0,3937
B	0,33	1,00	0,33	2,00	0,1374
C	1,00	3,00	1,00	5,00	0,3937
D	0,20	0,50	0,20	1,00	0,0752
C.R.	0,0016				

sustainab.	A	B	C	D	priority vector
A	1,00	0,33	3,00	1,00	0,1933
B	3,00	1,00	7,00	3,00	0,5447
C	0,33	0,14	1,00	0,33	0,0686
D	1,00	0,33	3,00	1,00	0,1933
C.R.	0,0030				

internal knowhow	A	B	C	D	priority vector
A	1,00	5,00	1,00	3,00	0,3937
B	0,20	1,00	0,20	0,50	0,0752
C	1,00	5,00	1,00	3,00	0,3937
D	0,33	2,00	0,33	1,00	0,1374
C.R.	0,0016				

internal knowhow	investment protection	strategy	sustainab.	internal knowhow	pv (strat.)	priority
A	0,3750	0,3937	0,1933	0,3937	0,5205	0,3684
B	0,1250	0,1374	0,5447	0,2010	0,2010	0,1500
C	0,1250	0,3937	0,0686	0,3937	0,0776	0,2286
D	0,3750	0,0752	0,1933	0,1374	0,2010	0,2529

Vendor A is also coming up as winner in this criterion, but this mainly depends on the investment protection, because this subcriterion is very important for the customer. The company will use this solution for at least four years and therefore it is important that there are possibilities for reuse or additional use of the equipment. Especially in sustainability vendor A is far beyond vendor C, but because of the importance of investment protection and the low priority of sustainability it does not really influence the final priorities. It might seem weird that strategy does not matter very much, but this is a subjective decision done by the customer.

5.1.7 weighting cost

As mentioned above costs are the most important main criterion, it is broken down in initial costs, operational expenditure and power usage. As you can see in the hierarchy, costs are mentioned as one part of the hierarchy, similar to the car example. Initial costs is covering the costs of buying the solution, operational expenditure arise from maintenance costs, management costs and all costs, except power and cooling, necessary for running the system. Power usage combines the power usage of the hardware of the solution and the appropriate amount of power necessary for cooling the whole equipment in the datacenter. For bringing costs into a ratio to each other the same approach as in the car example is used.

Table 29 weighting costs

costs	initial costs	opex	power usage	priority vector
initial costs	1,00	2,00	3,00	0,5396
opex	0,50	1,00	2,00	0,2970
power usage	0,33	0,50	1,00	0,1634
C.R.	0,0088			

initial costs	
A	2000000
B	1900000
C	1700000
D	1500000

initial costs	A	B	C	D	priority vector
A	1,00	0,95	0,85	0,75	0,2192
B	1,05	1,00	0,89	0,79	0,2307
C	1,18	1,12	1,00	0,88	0,2579
D	1,33	1,27	1,13	1,00	0,2922
C.R.	0,0000				

operational expenditure	
A	100000
B	130000
C	180000
D	80000

opex	A	B	C	D	priority vector
A	1,00	1,30	1,80	0,80	0,2797
B	0,77	1,00	1,38	0,62	0,2152
C	0,56	0,72	1,00	0,44	0,1554
D	1,25	1,63	2,25	1,00	0,3497
C.R.	0,0000				

power usage (kVA)	
A	18
B	12
C	16
D	14

power-usage	A	B	C	D	priority vector
A	1,00	0,67	0,89	0,7778	0,2036
B	1,50	1,00	1,33	1,1667	0,2956
C	1,13	0,75	1,00	0,8750	0,2217
D	1,29	0,86	1,14	1,0000	0,2533
C.R.	0,0003				

features	initial costs	opex	power usage	pv (cost)	priorities
A	0,2192	0,2797	0,2036	0,5396	0,2346
B	0,2307	0,2152	0,2956	0,2970	0,2367
C	0,2579	0,1554	0,2217	0,1634	0,2215
D	0,2922	0,3497	0,2533		0,3029

In this case it turns out that vendor A is quite expensive compared to the others, so the final decision matrix will bring up the final decision. As mentioned before costs are quite important in this decision. As we can see in this table, different units are mixed up, kVA and money are intermingled. Therefore the matrices consist of ratios between the affected alternatives, this brings all numbers into one scale and therefore it is possible to mix them up. The values for the other criteria have been evaluated by reports of some institutes or by rankings done by a questionnaire, so this action was not necessary.

5.1.8 decision for an enterprise storage solution

At the end we can build up the decision matrix consisting of all determined priority vectors of main criteria. The priorities of main criteria have been defined at the beginning of this chapter and of course we also need them to get the final ranking of vendors.

Table 30 final decision enterprise storage

	costs	features	relation	strategy	market	pv (main)	priorities
A	0,2346	0,3917	0,3599	0,3684	0,3773	0,3682	0,3232
B	0,2367	0,2994	0,2725	0,1500	0,1519	0,2065	0,2383
C	0,2215	0,1462	0,2919	0,2286	0,2697	0,2065	0,2265
D	0,3029	0,1627	0,0757	0,2529	0,2011	0,2697	0,2104
						0,2011	

As expected vendor A is the winner and in reality vendor A won too. The customer just used classic methods to evaluate the best offer, but came up with the same solution. Quite interesting is the fact that vendor B is on second rank, but the final decision of the customer has been between vendor A and C. This issue and a comparison between this method and the evaluation of the customer will be done in the results part.

5.1.9 benefit/cost ratio for an enterprise storage solution

As mentioned above the benefit/cost ratio is another possibility of including costs in an AHP decision process. This approach needs to separate the cost hierarchy from the benefit hierarchy.

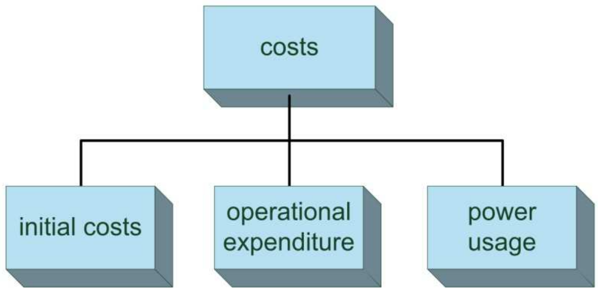

Fig. 15 cost hierarchy enterprise storage decision

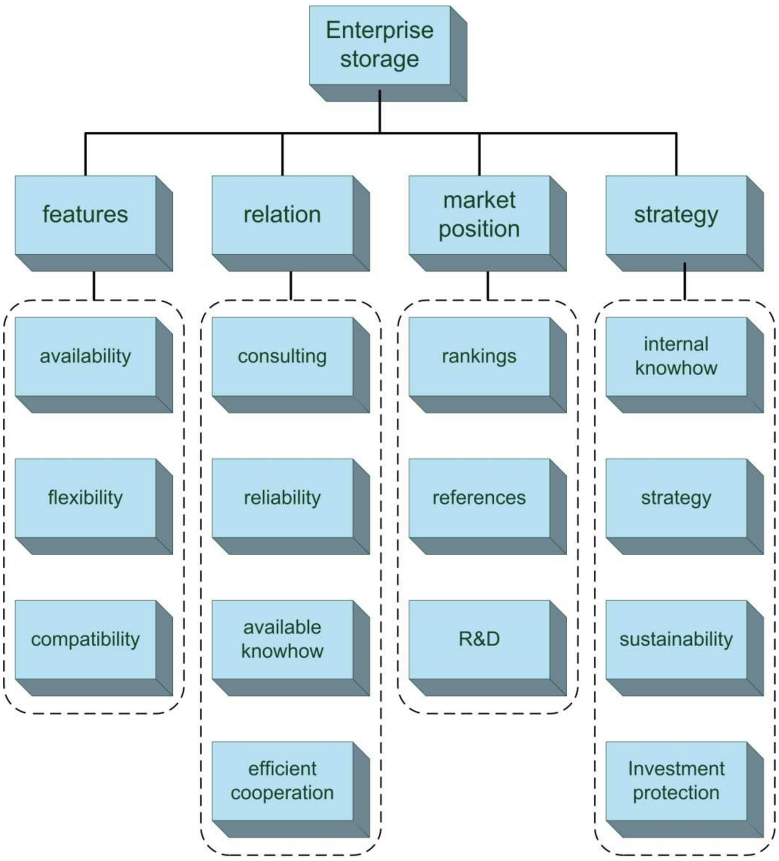

Fig. 16 benefit hierarchy enterprise storage decision

Therefore the weights for main criteria have to be calculated again. On the other hand it is possible to apply the cost weighting to the separated cost hierarchy. The normalized costs of each solution are summed up and normalized, afterwards the priority vector of costs is applied. For the benefit ranking the new weights for main criteria are applied to their subcriteria rankings.

Table 31 cost ranking enterprise storage decision

	initial costs	opex	power	priority vector	cost ranking
A	0,2817	0,2041	0,3000	0,5396	0,2616
B	0,2676	0,2653	0,2000	0,2970	0,2559
C	0,2394	0,3673	0,2667	0,1634	0,2819
D	0,2113	0,1633	0,2333		0,2006

This provides the following results for the benefit/cost ratio for the enterprise storage decision. The benefit/cost ratio in this table is already normalized for better comparison with former ranking.

Table 32 benefit/cost ratio enterprise storage decision

	features	relation	Strategy	market	priority vector	benefit ranking	cost ranking	benefit/ cost
A	0,3917	0,3599	0,3684	0,3773	0,3333	0,3748	0,2616	0,3618
B	0,2994	0,2725	0,1500	0,1519	0,3333	0,2409	0,2559	0,2378
C	0,1462	0,2919	0,2286	0,2697	0,1667	0,2291	0,2819	0,2052
D	0,1627	0,0757	0,2529	0,2011	0,1667	0,1551	0,2006	0,1953

In this case the ranking of alternatives stays the same no matter in which kind costs have been taken into account. The difference between the first three positions increased a little bit, because of course the weightings of benefits increased and therefore the alternatives with higher benefits gained additional advantages by the importance of the main criteria. Furthermore, the factor for costs in this ratio raises the difference too.

5.2 Virtualization decision

The second decision example covers a decision of the same customer concerning another topic. As already mentioned above cloud computing is currently seen as a strategy, but building an own cloud by virtualizing at least the servers in a datacenter is getting more and more common. Some strategists consider this server virtualization as the the first step to the cloud. There are many advantages in virtualizing the server landscape: flexibility, infrastructrure savings and efficiency are just few of them. In this case the customer already decided to do this step and was evaluating the different solutions for server virtualization on the market. Of course the hierarchy for this decision is different to the first example, other criteria have to be considered. Together with the customer the following hierarchy based on four main criteria has been developed.

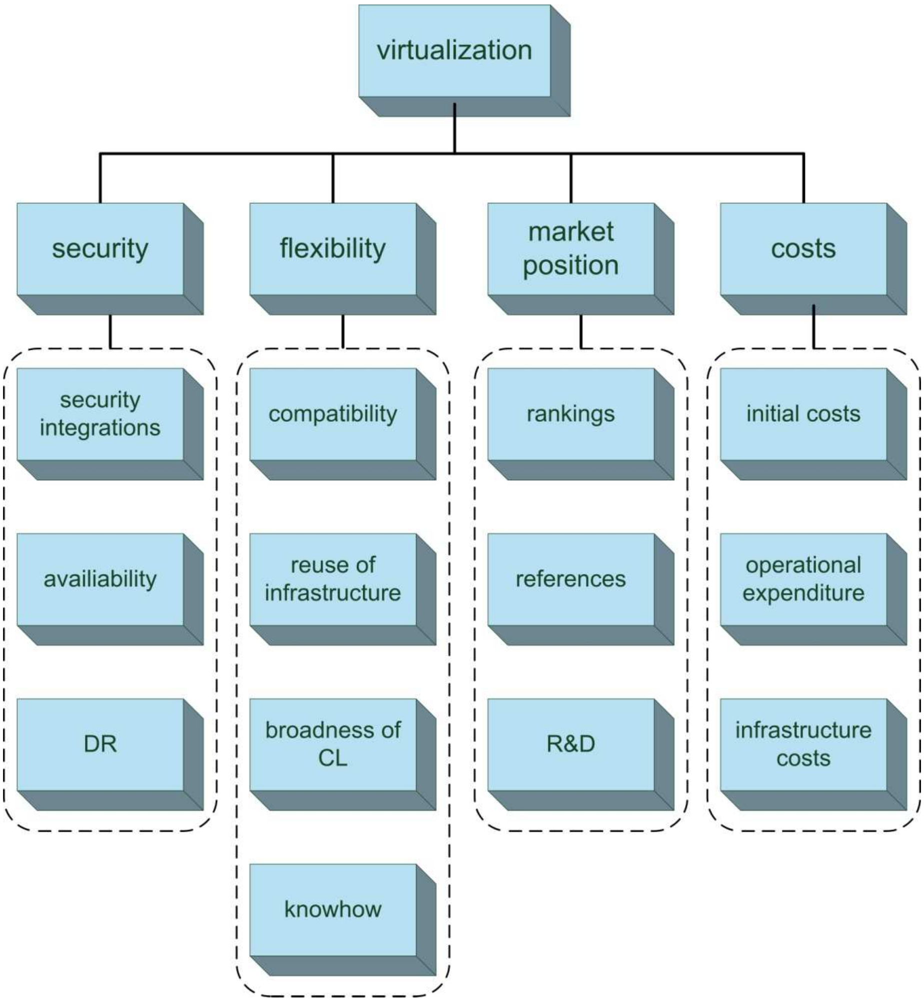

Fig. 17 virtualization hierarchy

The main criteria in this example are security, flexibility, market position and costs. Security is getting more and more important in virtualization, because even if systems or applications are located on one physical server different users have different rights. Furthermore it is important to increase availability of consolidated and virtualized datacenters. At this costumer they start to virtualize approximately 200 physical servers to fifteen new ones, so the new equipment has to have higher availiability by offering the same reliability of the whole infrastructure. Therefore Disaster Recovery possibilities also have to be weighted, just to have the opportunity to get high risk applications in the new infrastructure too.

The second main criterion in the virtualization hierarchy is flexibility, this mainly focuses on the customer's existing infrastructure and the openness to changes. Compatibility describes the transparency of the migration to the virtualized infrastructure, this means whether they can keep their operating systems, applications, drivers and so on as they are or many changes have to be done. Reuse of infrastructures is an important part, because it shows up if physical changes are needed in the datacenter like cabling, power circuits and cooling. The broadness of the compatibility list of the considered virtualization solution is in the subcriteria list, because it shows up the ability to change platforms in future without being bound to a small portfolio of choices given by the vendor. The last part of flexibility is the existing knowledge in the company and how much effort would be necessary in case of choosing a solution for readjusting employees knowledge.

Rankings in the third main criterion market express the ranking of the mentioned solution by different institutes. References covers feedback of other customers using this platform for their virtualization. R&D shows up the ongoing development of the solutions and sustainability of choosing this virtualization.

The fourth main criterion is showing up the costs of the different solutions. Initial costs show up the costs for licenses including three years maintenance, operational expenditure covers management overhead and power usage of the desired infrastructure and infrastructure implies the amount of money spent for new hardware in the datacenter. For this example just the most important tables will be printed. The first task is to weight the main criteria, the customer decided to give the following weights:

Table 33 virtualization main criteria weighting

	security	**flexibility**	**market**	**costs**	**priority vector**
security	1,00	1,00	3,00	0,50	0,2348
flexibility	1,00	1,00	3,00	0,50	0,2348
market	0,33	0,33	1,00	0,20	0,0819
costs	2,00	2,00	5,00	1,00	0,4486
C. R.	0,0016				

As shown in this table costs are the most important criterion in this example too. After finishing this calculation the benefit/cost ratio for this example will be shown to compare the results. As mentioned above security is covering some important parts for virtualization, the customer defined the importance of the subcriteria of security as follows, the details of all subcriteria will not be mentioned here, just the result of each main criterion.

Table 34 security ranking

	security integration	**availability**	**DR**	**priority vector**	**ranking**
W	0,0643	0,0550	0,0393	0,1047	0,0519
V	0,7153	0,2634	0,2696	0,6370	0,3123
X	0,0643	0,1178	0,1260	0,2583	0,1143
U	0,1561	0,5638	0,5651		0,5214

Values for the subcriteria are results of pairwise comparison matrices, the priority vector shows up the weight of each subcriterion over the other. As shown here alternative U seems to be the best solution concerning security, even if V is far better in security integration. The next table shows up the weights for flexibility and its subcriteria.

Table 35 flexibility ranking

	compatibility	reuse of i.	CL	knowhow	priority vector	ranking
W	0,1933	0,5579	0,1283	0,3908	0,5205	0,2482
V	0,5447	0,2495	0,5756	0,3908	0,0776	0,4185
X	0,0686	0,0963	0,2525	0,0675	0,2010	0,0939
U	0,1933	0,0963	0,0436	0,1509	0,2010	0,1169

In case of flexibility and its subcriteria alternative V seems to be the best solution, again these results arise by pairwise comparison based on inputs from the customer. According to the main criteria weighting matrix, market is the least important criterion, the results of pairwise comparison are as follows.

Table 36 market ranking

	rankings	references	R&D	priority vector	ranking
W	0,0643	0,0908	0,1119	0,1047	0,0935
V	0,7153	0,5888	0,5706	0,6370	0,5973
X	0,0643	0,0428	0,0451	0,2583	0,0457
U	0,1561	0,2776	0,2723		0,2635

Again alternative V got the best ranking, so it is up to the most important criterion to finish the decision. In this example costs are shown up as part of the hierarchy again and the pairwise comparison matrices for the subcriteria of costs have been populated as explained in the storage example by putting in ratios between both alternatives in each cell.

Table 37 costs ranking

	initial	opex	infrastructure	priority vector	ranking
W	0,3830	0,2459	0,3214	0,1048	0,3084
V	0,1915	0,4918	0,3214	0,2576	0,3517
X	0,3830	0,1639	0,3214	0,6375	0,2873
U	0,0426	0,0984	0,0357		0,0526

Furthermore, the priority vector has been applied to the different costs and so we get the final ranking for costs. At the end we need to apply the priority vector for the main criteria to the rankings of them and so the final decision matrix can be employed to receive the ranking for the virtualization solution.

Table 38 final decision matrix for virtualization

	security	flexibility	market	costs	priority vector	ranking
W	0,0519	0,2482	0,0935	0,3084	0,2348	0,2165
V	0,3123	0,4185	0,5973	0,3517	0,2348	0,3783
X	0,1143	0,0939	0,0457	0,2873	0,0819	0,1815
U	0,5214	0,1169	0,2635	0,0526	0,4488	0,1950

Alternative V is ranked on the best position for this customer and in the real world he came up with the same decision. The customer was thinking about choosing alternative U too, but it was too expensive for his needs. This application of AHP shows up the same decision, alternative U is ranked far behind alternative V mainly because of the costs.

Therefore the benefit/cost ratio of this example has been calculated too and is shown in the following. As mentioned in the car example costs in the benefit/cost ratio are fixed concerning their relation to benefits, therefore this approach will show up some changes in the ranking for the virtualization decision.

5.2.1 virtualization benefit/cost ratio

The first step in calculating the benefit/cost ratio is to separate the hierarchies for benefits and costs as mentioned above.

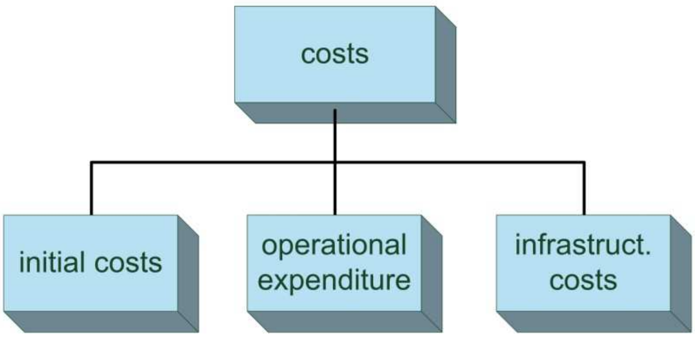

Fig. 18 cost hierarchy for virtualization

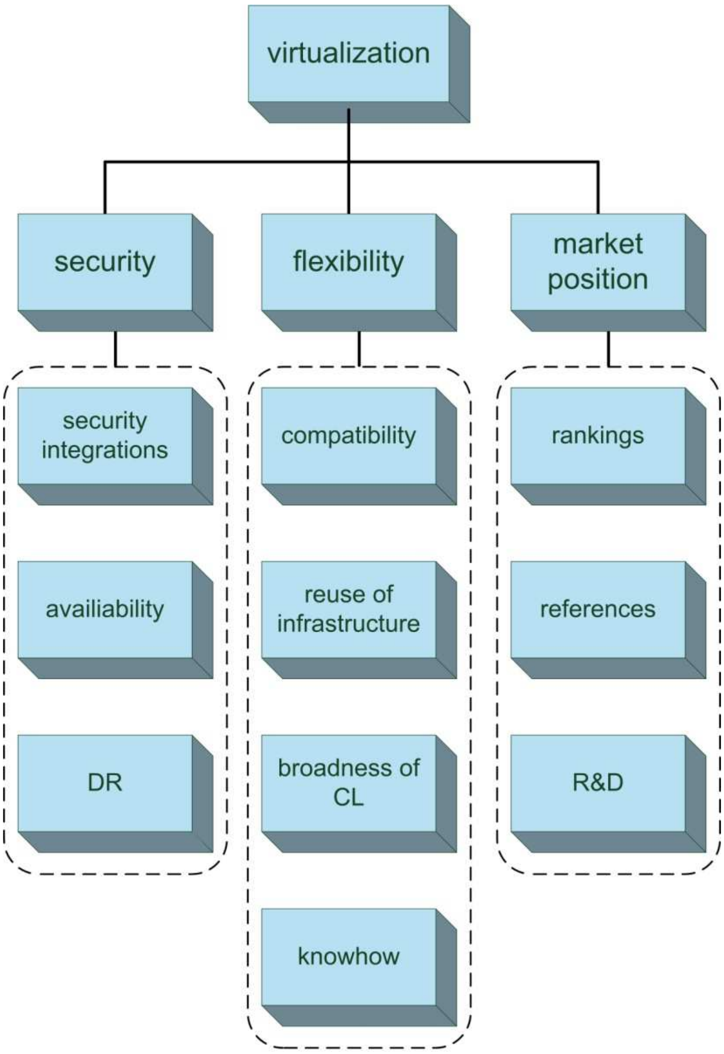

Fig. 19 virtualization hierarchy for benefit/cost ratio

Taking the normalized costs and applying the priority vector for costs to them leads to the ranking of alternatives concerning costs for this calculation. As mentioned above in this case this is not the inverse relation for getting the lowest ranking for the most expensive alternative, in this case the most expensive solutions gets the highest cost ranking. Furthermore, the weights for the subcriteria can be kept, but the priority vector for main criteria is changing. At the end the decision matrix for benefit/cost calculation for virtualization looks as follows.

Table 39 virtualization benefit/cost ranking

	security	flexibility	market	prority vector	benefit ranking	cost ranking	benefit/cost ranking
W	0,0519	0,2482	0,0935	0,4286	0,1420	0,0570	0,1930
V	0,3123	0,4185	0,5973	0,4286	0,3986	0,0489	0,6316
X	0,1143	0,0939	0,0457	0,1429	0,0958	0,0693	0,1070
U	0,5214	0,1169	0,2635		0,3112	0,3521	0,0684

Comparing the ranking of both calculations the winner stays alternative V, but rank three and four changed. This issue arises, because there is no weighting of costs compared to benefits again. Especially this ranking does not meet the expectations of the customer, further details will be discussed in the results section.

5.3 recruiting decision

This example will briefly cover a recruiting process. The values and criteria have been designed together with the Human Resources Manager and the responsible department head. The mentioned company is searching for a Presales Consultant in a technically oriented company and the managers have to decide between three internal applicants. There were some interviews with them and they wanted to test this method, because it is important to leave personal feelings out of the decision. In the following the designed hierarchy of this decision is mentioned. The main criteria are weighted up to their expectations and the weightings for the alternatives are defined up to their facts collected in the interviews. At the beginning the decision seemed to be quite hard and they were discussing a long time who will get this job. They did their own decision method too, this results will be discussed afterwards.

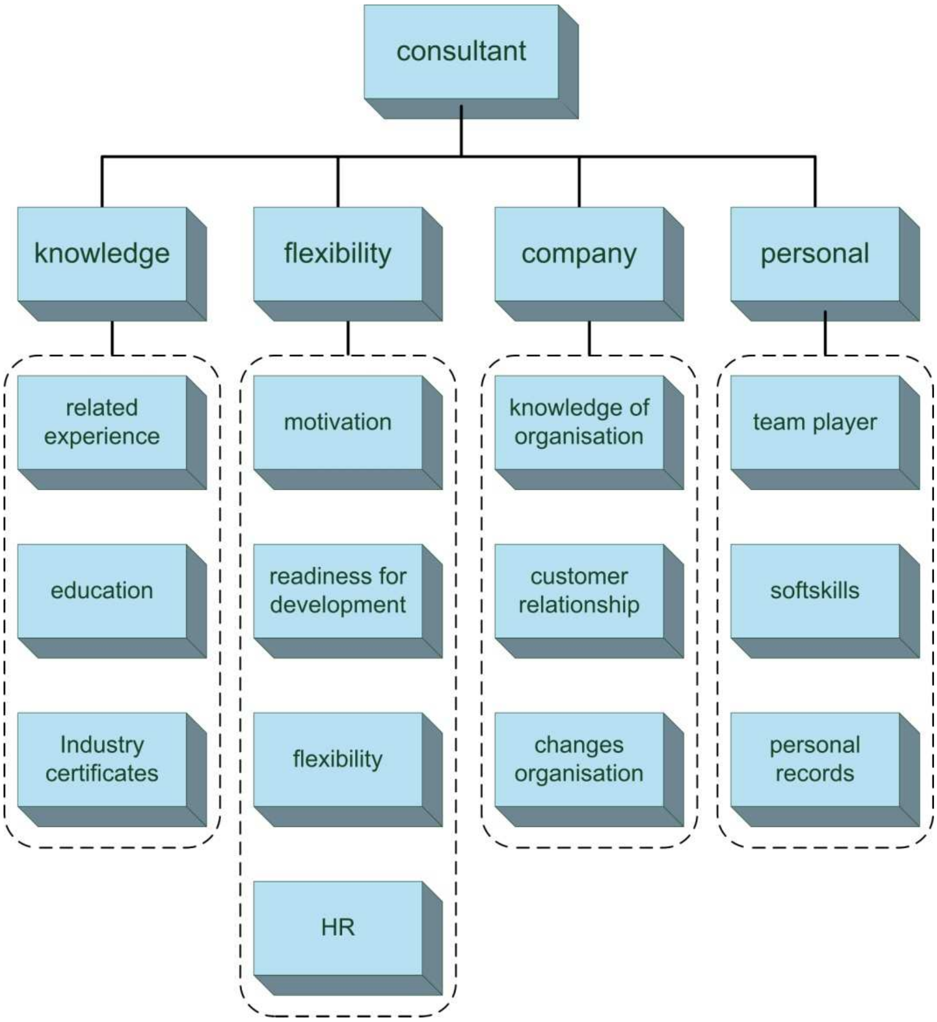

Fig. 20 hierarchy recruiting decision

The goal consists of four subcriteria, called knowledge, flexibility, company and personal. Knowledge reflects the basics of the candidate, considering his experience in this industry and the planned tasks. Furthermore, the educational level and the certificates for the related field of activity are taken into account. Flexibility shows the personal situation of the applicant and his attitude to this job. Motivation reflects the reasons why he applied for this job, readiness for development focuses on the openness for further education and exploration of new tasks. Flexibility is of course important for constant customer contact all the time. HR is also mentioned in there, it considers the inputs brought up by a HR management point of view. The third main criterion respects the needs of the company, this refers to knowledge about the processes and relations inside the company, existing relationship to customers and if the role change of the employee is critically affecting the organization. The last main criterion focuses on some personal details of the applicant like his ability to work in teams, additional soft skills like presentation and negotiation skills and if there were any special events in his history inside the company.

As already mentioned the weightings for the main criteria had been discussed with the responsible managers and turned out to be as follows.

Table 40 recruiting main criteria weighting

	knowledge	flexibility	company	personal	priority vector
knowledge	1,00	0,33	3,00	0,33	0,1426
flexibility	3,00	1,00	7,00	1,00	0,4018
company	0,33	0,14	1,00	0,14	0,0539
personal	3,00	1,00	7,00	1,00	0,4018
C.R.	0,0030				

Flexibility and personal aspects turned out to be the most important criteria, this is according to the expectations of both managers. Knowledge is important too, but can be acquired afterwards for this job, for other job descriptions this will probably have higher importance. The mentioned company related issues are something like nice to have, but not very important. So the ranking for the main criterion knowledge looks as follows.

Table 41 ranking experience

	experience	education	certificates	priority vector	ranking
M	0,0810	0,0629	0,1047	0,6370	0,0852
K	0,1884	0,2654	0,2583	0,1047	0,2145
O	0,7306	0,6716	0,6370	0,2583	0,7003

As mentioned in this table candidate O is the most experienced and educated applicant. Experience is the most important, certificates the second and education the least important subcriterion. According to the HR manger this weighting is like this, because education and certifications can be made up afterwards by additional trainings. The following table shows the ranking of the second main criterion, flexibility.

Table 42 ranking flexibility

	motivation	readiness	flexibility	HR	priority vector	ranking
M	0,6370	0,2000	0,6491	0,1782	0,0963	0,4872
K	0,2583	0,2000	0,0719	0,7514	0,0963	0,2717
O	0,1047	0,6000	0,2790	0,0704	0,5579	0,2411
					0,2495	

Flexibility is the most important subcriterion in this subhierarchy. In this criterion applicant M got the best ranking. The least important main criterion is ranked as follows.

Table 43 ranking company

	org. knowhow	CR	org . changes	priority vector	ranking
M	0,1047	0,2426	0,2654	0,1047	0,2341
K	0,2583	0,0879	0,6716	0,6370	0,2565
O	0,6370	0,6694	0,0629	0,2583	0,5094

Applicant O is winning this criterion too, mainly because of his very good customer relationship. This subcriterion is the most important one in this criterion, because if the applicant already knows many of the customers, it is easier to start the new role. The last and one of the most important main criteria is about personal details and is ranked as follows.

Table 44 ranking personal details

	team	softskills	records	priority vector	ranking
M	0,7306	0,4286	0,4545	0,7514	0,6574
K	0,0810	0,1429	0,4545	0,1782	0,1183
O	0,1884	0,4286	0,0909	0,0704	0,2243

In this case applicant M is winning again, as we can see in the rankings of the different subcriteria, he is the best applicant concerning teamwork, softskills and there are no records in his former position in the company. There is a significant advantage in this criterion for applicant M, evaluation of all leads to the final decision matrix.

Table 45 final decision matrix recruiting

	knowledge	flexibility	company	personal	priority vector	ranking
M	0,0852	0,4872	0,2341	0,6574	0,1426	0,4846
K	0,2145	0,2717	0,2565	0,1183	0,4018	0,2011
O	0,7003	0,2411	0,5094	0,2243	0,0539	0,3143
					0,4018	

In the final decision matrix applicant M turns out as the best candidate for this position. This result is somehow surprising, because the managers thought about taking candidate O, this will be further discussed in the results.

6 RESULTS

The results will be discussed in two parts, first the usability of the Analytic Hierarchy Process for managers will be described. The second will focus on the results of the examples and what results the customers got with his method.

6.1 usability of AHP

The most important step in starting working with AHP is to understand the hierarchy approach. It is crucial to analyze all objectives and to group them in main criteria, subcriteria and so on. The accuracy of a decision is reflected at least as much by the richness and detailedness of the structure and relations in the structure, as it is in assigning and manipulating numbers according to the theory. It turned out very practical to discuss the desired hierarchy with all involved people, because there is less chance to miss any details. The people I talked to liked the approach of breaking down the problems or decisions into a visualized hierarchy, not just for getting decision even thinking about it and bringing it into a drawing was adjudged very helpful.

Some of the involved people are using simple decision matrices or decision trees, so most of them were already used to weight criteria, but the approach to define relative importances between each criterion sometimes turned out a little bit difficult. On the one hand of course this approach seems quite logical, but on the other hand according to Saaty the scale reaches from 1 to 9 and if there are 4 criteria with enormous differences in their importance like A is much more important than B, C is similar to A, but D is very much more important than A and C, some of them had problems with fitting such constellations into the judgment matrices. After getting used to it they accepted this approach. Sometimes it turned out that filling up the matrices sometimes caused inconsistency of the matrix, but usually after quick corrections this problem was fixed.

The calculation of the eigenvector does not have to be understood by a manager using this tool. Of course it is necessary to check consistency and get the priority vectors, but if the excel spreadsheet is prepared, the results are mainly accepted by the involved people. It is necessary to keep the spreadsheet well designed and in order especially for big calculations, otherwise the received values or descriptions are mixed up and the excel calculations are not correct anymore. This happened in one case, I sent the prepared excel to the department manager of the customer and he copied some values into another sheet in excel and by doing this he destroyed the included references, therefore the priority vectors of the main criteria got mixed up and of course the final weighting did not work correct anymore. The interesting thing on this is, that he was able to repair this failure on his own, so he didn't know how the eigenvector is calculated, but he was able to link the different values to each other in the spreadsheet to get the right result. This showed me that he understood how the process worked even though he did for sure not invest very much time in getting an overview beside my short introduction.

6.2 example results

The three examples mainly delivered the expected results, but only the winners of the examples were the customer's choices too, the ranking of the other alternatives were mainly different. To evaluate the enterprise storage decision and the virtualization decision the customer used a questionnaire which had to be filled in by the vendors, afterwards a few excel tables have been populated with the values of the questionnaires. This excel tables were linked to a main page, this page summed up all the points given in the questionnaire. For example these questions led to points for the vendor.

Cache Protection	YES	Is Battery backup supported? Is the cache mirrored? If not mirrored, how do the system provide safety in case of failures?
Cache Size	min. 128GB	Per storage system
Cache min. /max.		Possible stages of expansion

Fig. 21 storage questionnaire

This small section of the questionnaire shows three questions, one with a mandatory answer, so if the vendor is not able to cover this, he will no longer be considered in the decision. The second question shows a minimum of 128GB if the bidder is not able to deliver this, he will also be left outside of the decision. If he fulfills 128GB, one point is brought into excel, if the amount is higher than the minimum 2, or if it is more than double the capacity, 3 points will be mentioned in the excel table. There were more than 70 questions like this, considering many technical features, power usage and so on in the questionnaire. This questionnaire also was the basis for the values for AHP. Their table for the final decision looks as follows, as mentioned the winner is the same.

		max. Points	Rating Product 1	Rating Product 2	Rating Product 3	Rating Product 5
Technology	Functionality	10	9,54	9,88	9,86	9,86
	Performance	7	5,98	6,50	6,85	6,53
	Flexibility	2	1,73	1,83	1,90	1,77
	Compatibility	4	3,90	3,92	3,98	4,00
	strategy	3	2,73	2,47	2,87	2,47
Vendor	Rating of the Vendor	7	2,33	1,94	1,94	2,33
	Competence	7	2,92	3,38	3,15	3,03
	References	7	5,60	6,07	6,53	5,60
Price / GreenIT	Infrastructure	1	1,00	1,00	1,00	1,00
	Aircon	1	1,00	1,00	1,00	1,00
	Power	1	1,00	1,00	1,00	1,00
	Purchasing	40		40,00	37,90	37,72
	Management	10		5,96	8,78	10,00
		100	**37,74**	**39,01**	**40,08**	**38,59**
			4.	**2.**	**1.**	**3.**

Fig. 22 customer storage evaluation

The order of vendors mentioned in our example is according to the columns in this figure D-C-A-B. On the one hand, the result that the first rank stays the same is satisfying, but on the other hand it has been investigated where the difference is coming from. The values are normalized in the customer's calculation too, but at the end it turned out that the customer was just summing up all the points no matter where they came from, so one point had got the same value whether it was coming from the market position of the vendor or from flexibility of the storage array. In case of AHP the different importance of criteria is considered and therefore the values are different.

The virtualization example is quite similar to the storage example. The winner stayed the same as in their calculation, but the ranking was different again. The customer employed for his evaluation the same excel as mentioned above and alternative U has been on rank two. In our example alternative W is ranked on second position and alternative U on third. Alternative U is quite expensive compared to the others and therefore the ranking got even worse by applying the benefit/cost ratio. The results with inclusion of costs in hierarchy are different compared to customer's, because of the weighting of criteria again.

Both examples are calculated concerning costs in both ways, but it turned out that the approach of including costs in the hierarchy and giving them a weight compared to benefits delivers more realistic results than the way employing the benfit/cost ratio. The managers told me that they want to apply a weight for costs, especially the virtualization example shows that alternative U would never be considered in case of the benefit/cost ratio but it was in their final discussions concerning the final solution.

The third example is completely different concerning the topic than the other ones. The mangers responsible for the recruiting decision used a simple plus/minus list for their decision and according to their approach applicant O won, candidate M was ranked second and K stayed on the last position. In our example, applicant M won the ranking by far. This result was very interesting for the affected managers, they already wanted to decide for applicant O, but now they are thinking about it again. Both liked the approach of AHP in this case very much.

6.3 AHP vs. simpler methods

Compared to the simpler examples of decision making mentioned above and the approaches employed by the involved managers AHP is quite complex in using it the first time. Overall, the outcome seems to be more precise and usable for more complex decisions. For simple decisions the decision tree or PMI method deliver quite good results and can be employed. If AHP is already prepared, so the prebuilt Excel or one of the available software tools is ready to use, it is worth to use it and to start the creation of the hierarchy. Furthermore, it turned out that building up the hierarchy for AHP makes the managers thinking about the problem in more detail, so they need to take enough time to think about the problem and so the probability for a overhasty decision is much less. Many decisions are done wrong or just by guessing, just because of time pressure, therefore it seems positive that AHP makes the decision maker think about the problem a bit more.

6.4 Conclusion

Overall AHP turned out to be a simple and useful tool for managers, after they got a basic introduction concerning building up the hierarchy and any tool to calculate the values. As discussed above these examples were quite up to the expectations of the customers and all of them mentioned this approach as quite helpful.

On the other hand, one has to be careful in building up the hierarchy and just take the results as they are and execute the decision. Small failures during building up the hierarchy can cause significant errors in the final ranking and therefore the results have to be checked for plausibility every time AHP is employed.

To sum up AHP seems to be worth and good to be used in complex decision problems, but for simple decisions it is easier to employ one of the simple methods. If AHP is applied, enough effort has to be taken to create a reliable hierarchy and the results have to be checked.

7 LIST OF TABLES

8 LIST OF FIGURES

9 REFERENCES

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