A Hierarchical Multi-Attribute System Approach to Personnel Selection

Eva Jereb,* Uros Rajkovic and Vladislav Rajkovic
University of Maribor

In this paper, an approach to decision making in managing human resources that integrates multi-attribute decision making techniques with expert systems is described. The approach is based on the explicit articulation of qualitative decision knowledge which is represented by a tree of attributes and decision rules. The decision making process is supported by DEXi, a specialized expert system shell for interactive construction of the knowledge base, evaluation of options, and explanation of the results. Practical use of the shell is illustrated by an application in the field of personnel selection for a top manager position.

Introduction

The business enterprise needs managers who will give full scope to individual strength and responsibility, and at the same time give common direction of vision and effort, establish teamwork, and harmonize the goals of the individual with the common weal (Drucker, 1955; Milkovich & Boudreau, 1997). This ensures that individual and corporate objectives are integrated and also makes it possible for managers to control their own performance: “Self-control means stronger motivation: a desire to do the best rather than just enough to get by. It means higher performance goals and broader vision” (Armstrong & Baron, 1999).

The problem is “how to find a manager who will be able to translate business strategy into action.” The decision to hire (or to appoint) such a manager requires clear identification of the criteria (attributes) that distinguish successful from unsuccessful performance and use only predictive measures of success which are reliable and valid. Without a systematic approach, that examines reliability and validity, no relationships can be demonstrated between selection criteria and selection predictors. Decisions thus remain subjective, of dubious value and open to challenge. In contrast, the stronger the relationship between predictors and criteria, the more accurate the employment decision and the easier it is to satisfy requirements that selection procedures must be objective, nondiscriminatory, and result in the best candidate being selected (Beardwell & Holden, 1997; Stone, 1998). The choice of selection criteria (attributes) should be consistent with the organization’s strategic direction and culture (Stone, 1998). Finally, as Cascio (1991) points out, “more accurate predictions result in greater cost savings (monetary as well as social).”

The approach to support selection of managers that is described in the paper integrates multi-attribute modeling and expert systems. The solution of the selection problem is based on a multi-attribute hierarchical model and implemented with existing information technology. The basic principle of the multi-attribute decision making is a decomposition of the decision problem into smaller less complex sub-problems. This makes the problem transparent, and understandable; the decision explainable, and more effective. This method turned out to be very effective in different fields like banking, pharmacy, public administration, etc. (Bohanec, Zupan, & Rajkovic, 2000; Klein & Methlie, 1995; Milner, 2000).

Further in the paper, the methodology concerning:
(i) multi-attribute modeling, (ii) use of the tool DEXi, and (iii) problem solving, is described. Then the use of the system in selecting a top manager is presented through:
(i) problem identification, (ii) project setup, (iii) modeling, (iv) options identification, (v) options evaluation and analysis, (vi) decision making, and (vii) implementation.

Methodology

Decision support is a broad discipline concerned with supporting people in making decisions. It is a part of
decision sciences, together with normative and descriptive approaches to decision making (Clemen, 1996). Decision support encompasses a number of disciplines, including operations research, decision analysis, decision support systems, data warehousing, and group decision support (Bohanec, 2001; Mallach, 2000; Triantaphyllou, 2000).

The general approach originates in decision analysis, a discipline popularly known as Applied Decision Theory. Decision analysis provides a framework for analyzing decision problems by (Clemen, 1996): (i) structuring and breaking them down into more manageable parts; (ii) explicitly considering the possible alternatives, available information, involved uncertainties, and relevant preferences; (iii) combining these to arrive at optimal or at least “sufficiently good” decisions.

For multi-attribute modeling, we use a specific technique referred to as qualitative hierarchical modeling (Bohanec, 2003) for which we use a computer-based supporting tool named DEXi (Jereb, Bohanec, & Rajkovic, 2003).

### Multi-Attribute Modeling

The basic principle in multi-attribute modeling is a decomposition of a decision problem into smaller and less complex sub-problems (Figure 1). Options are decomposed onto different dimensions, usually called attributes, parameters, or criteria. In other words attributes are variables that represent decision sub-problems. They are usually organized hierarchically so that the attributes that occur on higher levels of the hierarchy depend on attributes on lower levels. According to their position in the hierarchy, we distinguish between basic attributes (leaves or terminal nodes) and aggregate attributes (internal nodes, including the root(s) of the hierarchy). Each option is first described by a vector of values of the corresponding attributes. The vectors are then evaluated by a utility function, which is previously defined by the decision maker(s), representing his/her or their goals. Utility functions define the relationship between the attributes at different levels, i.e., for each aggregate attribute they define a mapping from its immediate descendants in the hierarchy to that attribute. Thus, utility functions serve for the aggregation of partial sub-problems into the overall evaluation or classification (Bohanec & Rajkovic, 1990, 1995; Jereb & Jereb, 1997; O'Keefe, 1989; Saaty, 1993; Todorovski & Dzeroski, 2003).

The multi-attribute model is used in the following way. First, the options are presented by basic attribute values. Each option is then evaluated by an aggregation that is carried out from the bottom to the top of the hierarchy according to its structure and defined utility functions. The evaluation result $F(a_i)$ is supposed to be equal to the utility function $F(x_1,x_2,\ldots,x_n)$. The overall evaluation (utility) of an option is finally obtained as the value of one or more root attributes. On this basis, the options are compared and ranked; the best one can be eventually identified and chosen by the decision maker (Bohanec, 2003; Greco, Matarazzo, & Slowinski, 2002; Jereb & Rajkovic, 2001).

The majority of current multi-attribute methods and systems (DAS, 2001; Younes, 2001) are used for developing what we refer to as quantitative decision models. In such models all the attributes are continuous and typically represent decision maker’s preferences by linear utility functions. Utility functions are then typically defined in terms of attributes’ weights, for example, as a weighted average of lower level attributes.

Our modeling approach is based on qualitative decision models. These models are also hierarchical, but differ from the quantitative ones in two important aspects:

- Instead of numerical attributes, which are used in quantitative models, the qualitative models utilize qualitative (cardinal or ordinal) attributes, of which values are usually words rather than numbers.
- Instead of numerical utility functions, which are represented analytically, such as the weighted sum, qualitative models use discrete functions that are defined point by point in form of tables where each point represents a decision (Rajkovic, Bohanec, & Batagelj, 1988).

### The Tool DEXi

In order to develop and employ qualitative decision models the tool DEXi (Jereb et al., 2003) was used in our case. This computer program was developed in collaboration between Jozef Stefan Institute and University of Maribor, Faculty of Organisational Sciences. It facilitates the following:

1. Acquisition of attributes and model structure.
2. Acquisition and consistency in checking decision rules.
3. Description, evaluation, and analysis of (possibly incompletely defined) options.
4. Explanation of evaluation results and reporting.

DEXi is a decision modeling program based on attributes arranged in a form of a tree structure. These attributes have discrete values and ordinary words can be used to define them. Options are described with the values on the leaves of the tree (structure). Upper nodes are so called aggregate attributes among which the root of the tree presents the final result of the evaluation.

The aggregation of sub-attributes (nodes) into every upper attribute is done on the basis of utility functions which accompany every node that is not a leaf of the tree. Utility functions are discrete and are represented in tabularic forms. Each row of the utility function table can be read as a simple logical expression (rule). At the beginning these tables are usually generated from linear (hyper surface) approach based on weights of attributes. Further on utility functions can be checked by reading function tables as logical expressions and changed if necessary.

Good graphical and reporting capabilities of DEXi help explain and comprehend decision results. The decision-support modeling is carried out in several problem solving stages shown in Figure 2.

In general, the approach is iterative: as indicated in Figure 2 previous stages can be revisited if necessary. However, it is most desired if the final decision is reached in just one try by following these stages sequentially.

A more detailed description of the stages and use of this methodology in selecting managers will be explained further on.

![Figure 2. Problem solving stages.](image)

The Use of the System in Selecting a Top Manager

In this section, the stages of a typical decision support project are described and demonstrated within a case study.

**Problem Identification**

This initial stage is entered as a result of becoming aware that a decision making problem has occurred that is sufficiently difficult, important, or both to require a serious, careful, and systematic approach (Bohanec, 2001; Jereb, 2003).

This was the case in a Slovenian pharmaceutical company. Their problem, i.e., selecting the top manager for the new daughter company abroad, was suitable for a decision support modeling approach. The problem had some specific properties, typical for this approach:

- it dealt with options or alternatives, i.e., entities or actions of similar type in the sense that they could be compared among themselves;
- the goal was to select one option, or to evaluate or rank options in some preferential order;
- the problem could be decomposed into smaller, less complex sub-problems;
- the options could be described by basic features, i.e., vectors of values corresponding to the problem decomposition;
- the evaluation of options could be represented by one or more mappings from basic features to one or more overall evaluations or classifications.

**Setting the Project**

In addition to standard project set-up activities, i.e., resource planning, there are two important issues specific to decision support, which need to be addressed in this stage: who will be the member of project team, and which modeling methodology to choose.

In general, decision support projects involve four types of collaborators, either individuals or groups:

- **Problem owners**: Individuals or representatives of organizations who need to make the final decision.
- **Experts**: People knowledgeable in the field of the decision. They need not make the decision, but are expected to know, for example, the properties of good decision, to formulate the basic features of options, and to contribute to the design of models by suggesting suitable problem decompositions and utility functions.
- **Decision analysts**: Methodologists with knowledge and experience in decision analysis. They should know how to apply the decision support methodology and handle corresponding tools. Often, they take the role of moderators or even leaders of the project team.
- **Users**: The ones that are affected by the decision.
In theory, these groups are distinct but in practice they often get intermixed on an individual or group level. For example, it is not uncommon for a problem owner to play the role of an expert, user, or both. Sometimes, decision analysts may take the role of experts, too (but should avoid being considered experts based on unreasonable expectations of the problem owner).

In the case of the pharmaceutical company the problem owner was the board of the company. Two human resource management experts (i.e., one from our university team and one from the pharmaceutical company), and a decision analyst also from our university team were actively involved in model development. The pharmaceutical company was considered as the user.

In the next stage, the decision analysis method had to be chosen. The method DEXi was chosen as it fits the characteristics and requirements of the project.

**Modeling**

At this stage a qualitative multi-attribute model was developed. The development was hand-crafted, based on collaboration within the problem solving team. It included brainstorming, discussions, interviews, and argumentation. The decision owners provided goals and restrictions, experts suggested attributes and criteria, while decision analysts conducted the process and formalized the findings in terms of a model.

Next relevant questions were considered:

- How to decompose the problem? Which are the relevant attributes? How do they contribute to the solution?
- Which are the relations between attributes? How to structure them within the evolving hierarchy?
- What are the criteria (i.e., preferred attribute values)? Which criteria are more important than others and why? To which extent? How to aggregate basic features into an overall evaluation/classification?
- How to measure options, i.e., assess and/or obtain their descriptions?

The modeling stage typically proceeded in four consecutive sub-stages:

1. **Identifying attributes**: The goal was to identify all the relevant attributes and especially not to forget any important ones. This was done in four brainstorming sessions. The result was an unordered list of 40 attributes including duplicates or redundant items. These attributes were then structured in the next stage.

2. **Structuring attributes**: The goal was to develop a hierarchy of attributes based on their inter-relations and anticipated influence on the final decision. The process involved a number of techniques: structuring, comparing, and cleaning up the list of attributes, bottom-up aggregation, top-down decomposition, and even a middle-out mixture of techniques. In order to avoid a combinatorial explosion in the fourth stage, it is required by DEXi that each aggregate attribute depends on as few lower level attributes as possible, i.e., typically two or three, but not exceeding four. The result of this stage was a tree of attributes (see Appendix).

3. **Defining attribute scales**: In this sub-stage, the attributes were defined in terms of type (i.e., nominal, ordinal or continuous) and values that could take (specific intervals, discrete values, etc.). DEXi is restricted to nominal and ordinal attributes, whose values are represented by words, such as “low,” “acceptable”, or “inappropriate”. The number of values should be kept small, but at the same time big enough to distinguish between qualitatively different situations. In our case the size of attribute scales gradually increases from bottom to the top of hierarchy, by using three values at the basic level and five values for the root attribute.

4. **Utility functions**: The role of utility function is to define a mapping from lower level attributes’ values to a higher level aggregate attribute value. In DEXi utility function of every aggregate attribute is presented point by point as a table where rows can be read as logical expressions. For example in Figure 3 row number 4 can be read as: if Education attribute is estimated as appropriate and Skills are estimated as good then the value of aggregate attribute Know-how is good. Row number one on the same figure presents aggregate rule and can be read as: if Education is less appropriate then no matter the value of aggregate attribute Know-how is good. Row number one on the same figure presents aggregate rule and can be read as: if Education is less appropriate then no matter the value (marked with a symbol *) of attribute Skills the value of Know-how is less appropriate.

It is convenient to start utility function elicitation process by denoting weights of importance of each attribute. It means that at the beginning linear surface is accepted as a utility function. It is known that in general a weight of an attribute is a function of its own value. In practice, that means that at least at the edges of attribute space some changes are necessary. In our example, shown in Figure 4, if the value of Education is less appropriate and the value of Skills is good, then according to the linear surface using weight 50% for each attribute (Education and Skills), the value of Know-how should be between appropriate and good. We have changed the utility function according to our preferences.
rules in Figure 3 so that the resulting value of Know-how in this combination is less appropriate. In DEXi, we can change those utility function values point by point according to our opinion.

In general, the stage of modeling is the most difficult and demanding part of the whole process. It heavily depends on experts’ knowledge and decision analysts’ skills, and it is still more art than science. However, a successful development of a model usually leads to a fairly smooth continuation and likely completion of the project (Bohanec, 2003).

**Identification of Options**

This stage is concerned with options from which the best one (or several best ones) is to be chosen, or which are to be ranked in preferential order.

Consequently, this involved option identification and option description. Options were collected and a database of options was created. In our case four candidates from inside and one from outside of the pharmaceutical company needed to be investigated in detail in order to determine their characteristics that corresponded to basic attributes. Notice that in DEXi options need not to be fully described and can therefore still contain some missing values. However, it is desired to fully define the options whenever possible.

**Option Evaluation and Analysis**

At this stage the model and data about options get fully utilized in order to search for the solution of the problem. This involves two sub-stages: option evaluation and option analysis, which are usually performed iteratively, simultaneously, or in combination until sufficient evidence is obtained to enter the next stage of the project.

First the option evaluation was carried out. Each option (candidate) was evaluated in a bottom–up way: its basic values were aggregated from bottom towards the top of the hierarchy according to the decision rules. As a result, each option was assigned a qualitative evaluation value or, in the case that the option was described by imprecise or missing basic values, by a set of possible evaluation values. The evaluation results are shown in Figure 5. One of the candidates was evaluated as less-appropriate, two as good, and two as excellent.

Then the option analysis followed. This encompassed a number of various techniques aimed at better understanding, justification and explanation of the evaluation process.

With DEXi we typically use three such techniques:

- **What-if analysis** assesses the effect of changing some basic attributes’ value(s) to the partial or overall evaluation of a chosen option.
- **Sensitivity analysis**, similarly as the what-if analysis, assesses the effects of changing utility functions.
- **Selective explanation** identifies the most important advantages and disadvantages (pros and cons) of options, which is important for the justification of the decision.

There are many interesting questions that can be raised at this stage and of which answers may provide valuable evidence for making the decision:

- How were the options evaluated? Which one is the best? How do they compare with each other? Where are the most important differences between them?
- Are the evaluations in accordance with expectations? If not, why?
Decision

The actual decision or choice is based on evidence collected in previous stages. This involves either selecting the best option or making some preference order of options, which often includes some cut-off line that divides acceptable (accepted) options from unacceptable (rejected) ones.

In our case we had five candidates. The option analysis showed that candidate E was less-appropriate because: (i) he/she had some health problems, (ii) and his/her working approach was only appropriate while the working approach of other candidates was good or very good. So candidate E was eliminated immediately. Candidates B and C were good and candidates A and D excellent. Actually we could just choose among candidates A and D but the option analysis showed that both candidates were just appropriate in knowledge of foreign languages. In our case this was not good because the daughter company was established abroad. So we took under consideration also candidates B and C. Candidate B was quickly eliminated because: (i) he/she also had only appropriate knowledge of foreign languages, (ii) and had only good working approach while other three remaining candidates had very good working approach. After that also candidate C was eliminated because: (i) he/she had minor health problems, (ii) and was only appropriate in decision making. Then we compared candidates A and D and found out that: (i) candidate A had only appropriate technical skills while candidate D had good technical skills, (ii) candidate A had good efficiency while candidate D had very good efficiency, (iii) and candidate A had appropriate self-control characteristics while candidate D had good self-control characteristics. On the basis of option analysis the company’s board then made the final decision. They chose candidate D and decided to send him/her on a language course.

For easier overview and better understanding the analysis and the decision making stage are supported by graphs (see Figure 6). For example, we compared three attributes: (i) skills, (ii) efficiency, (iii) and personal characteristics. In Figure 6 it can be seen very quickly that candidates B and C are not as good in efficiency and personal characteristics as candidates A and D. Candidate D is better than candidate A also in efficiency.

Deployment and Implementation

In the deployment stage, we documented the decision and communicated it to the parties that have not been involved in the decision making process. For most cases it is essential to do this in a comprehensible and transparent manner, including a detailed description of the decision problem, components of the model (i.e., attributes, their relationships and values), options, and evaluation results. Most importantly, the final decision must be carefully justified and explained, typically drawing from the findings of an extensive analysis of options.

The implementation stage is concerned with how the decision is materialized or in other words that it is put into real life. It may or may not be considered as a part of the decision making process, but it can nevertheless benefit significantly from a properly conducted decision making process. For example, even the best option can have some weak points. When these have been explicitly identified in the process (typically in the option analysis stage), it is more likely they are properly handled or even avoided in the implementation stage.

Conclusions

The model development stage is central to the decision support approach used and crucial to the success of the project. Among all stages it is the most difficult one, involving the most expertise, requiring active engagement of all team members and typically the most time and other resources. Thus, any further improvements in terms of methodology, tools, organization, and effectiveness would have an immense impact on this stage and decision support process in general.

The amount of work required for a decision support project varies considerably. The pharmaceutical case gives some hints about the minimal duration of a fairly difficult real life decision support problem. Together with collecting data about candidates it took us 1 month.

In cases where data has to be gained from outside (e.g. by project submission forms or from external evaluators) or when the results of evaluation must be communicated to others (e.g. for further approval) a careful preparation of the so-called project documentation is absolutely vital. This means not only a documentation of the decision model and steps taken in its creation, but also various forms for
data acquisition and final reports intended for the explanation and justification of taken decisions.

The advantages of involving expert systems into personnel selection are:

- **Dealing with the so-called soft data:** By personnel selection a lot of data is impossible or hard to quantify.
- **Interactive work:** Personnel selection, in our case for a top manager, demands a certain knowledge interaction.
- **Rules for certain areas:** Even though personnel selection is not a routine, rules can be made for some steps.
- **By the selection we could ask the expert system the following question:** “Which candidate is the most suitable one?” The expert system would give us the answer and an explanation.

- **Using computer programs like DEXi,** that has proved to be user friendly, easy to operate and surprisingly useful in the field of personnel selection. DEXi’s particular strong points were: easy construction and editing of attribute hierarchy, definition of utility functions using both decision rules and weights and flexible generation of reports with the ability to export them into other software.

We believe we have shown with our case what a multi-attribute decision support methodology is about, what it can do and what it cannot and that it can be very useful in the field of personnel selection, especially when selecting key employees.

**Appendix**

*Tree of attributes*

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager's adequacy evaluation</td>
<td></td>
</tr>
<tr>
<td>- Work</td>
<td></td>
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<tr>
<td></td>
<td>Educational qualification</td>
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<tr>
<td></td>
<td>Field of education</td>
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<tr>
<td></td>
<td>Educational degree</td>
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<tr>
<td></td>
<td>Knowledge of foreign languages</td>
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<tr>
<td></td>
<td>Interpersonal skills such as active listening, reading, writing</td>
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<td></td>
<td>Written and unwritten communication skills, non-verbal communication</td>
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<td></td>
<td>Technical competence on the job</td>
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<td></td>
<td>Organisation skills – to organize work meaningful and efficient</td>
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<td></td>
<td>Ability of taking the right steps and criteria to solve a problem in time</td>
</tr>
<tr>
<td>- Efficiency</td>
<td></td>
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<tr>
<td></td>
<td>Quality of work</td>
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<tr>
<td></td>
<td>To do work and solve problems in time</td>
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<td></td>
<td>To be able to achieve seted goals</td>
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<td></td>
<td>To be curious and novelties liking, his solutions should be original and applicable</td>
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<tr>
<td></td>
<td>Economical use of resources</td>
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<tr>
<td>- Personal characteristics</td>
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<tr>
<td></td>
<td>Policy-making abilities</td>
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<td></td>
<td>Ability to delegate work and responsibility</td>
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<td></td>
<td>Ability of explaining goals in an understandable way</td>
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<td></td>
<td>To be responsible for his work and doing</td>
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<td></td>
<td>To be able to decide on ideas correctly and methodically</td>
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<td></td>
<td>To be reliable and consistent by working</td>
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<tr>
<td>- Working approach</td>
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<tr>
<td></td>
<td>To be cooperative and willing to help others</td>
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<td></td>
<td>Innovative mind at work and in problem solving</td>
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<td></td>
<td>To be willing to solve problems</td>
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<tr>
<td></td>
<td>To be willing to learn, travel, do some extra work</td>
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<tr>
<td></td>
<td>Other personal characteristics</td>
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<tr>
<td></td>
<td>To confide in his/her abilities, knowledge, power</td>
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<td></td>
<td>To be emotionally stable and mature to maintain a goodwill climate</td>
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<tr>
<td></td>
<td>Self-control and pragmatism to set priorities</td>
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<tr>
<td></td>
<td>Appurtenance to the organisation or company</td>
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<tr>
<td></td>
<td>Personal development aims</td>
</tr>
<tr>
<td></td>
<td>To be in suited physical and psychological condition</td>
</tr>
</tbody>
</table>

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References


