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MULTICRITERIA APPROACH TO ENVIRONMENTAL DECISION-MAKING IN A COMPANY – A PATH GOAL PROGRAMMING APPLICATION

In the paper we propose a practical application of the path goal programming approach, by which we understand a goal programming approach with goals being not numbers, but paths in networks. This method, with goal paths corresponding to desired schedules of environmental investment implementation, is used for the environmental decision-making in a selected company. The company has to introduce some investments aimed at natural resources reduction. However, not all the required investments can be realized in one budgeting period, because of budget constraints. The desired compromise schedule of investment realization has to be worked out. This schedule becomes the goal. The path goal programming method helps to reduce the undesired deviations from the goal schedule.

Keywords: environmental decisions, environmental awareness, path goal programming

1 Introduction

The dynamic development of industry and population explosion have been observed since the twentieth century. It has been leading to an excessive use of natural resources and environmental devastation. Thus, there is a need for a change of companies' attitude toward nature. This need was noticed during the Conference of the United Nations in Rio de Janeiro in 1992. The delegates assembled at the conference stated clearly that environment, economy and society were closely linked. The concept of sustainable development was

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created, meaning a development where the balance between economic growth, environmental protection and human development is preserved.

That is why the environment plays a more and more important role in decision making in companies. Apart from the obvious goals such as profit increase or cost minimization, the companies more and more often have to take into account the negative influence of their activity on the environment and to minimize it. They also have to make investments minimizing this negative influence.

In this paper we deal with decisions about such investments. They have to be made on the basis of several criteria: cost (the investments should be as cheap as possible), time (the negative influence on the environment should be eliminated as soon as possible), reduction value of the negative influence of various factors of the company activity on the environment (this value should be as high as possible) and influence of the environmental decisions on company image and its compliance with law (of course this factor has to be maximized too). All the above listed criteria were taken into account in various stages of the decision process in the studied company and three actions were selected for implementation. In the final stage the budget criterion remained to be considered. The budget criteria made it necessary to distribute the implementation of the selected actions in time, thus to choose a schedule of their implementation. We proposed to use the so called path goal programming in this stage.

Goal programming is a very well known tool for multicriteria decision making. However, in all goal programming versions the goals are numbers – sometimes "generalized" (interval, probabilistic or fuzzy), but always numbers (surveys of all the existing goal programming approaches can be found e.g. in Chang et al. (2012); Ghahtarani and Najafi (2013); Nha et al. (2013)). As mentioned above, in the decisions considered in this paper we had to refer to schedules: the desired schedules played the role of goals. That is why the path goal programming was used in this case, whose idea was proposed for the first time by the present authors (Kuchta and Urbańska, 2012). The path goal programming takes into account deviations from a desired schedule, thus it helps to find an optimal schedule of investments. The original idea of the method is extended here and applied to the company in question.

The outline of the paper is as follows: In Section 2 we present briefly the concept and state of art of the multicriteria approach in environmental management and, more generally, in sustainable decision making. In Section 3 we analyse one instance of environmental decision making in the company studied. In Section 4 we apply the path goal programming to the scheduling of selected investments in the company studied.

2 Multicriteria analysis and environmental management

Environmental management in companies is one of the latest trends in the theory of organization and management. It has been dynamically developing since the 1990s (Graczyk, 2008; O'Brien 2000). One of the reasons for this ongoing development is the increasing environmental awareness among human beings, who often have the double role: that of the private persons, wanting to live in healthy and good conditions, and that of workers or employees in companies, who exercise pressure on the management to take into account the environment. Environmental awareness can be described as: ideas, values and opinions about the environment which for human beings is a place of life, personal development and social life (Papuziński, 2006).

Environmental decisions are taken on four basic levels: on the operational level of companies, on the tactic level of companies, on the strategic level of companies and on the level of legal regulations of a state (Graczyk, 2008; Merad et al., 2013). In this paper the company strategic level is the most important one. Companies should integrate environmental and economic objectives. If this is so, environmental objectives become usual components of business management. The environmental decisions include decisions concerning prevention, compensation, reduction, regulation, innovation, vitalization and substitution (Nahotko, 2002). In our case, we are dealing with investment decisions concerning substitution of a heat source with another one, with the objective of energy saving, as well as investment decisions concerning reduction of water and gas usage.

By implementing the concept of environmental management a company can achieve two kinds of benefits: direct and indirect. The reduction of operational cost, e.g. thanks to the reduction of the use of natural resources and of waste management costs, is a direct benefit. Another direct benefit is the reduction of environmental fines. The reduction of social costs, such as environmental pollution and natural resources depletion, and the creation of an eco-friendly image, is an indirect benefit.

The environmental management is a part of what we call sustainable management (Daub and Ergenzinger, 2005). Environmental or sustainable decision making in a company is always a multicriteria decision making process, where the criteria have to be taken from at least two groups: that of economic criteria and that of environmental ones (there are many definitions of sustainability – see e.g. http://sustainability.about.com/od/Sustainability/a/What-Is-Sustainability.htm – the specific criteria may change, but usually some so-called social criteria are taken too). There is a vast literature on multicriteria decision making in environmental or sustainable management. The authors apply all the most popular and verified in practice multicriteria decision making methods, such as ELECTRE, PROMETHEE, distance from ideal solution methods (a review can be found e.g. in Merad et al., (2013); Doukas et al., (2007); Khalili-Damghani et al., (2013); Macharis et al., (2012)), in order to select projects (actions) which should be implemented. Also the goal programming (crisp, interval, fuzzy or stochastic) is used in order to select projects within the framework of sustainable (environmental) management (Bilbao-Terol et al., 2012; Khalili-Damghani et al., 2013), but never to schedule them. In general, we are not aware of any literature where the question of seeking the optimal schedule for environmental (sustainable) actions is considered. In our opinion, this is the main novelty of the present paper, along with the application of goal programming to the question of optimal schedule search.

3 Environmental decision in the company under study

The company which is the object of the present case study is a large Polish company, not willing, however, to reveal its identity. The company has been following an environmental policy following all the goals mentioned in the introduction. The case described here is a decision making process within the company's consequent implementation of its environmental policy. Unfortunately, not all the details of the decision making process were given to the present authors, hence our presentation has to be rather superficial.

At first the company environmental policy was analysed by managers and experts. Then the company managers prepared a workshop. The aim of the workshop was to analyse all the activity areas of the company in terms of environmental management. Employees and managers of the company took part in the workshop. The result was the identification of a handful of possible solutions which were propositions of environmental decisions. 38 possible solutions (we will call them also projects, actions or investments) were identified. However, not each of them had a chance for realization. The criteria for selecting solutions were set by the managers. In this way, a list of criteria was made. They are, in order of importance:

a) the economic criteria,
b) the legal criteria,
c) the ecological criteria.

Managers and experts have analysed all the possible solutions and checked their compatibility with the company environmental policy, taking into account (entirely informally, during workshops and expert meetings) the goals and their hierarchy. However, some of the legal requirements were fixed, i.e. they had to be fulfilled under all circumstances. Three solutions listed below (Tables 1, 2, 3) were selected. Other top-priority actions included the exchange of traditional light switches for photoelectric cells in all the buildings and modernising the drainage ditch in order to use rain water to fill up the fire-fighting water tank. Both were excluded for the moment: the former because of a complicated legal procedure necessary to accomplish before starting the project, the latter because it seemed to bring fewer financial advantages than the three solutions selected eventually.

For each selected action a goal was identified as well as an indicator measuring the achievement of the goal. As it was known from the beginning that it might not be possible to achieve all the goals fully, at least not immediately, the steps of gradual goal achievements were elaborated, together with the corresponding cost. The results are shown below:

Table1

Solution I and its characteristics

Description	Construction of a pipeline installation for heat distribution
General goal	Energy saving
Specific goal	Replacement of the heat obtained from electric heaters with heat obtained from gas
Total cost	$10 000
Stages	Stage I: pipeline installation in the store house (50% of the cost), Stage II: pipeline installation in the factory building

Source: company internal documents

Table 2

Solution II and its characteristics

Description	Heat cast on freon systems
General goal	Water usage and effluents reduction
Specific goal	Reducing the amount of water used for cooling systems
Total cost	$13 000
Stages	Stage I: Heat cast on half of the existing production lines (50% of the cost) Stage II: Heat cast on the other half of the existing production lines

Source: company internal documents

Table 3

Solution III and its characteristics

Description	Automatic system of water outmeasuring
General goal	Gas usage reduction
Specific goal	Reducing the amount of water consumed for steam preparation
Total cost	$20 000
Stages	Stage I: the system on half of the existing production lines (50% of the cost) Stage II: the system on the other half of the existing production lines

Source: company internal documents

The three investments selected were consistent with the company environmental policy. However, the company had a limited budget. As the budget was too small to realize all three investments in one budgeting period, the decision had to be made how to schedule them. The path goal programming approach, proposed in Kuchta and Urbańska (2012) and applied to the discussed case in the next section, supported the management in the decision making about the investments schedule. The company management decided to limit the decision manoeuvre to two budgeting periods.

4 Path goal programming approach applied in the company under study

The idea of path goal programming is to treat network paths, which may represent schedules, as goals and to minimize negative deviations from the desired schedules. The idea of path goal programming was presented in Kuchta and Urbańska (2012). The formulation there, however, concerns just one investment and combines one schedule goal with a "classic" numerical goal. Here we apply this approach in a situation with three investments and three desired schedules treated as goals, with the numerical goals taken into account in an informal way during workshops and expert evaluations in the company. The decision to be made refers to two budgeting periods.

As it is always the case in any goal programming application, first the company management were asked about their goals – here, the desired schedules for the implementation of each of the selected solutions. They were asked to be moderate, i.e. not to choose the quickest schedules for all three investments, which, clearly, could not be achieved because of budgetary limits. The managers were asked to reveal not the ideal schedules, but only those which would make them fairly satisfied.

First, the managers said they wanted to achieve, if possible, three things:

a) after the first budgetary period they wanted to be able to announce to the public that they had already introduced a pro-environmental solution, even if it had to be just one solution and even if it was not implemented fully,
b) after the second budgetary period they wanted to be able to announce to the public that they had implemented all three solutions, again, not necessarily fully,
c) after the second budgetary period they wanted to have at least one of the solutions implemented fully, preferably the second solution.

Having these statements in mind, the authors presented to the managers three goal schedules, shown in Figure 1. They were accepted as goal schedules, although of course other schedules would also satisfy the management requirements a), b), c).

Figure 1 presents the network of the decision considered here. Each of the three parts of the network refers to one of the investments (the solutions from Table 1, 2 and 3). The arcs starting in nodes 1, 2 and 3 stand for the decisions concerning each investment in the first budgeting period. The arc from node 1 to node 110 denotes the decision not to do anything regarding solution I in the first budgeting period, while the arc from node 1 to node 111, the decision to implement 50% of Solution I in the first budgeting period, and the arc from node 1 to node 112, the decision to implement the whole solution I in the first budgeting period. The arc from node 112 to 122 denotes the only possible decision in the second budgeting period in case the whole Solution I is implemented in the first period: not to do anything about this solution. Both arcs leaving node 111 correspond to the two decision possibilities about Solution I in the second period in case half of it was implemented in the first decision period: to leave it as it is (the arc leading to node 121) or implement the other half of it (the arc leading to node 122). The arcs leaving node 110 can be interpreted analogously (this node stands for the situation when nothing was done about Solution I in the first budgeting period, thus in the second period it can be left undone (120), implemented in 50% (121) and implemented fully (122)). The other arcs have the same meaning, but refer to the other two solutions. The three arcs leaving node 0 are auxiliary arcs, whose task is to link the decisions about the three solutions into one decision process. The arcs entering nodes 13, 23 and 33 have a similar role.

The patterns of the arcs represent the schedule goals proposed to the managers on the basis of their opinion. The dotted arcs show the desired schedules. We can see that if the proposed schedules were achieved, Solution I would be implemented only in 50%, but already in the first budgeting period, Solution II would be implemented fully, but it would be started possibly only in the second budgeting period. As far as Solution III is concerned, it would be implemented in 50%, and this would happen only in the second budgeting period.

The hatched arcs represent positive deviations from the desired schedules: quicker and fuller than desired implementations of the three solutions. The company would be even more satisfied if some of the hatched arcs were used. The continuous arcs represent the negative, undesired deviations. Each use of a continuous arc means a behind-schedule implementation of one of the solutions.

The budget for each budgeting period was set to $12 000. The implementation cost is given in Tables 1, 2 and 3.

Now we can formulate the following dynamic goal programming model:

Objective function: $\delta_1^+ + \delta_2^+ + \delta_3^+ \to \min$ (1)

where $\delta_1^+, \delta_2^+, \delta_3^+$ are, the negative deviations for the schedule for Solution I, II and III, respectively.

The deviations are defined in the following way:

$$p_{1-112}x_{1-112} + p_{1-111}x_{1-111} + p_{1-110}x_{1-110} + \\ + p_{112-122}x_{112-122} + p_{111-122}x_{111-122} + p_{111-121}x_{111-121} + \\ + p_{110-122}x_{110-122} + p_{110-121}x_{110-121} + p_{110-120}x_{111-120} + \\ + p_{122-13}x_{122-13} + p_{121-13}x_{121-13} + p_{120-13}x_{120-13} + \delta_1^- - \delta_1^+ = 0 \quad (2)$$

$$\begin{aligned}&p_{2-212}x_{2-212} + p_{2-211}x_{2-211} + p_{2-210}x_{2-210} + \\ &+ p_{212-222}x_{212-222} + p_{211-222}x_{211-222} + p_{211-221}x_{211-221} + \\ &+ p_{210-222}x_{210-222} + p_{210-221}x_{210-221} + p_{210-220}x_{211-220} + \\ &+ p_{222-23}x_{222-23} + p_{221-23}x_{221-23} + p_{220-23}x_{220-23} + \delta_2^- - \delta_2^+ = 0\end{aligned} \tag{3}$$

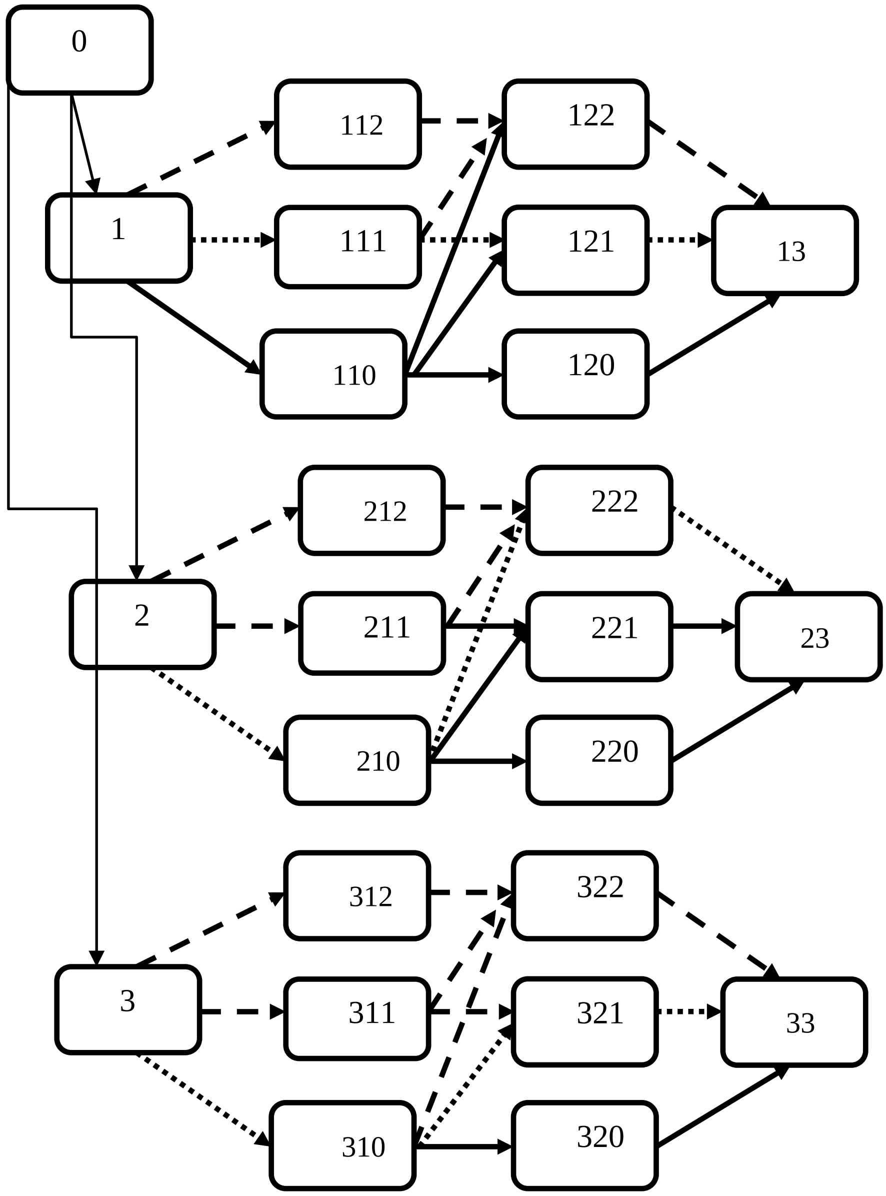

Figure 1. Decision network

$$\begin{aligned}&p_{3-312}x_{3-312}+p_{3-311}x_{3-311}+p_{3-310}x_{3-310}+\\&+p_{312-322}x_{312-322}+p_{311-322}x_{311-322}+p_{311-321}x_{311-321}+\\&+p_{310-322}x_{310-322}+p_{310-321}x_{310-321}+p_{310-320}x_{310-320}+\\&+p_{322-13}x_{322-13}+p_{321-33}x_{321-33}+p_{320-33}x_{320-33}+\delta_3^- -\delta_3^+=0\end{aligned} \quad (4)$$

where the x_{i-j} are binary decision variables, taking on value 1 if the arc leading from node *i* to node *j* is used and value 0 otherwise. p_{i-j} are coefficients equal to 0 if the corresponding arc belongs to the goal schedule, to 1 if the arc causes an undesired deviation from the goal schedule and to -1 if it causes a positive deviation from the goal schedule.

In our case (Figure 1) we have thus:

$$\begin{aligned}&p_{1-112}=-1,\ p_{1-111}=0, p_{1-110}=1, p_{112-122}=-1,\\&p_{111-122}=-1, p_{111-121}=0,\ p_{110-122}=1\\&p_{110-121}=1,\ p_{110-120}=1,\\&p_{122-13}=-1, p_{121-13}=0, p_{120-13}=1;\end{aligned} \quad (5)$$

$$\begin{aligned}&p_{2-212}=-1,\ p_{2-211}=-1, p_{2-210}=0,\ p_{212-222}=-1,\\&p_{211-222}=-1, p_{211-221}=1,\ p_{210-222}=0\\&p_{210-221}=1,\ p_{210-220}=1,\\&p_{222-23}=0, p_{221-23}=1, p_{220-23}=1;\end{aligned} \quad (6)$$

$$\begin{aligned}&p_{3-312}=-1,\ p_{3-311}=-1, p_{3-310}=0,\ p_{312-322}=-1,\\&p_{311-322}=-1, p_{311-321}=-1,\ p_{310-322}=1\\&p_{310-321}=0,\ p_{310-320}=1,\\&p_{322-33}=-1, p_{321-33}=0, p_{320-33}=1;\end{aligned} \quad (7)$$

Then we have the network constraints, assuring that exactly three investments are considered and that the decision in case of each of the investments is unequivocal and actually taken:

$$x_{0-1}+x_{0-2}+x_{0-3}=3 \quad (8)$$

$$\begin{aligned}&x_{1-110}+x_{1-111}+x_{1-112}=x_{0-1}\\&x_{2-210}+x_{2-211}+x_{2-212}=x_{0-2}\\&x_{3-310}+x_{3-311}+x_{3-312}=x_{0-3}\end{aligned} \quad (9)$$

$$\begin{aligned}&x_{1-112}=x_{112-122}\\&x_{2-212}=x_{212-222}\\&x_{3-312}=x_{312-322}\end{aligned} \quad (10)$$

$$x_{1-111} = x_{111-122} + x_{111-121}$$
$$x_{2-211} = x_{211-222} + x_{211-221} \tag{11}$$
$$x_{3-311} = x_{311-322} + x_{311-321}$$

$$x_{1-110} = x_{110-122} + x_{110-121} + x_{110-120}$$
$$x_{2-210} = x_{210-222} + x_{210-221} + x_{210-220} \tag{12}$$
$$x_{3-310} = x_{310-322} + x_{310-321} + x_{310-320}$$

$$x_{110-122} + x_{111-122} + x_{112-122} = x_{122-13}$$
$$x_{210-222} + x_{211-222} + x_{212-222} = x_{222-23} \tag{13}$$
$$x_{310-322} + x_{311-322} + x_{312-322} = x_{322-33}$$

$$x_{110-121} + x_{111-121} = x_{121-13}$$
$$x_{210-221} + x_{211-221} = x_{221-23} \tag{14}$$
$$x_{310-321} + x_{311-321} = x_{321-33}$$

$$x_{110-120} = x_{120-13}$$
$$x_{210-220} = x_{220-23} \tag{15}$$
$$x_{310-320} = x_{320-33}$$

where (8) assure that exactly three solutions will be considered, and (9)–(15) are balance constrains for the individual nodes from Figure 1.

Finally, we have budget constraints for the two budgeting periods:

$$k_{1-112}x_{1-112} + k_{1-111}x_{1-111} + k_{1-110}x_{1-110} + k_{2-212}x_{2-212} + k_{2-211}x_{2-211} + k_{2-210}x_{2-210} + k_{3-312}x_{3-312} + k_{3-311}x_{3-311} + k_{3-310}x_{3-310} \leq B1 \tag{16}$$

$$\begin{aligned}&k_{112-122}x_{112-122} + k_{111-122}x_{111-122} + k_{111-121}x_{111-121}\\ &+k_{110-122}x_{110-122} + k_{110-121}x_{110-121} + k_{110-120}x_{111-120} +\\ &+k_{212-222}x_{212-222} + k_{211-222}x_{211-222} + k_{211-221}x_{211-221}\\ &+k_{210-222}x_{210-222} + k_{210-221}x_{211-221} + k_{210-220}x_{211-220}\\ &+k_{312-322}x_{312-322} + k_{311-322}x_{311-322} + k_{311-321}x_{311-321}\\ &+k_{310-322}x_{310-322} + k_{310-321}x_{311-321} + k_{310-320}x_{311-320}\\ &\leq B2\end{aligned} \tag{17}$$

where $B1$ and $B2$ are, the budgets for each period (in our case both are equal to \$12 000) and k_{i-j} are the costs linked to each decision. In our case, according to Tables 1, 2 and 3, we have:

$$k_{1-112} = 10\,000, k_{1-111} = 5\,000, k_{1-110} = 0$$
$$k_{112-122} = 0, k_{111-122} = 5\,000, k_{111-121} = 0,$$
$$k_{110-122} = 10\,000, k_{110-121} = 5\,000, k_{110-120} = 0$$

$$k_{2-212} = 13\,000, k_{2-211} = 6\,500, k_{2-210} = 0$$
$$k_{212-222} = 0, k_{211-222} = 6\,500, k_{211-221} = 0,$$
$$k_{210-222} = 13\,000, k_{210-221} = 6\,500, k_{210-220} = 0$$

$$k_{3-312} = 20\,000, k_{3-311} = 10\,000, k_{3-310} = 0$$
$$k_{312-322} = 0, k_{311-322} = 10\,000, k_{311-321} = 0,$$
$$k_{310-322} = 20\,000, k_{310-321} = 10\,000, k_{310-320} = 0$$

The solution of problem (1)-(17) is:

$$x_{1-111} = x_{111-121} = x_{121-13} = 1$$
$$x_{2-211} = x_{211-221} = x_{221-23} = 1$$
$$x_{3-310} = x_{310-321} = x_{321-33} = 1$$

the other x_{i-j} being zero. This gives us $\delta_1^+ + \delta_2^+ + \delta_3^+ = 1$, and $\delta_1^+ = 0, \delta_2^+ = 1, \delta_3^+ = 0$.

The value $\delta_1^+ + \delta_2^+ + \delta_3^+$ is a measure of the number of periods the investments will be behind schedule. In our case Solution II will be behind schedule in the second budgeting period (however, in the first budgeting period it will be ahead of schedule – we would have then a positive deviation from the schedule). Solution I and III will be exactly on schedule in both periods. Thus, postulate c) would not be satisfied. However, the management of the company accepted this, as the first two postulates would be held.

In fact, it might always be useful to consider alternative solutions. In our case we might seek other solutions with the objective function $\delta_1^+ + \delta_2^+ + \delta_3^+ = 1$, but $\delta_2^+ = 0$. The alternative solutions are obtained, if they exist, by adding to the model the additional constraint $\delta_2^+ = 0$. However, the managers preferred to have $\delta_2^+ = 1$ (their third postulate not fulfilled) rather than $\delta_1^+ = 1$ or $\delta_3^+ = 1$ (the other postulates not fulfilled), thus the current solution was finally accepted. With this solution all three actions would be implemented in 50% after the second budgetary period and action 1 would be implemented in 50% already after the first budgetary period, which satisfied the management.

Conclusions

In this paper we described and applied the path goal programming approach, which allows to consider schedules as goals. The application concerned a big company implementing an environmental policy which had to choose between various desired environment-influencing investments, as the budget did not allow to implement all of them at the same time. Not only the investments had to be chosen, but also a compromise implementation schedule. Three investments have been chosen using an informal multicriteria decision making process, and the authors helped to determine satisfactory schedules of their implementation. We formulated a path goal programming model allowing to find a solution which best suited the desired schedule. Solving the model (which turned out to be, in the final stage, a linear programming model with 18 decision variables) allowed to minimize negative deviations from the desired schedule.

Our future research will go in two directions. The first one is a further development of the path goal programming approach. The negative deviations from the schedule can be weighted according to their distance from the desired schedule and their significance for the environment or the internal objectives of the company. This is a problem still to be considered – in this paper the deviations do not have any weights. The other research direction is the consideration of more complex environmental decisions. This will be accomplished, among other things, in cooperation with the company considered in this paper. The first step will be to persuade the management to use formal methods also in the initial investment selection process. For the moment this phase is accomplished in a totally informal way, but many authors propose fairly simple and verified in practice formal sustainable multicriteria decision making methods (e.g. Merad et a. 2013) which might facilitate the process and make it more effective.

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