traced back to the subjective scales used when the data were collected. The projects range from 1 to 2,500 GWh, whereas the conflict scales were restricted to the digits −4 to +4. Since the overwhelming majority of potential projects are small, the scales were soon exhausted and left no room for the larger projects. This was confirmed by participants in the data collection and acknowledged by the Water Resources and Energy Administration. We therefore concluded that the data (which cost $10 million to collect) were unsuitable for rational analysis. The Ministry of Environment had committed two methodological errors which partly neutralized each other. First, they had not considered production when they ranked the projects and thus selected projects only on the basis of their doing little damage. Secondly, since the damage done by larger projects had been underestimated, some did get a reasonable ranking after all.

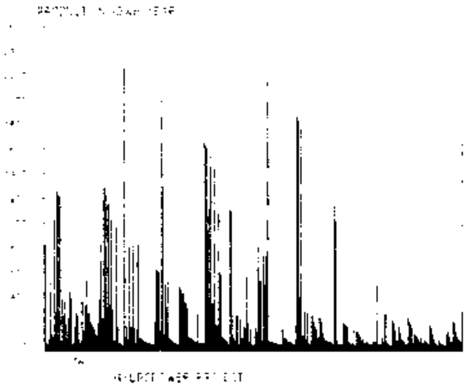
Figure 7: The 542 projects, each represented by a bar, are ordered according to the alternative ranking list. The height of the bar indicates the project's energy production. Larger projects tend to appear to the left, indicating high priority for these projects.

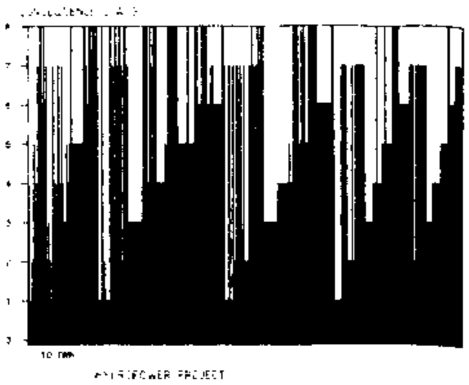
Figure 8: The 542 projects are shown in the same order as in Figure 7, but the heights of bars now indicate the conflict or damage associated with each project. The black area to the left of the 10 TWh mark represents the potential nationwide damage if 10 TWh were developed according to the ranked list. Since fewer projects are needed, the area is much smaller than in Figure 4.

We proposed to the board that we partly rectify the data with artificial nonlinear rescaling and then proceed with our rational ranking method. This proposal was accepted and our project was continued.

When we applied our ranking method to the revised data set, we came up with a list of 35 projects to produce 10 TWh (Figures 7 and 8).

The main improvement from the choice shown in Figures 3 and 4 to that shown in Figures 7 and 8 is that the large number of very small projects has been eliminated from the 10 TWh-list, with a corresponding 70 percent reduction in cumulative damage. This time, the Water Resources and Energy Administration found our results interesting. The Ministry of Environment could not accept the revised data set, however, and found it impossible to back this approach.

Cooperation

Even though our work was based on nonlegitimized data, the ministry now acknowledged its principal merits. We were therefore invited to cooperate with them. Through this joint effort, we were able to identify the main reason that the project had gone awry: The overall goal had not been clearly stated at the outset. The terms *conflict* and *damage* had been confused from the very beginning. While the terms were often used as synonyms, the ministry generally preferred *conflict* (conflicts being more important for politicians), while we had consistently used *damage* (which sounded more rational). In reality, we had been working in two separate dimensions. The ministry had worked along an economy-conflict line, trying to pinpoint the most appropriate trade-off between those two objectives. We, on the other hand, had worked along an economy-damage per GWh line (Figure 9).

Figure 9: Misunderstandings illustrated. The ministry was concerned about which trade-off rate would be appropriate between the objectives of economy and avoiding conflict. Assuming the length of the economy-conflict line to be unity, any trade-off rate can be represented by a point on the line. The closer the point is to the other end, the more weight on that endpoint. Simultaneously, we tried to select an appropriate trade-off point, but unknowingly in another dimension, a dimension between the objectives of economy and avoiding damage.

We recognized that the troublesome data base consisted of a mixture of measurements of conflict and measurements of damage with conflict preponderating. We therefore agreed to consider them as measurements of conflict, with the implication that it is not meaningful to add "conflicts" across projects. Thus, our nationwide "sum of consequences" concept lost its sting.

The ministry, on the other hand, acknowledged that to minimize damage is also an important issue. Lacking that kind of data, however, put us in an awkward position. To collect more data was out of the question. Literally at the last minute, the ministry came up with the idea that we could use the inverse of energy production as a proxy attribute for damage. By substituting the objective "minimize nationwide damage" with "maximize the size of each project" we achieved de facto the same end.

The ensuing goal hierarchy thus had three subobjectives for each particular project: (1) Minimize conflict (attribute: consequence class); (2) Maximize economy (attribute: construction cost/energy production); and (3) Minimize damage (attribute: 1/energy production).

The only problem left was to assign weights to the three subobjectives. This was clearly a policy question and was best left to the ministry. To make the task

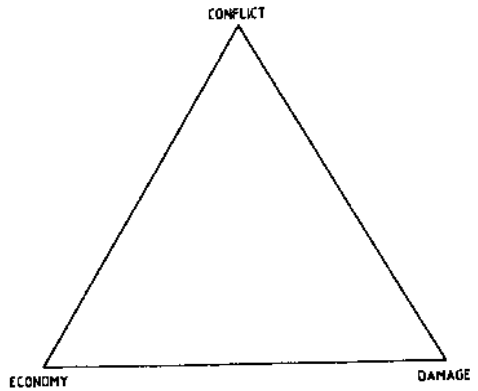

Figure 10: Synthesis: we agreed to add a third dimension to Figure 9, a conflict-damage line, to create a three-dimensional weight diagram. Each point in the triangle can be interpreted as a set of weights; we, wd and wc (the weights for economy, damage and conflict). The problem now was to select the most appropriate point in the triangle.

easier, we developed a spreadsheet decision support system where one could specify the weights of the three objectives and immediately get a ranking list of the 542 projects. We found that an additive utility function was suitable. This implies that the sum of weights is 1, which helped us communicate the idea of weighing, since a set of three numbers with a constant sum can be represented as a point in a triangle (Figure 10).

With the help of this system, one could produce almost any internally consistent ranking list, and for the first time, the question of selecting a ranking list was identified as a question of choosing a policy. The ministry used the system as an aid behind the scenes to modify their initial proposal. This was essentially done by juggling the weights until a qualitatively satisfying ranking list appeared. Visual inspections of diagrams like those in Figures 3 and 4 and Figures 7 and 8 were important. From a satisfying ranking list, they could then single out projects with unexpected positions for closer inspection. In this way, they used a consistent ranking machine to enhance their own expertise and knowledge of details. A modified proposal was prepared and accepted by the Parliament in the fall of 1986. The Ministry of Environment plans to use the system for subsequent reevaluations of the master plan.

Reflections

From our practical point of view as decision analysis consultants, we have gained several useful insights from this experience. In order of importance: (1) State your main objectives clearly; (2) Do not skip exploratory data analysis; (3) Avoid subjective measurement scales; (4) Do not give in; you may reach the other end of the tunnel.

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John M. Raaheim, Head of Division, and Gulbrand Wangen, Ministry of Environment, PO Box 8013 DEP., 0030 Oslo 1, Norway, write "The Ministry of Environment has been asked to verify the work done by the authors of the article "Ranking hydroelectric power station projects with multicriteria decision analysis."

The article makes reference to the Master Plan for Water Resources which has been presented in two Reports to the Storting (Parliament) No. 63 (1984-85) and No. 53 (1986-87). To understand the approach used in preparing the Master Plan, it is important to have in mind that in the late 1970's there was a growing opinion against hydropower development in Norway which caused a lot of conflicts. The most famous of them all was the Alta Hydro-Electric Project which involved conflicts with aboriginal rights, massive demonstrations, and 600 policemen to clear the way for the working forces. For the first time in history, the decision on development made by the Storting was brought to the Supreme Court.

Avoidance of similar conflicts was one of the main reasons why the Storting in 1980 asked for a Master Plan to set priorities on future development of hydropower projects. The mandate for the project was to minimize the conflicts and at the same time take into account the overall economy of the different hydroelectric projects.

The authors have made a comparison between the ranking method used by the Ministry, called "irrational" and their own method which they call "rational." It is interesting to observe that when using the "rational" method one may, according to the authors, obtain results which seem to be politically impossible. Using the "irrational method," which is partly based on an intensive hearing process, has so far resulted in one decision by the Storting on the first Report and one decision by the Government on the second Report. In the opinion of the Ministry, a discussion on the rationality of different methods is rather uninteresting as far as political rationality is not included in the discussion concept.

At the end of the article the authors make a rather surprising statement saying that the new ranking method, developed in cooperation with the Ministry, identified for the first time that the question of selecting a ranking list was a question of choosing a policy. Maybe that was a new discovery for the authors; for the Ministry, however, it has been obvious that setting weights on different objectives *is* a question of choosing policy.

When preparing the second Report to the Storting, not the first Report as stated in the article, the Ministry has tried to use the new ranking method. This method included the objective of minimizing the damage, with the attribute: 1/energy production, in addition to the economy and conflict objectives. In the second Report the Ministry has concluded that introduction of a third objective will not alone make any changes to the ranking list. The weights on the economy and minimum damage objectives have to be increased by at least 50 percent with a similar decrease in the conflict objective, in order to get significant changes in the ranking list. So far the Ministry has not received political signals which could defend a change of this size in the weights for the objectives. The development of a new ranking method will additionally necessitate considerable adaptions to the existing data in the Master Plan. The uncertainty related to this adaption is obvious, and the existing method is therefore so far seen to be preferable.

In spite of this conclusion, the Ministry acknowledges the methodic work done by the authors. The cooperation between the authors and the Ministry has led to better insight in the difficulties related to project ranking based on technical/economic and environmental impact criteria.

Finally, the Ministry wants to make a comment on the cost and the use of the collected data for the Master Plan. These data are, according to the authors, unsuitable for a rational analysis. This is, however, not true. Experience has shown that the information gathered, which includes thematical maps describing the overall situation for important user interests and potential conflicts caused by the hydroelectric projects, will be of particular value in the subsequent stages of the licensing procedure for hydroelectric projects and in water management planning at the county and the municipal level."

The State of the Art of Linear Programming on Personal Computers

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The phenomenal growth of microcomputers in both market size and technology has resulted in a proliferation of management science/operations research science software, including linear programming (LP) software. An earlier survey of LP software was published three years ago. This broad summary of LP software highlights recent advances, such as spreadsheet-based software and model generation systems, and discusses its enhanced capability to handle larger problems, greater speed, and better user interfaces.

The phenomenal growth of microcomputers in both market size and technology has been accompanied by a proliferation of MS/OR software. Since my first survey of linear programming (LP) software was published in *Interfaces* [Sharda 1984], a number of hardware and software advances have improved the state of the art of the microcomputers. New microcomputers have been introduced, such as Intel 80286 chip-based computers, IBM's RT/PC, various versions of Macintosh, and most recently, 80386 chip-based computers. In addition, hardware and software have been developed to break the IBM-PC's 640K limit on addressable memory. Now it is possible to access several megabytes of memory on a PC.

I conducted a survey to determine if state-of-the-art linear programming software has kept pace with the advances in microcomputer technology. Unlike my earlier survey, this one does not review

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