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Numerical and Verbal Decision Analysis: Comparison on Practical Cases

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ABSTRACT

Numerical decision analysis (NDA), derived from statistical decision theory, is very well known. Verbal decision analysis (VDA), oriented towards so-called unstructured problems, where the qualitative and uncertain factors dominate, is a newer direction in decision theory and practice. Verbal and numerical decision analyses (DAs) have been compared in an experimental setting, with groups of students. This paper presents the results of a comparison in the context of live practical tasks. Both approaches were attempted on two comparable choices, facing both Russian and US government agencies, involving a choice between oil and gas transportation options. The resulting methodological insights are generalized into a systematic comparison of the strong and weak features of each approach. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: multi-attribute decision theory; verbal decision analysis; choice of pipeline route; qualitative measurement

1. INTRODUCTION

Anyone who has tried to apply decision analysis (DA) to a practical task knows from experience that it is not only a question of using some technique but is also a question of the applicant's skill. This means that a DA is not a formal, objective science for finding the best decision. Rather, it is a process of helping people to understand a difficult problem and to express their personal values and wishes with respect to it. Thus, the person who helps others to analyse a problem (analyst, consultant) must know the science of decision-making and possess good decision-making skills (Larichev, 1979; Raiffa, 1982).

Recently, an additional problem in the complex world of consultant activity has become apparent: the abundance of different analytical techniques. It is difficult to select the appropriate decision method for a practical task, especially in an organizational context. One must take into account distinguishing features, not only of the decision method and the task, but also important features of an organization and of the decision maker (DM).

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Nowadays, there are many different decision analytical techniques, which have been developed by various research schools (Brown *et al.*, 1974; Keeney and Raiffa, 1976; Saaty, 1980; Von Winterfeldt and Edwards, 1986; Roy, 1996; Larichev and Moshkovich, 1997). Together, they comprise a toolbox for modern consultants helping a client to solve practical problems. But how should this toolbox be used? How do we select a tool adequate for a given practical problem?

We have focused attention on a particular area of application: natural resource development in the Arctic. Our comparative observations relate specifically to this context, although they may generalize beyond it. There are some distinctive features from a decision-making point of view.

- Typically, there are few options, but many evaluation criteria.
- Several interest groups are involved (to different degrees) in the decision-making process. They could be called *active groups*. Active groups sometimes have different criteria for option evaluation. Even with the same criteria, they have different preferences with respect to options.
- There are large uncertainties surrounding the evaluation of options and the selection of the best one. This uncertainty cannot be removed before making the decision. Human knowledge

of the many natural processes in the Arctic is limited and only many years of careful observation can gradually expand it. That is why the possibilities for reliable measurements of many important factors are limited.
- As with many strategic decisions, the consequences are long-term.

2. RESEARCH APPROACH

There have been important, if not extensive, attempts to compare some DA tools in a laboratory setting. Laboratory studies can be very useful in the psychological evaluation of a decision technique. However, there is no assurance that they will provide all the information necessary for the application of a decision method by real DMs in the real world, including how they are influenced by the specifics of the context. We have tried to make the comparison in the context of the real application of decision techniques.

A natural start would be to have a single DM use different analytical techniques on the same live problem. However, real DMs addressing important tasks, especially under exacting organizational pressures, do not play games. They are understandably reluctant to depart too much from the normal practice of using just one currently favoured approach. In any case, the cognitive context changes, perhaps dramatically, after one approach has been tried on the problem, not to mention the methodological nightmare of measuring what difference a decision aid made to the quality of the decision in a given instance (Brown, 1989).

We tried a plausible approximation to the ideal in a research project designed to compare qualitative and quantitative DA in the context of Arctic natural resource decisions. We took two very similar problems (land use for oil and gas production). On the basis of practical experience, we hoped that the great similarity of the problems would define similar requirements for their solution. In such conditions, there is a real opportunity to observe the differences between the approaches. We asked the chief proponent of each approach to apply it to one problem, acting as a consultant. To add insight to the comparison, in each case a proponent of the *other* method applied it *off-line*, as a kind of thought experiment.

Even so, the comparison was potentially confounded, notably by institutional differences (American versus Russian), the DM's personal characteristics and whether the choice is live or dead (i.e. a past decision). The difficult trade-off was between achieving firm findings and having them apply to more than a narrow class of cases. In any case, the case material presented here cannot do more than make concrete any generalizations on how the two approaches compare. Those generalizations derive primarily from a review of the somewhat sparse literature and the authors' years of experience applying their own favoured techniques.

Both cases involved aiding a pending government choice on what to do about the construction of an environmentally hazardous oil and gas pipeline. One case was whether the Russian Government should pipe gas from Western Siberia over land or under the sea. Our two Russian team members applied their qualitative approach, working with the main participants, while the American team considered how they *would have* applied their quantitative approach to the same material.

The other case was retrospective: whether American regulators should have permitted an oil company to build a causeway to an oil field in the Arctic Ocean. The American team reconstructed how its approach would have been applied to a recent decision, working with the same people who had been involved; this was followed by a brief consideration by the Russian team of how they would have approached the case.

3. DECISION ANALYSIS (DA) TECHNIQUES

A common DA approach is to initially consider the parameters describing a problem (or option evaluations on the criteria) in a qualitative way. They are then transformed into quantitative form by various means.

However, there is a quite different variant of DA for which only qualitative (verbal) variables are used without any transformation into numbers (Larichev, 1987, 1992). Qualitative categorical or verbal decision analysis (VDA) relies on natural language and non-numerical categorization of the considerations in a choice. Quantitative or numerical decision analysis (NDA)

represents uncertainty and value in the form of numbers, and combines them in a quantitative model (derived from statistical decision theory). The former approach has been associated with Russian DA, and the latter with Western analysis. They may draw out different aspects of the same problem. In this study, we tried to compare these two, quite different kinds of DA, i.e. verbal and numerical.

3.1. Verbal decision analysis (VDA)

VDA tries to structure a problem by using the natural language commonly used by a DM, active parties participating in the decision process and potential experts. The goal of structuring is to define the main factors or criteria that could be applied for the evaluation of decision options initially given. For each criterion, a scale for the evaluation is constructed with a small number of quality grades. Some verbal expressions from the language are used to describe the quality grades located from best to worst (e.g. 'no damage to the environment', 'moderate damage to the environment', 'great damage to the environment').

In the framework of VDA, special comparative methods have been developed (Larichev and Moshkovich, 1997). In each method, only verbal evaluations of the criteria are used at all stages of an analysis, without transformation into quantities. This means that only logical consequences of qualitative relations between verbal evaluations are used in the process of analysis.

In the VDA toolbox, there are methods adapted to problems with few options and many criteria. These typify Arctic resource problems and so are of particular interest here. One of them is the method of pair-wise compensation, suited to a relatively small number of initial options. The options are compared in a qualitative, pair-wise way, identifying their relative merits and deficiencies. One seeks a condition when the advantages of one option are dominated by the advantages of the other.

First, the DM performs a psychologically valid operation (e.g. comparison of two objects which differ only on two or three criteria; Larichev, 1992). When comparing the two options, the DM finds partial compensation for some disadvantages of one option by disadvantages of the other one. The DM's answers are constantly checked for contradictions. Any contradictory answers are shown to the DM to give him a chance to eliminate them. Any evaluations on criteria that are not really different between options are eliminated from the analysis, thereby simplifying the comparison. The operation of the compensation is mathematically sound under conditions of preference independence (Keeney and Raiffa, 1976).

Pair-wise compensation compares two options in terms of a binary relation, which can be in one of three conditions: dominance, equivalence or incomparability. When the evaluations of options are very conflicting, the psychologically valid operations of comparison do not guarantee identifying the best one. The options are incomparable. The problem may be resolved by creating a new, more promising option that may be better than the two initially given (i.e. a new variant). Experts are involved in this creative process and in defining the condition for implementing the new option. At every stage of the decision process, VDA helps the DM to reduce the decision to a more manageable size.

The positions of different active groups, and the differences between them, are analysed in a similar way. Promising new options are developed in the process of searching for agreement between the active groups. The methodological basis of VDA and related decision methods are described in Larichev (1987, 1992) and Larichev and Moshkovich (1997).

3.2. Numerical decision analysis (NDA)

The NDA paradigm is familiar to Western audiences (e.g. Keeney and Raiffa, 1976; Watson and Buede, 1987) and needs only a few observations here. NDA essentially translates the judgement and knowledge relevant to evaluating some choice into a quantitative model. Normally, it calculates a numerical value for each option, in order to identify the best. For example, a probability and utility are attached to each possible consequence of an option, and the option with the highest probability-weighted (expected) utility is logically preferred. This type of model often suits a case where uncertainty is critical.

In many environmental management decisions, the critical issue is conflicting objectives and another common model often works well. The competing criteria are listed along with a numerical measure of the relative importance of each. The impact of each option is scored on each criterion, and the preferred option is (with some exceptions) the one with the highest importance-weighted

impact. Thus, high impact in areas of little importance balances out low impact in areas of great importance. This linear additive model is a special, but commonly applicable, case of more universally applicable multi-attribute utility analysis (MUA).

An NDA approach is normally comprehensive, in the sense that it purports to characterize *all considerations* relevant to a choice, i.e. values and assessments, even if at a highly aggregate level. For example, an importance-weighted impact model does not attempt to reduce the criteria considered, although it may group them into a few *classes*.

4. RUSSIAN CASE: YAMAL PIPELINE

Development of the Yamal gas fields in Western Siberia has become a matter of national importance for Russia. This development has, however, many unresolved problems. An essential one is the choice between two routes connecting the gas fields to the existing gas pipeline system. During the development of the project, the idea of straightening the pipeline, by crossing Baidaratskava Bay, received strong support (sea route). A second, land route crosses the Yamal Peninsula to the east of the bay (land route).

Thus, the task is one of decision-making with two options. As we shall see, this problem concerns the interests of different groups influencing the choice, unknown natural conditions and contradictory appraisals of the alternatives on various criteria, as well as other things. For a more detailed description of this case, see Andreyeva *et al*. (1996).

4.1. Options

The two options are a sea route crossing the bay and a land route. The following distinguishing characteristics were initially included in the analysis: (1) length of the route; (2) terms of construction; (3) time for construction; (4) cost of construction; (5) impact on the environment; (6) risk of pipeline rupture accidents; (7) consequences of pipeline rupture accidents; (8) time needed to recover from an accident; and (9) uncertain and unknown factors. In terms of point (6), the option of crossing Baidaratskaya Bay involves unique features that could cause an accident: (a) the instability of the shore because of permafrost processes and sea ice impact; (b) the rupture of or damage to the pipeline by ice scouring; and (c) ice conditions in the Kara Sea, where iceberg sections are capable of reaching Baidaratskaya Bay. In terms of point (9), the analysis clarifies that the decision must be made under conditions of major uncertainty due to delays in the start of construction.

4.2. Active groups

Before comparing the two options, we must analyse who will make the choice and how. It is unlikely that the choice of option will be made by a single senior DM because of the high cost of this project. Instead, several institutions and organizations are taking part, either directly or indirectly, in the decision, which we shall call 'active groups'. Examples of these active groups are as follows: the Russian joint stock company 'Gasprom', which ordered the development of the project; the Ministry of the Economy, which evaluates the economic considerations and economic efficiency of the future project and approves a design; the local authorities in the Yamal region, who must consent to an option for the pipeline; and so on. The active groups have different motivations for their choice of an option, different technical orientations and contradictory opinions towards the criteria. As one might expect, the groups supported different options.

5. THE APPLICATION OF RUSSIAN VDA TO THE YAMAL CASE

5.1. Evaluating the options

The research team looked at the options through a 'fog of uncertainty' that derived partly from the difficulty in measuring the options in terms of the criteria. How does one evaluate cost in a time of inflation? How does one evaluate the probability of an accident in the absence of information, reliable models or long-term observational data?

In the Yamal case, the essential difference between the options involved crossing Baidaratskaya Bay (sea option) and the construction of an additional 160 km of pipeline (land option). It is natural to take into account only the criteria where we can find an essential difference between the options in terms of those criteria. Let us describe some of these criteria.

1. *Cost*. The initial approximate estimations show that the cost of the sea option (C_{sea}) is a little bigger than that of the land option (C_{land}).
2. *Ecological impact*. Both options have a negative impact on the environment. Although the sea option contains some uncertainty, this influence is much larger for the land option, which occupies a lot of land and crosses many rivers.
3. *Probability of an accident*. Because of unstable shores and the possibility of ice scouring, the probability of an accident in the sea option is greater.
4. *Consequences of an accident*. An accident is usually connected with an explosion and destruction of the environment for the land option. In the case of the sea option, there would be no explosion, but gas could rise through the water and cracks in the ice. The land option is clearly worse.
5. *Reliability of the gas supply*. Repair of the pipeline after an accident requires much more time with the sea option, particularly because the bay is ice-free for only 60–70 days of the year. The sea option is clearly worse.
6. *Uncertain and unknown factors*. Many such factors are connected with the realization of the unique project of crossing Baidaratskaya Bay. The sea option is clearly worse.

These comparative, qualitative evaluations are practically all that we can measure; others are more difficult. How does one draw conclusions with such weak measurements?

5.2. Comparison of the options

Below is an analysis corresponding to the interests of Gasprom. As noted, VDA methods do not guarantee that pair-wise comparisons of the disadvantages of two alternatives will always lead to a clear preference. This situation resulted in the two Yamal pipeline options. The greater uncertainty and lesser reliability of gas supply for the sea option were worse than the ecological impact from the land option. But the negative consequences of an accident for the land option were worse than the greater probability of an accident with the sea option. The research team, working with the DMs and experts, undertook the development of a new, more promising option out of the existing ones.

5.3. Developing a new variant

In this case, as in many others, the practical value of DA involves not only the comparison of existing options but also the creative invention of new ones. A method for aiding strategic choice permits not only the comparison of several options but also a definition of the requirements for a new, more desirable option. That is, the method asks the question, what needs to be changed in one option to make it equal to or better than the other option?

Discussions with experts suggested ways in which the negative aspects of the sea option could be removed.

1. To eliminate the influence of seashore instability, special shafts could be constructed at a safe distance from the sea and the pipeline put through them. This construction would incur additional costs, C_{shafts}.
2. To avoid damage to the pipeline due to ice scouring, the pipeline can be laid in special trenches 1.5-m deep. They would be deeper than the project plan calls for, so the costs, $C_{trenches}$, will also be additional.
3. Icebergs are a very rare but dangerous event in the bay. A special observation service and a special ship to drag the iceberg away would eliminate this problem. Let us denote the cost of the service and ship by C_{ice}.

Adding these features to the old sea alternative creates a new option with an element of uncertainty approximately equal (in the view of the experts) to the traditional land option. Thus, no significant differences would exist between the sea and the land routes, except for cost and ecological impact. The cost of the new sea option, $C_{sea} + C_{shaft} + C_{trenches} + C_{ice}$, would clearly be more expensive. The land option will still result in greater environmental destruction. However, now the comparison can be considered as one between higher costs and lower environmental protection. The comparison between two factors presents a real, critical choice.

5.4. Analysis from the positions of the active groups

An analogous analysis was made of the positions of the other active groups. Development of the new option was useful in this case too. The final choice has not yet been made. However, the results of the analysis had an influence on the DM:

the additional study of seashore instability has been carried out. The preliminary solution is in favour of the new sea version.

6. NDA APPROACH TO THE YAMAL CASE

NDA could be attempted on the same problem. Larichev *et al.* (1995b), for example, presented a hypothetical 'importance-weighted impact' model based on the same set of criteria: cost, ecology, accident risk, etc. However, instead of presenting the perspective of each active group (as in the above VDA), the analysis could represent the view of any given person who wished to make up his mind on which pipeline route best served the nation's interest or to argue a case before a public audience. For example, the impact and importance inputs might be supplied by a responsible citizen or government official, and the conclusions would be attributed to that person.

The evaluation scale was from 0 to -100, where 0 is no impact of any kind and -100 is the worst plausible impact on all criteria. On one illustrative set of inputs, proposed by a research colleague, the land route scored -20 and the sea route scored -15. Thus, that evaluator would appear to favour the less damaging sea route. (This was largely because she considered ecology by far the most important criteria and assessed the land route as having a significantly larger ecological impact.) The effect of alternative inputs by the same or other evaluators could be readily calculated.

7. AMERICAN CASE: NIAKUK CAUSEWAY

7.1. Background

In the late 1980s, BP sought permission to develop an oil field on Niakuk Island, 1.25 miles off the Arctic Beaufort Sea shore, with a gravel causeway to pipe the oil ashore. The regulatory regime, through various statutes, required that that a permissible project must not exceed certain levels of different kinds of environmental damage, and also that it should 'serve the public interest'. There were three salient permitting options: no oil field, one with and one without a causeway, i.e. using slant drilling.

As the lead agency, the Alaska District of the Corps of Engineers (CoE) issued a permit to develop the oil field, but without the causeway (on the grounds that it failed a fish habitat standard). After some national controversy, CoE headquarters in Washington rescinded the findings pending additional data. BP eventually opted to develop the field using slant drilling, and it proved profitable (even though BP had argued that slant drilling would make the project uneconomic).

The main interest in this case, from the point of view of our broader research project, had been to develop a reusable procedure for regulating similar projects (Flanders *et al.*, 1998). However, it also serves as an example (retrospective) of a specific current decision and can be viewed from that perspective, for the purposes of this paper.

7.2. Application of American NDA in the Niakuk case

The research team met with the regulator 4 years after the events described to develop an NDA-oriented aid that could have been used to support the initial local permitting decision, or the subsequent challenges. We worked with the same government and industrial institutions, and most of the specific individuals within them, who had been involved in the original stages. Each party was presented with an analysis to be treated *as if* BP had submitted it in support of their application. The analysis was intended to faithfully reflect whatever knowledge and thinking was available at the time (without attempting to improve them). Its contribution was to find the best way to *communicate* the likely consequences of each and also to determine if those consequences were acceptable.

We considered three alternative formats within a multi-attribute utility NDA paradigm: qualitative, graphic and numerical. In each case, all consequences—economic, environmental, strategic, etc.—were considered, no matter how intangible. The impacts on them were based only on knowledge available at the time. Option evaluation was based both on acceptable thresholds for each impact and compensation among them.

We posited that the industry applicant for BP make his case in this format, consistent with the conventional project description that he actually made. The regulator would second-guess the applicant, using his normal judgement, but again in

this format. The intent was that this format could lead to a sounder or more easily reviewed CoE decision.

The major disadvantages to the causeway over slant drilling were the impacts on anadromous fish, ecosystem quality and pro-wilderness public sentiment. It had advantages in terms of construction employment and a precedent effect for the oil industry. The precedent effect means that causeways would continue to be an available option for the industry in oil field development.

We hypothesized some 20 criteria identified and weighted by regulators, consistent with actual regulatory guidelines. Impact scores for each were imputed to the applicant. The importance-weighted impact calculated from these inputs favoured the causeway option (which the applicant sought permission for). Details and presentation are reported in Flanders *et al.* (1998).

The analysis makes clear that the argument favouring the causeway depends largely on the high impact and importance attached to three measures of industry profitability. This is what one might expect if this was a submission from the oil company applicant. The regulator does not have to accept that, of course, and he can substitute his own assessments when coming to a decision.

7.3. Re-analysis with authoritative input

We re-ran the above analysis, to conform to the judgement of regulatory staff at the CoE in Alaska, who had actually been responsible for the original decision. This final analysis was based on numbers for predicted impacts and importance that reflected their recollection of the knowledge and judgements they used at the time. This analysis did, in fact, confirm the decision actually made: to permit development of the Niakuk oil field, but with the slant drilling oil transport option. Although, under this reconstruction of the application process, the permitting decision was unchanged, it appeared more resistant to subsequent challenge or political manipulation.

7.4. VDA approach to the Niakuk case

The Russian team gave a little thought to how VDA qualitative analysis of the Niakuk decision might have proceeded. Their analysis singled out eight critical criterion variables. A new option was developed, based on CoE input: a sub-sea pipeline below the ice scour level of the ocean's floor was included. One of the criteria, social consequences, was considered to show no difference among the options and would be ignored. Qualitative analysis does not attempt to draw out every single point of difference in detail. It seeks only the 'broad brush strokes'.

Because the causeway option failed the regulatory threshold for impact on anadromous fish, it was considered unacceptable on environmental grounds and was eliminated as an option. The question then arises: is there another option that could be used as a better alternative to slant drilling? The major differences between the two remaining options are found in the cost of construction, the number of uncertain factors and the reliability of the pipeline. The buried pipeline has disadvantages in terms of extra cost and reliability. Slant drilling is disadvantageous due to its many uncertain factors, which may block its effective realization. According to BP evaluations given in their application, slant drilling could not be profitable enough.

At this point, the qualitative analysis would need to consider whether the disadvantages of the buried pipeline could be made at least equal to slant drilling. The buried pipeline, according to the analysis, has a number of advantages over the alternative. Reducing the cost of construction or increasing the reliability to the level of slant drilling might make a buried pipeline a better alternative. In any case, a VDA analysis along these lines could aid the problem analysis by showing where the critical differences lie.

8. COMPARISON OF THE TWO APPROACHES

On the basis of our practical experience, including the above, in applying two quite different approaches to very similar problems, we attempted to compare the approaches. The comparison involves consideration of two issues: the general pros and cons of each approach and the circumstances under which one or the other is favoured.

Undertaking such a comparison, we appreciate that NDA is much more widely known and has, to date, undergone much more development and application than VDA. However, considering the potential of development for each approach permits investigation of the possible limits of its applicability in practical tasks. In our opinion,

three groups of comparative criteria should be taken into consideration: methodological, institutional and personal.

8.1. Methodological criteria

Seven key methodological criteria characterize an approach.

8.1.1. Measurement of options on the criteria

There are several arguments for people giving and receiving information in a verbal form. For example:

1. People use the verbal way of communication much more easily than the numerical way. Probability theory appeared many thousands of years after the development of language.
2. Words are perceived as being more flexible and less precise, with various cornmunicative functions and, therefore, seem better suited to describe vague options and characterize imprecise beliefs.

Erev and Cohen (1990) stated that 'forcing people to give numerical expressions for vague situations where they can only distinguish between a few levels of probability may result in misleading assessments'.

However, there are positive arguments for utilizing quantitative forms of information. For example:

1. People can attach a degree of precision, authority and confidence to numerical statements more readily than to verbal statements.
2. It is possible to use quantitative methods of information processing (e.g. Bayes theorem).

Experiments with financial games over many years by Professor T. Wallsten and his colleagues demonstrated no essential differences in the profit received by subjects or in the accuracy of their evaluations if information was presented in a qualitative or quantitative form (Erev and Cohen, 1990; Budescu and Wallsten, 1995). However, there was a strong and clear difference in the number of preference reversals (Gonzalez-Vallejo and Wallsten, 1992) between binary choice decisions and the bids for lotteries based on the events. Preference reversal is a familiar effect in human behaviour. The frequency of predicted reversal was significantly decreased in the verbal relative to the numerical display mode. This means that subjects were much more consistent (an arguable merit) in their verbal than in their numerical expressions.

A second important result was that people can reach an agreement much faster when using the verbal mode of communication (Erev *et al.*, 1991). Because not everyone understands imprecise communications identically, verbal communication benefits society in certain situations (but not all) by facilitating heterogeneous choices. One experiment demonstrated that the frequency of vague communication increases in a controlled social setting when its use is beneficial for the group.

Comparative probabilities have been studied in a systematic way by Huber and Huber (1987). Let us stress some results. Lay-people (adults as well as children) use comparative verbal probabilities much more often than numerical ones. They use them for tasks of an objective nature (spinning a circular disc) as well as for tasks of a subjective nature (sports competitions, games). According to those authors, the evaluation of comparative verbal probabilities is much more reliable than for quantitative probabilities.

8.1.2. Consideration of alternatives

The two methods differ considerably in terms of whether they force the consideration of alternatives. The qualitative approach seeks resolution of the decision problem by engendering a search for another alternative that has not previously been considered. As seen in the Yamal case, this alternative can be a new option developed by altering the negative features of one option from those given initially. The quantitative approach, although it can consider other alternatives, does not use their creation as a tool in the analysis. Someone looking for alternatives could use a qualitative analysis to see where the largest disadvantages of the existing options lie and try to develop a third new one based on it. Here again, the quantitative approach does not force considerations of alternatives, but mainly reduces the differences between existing options to numbers.

8.1.3. Complexity reduction

The qualitative approach eliminates much of the complexity by reducing the questions down to the bare essentials of difference. In the Yamal pipeline case, this difference came down to a trade-off between environmental impacts and cost. Although the qualitative approach can reduce several factors to numbers, as was the case

there in reducing uncertainty to a dollar value, it does not try to equate *everything* to dollars. This approach has the advantage of clearly highlighting the main differences.

The quantitative method does not so much reduce the complexity *per se*, but brings to bear a common denominator. A chief issue between the two methods is whether the numbers created under the quantitative approach are 'real': do they truly reflect psychological states, i.e. states in which numerical intervals are equidistant and values placed on different impacts in fact follow a common scale and are thus comparable?

8.1.4. Providing the desirable decision output

The NDA approach ultimately gives a utility value to each option. After that, it is possible not only to nominate the best alternative but also to specify the difference in utility between the options. This means that the output of NDA methods is rich enough to give DMs the basis for detailed evaluations and comparison of any options, including any new ones.

In using a VDA approach, one is trying to construct a binary relation between options. Two options can be in a relation of dominance, equivalence or incomparability. In the latter case, they cannot be compared on the basis of psychologically valid operations of information elicitation. This means that the VDA approach cannot give recommendations to DMs in the incomparability case.

8.1.5. How exact is exact enough?

Experiments were carried out at Texas A&M University, where students solved the same experimental tasks using three different decision support systems (Larichev *et al.*, 1995a). Two of these were based on MUA and represented the NDA approach. One system (ZAPROS) was from the toolbox of VDA methods (Larichev and Moshkovich, 1997). ZAPROS is a decision support system for constructing a partial order over a set of options (not all options are comparable). It does not require the conversion of qualitative measures into quantitative form.

The results of the two systems based on MUA are much less coincident with each other than with results obtained through ZAPROS. This suggests that quantitative methods are *very sensitive to small errors* in DMs' and experts' answers.

8.1.6. Mitigating uncertainty

One universally accepted goal for decision method application is reducing the confusing effect of an uncertainty. The approaches deal with uncertainty in very different ways. VDA, at least in the Yamal case, examined the cost of reducing uncertainty. That is, it converts it into a monetary figure: how much will reducing uncertainty to an acceptable amount cost? Even if DMs do not decide to pay for that reduction, it is not an unknown. A public debate can be pursued in which the cost of uncertainty carries a concrete figure. The NDA approach attempts to quantify the amount of uncertainty. Here again, the DM has to be able to think in numerical terms to provide all estimates. The pay-off is that the analysis can derive a single estimate of uncertainty to go with the single estimate of utility. Moreover, the uncertainty can be graphically presented.

8.1.7. Time spent and cognitive burden on DM

From a practical point of view, it is important to stress features of the method that minimize the time needed and the cognitive burden. We have such evaluations for both approaches. NDA was applied to a new, but live, case similar to Niakuk, with two options and 30 criteria. The elicitation of preferences and judgements from a project manager, who had a bachelor's degree in biology and was unfamiliar with the approach, took about four hours. She had been concerned about diverting time from another pressing commitment in order to participate in the exercise. However, afterwards she said that the process of elicitation with immediate computer feedback on the permitting implications helped her to think effectively. Moreover, it took no more time than she would otherwise have had to spend on making a recommendation on the permit. She did not find the answering to be cognitively uncomfortable.

In the Yamal case, the DM spent less than one hour answering the questions needed to compare two initial options. Thus, the time burden was still less than NDA. The questions were posed in natural language and the DM was not really aware that a decision method was being used.

8.2. Institutional criteria

Institutional criteria include: how communications in and between organizations can be improved; how easy it is to use the approach; which approaches are vulnerable to cultural differences.

8.2.1. Improvement of communication

Both approaches may be considered an improvement over the often-confused discussions surrounding oil and gas development in the Arctic. Achieving greater clarity does, to some extent, provide improved communication.

The VDA approach more directly serves communication because the sentences taken from the language used by the DM and active groups comprise the verbal quality grades on the criteria scales. The VDA approach is well adapted to reality. This means it does not require from either the DM or the expert any prior knowledge of decision methods, but makes the method 'invisible' to a user. The method is a completely natural tool for the user, and is adapted to ways of information exchange pre-existing within and between organizations.

On the other hand, the NDA approach can present its findings in graphically telling forms because of its numerical basis. Our research did not specifically attempt to measure improvements in communication, but other regulators who work with the CoE agreed that the analyses were improvements. This area will be the subject of future research.

8.2.2. Cultural differences

It is necessary to stress the cultural differences influencing the applicability of different approaches. Numerical evaluations are more common in American than in Russian culture. Acceptability of numerical evaluations, even in cases of difficult public choice, is demonstrated by the use of so-called 'contingent valuation', which requires one 'to put a price tag on goods not traded in any market place' (Fischhoff, 1996). In addition, cost-benefit analysis is required for significant federal actions. That is why NDA is accepted more widely in the US than in Europe.

8.3. Personal criteria

Among personal criteria, it is natural to include: what level of education has the DM reached; and how do the professional habits of a consultant influence the selection of an approach.

8.3.1. Educational level of the DM

The DM has to be educated enough to know how to obtain a valuable output from the analysis and to know how to use a consultant's help. It is a question of practical experience and intellectual ability of the DM. Such qualities are prerequisites for the utilization of any analytical technique.

Personal education in DA helps the DM to accept the NDA approach. VDA methods do not require from a user any specialist knowledge in DA. The VDA approach is especially appropriate in situations where a decision is taken in new circumstances or in conditions of uncertainty.

8.3.2. Professional habits of a consultant

Consultants working in different countries often use quite different analytical techniques in the process of analysis. French consultants use ELECTRE methods (Roy, 1996) much more often than AHP methods (Saaty, 1980). Russian consultants use VDA methods. MUA and AHP are the most popular DA methods in the US.

The existence of different schools of decision research defines to a great degree the toolbox and professional habits of a consultant. There are positive and negative consequences of this situation. A positive one is that it is possible to stress the professional habits developed by the consultant in dealing with one kind of analytical technique. DA is a combination of art and science. To develop the art of successful application of a decision analytical technique, one has to practice it. A negative consequence of the consultant's attachment to one kind of analytical technique is that it limits the number of possible analytical tools that can be successfully used for different kinds of practical problems and fosters the utilization of one analytical technique in cases when a quite different approach would be more effective.

To a large extent, the negative consequences are defined by the contemporary state-of-the-art in DA. This field of research lacks comparative studies of the conditions for the application of different analytical techniques. We noted above the difficulties in undertaking such studies. However, the maturity of a research field may be reflected in its ability to classify and match its tools and tasks.

9. CONCLUSION

The case studies had a practical value for the DMs. In the Russian case, a new option that was acceptable to the majority of active groups defined the future development of the big project. In the American case, a framework for regulatory decisions has been developed (Flanders *et al.*,

1998). The last 30–40 years of experience in applying decision analytical techniques has demonstrated that there are no universal tools for any kind of problem. Similar decision problems are successfully solved by analysts from different countries using quite different tools.

The usual line of research is to use laboratory studies to develop and evaluate some tools for the real world (Fischhoff, 1996). The research presented in this paper took the opposite direction: to study the applicability of tools for the real world and to formulate new problems for laboratory research. Such an approach has its merits and could give a consultant an additional perspective on how different tools relate to the particular features of decision-making problems.

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