COMPLEXITY AND UNCERTAINTY IN ARCTIC RESOURCE DECISIONS: THE EXAMPLE OF THE YAMAL PIPELINE

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Abstract: This paper describes how a qualitative form of analysis, developed by Russian decision scientists, was used to assist Russian governmental organizations in deciding whether to route a gas pipeline over land or under sea on the Yamal Peninsula in Siberia. Complexity was reduced, and uncertainty translated into cost, through the development of superior alternative options. The analysis suggests, more generally, that Arctic resource decisions can be restructured to make tradeoffs clear and, perhaps, more understandable to a broader audience.

INTRODUCTION

> Unlike good science, good policy analysis must deal with opinions, preferences, and values, but it does so in ways that are open and explicit and that allow different people, with different opinions and values, to use the same analysis as an aid in making their own decisions (Morgan, 1978, p. 971).

Society's need to preserve the physical integrity of the Arctic and to manage its natural resources soundly and defensibly calls for systematic integration of conflicting economic, social, and environmental considerations. Decisions of this sort are common in the Arctic because most resources, even in long-time capitalist countries, are publicly owned or at least publicly regulated. The array of considerations arising during oil and gas development reflects a variety of public and private concerns. The development of oil and gas fields and the construction of pipelines to carry their products have proved particularly controversial in the North American Arctic (Berry, 1975; Berger, 1977; Westermeyer, 1987). A

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seemingly paralyzing constellation of considerations characterizes oil and gas development, as commercial, indigenous, local government, environmental, and national concerns intertwine and compete.

In Russia, following the opening of the economy and the drive to obtain export income, oil and gas development now also must be publicly justified (Osherenko, 1995; Chance and Andreyeva, 1995). One instance has been the proposed construction of a gas pipeline around or across Baidaratskaya Bay, on the western side of the Yamal Peninsula (Fig. 1). Gas field development on the peninsula had been stalled following a critical state expert commission's report (Expert Commission, 1989) that pointed out the possible environmental damage to the resources of the area, resources that are of regional, national, and international significance.

In 1993, however, Russian President Boris N. Yel'tsin declared that the Yamal gas fields were to be developed. Thus, the most difficult decision now has been made. Other complex issues, however, remain. Moving gas from the Bovanenkovo and other fields to the main pipeline in the south requires the construction of a new pipeline system. A conventional (inland) route would run southward down the western part of the peninsula (Fig. 1); a shorter, alternate route, located farther west, would include an underwater crossing of Baidaratskaya Bay.

The choice between these two routes is controversial, complex, and filled with uncertainty. Construction is being pushed ahead and the government soon must make a decision. It must do so based upon available information, which does not lead to a clear preference. Uncertainty, therefore, surrounds the decision, uncertainty that is difficult to remove. In this paper we examine the process whereby a pipeline construction research institute charged by the Russian Government with recommending a route arrived at a decision. We demonstrate how a structured analysis was used to help make and validate the choice. The case study is part of a research project designed to develop and compare the application of Russian and American decision-aiding techniques to Arctic environmental decisions.

DECISION ANALYSIS

Decision analysis in the research reported here refers to a particular body of work associated with analyzing and improving the way in which decisions are made. The techniques employed are not intended to supplant experts or decision makers, but to help those people clarify their choices and utilize their judgment and knowledge more effectively, both to gather information and to select among "terminal" options.

A medical analogy may help communicate the role of decision analysis. A physician, upon encountering a sick person, decides whether to order one or more tests to help her diagnose the problem. That determination depends on how diagnostic the tests are believed to be and the risk of making a serious error without them. In decision analysis, this would constitute the information-gathering stage. From the tests and any other information, the physician may diagnose (infer) a disease, with greater or lesser conviction. In many cases, these two steps will provide her with a clear answer and a definite therapy (her terminal decision). In other cases, however, she may to have make a non-obvious choice

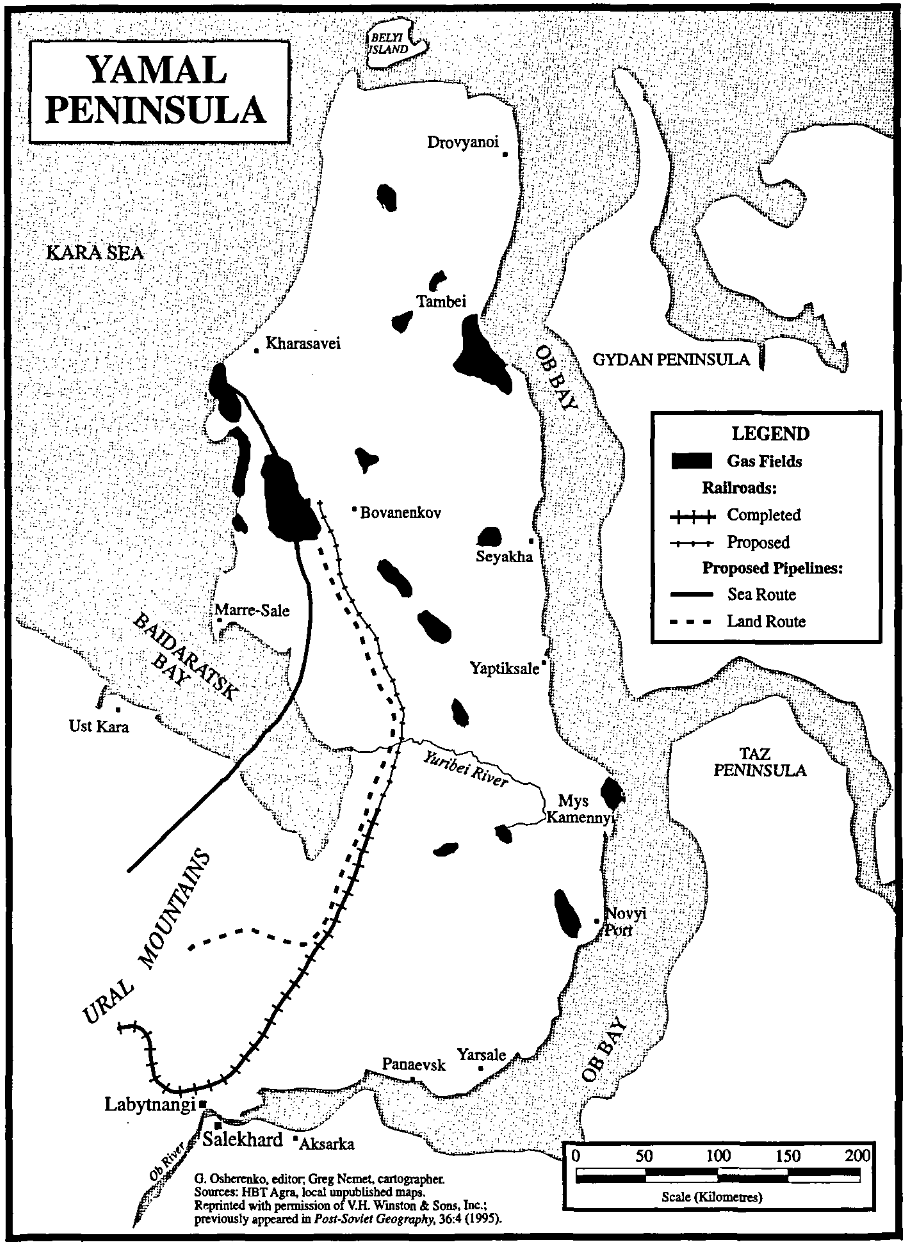

Fig. 1. Yamal Peninsula.

among two or more therapies. This choice may be difficult because of uncertainty (ambiguity in the diagnosis, with the risk of treating for the wrong disease) or because of conflicting objectives (prolonging life traded off against making life more comfortable). The doctor may make a "gut" decision, based informally upon her own experience, or use formal decision analysis to systematically organize the various considerations that her "gut" would take into account intuitively. It may or may not produce the same choice. The considerations may be organized quantitatively, using probabilities of diseases and utilities of consequences for the patient (the numerical decision analysis or NDA approach), or it may be qualitative, as in the present categorical decision analysis (CDA) approach, resembling closely how the doctor normally thinks through the problem. In any case, it is a representation of personal judgment, rather than, say, an expert system or an attempt at deriving an objectively "correct" decision (Larichev, 1987).

In the case of the Yamal Pipeline, two serious route options (terminal decisions) were under consideration. Decision analysis seeks to improve and explicate decision making by clarifying choices and grounding the decision in a consistent logic. It formally describes the considerations that go into a choice—options, goals, and predicted consequences—and demonstrates their logical implications for action. There are two basic variants: quantitative and qualitative. The quantitative approach, i.e., numerical decision analysis (NDA), represents uncertainty and value judgments in the form of numbers (probabilities and utilities) and computes the preferred choice in terms of, say, maximum expected utility (Watson and Buede, 1986). NDA has been widely used in the West in government and other applications (Brown 1987). The qualitative approach, categorical decision analysis (CDA), relies primarily on natural language and on non-numerical categorization (Larichev et al., 1995). CDA has been most fully developed and used in Russia (Larichev and Moshkovich, in press). The Yamal pipeline decision was selected as the first case study to illustrate the Russian CDA approach applied to a Russian case and is the focus of this paper. The methodology is described in Larichev et al. (1995), along with a brief indication of how it might have been addressed using NDA. A parallel case illustrating the American NDA approach applied to a North American case (permitting oil construction projects in Alaska) is currently being developed (Brown et al., 1995).

BACKGROUND ON PIPELINE ISSUE

Under its current energy policy, Russia is seeking to increase the share of natural gas in its domestic fuel balance. This policy is premised not only on an ecological preference for gas, but on the more advanced technological capabilities of the Russian gas industry. An emphasis on natural gas will support a strategic Russian industry (cf. Porter, 1990) and assist in the rapid stabilization of the economy as a whole.

Over the last 30 years, the exploration and development of new gas (and oil) fields have served as the foci of the Soviet governmental investment policy (Gustafson, 1989). The success of exploration and the increasing export of oil and gas encouraged this investment practice. Now, given a severe Russian federal budget deficit and the complex financial situation of both the oil and the gas industries, thorough assessments must precede major investments in new gas development projects. These assessments often employ comprehensive systems analytic methods.

The most promising region for development of new natural gas reserves is in

West Siberia, which contains over 80% of Russia's known gas reserves. The general decline in the country's industrial production has affected even the well-being of the gas industry, representing one of the last sectors of the economy to register falling output. The first absolute reduction in output came in 1993, amounting to 26 billion cubic meters below 1992 production. In 1994 Russian gas output declined by 1.7%, and fell by an additional 2.3% for the first half of 1995. Thus, preventing further declines in production, at least for the next 2-3 years, is central to the government's program to revive the energy sector. After that, steady growth is expected to result from the development of large new gas fields, primarily located in the far north of West Siberia.

The Yamal peninsula has become the key to realizing this goal. Its potential natural gas reserves are in the 10 to 20 trillion cubic meter range, according to various experts' estimates. Yamal gas and oil resources thus are recognized as one of Russia's great commercial assets.

The main element of this project is a system that will deliver gas from the west-central part of the peninsula to the main pipeline in European Russia. This system will consist of three pipelines with a projected gas transmission capacity of 83 billion cubic meters per year. These pipelines must cross Arctic and subarctic tundra with complex areas of permafrost and swamps dotted with numerous lakes. Building materials, such as gravel, are scarce. The length of the new pipeline depends on the variant selected. After consideration of several variants, project planners have selected two alternatives for further study. The more direct variant ("sea route," 496 km) crosses Baidaratskaya Bay, thus avoiding the northern reaches of the Ural Mountains; a somewhat longer (all-land) route extends southward along the western part of the Yamal Peninsula, then turns to the west, and crosses the Ural mountains (654 km) (Fig. 1).

Each variant has certain advantages and disadvantages. To clarify these options and to select the best one, a feasibility study was prepared. Initially, the Gas Project Institute in St. Petersburg (Giprospetsgaz), which preferred the land route, had responsibility for the development of the project. Later, another gas planning and design institute (Yusniiprogaz), located in Donetsk (Ukraine), but traditionally involved in developing gas pipeline projects in the North of the former Soviet Union, became the lead institute; it advocated the sea route. Now both institutes are participating in the feasibility study, and both are insisting upon their initial points of view. During the last two years, Gazprom, the monopoly joint-stock company formed out of the former Ministry of the Gas Industry, has held several hearings regarding the selection of an option. Provisionally Gazprom's leadership has concluded that the sea route is preferable. In their view, the high probability of accidents resulting from complex permafrost and hydrological conditions along the land route make its first 496 km, in actual practice, comparable to the totality of sea route in terms of the risk of accidents. When the additional 158 km of the land route and the need to cross the Ural Mountains are factored in, the land variant is less desirable than the sea route. The sea option supporters acknowledge that the construction and use of that variant of the pipeline will involve uncertainties and predictable obstacles that will require expensive special technology. But, if the difficulties are all overcome, they argue that Russia will have gained experience of global significance, placing oil and gas development of the Arctic Basin's outer continental shelf in a new and more favorable perspective.

Although Yel'tsin had decreed a 1993 start, the project has not yet commenced. The investigation of natural regimes and distinctive features along the routes has required more time than had been expected. Investment remains a major problem, the plan being to use monies from the federal government, gas company funds, and foreign participants. By the end of 1993, however, government and gas company funds had proved insufficient to start construction. Foreign partners are not yet identified, and thus negotiations are still under way at Gazprom in 1995. The most recent edition of the feasibility study has passed the evaluation of the special commission established by Gazprom in 1993. This edition represents completion of the first stage in what is to be Gazprom's final assessment in selecting a pipeline route.

Choosing between the two options depends on unknown (or, at best, incompletely understood) natural conditions and on contradictory appraisals of the alternatives. A consideration of these alternatives follows. The different groups involved—private companies, the indigenous peoples, local governments, and the central government—favor one alternative or the other. Politically, the preference of each group must be considered in making a decision. The description of the two options below is based on the analysis of the Donetsk institute (Yusniiprogaz). It recommended the "sea route" and is now recognized as the lead research institute on the project feasibility study.

RESEARCH/CONSULTING PROCESS

Two Russian members of the research team had several meetings with Gazprom decision makers and then spent several days with Yusniiprogaz personnel—a team of engineers and their leader, who developed the feasibility study—as well as with decision makers. Reports of both institutes involved in the preparation of the feasibility study were used in these meetings. Gazprom had requested that Yusniiprogaz come up with a recommendation based on the totality of the evidence. Thus, although not providing the sole perspective on this issue, Yusniiprogaz has played a key role in its assessment. At the time of the visit, the sea route had been submitted by the authors of the feasibility study to Gazprom as the only one recommended. From the institute's perspective, all relevant data had been collected and the problem defined. But had the right decision been made and, given the complexity of the issue, could Yusniiprogaz justify its recommendation? From both the literature and discussions with experts, the following eight considerations were deemed critical to validation of the route decision:

1. *Route length*. The sea option is 496 km, some 160 km shorter than the land route, but 68 km of it is across the waters of the bay.

2. *Construction conditions*. Construction conditions are difficult for both options. The land route must cross a large expanse of permafrost, rivers, and lakes. The sea route requires working during

a limited period (2-2.5 months) each summer when the bay is free of ice. The part of sea route that crosses land has the same permafrost conditions and water obstacles as those found along the land route.

3. *Available expertise and technology.* Russia, as well as other countries, does not have the appropriate technology for sea-bottom construction in an Arctic basin. It does have considerable experience in building pipelines across land in permafrost areas. A Dutch company, Haarema, was initially selected to develop the sea route. Although a final agreement has not yet been reached, Haarema is likely to be designated as the main partner in these operations, within a new joint venture known as "Petergaz."

4. *Construction cost.* Cost is an important factor, but quite difficult to estimate. In principle, the cost of the land route can be calculated from the cost of labor, equipment, material and transportation. The past hyperinflation of the ruble has until recently made any attempt to estimate cost extremely difficult. The cost of the sea route involves additional uncertainties, because prior experience in construction under these conditions is lacking. The participation of the foreign firm increases the use of hard currency in all expenditures.

5. *Environmental impact.* Both options have a potential negative effect on the environment. The land route will cross many ecologically important habitat areas and migration routes, including reindeer pastures, wildlife refuges, hunting lands, and rivers and lakes famous for their productivity and fishing resources. The sea route, lying farther to the west and being shorter, will have comparatively less impact on the terrestrial ecosystems. It may, however, have unexpected impacts on the marine ecosystems of the bay during construction.

6. *Risk of pipeline ruptures.* The Baidaratskaya Bay situation is unique. Specific physical conditions here could contribute to an accident: (a) the shores of the bay are unstable because of nearly year-round permafrost action and sea-ice impact; (b) indications of ice scouring exist on the bottom of the bay; and (c) experts believe that icebergs can enter Baidaratskaya Bay.

7. *Consequences of pipeline ruptures.* An accident on the land-based pipeline would probably create an explosion and fire. The result would be the complete destruction of the vegetation cover, an upsetting of the thermal regime of the permafrost, and the possible death of wild animals. The repair work would create further extensive and long-term environmental damage. An underwater

accident would have much less environmental impact: it would not involve an explosion, the gas does not dissolve in water and is non-toxic, and the ice cover is not solid, thereby allowing gas to escape via cracks into the atmosphere. The appearance of an air-temperature inversion (promoting air pollution build-up) is not a concern in this unpopulated area, and is not likely to occur.

8. *Recovery time after an accident.* This factor affects the reliability of gas supply. In the land-route case, the pipeline could be repaired almost immediately. Repair of the underwater pipeline, on the other hand, could take a long time. Work would be limited to the 8-10 weeks when the bay is ice-free. Furthermore, the repair would require special equipment and techniques. One suggested engineering solution is to construct one extra line in the pipeline string into which gas could be diverted in the event of the rupture of one or more of the operating lines; in this case what would be involved is the construction of four pipelines instead of three. There are major uncertainties and risks involved here. The sea option with respect to this eighth consideration, therefore, clearly is much worse.

STRUCTURED COMPARISON OF OPTIONS

As noted above, the decision methodology employed was categorical decision analysis (CDA). CDA is based on research conducted in the former Soviet Union. It was developed for the solution of unstructured problems, which can be described largely only in terms of qualitative, uncertain factors, inasmuch as reliable mathematical probabilities and utilities are impossible to obtain. To create a reliable base for a comparison, natural language is used to describe the problem. CDA permits the ordering of the alternatives, their classification, or the selection of the best variant from among several alternatives based on multiple criteria (Larichev, 1992). Unlike the American NDA approach, it does not measure options on a "ratio scale" registering the magnitude of intervals.

For Arctic regulatory problems, the most appropriate method from the CDA toolbox is a variant of the ASTRIDA method (Berkeley et al., 1990), developed for problems of strategic choice under conditions of small number of alternatives and many criteria. The method permits the use of verbal estimations and comparative or nominal (not absolute) measurements. A test for preference independence (Keeney and Raiffa, 1976) for criteria having verbal estimations is incorporated. Alternatives are compared by pairs using a certain "verbal compensation operation." In the event that two alternatives are non-comparable or the best alternative is not satisfactory for the decision maker, the method allows one to define a direction in which the evaluations of existing alternatives can be improved. It creates an "image" of a desirable alternative.

Systematic analysis of options involved the distillation, from the eight considerations discussed above, of only those criteria demonstrating significant and clear differences between the options and focusing on them. Elimination of considerations where the differences between the two alternatives were very uncertain or otherwise undetectable was the first step. For example, one cannot readily measure the difference in construction time because it is highly uncertain for both routes.

The following six criteria (with symbolic abbreviations) were retained; for some, distinctive assessment issues for further research are identified.

1. *Cost of construction* (C). This includes any effect resulting from construction conditions and available expertise and technology discussed above. Assessment issue: This is one criterion that lends itself naturally to quantitative estimation. A foreign firm would estimate the cost of crossing Baidaratskaya Bay (C_{sea}) in United States dollars. How does one then estimate the cost of the land route (C_{land}), which would be paid for in rubles? The obvious solution is to convert the cost of the land route to U.S. dollars as well. The prices for the factors of production can be determined because international markets now exist in Russia for equipment, workers, and material. The initial estimates showed that C_{sea} is a little larger, but further research is ongoing.

2. *Ecological impact* (E). E_{land} appears greater.

3. *Probability of accident* (P). Assessment issue: Existing data on pipeline operations in the Russian North allow risk assessments for the land route. Known cases of gas pipeline accidents in mountain regions can add precision to these assessments. On the other hand, risk assessment for the sea route is difficult. Statistics do not exist for the operation of an underwater pipeline under severe Arctic conditions. Because of the unstable shore and the possibility of ice scouring, P_{sea} appears greater.

4. *Consequences of an accident* (Q). Q_{land} is clearly worse.

5. *Gas supply reliability* (R). This reflects the time needed to recover from an accident. No country, including Russia, has experience in conducting repair work under the sea-route conditions. The sea route would require, therefore, long-term observations and prolonged investment in scientific research. R_{sea} is clearly much worse.

6. *Uncertain and unknown factors* (U). Highly uncertain considerations affecting both options were not distinguished, but a major difference in overall uncertainty was treated as a criterion. The Baidaratskaya Bay route, because it is unique, involves many uncertainties and imponderables. U_{sea} is clearly worse than U_{land}.

Table 1 summarizes these preliminary comparisons, with the better option

TABLE 1

Evaluation of Land-Route and Sea-Route Options, Yamal Gas Pipeline, Russia[a]

Criteria	Baidaratskaya route	Land route
1. Cost	C_{sea}	***C_{land}***
2. Ecological impact	***E_{sea}***	E_{land}
3. Probability of accident	P_{sea}	***P_{land}***
4. Consequences of an accident	***Q_{sea}***	Q_{land}
5. Reliability of gas supply	R_{sea}	***R_{land}***
6. Uncertain and unknown factors	U_{sea}	***U_{land}***

[a]The more advantageous route according to a particular criterion is noted in bold italics.

highlighted for each criterion. The inequalities are all that can be measured. It may be that the compact display in Table 1 will be sufficient to enable some decision makers to make up their mind. If not, what other approaches can be used as the basis for such an important decision using such weak measurements?

DESIGNING NEW OPTIONS

Simon (1960) defines three stages in decision making: intelligence, design, and choice. Thus far most decision analysis (CDA and NDA, and other decision aids) has been devoted to the third stage, which is easier to formalize, and has focused on comparing existing options. Decision analysis, however, also may be used to enhance the second stage, by creatively inventing new options, and this approach was used here. By engaging only in qualitative comparisons, one can determine incomparability—i.e., a situation in which some evaluations are better for the first option and some better for the second. At this level, the greater uncertainty and lesser reliability of gas supply for the sea-route option results in an overall more negative assessment than the unfavorable ecological impact of the land-route option. But the negative consequences of an accident for the sea option are less than for the land option. Given the existence of incomparability, the ASTRIDA interactive computer method proposes to the user a direction for developing a new promising option by adjusting the evaluations for one existing option. The analysis shows that one cannot change the land option (the traditional way of construction). But it may be possible to change the sea option. The main interconnected disadvantages of the Baidaratskaya route are a greater uncertainty and larger probability of accident. The possible direction of development of new variants consists in finding a way to change these characteristics.

Discussions with the experts at Yusniiprogaz in Donetsk suggested ways in which the negative comparisons of the sea option could be removed. A new sea-route option was produced through a reduction in the amount of uncertainty as a result of the addition of certain technically feasible features to the original sea-route option:

1. To eliminate the influence of seashore instability, special shafts (tunnels to the bottom of the bay) could be constructed at a safe distance from the coast, and the pipeline routed through them. This construction will incur additional costs designated as C_{shafts}.

2. To avoid damage to the pipeline from ice scouring, the pipeline can be laid in special trenches 1.5 to 2 meters below the bottom of the bay. They would be deeper than the project plan calls for, so the costs, $C_{trenches}$, also will be additional.

3. Icebergs are a very rare but dangerous phenomenon in the bay. A special observation service and a special ship to drag the iceberg away would eliminate this problem (of icebergs damaging the pipeline by gouging the bay floor). 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 possessing an element of uncertainty that is approximately equal to the traditional land option. The probability of an accident for the new sea option, therefore, is not very different from that for the land option. With the development of a special repair service for the underwater trenches, the reliability of the gas supply could be made equal. Given these modifications, no significant differences exist between the sea and land routes, except for cost and ecological impact. The cost of the new sea option (C_{sea} + C_{shaft} + $C_{trenches}$ + C_{ice}) clearly will be more expensive. The land option still will create greater environmental destruction. But now the comparison can be considered as one between higher costs and better environmental protection. Such a comparison, between two factors, is easier to make and is more intuitive than the comparison of multi-criteria options.

As noted earlier, Yusniiprogaz decided in favor of the sea route. But the experts participating in the study reported here recommended additional field studies to clarify some unique traits of the natural processes. These studies are intended to increase pipeline safety and decrease the negative impact on the environment.

Despite the exercise above, uncertainty remains in either option. That is why consideration is limited to the factors for which essential differences truly exist. The decision analyst tries to reduce the problem to one with psychologically valid information-processing operations. In the present case, the comparisons of the options resulted in distinct evaluations on only two criteria (cost and environmental impact). Given such circumscribed operations, people produce much more reliable answers (Larichev, 1992).

DISCUSSION AND CONCLUSIONS

A point that should be reiterated here is that the above analysis reflects one key decision maker's (Yusniiprogaz) decision; it does not represent an impersonal, objective analysis per se. The decision analysis did, however, help to objectify the decision-making process. In so doing, it opened the way for "good" policy analysis, as defined by Morgan in the opening quote. The analysis addressed a seemingly paralyzing array of problems by using an approach that enabled the decision maker, after data gathering and diagnosis, to rank the criteria and reduce the apparent complexity. Reduction at this phase is different from a claim that most assessments are, from the beginning, unnecessarily complex (cf. Hollings, 1978, p. 6). Rather, the point is that actual decisions can be made based upon a few criteria and that natural resource decisions may not be, in the end, as complex as they initially appear.

To reduce complexity, the analysis provided a means for considering uncertainty and in the process removed a major drawback of the sea route. Uncertainty in this study was reduced in part by incorporating technological innovations in the decision-making process, making it possible to avoid specific geographical features (the coastline), and in part through monitoring, to warn of events of unknown frequency (icebergs). This approach considers the value of uncertainty to be the cost of the technology and the monitoring needed to remove it.

With experience, an uncertain factor may be transformed into a risk of known probability. Because of this transformation, research and monitoring may be better ways to deal with uncertainty than a fixed technological solution. Furthermore, in considering uncertainty in these terms, the decision maker may be willing to accept some uncertainty to reduce cost.

Were the cost of the sea route lower than the cost of the land route, including the technology to remove the uncertainties, the choice would be clear. Because the cost of the sea route is greater, a balance between cost and the environment remains an issue. One cannot expect that all groups concerned with a resource decision will appreciate the new clarity. Some may oppose the entire idea of trading off cost with environmental protection, believing that even this sort of comparison does not capture the intrinsic value of either position. They may argue that the value of environment cannot be equated to or compared with a specific dollar figure (the environmentalist position), or that business efficiency should not be traded off against environmental consequences of unknown importance (the industry position). A business also may feel that it is better to conceal potential costs as uncertainties that must be borne by the public. That is, it may want to sell an apparent uncertainty to the government or public as a necessary social cost rather than, as done in this study, considering it as an explicit expense to be factored into the total costs of a particular option. Finally, some groups, whose tactics revolve around delay and obfuscation, may view an array of uncertain arguments as beneficial to this tactic.

On the other hand, a new option not only makes the main features of crucial choice evident for the government and public, it also creates a basis for an agreement between different active groups. The new option, offering a clear comparison between cost and environmental impact, creates a possible way out of a deadlock. As noted above, the Russian government, unlike its Soviet predecessor, no longer makes decisions unilaterally, but must demonstrate that the interests of all concerned groups have been considered. This method of analysis makes it possible for various groups to see how their rankings of criteria are similar or different. From this, they may see how they can yield on an issue that is unimportant to them in exchange for a gain in an area that is.

The new variant also can provide an invisible benefit to the oil and gas industry: it points out that the use of new technology often can provide new solutions to major future problems. The development of new variants to engineering problems involving uncertainty has proven significant in the past. The development of a passive cooling system in Trans-Alaska Pipeline supports came in response to environmental concerns, but saved the pipeline company considerable money in possible repairs. The system also yielded useful insights into other construction projects on permafrost. Thus, a decision-aiding methodology that draws out new approaches could have advantages beyond the simple clarification of difficult decisions. The use of ASTRIDA in this case study suggests that a systematic method for developing new variants to seemingly intractable problems is possible. Given the difficulties of Arctic resource decisions, its employment should be considered elsewhere.

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