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Comparing uncertain alternatives for a possible airport island location in the North Sea

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Abstract

This paper presents a methodology for making decisions based on uncertain information through the use of an analytical feasibility study of an airport island in the North Sea as an alternative to the present inland airport, Amsterdam Schiphol, in The Netherlands. The multidisciplinary project, called Flyland, quantified several conflicting aspects, including uncertainties, for each of five alternative locations for the new airport. The methodology combines the Analytic Hierarchy Process and Monte Carlo approaches and allows comparison of the alternatives on the basis of their morphological and ecological effects. The resulting scores rank the alternatives and quantify the distinctions between them by taking uncertainties into account. We found that with respect to morphology and ecology, it is most favourable to keep the Dutch national airport inland. The methodology can easily be extended to include other factors and reflect a wider range of multidisciplinary aspects (costs, accessibility, environmental aspects) of the airport island location.

1. Introduction

At the end of 1999, the Dutch government initiated a research project to study the feasibility of an offshore airport in the North Sea. This island should replace Amsterdam Schiphol airport (Fig. 1) from the year 2020. The project was called 'Flyland, Research Programme Airport in Sea' and started in 2001. Several aspects

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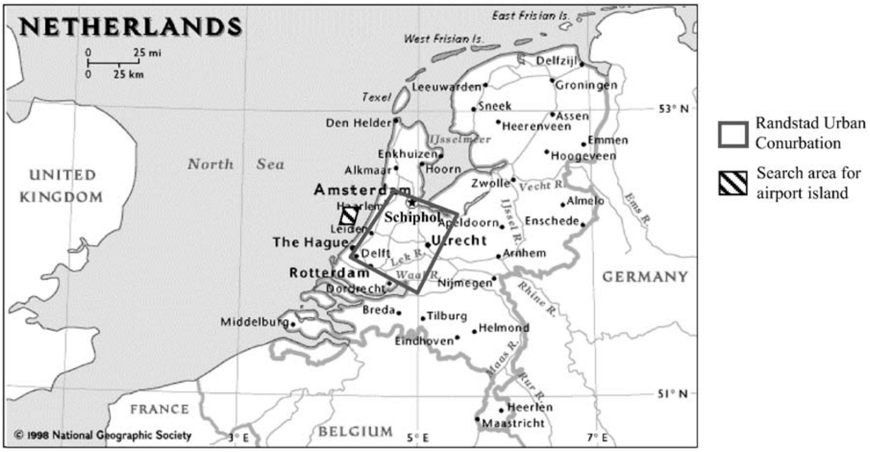

Fig. 1. The Dutch national airport Schiphol, located in the densely populated crowded Urban Conurbation the Randstad. The possibilities for an offshore island are investigated within a search area between 13 and 30 km from the coast.

of the island are being investigated, for example, marine ecology and morphology, accessibility, legal, financial and economical aspects (for more general information about the project, see the Flyland web site [1]).

Replacing Schiphol Airport by an airport island is a huge project, which has consequences for many people, groups and authorities. It is a multidisciplinary problem in which several conflicting interests have to be considered. Some effects of the airport island cannot be predicted very accurately yet. This is caused by the unique character of the project, the fact that the research concerns future developments and by the lack of reliable data and appropriate models. In spite of these uncertainties, a decision will need to be made at a certain point in time and this will probably be well before additional research might be able to diminish the uncertainties significantly. This limited time span also raises the question whether such a reduction in uncertainties is actually necessary for decision making. Otter and Capobianco [2] report that coastal managers are increasingly forced to take decisions based on information that is surrounded by uncertainties. This paper investigates whether it is possible to base a solid decision concerning the airport island on the current, uncertain information. Studying the decision process also leads to indications as to which part of further research should be given priority, so that the available research time can be spent efficiently.

This first stage of Flyland ended in October 2001 and is followed by a second stage that will continue until December 2004. We could therefore use only data from stage 1. The final report of stage 1 of Flyland [3] treats the predicted morphological and ecological effects of an airport island without the aim to recommend any decision. Other effects will be been evaluated in the next stage.

In Asia, several airport islands have already been built but under different conditions. Besides, no comprehensive studies of the decision-making process were made—or have been reported—for those airports. Sen and Yang [4] describe methods for decision making under uncertainty. Alternatives are compared for a number of criteria and scores for the alternatives are determined. However, none of the existing methods is suitable for application in the decision concerning the airport island, because they do not comply with the relevant multidisciplinary and uncertain information as is available in this case. The available methods either deal with multiple criteria or with alternative-specific differences in uncertainty of a criterion; the combination of both multiple criteria and alternative-specific differences in uncertainty of each criterion has not been made before.

This paper presents a method to arrive at a decision in a large, multidisciplinary project, in spite of uncertainties about the effects of the different alternatives. The combination of two existing methods makes it possible to evaluate the various effects of the alternatives, including their uncertainties. This method was successfully applied towards alternatives for an airport island in the North Sea on the basis of the theme Marine Ecology and Morphology. Other research themes could not be considered here, as information on them is not yet available. However, the method allows taking them into account if they can be expressed quantitvely.

This paper is built-up as follows. In Section 2, the research on the airport island in the North Sea is introduced. The island alternatives are described, together with expected effects. Section 3 treats the method for making a comparison between the island alternatives. Section 4 contains the comparison of the results and Section 5 discusses their reliability. Finally, in Section 6 conclusions are drawn.

2. The Flyland project

A search area was defined for the location of the possible airport island in the North Sea. Its eastern boundary is 13 km from the coast, the northern boundary is at IJmuiden, the western boundary is 30 km from the coast, and the southern boundary is at Scheveningen. Fig. 2 shows the island alternatives that were considered. They are research alternatives, which means that they have no social or political meaning but are just chosen to investigate the limits of the effects to be expected. Alternative Base is the main alternative, the other alternatives are moved with regard to this alternative: alternative North is located further to the north, alternative Cross further offshore and alternative South further to the south. The location of the airport island influences several processes in the sea, as well hydrological as morphological and ecological, for example currents, sediment transport and the transport of organisms to the coast. Furthermore, the extent of a harmful effect depends on the location it strikes. The last alternative that is investigated is alternative Size, which is 25% bigger than alternative Base. The size of the island also influences several processes and for example determines the amount of silt that should be dredged for building the island.

The effects of the island alternatives were all determined in comparison with the future effects of the present inland airport Amsterdam Schiphol, here indicated by V_0 (Alternative 0, i.e. ‘do nothing’) [3]. This alternative includes all effects that are

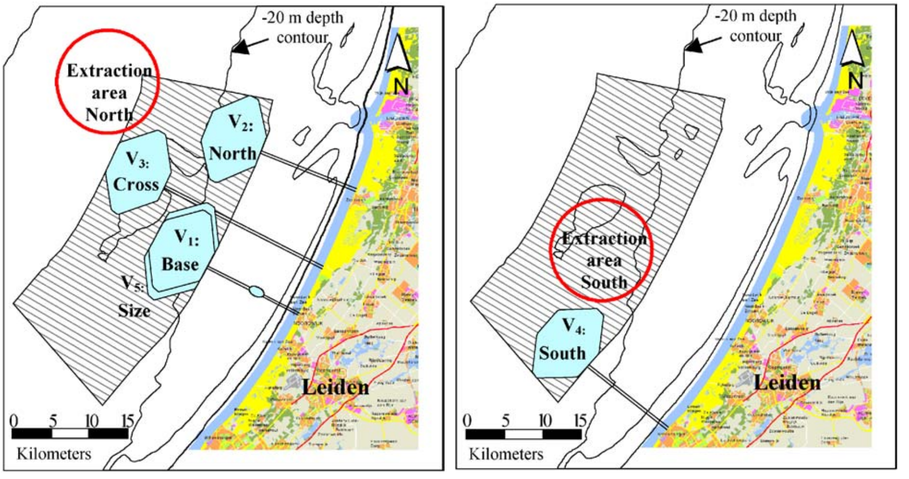

Fig. 2. Five island alternatives (Base (V_1), North (V_2), Cross (V_3), South (V_4) and Big (V_5)) and two sand extraction areas (North and South) are investigated. Alternative Size (V_5) has the same location as alternative Base (V_1) and is 25% larger.

expected in case the airport island is not build and the airport has to expand on its present location.

Our ability to predict the natural developments is still quite limited. Therefore, many natural processes had to be simplified in the Flyland project or could not be included at all. An example is the long-term morphology of the seabed. The seabed is not flat, but covered with various types of large-scale seabed patterns. At the moment, we understand why which large-scale bed patterns occur in the North Sea [5]. However, we cannot predict their wavelengths, amplitudes or spatial variations, but they do affect ecology because, for example, ecologic activity is known to occur mainly in troughs of large-scale sand ridges or sandwaves. The morphological seabed evolution should be included if we want to predict, e.g., the effects of silt loss on marine ecosystems during the island's construction.

We are only beginning to understand the generation mechanisms of long-shore bars along the coast and cannot yet explain the difference in their behaviour North and South of the IJmuiden harbour moles [6]. This spatial transition in behaviour might be related to the nonlinearity of the system, leading to multiple equilibria. Predicting the morphologic evolution due to autonomous development (natural processes and human interventions) is even less explored at the moment. Roos and Hulscher [7] present an overview of the larger-scale man-made structures (e.g., sand and gas mining, navigation channels). Data assimilation techniques enhance our ability to predict [8,9], but their application is still limited to idealised cases so that such knowledge cannot be used for reducing uncertainty in the Flyland project.

The eight research themes of Flyland cover the various multidisciplinary effects of an airport island (Table 1). In this work, we used the predicted effects of the final report of stage 1 of Flyland [3] for morphology and ecology without further

Table 1
The eight research topics of Flyland

Nos.	Research topic
1	Marine ecology and morphology
2	Birds and flight safety
3	Accessibility
4	Operational integrity
5	Spatial planning
6	Environmental aspects
7	Legal aspects
8	Financial/economic aspects

The research of topic 1 started first and is the only one that could be taken into account in this paper.

questioning the correctness of this information in itself, as the latter was not the aim of our study.

The construction of an airport island—including the sand extraction necessary for the construction—affects organisms like fish, birds, and sea mammals and user interests such as fisheries, public safety (protection of the coast), the shipping industry, and recreation. An example of an effect is the appearance of a silt plume during the construction of the island; large quantities of silt may be lost as a plume in the water column during sand extraction. Less light will be able to penetrate and this would lead to reduced growth and species shifts in algae. This is likely to affect the entire food web. Moreover, the change in composition of algal species might generate a permanent foam layer on the Dutch beaches. Sand extraction activities in themselves also signify a disturbance of the local ecology.

3. AHP and Monte Carlo methods combined

The method used in this paper for the comparison of alternatives is a combination of two approaches, the Analytic Hierarchy Process (AHP) and the Monte Carlo method. The former is a variant of a multi-criteria analysis, introduced by Saaty in the 1970s [10]. This intuitive and relatively easy method for making decisions has been successfully applied in a wide range of problems [11–13]. The AHP attaches weights to criteria in a more or less systematic way and determines how well each alternative scores on each criterion [10,12,14]. If uncertainties are ignored, the scores are unique, i.e. single-valued.

In the case of the airport island in the North Sea, it is impossible to determine unique scores because the uncertainties are considerable. We extended the AHP with information about uncertainty by combining it with the Monte Carlo method, which takes the range of possible values of the variables and their probability into account [15,16]. This resulted in a probabilistic score of each island option on the various criteria. It allowed us to evaluate differences in scores but also a possible overlap

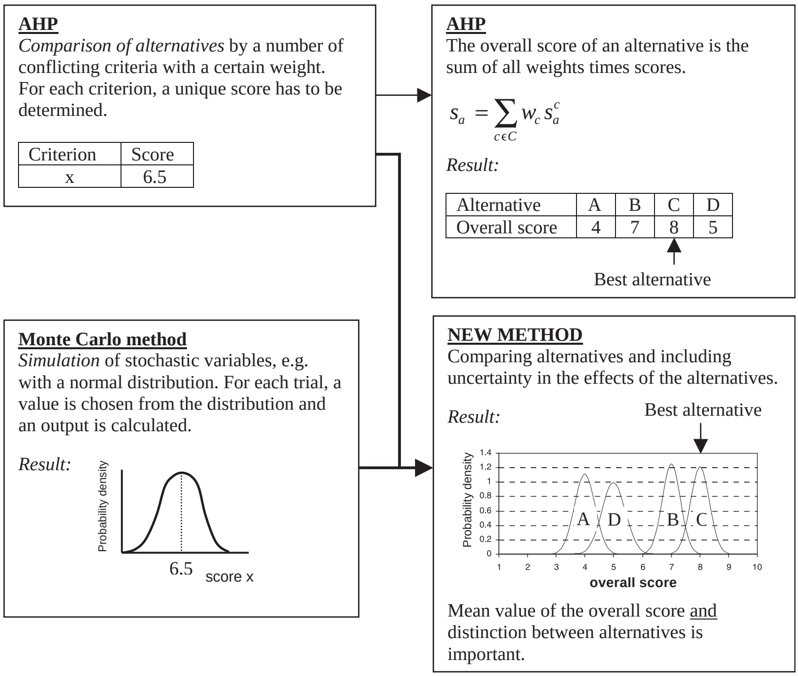

Fig. 3. Combination of the AHP and Monte Carlo approaches in a new method.

between them. Fig. 3 illustrates how the AHP and Monte Carlo approaches are combined.

3.1. *Selection of the set of criteria*

The first step in applying the new method is determining a set of criteria to be used in the comparison, i.e. specifying the effects on which the alternatives are compared. Sen and Yang [4] and Baird [17] describe a number of conditions that a set of criteria has to satisfy. The most important ones are that the criteria should be minimal, complete and not redundant. That means that all aspects of the decision problem should be considered, but non-relevant aspects should not be included and aspects of the decision problem should not be considered twice.

As effects that are equal for the five island alternatives would not enable us to distinguish between them, we only looked at those effects that differ between the alternatives. For example, we did not include the risk of foam on the Dutch beaches due to toxic algae species (see Section 2) because the predicted effects are the same for all alternatives [3]. Furthermore, effects that are obviously too small to generate a significant distinction were omitted. For all alternatives the changes in water depth in lee of the island are for example so small, i.e. smaller than 1% [3], that this criterion is not included.

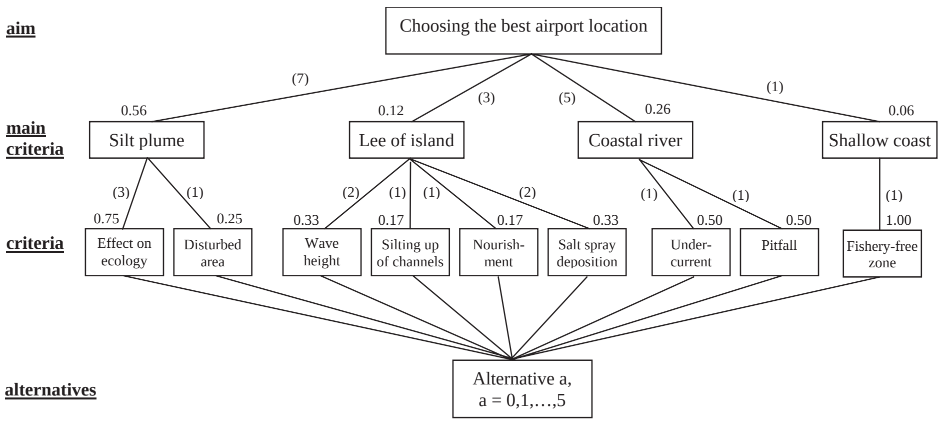

Fig. 4. Hierarchy of the decision problem, consisting of main criteria and secondary criteria. The main and sub-weights of the criteria are shown as numbers above the text boxes. The numbers between brackets indicate how much more important a criteria is considered to be than the other criteria in its branch.

Applying these rules to the Flyland case led to the nine criteria presented in Fig. 4. Four main criteria were used to describe the morphological and ecological effects of the island alternatives:

1. the extent of the 'silt plume';
2. the extent of the 'lee of island' region where wave heights and transport of sediment along the coast are affected;
3. the strength of the 'coastal river' formed by the fresh water discharges from the rivers Rhine and Meuse, which flow along the coast as a plume to the North (this also affects the transport of for example fish larvae to the coast);
4. the reduction of the 'shallow coast' region, which is ecologically important and therefore also influences user interests like fisheries.

In order to arrive at a set of mutually independent criteria, a splitting was made into main and secondary criteria (see Fig. 4). This ensures that the various aspects of the decision problem were only considered once [12]. The AHP approach was applied to the two levels.

3.2. Determination of weights

The AHP approach to determine weights consists of a pair-wise comparison [10,12,14]. For any pair of effects, the user or group of users determines (subjectively) which is more important than the other. The AHP contains a standardised procedure to translate this into weights in a non-subjective manner.

The numbers between brackets in Fig. 4 express the relative impact of each criterion within its branch. Of the main criteria, we judged the criterion 'silt plume' to be the most important—which means 7 times more important than the least important main criterion, 'shallow coast' (for the interpretation of these values, see

Appendix A.). The (subjective) reason for considering the 'silt plume' criterion as the most important one is that it describes permanent effects that would affect a very large area in the North Sea. The second most important criterion was determined to be 'coastal river' because these effects are also possibly permanent, but involve a smaller part of the North Sea than the 'silt plume' criterion. We considered the 'lee of island' criterion less important than the first two criteria because it involves effects that can, to a large extent, be overcome by restraining measures and are not irreversible. Furthermore, this criterion involves only the area in the lee of the island (a smaller area than involved in the first two criteria). We estimated the criterion 'shallow coast' as least important because it relates to just a very small area around the airport island and its effects will therefore be limited.

Of the secondary criteria of the criterion 'silt plume' (see Fig. 4), we considered the 'effect on ecology' to be more important because its effects concern a larger area than the 'disturbed area', which is concentrated around the island and the sand extraction activities. For the criterion 'lee of island', we determined the sub-criteria 'silting up of channels' and 'nourishment' to be less important than the other two because they merely involve more maintenance while the other two can form a threat to the safety of the coast and the ecology of the dunes. The AHP method then established weights for the criteria and sub-criteria by using the numbers between the brackets in Fig. 4 [9,11,13]. The resulting weights are shown above the boxes in Fig. 4 and the total weights in Table 2.

3.3. Normalisation of effects to scores

The criteria from Table 2 all had different units (e.g. %, km/day or km^2) so we needed to normalise them before we could add them to an overall score for each alternative. If the effect of alternative a on a criterion c has the value X_a (e.g. an area

Table 2
Criteria and weights used in the comparison

Main criterion	Weight (w_c)	Criterion (c)	Weight (w_c)
Silt plume	0.56	Effect of loss of silt on ecology	0.42
		Disturbed area	0.14
Lee of island	0.12	Change in wave height	0.04
		Silting up of channels	0.02
		Change in need for beach nourishment	0.02
		Change in salt spray deposition	0.04
Coastal river	0.26	Decline of coastward near-bed current	0.13
		Pitfall	0.13
Shallow coast	0.06	Zone without fishery around island	0.06

The weights (w_c) for the criteria (c) considered here consist of the product of the weights of the main criteria and the weights of the sub-criteria (see Fig. 4). The values for both main and sub-weights are based on the AHP method.

in km^2), a score between 1 (worst) and 10 (best) is determined from

$$s_a^c = m^c X_a + n^c, \tag{1}$$

where m^c and n^c are constants that limit the score to the interval just mentioned. Eq. (1) transforms the dimensional effect of an alternative into a score between 1 and 10, so that all effects of the alternatives can be weightily added and alternatives can be compared.

3.4. Quantification of the uncertainty in the effects

What is new in our approach is that it takes uncertainty into account, which therefore needs to be quantified. This can be done by using the Flyland research results [3]. For each predicted effect, a probability distribution can be determined that represents the range of values the effect can assume and the probability distribution for values in this range (for details see [18]). For most of the criteria, we used a normal distribution (characterised by the mean value, μ_c, and the standard deviation, σ_c). In cases where negative values cannot occur, we applied a Rayleigh distribution. Finally, for criteria for which no information was available except an indication of the range of possible values, we assumed a uniform distribution.

An example of a criterion with a normal distribution is 'Change in wave height'. The mean value μ_{c3} was presumed to be the change predicted in the Flyland report [3]. The standard deviation σ was taken to be the maximum predicted deviation from the mean value (20%) for this criterion [3].

No estimates of uncertainties are available from the Flyland study for alternative 0 (not building the airport island). Yet, the autonomous developments are known to be uncertain. However, this uncertainty is caused by the same processes as the uncertainty in any of the other alternatives. Information about the current situation is most reliable, which means that the bigger the change from the current situation for a criterion, the bigger the uncertainty. Therefore, we made the assumption that the uncertainty in each criterion for alternative 0 equals the smallest uncertainty for any of the island alternatives.

3.5. Calculating overall scores

Scores on the various criteria (see Table 2) could then be calculated with Eq. (1) and by performing Monte Carlo simulations in which all possible values of the effects were taken from the probabilistic distributions for the criteria. The simulations produce an output that includes the joint distribution of the various uncertain inputs.

The overall score of an alternative (s_a) was computed by adding the products of the weight (w_c) of criterion c and its corresponding score (s_a^c) of the alternative for that criterion c

$$s_a = \sum_{c \in C} w_c s_a^c \tag{2}$$

Table 3
Summary of the steps leading to the method used in this paper

Step 1	Selection of the set of criteria. Only distinctive criteria are included and criteria should be mutually independent.
Step 2	Determination of weights for the different criteria by pairwise comparison (AHP approach).
Step 3	Normalisation of the effects of the alternatives to scores for the alternatives by Eq. (1).
Step 4	Quantification of the uncertainty and the distributions of the predicted effects, e.g. a normal distribution $N(\mu, \sigma)$.
Step 5	Simulations by Monte Carlo method to calculate overall scores for the alternatives by Eq. (2).

with $a = 0,1,\ldots,5$ denoting the six airport alternatives and c is one of the nine criteria (see Table 2).

Table 3 summarises the steps necessary to implement the method.

Alternatives could subsequently be compared in the following way. The alternative a that has the highest mean overall score (s_a) is considered the best alternative. This is hardly different from the standard AHP. However, this puts us in a position in which we could evaluate the distinction between alternatives from the distribution of the scores. If the distributions overlap to a certain extent, the distinction is considered small and a choice cannot really be made. However, the smaller the overlap between the distributions, the smaller the probability that the alternative ranking second best will actually be better than the first, which allows a more certain decision. One of the advantages of this approach is that the available information can be presented in full to the decision-makers, such that they can decide about the risk of making the wrong decision.

4. Scores and uncertainties: distinct rankings?

Calculating overall scores for the five island alternatives and the inland alternative led to the results shown in Fig. 5 (see [18] for details). The mean overall score of alternative 0 (not building an airport island) is the highest (8.4), which means that from an ecological and morphological point of view it is better not to construct an airport island at all but retain the Dutch national airport inland. The distinction between alternative 0 and the best island alternative (V_3) is large, as can be seen in detail in Fig. 6a. The probability that V_3 scores equal to or better than alternative 0 is only 1.8%.

In the relative comparison between the island alternatives, alternative ‘Cross’ (see Fig. 2) turned out to be the best (overall score 7.3 ± 0.4), which means that locating the island further offshore reduces the morphological and ecological effects. The distinction between this best alternative and the other ones is quite large (see Fig. 6b): the probability that alternative ‘Cross’ (V_3) really is the best island option is 92%. Comparing the ‘Base’ and ‘North’ alternatives (see Fig. 2) leads to almost overlapping scores (see Fig. 5), so that these alternatives cannot be distinguished.

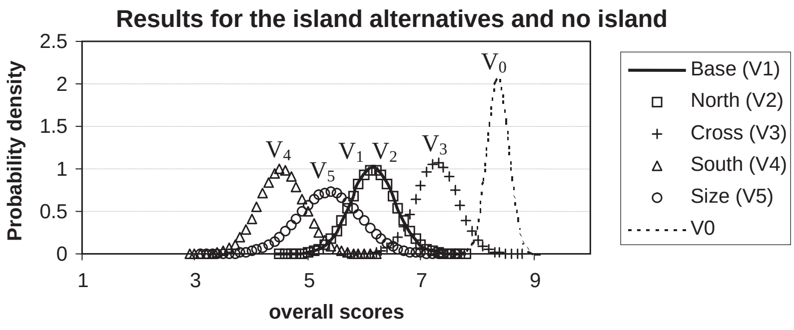

Fig. 5. Overall scores for the five island alternatives and the (inland) zero-alternative. The zero-alternative (V_0) scores best, followed by island alternative Cross (V_3).

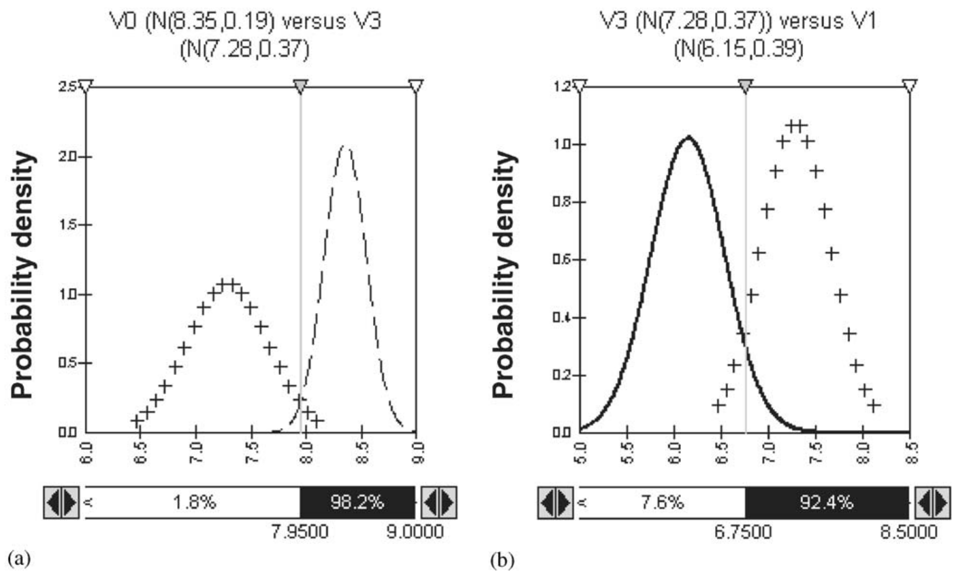

Fig. 6. Both the zero-alternative (V_0) and the best island alternative V_3 (a) and V_3 and V_1 (b) are well distinguished [@ RISK software package].

The low overall score of alternative 'Size' (5.4±0.6) shows that enlarging the island is a less attractive option. Locating the island and the sand extraction area more to the South (alternative 'South') scores significantly lower than the 'Base' alternative, with a probability of only 2% that alternative 'South' scores better than alternative 'Base'.

5. Sensitivity analysis and discussion

The alternative 'Cross' (V_3) turns out to be preferable, but how sensitive is this result to the different criteria (see Table 2)? This is shown in Fig. 7. The criterion

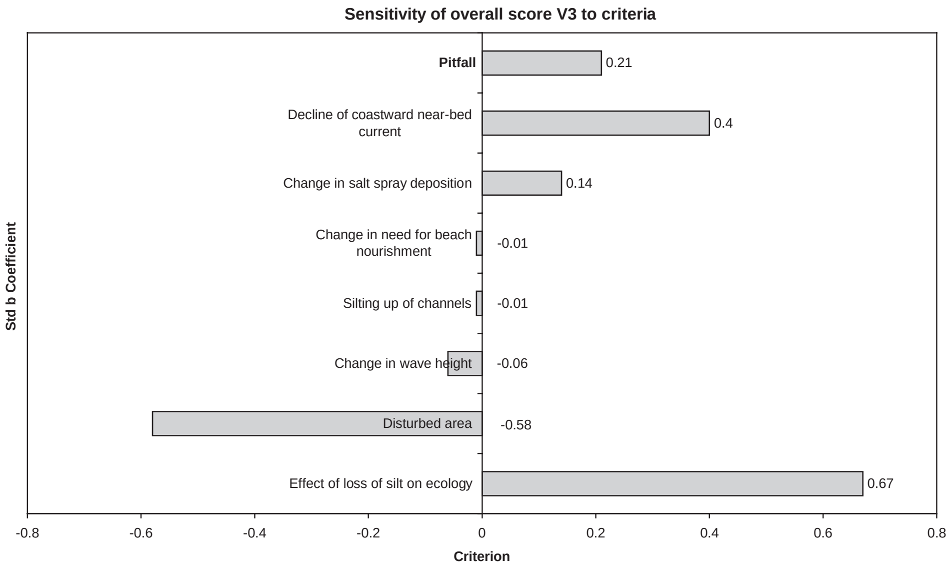

Fig. 7. Sensitivity of the results of alternative Cross (V_3) to the criteria c, as listed in Table 2. The results turn out to be the most sensitive for criteria with a large weight. The results are not sensitive to the criterion 'Zone without fishery around island' because this criterion does not contain uncertainty.

'Effect of loss of silt on ecology' turns out to influence the results most, which is caused by its large weight, $w_c = 0.42$. However, the sensitivity is not only determined by the weight, which can be seen by comparing the sensitivity to criteria 2, 7 and 8. Although the weights of these criteria are almost the same, the sensitivity of the results to these criteria is really different.

5.1. *Sensitivity to the estimated distributions*

Because of the large sensitivity to the criterion 'Effect of loss of silt on ecology', it is possible that its assumed probability distribution also influences the result. To investigate this, we ran additional simulations with different distributions (see Fig. 8).

We treated the ecology criterion somewhat differently, as no quantitative data were available for it. Therefore, the scores (s_a^c) were determined directly from assumed uniform distributions. These distributions are based on qualitative information [3] about the ranking of the effects of the alternatives, while no information was available about the difference between the alternatives. Fig. 8b represents the situation in which the distributions for V_1 and V_2 are closer to, and partially overlap, the distribution for V_3. Running a simulation with these data showed that the distinction between the alternatives V_3, and V_1 decreases. The probability of V_1 scoring better than V_3 increases from 8% (see Fig. 6b) to 16%. In the case of the distributions of Fig. 8c, this probability even increases to 30%. However, the simulations show that—even with the smallest difference between the distributions—the ranking of the alternatives does not change.

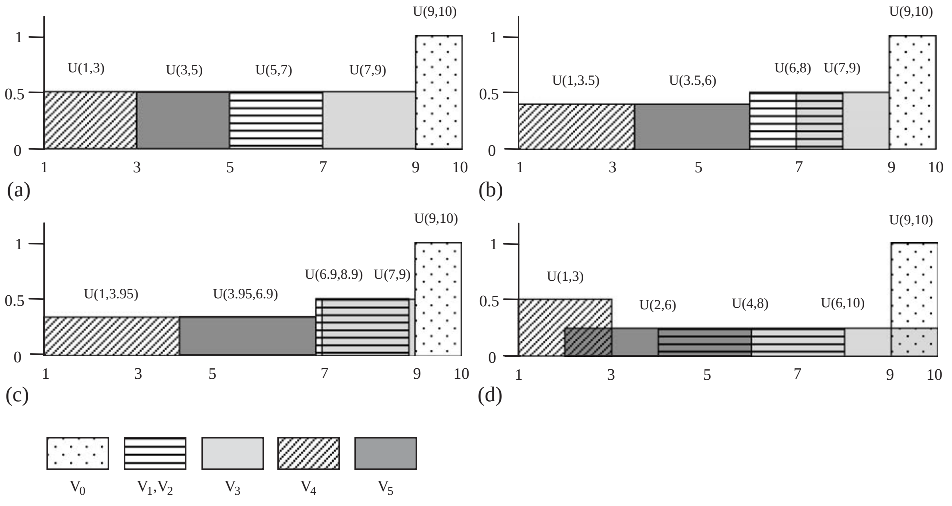

Fig. 8. Different distributions for the criterion 'Effect of loss of silt on ecology': (a) the default distributions, (b) the distributions of V_1 and V_2 are closer to the distribution of V_3 and partially overlap, (c) the distributions of V_1 and V_2 are almost equal to the distribution of V_3 and (d) the range of possible values for the alternatives is bigger and the distributions overlap.

In the case of a larger variance in the distributions of the island alternatives (Fig. 8d), the alternatives become less distinct. In this case, the mean values of the overall scores do not change, but the overlap between the alternatives becomes larger. The probability that alternative 'Cross' (V_3) is the best decreases from 92% (see Fig. 6b) to 84%.

The uncertainty of alternative 0 was taken to be equal to the smallest uncertainty of the island alternatives (see Section 3). To check the influence of this assumption, we carried out a simulation in which the uncertainty of alternative 0 was made equal to the largest uncertainty of the island alternatives. The probability that V_3 scores better than alternative 0 now increases from 1.8% to 5.0%. So, increasing the uncertainty of V_0 reduces the gap between V_0 and the best island alternative, but only to a limited extent.

5.2. Sensitivity to the weights

To check the sensitivity of the results to changes in the weights of the criteria, we modified the original weights. Since the criteria 'silt plume during construction' and 'widening of the coastal river' have large weights on which alternative 0 and alternative 'Cross' (V_3) score very well, these were reduced (Table 4). Fig. 9 shows that this does not affect the final ranking of the alternatives. This means that as long as the criteria 'silt plume' and 'coastal river' are clearly more important than the other two main criteria, the ranking of the alternatives is not affected. Reducing the 'silt plume' and 'coastal river' weights does, however, reduce the gap between the alternatives (cf. Figs. 5 and 9).

Table 4
Original priorities of the main criteria (see Fig. 4) and adjusted priorities to check the sensitivity to the weights

Priority of main criterion	Silt plume	Coastal river	Lee of the island	Shallow coast
Originally chosen priority	7	5	3	1
Original weight	0.56	0.12	0.26	0.06
Priority in new simulation	2.5	2	1.5	1
Weight in new simulation	0.38	0.20	0.28	0.14

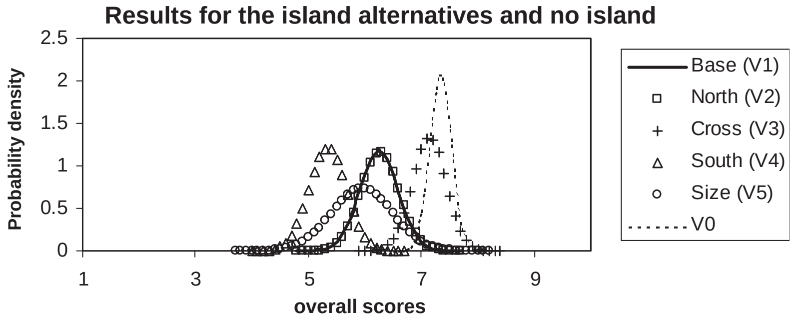

Fig. 9. Overall scores for the five island alternatives (V_1-V_5) and the (inland) zero-alternative (V_0) in case the difference in weights of the main criteria is less (see Table 4).

For values of the weights of the criteria 'loss of silt' and ' coastal river' smaller than 0.35 and 0.25, respectively, the order of preference can be reversed. Especially the overall score of alternative 0 is sensitive to the weights of the main criteria. This alternative changes from best to worst alternative in case of high weights for the criteria 'lee of island' and 'shallow coast'. Alternative 'Cross' (V_3) is less sensitive to the weights and is only passed by alternative 'Size' (V_5).

As changing the weights of the criteria can affect the final results, different insights about the priority of the aspects will lead to different results in the decision problem, which forms both the difficulty and flexibility of a multi-criteria method. The advantage of AHP is that it has a standard way of choosing the weights. Furthermore, with the method presented in this paper the sensitivity of the results to the weights can be checked so that one can determine the range of chosen weights for which the results are valid. Even though people may disagree about certain weights they may come to an agreement about the results of the analysis so that the best alternative can be chosen.

6. Conclusions

This paper presents a method for making a decision about a possible airport island location in the North Sea based on uncertain information about the effects of the alternatives.

Our application of this method to the criteria of *morphology and marine ecology* showed that the alternatives can be well distinguished (see Figs. 5 and 6) and a solid decision is possible for both the choice between the inland airport and the airport island and between the island alternatives. The zero-alternative V_0 gives the highest overall score unless weights are varied in an arbitrary way, which means that for ecology and morphology it is better not to construct an airport island at all, but to keep the Dutch national airport inland. The probability that the order of alternatives would be reversed—i.e. that the best island alternative, V_3, scores better than V_0—is only 1.8%. Alternative 'Cross' (V_3) represents an airport island further offshore and turns out to be the best of the island alternatives. This alternative is well distinguished from the other island alternatives; the probability that it is the best island option is 92%.

We tested the sensitivity of the results by varying weights and distributions. As could be expected, the weight of a criterion mainly determines its importance to ranking (Fig. 6). We also showed that the gap between the alternatives increases when the uncertainty of a criterion is reduced. Together, this indicates that when alternatives are not well distinguishable, an attempt should be made to lower the uncertainty of effects with large weights.

Simulations with different distributions for the most important criterion, 'loss of silt on ecology' (see Fig. 8), showed no changes in the ranking of the alternatives but in the distinction between them.

We also found that, as long as the order of priority of the main criteria is not violated (i.e. 'loss of silt', 'coastal river', 'lee of the island' and 'shallow coast'), the ranking of the alternatives will generally not change, unless the weights become very small.

So the results of the decision problem do depend on subjective choices about criteria, weights and distributions. This may seem unfavourable, but is inherent to the fact that these choices vary between individuals and stakeholders. However with a thorough analysis of the sensitivity of the results to these choices, the range for which the results are valid can be determined and people can come to an agreement in spite of different preferences.

One of the strengths of the method presented in this paper is that it can easily be adjusted to other insights, for example in a later stage of the decision making process. It is a powerful tool for making decisions pertaining to complex situations surrounded with uncertainties, since there is normally little or no time to reduce uncertainties through projects like Flyland. The results presented here for a possible offshore airport are based on the theme *Marine Ecology and Morphology* and are therefore not representative for the entire case. The final decision should include other aspects as well.

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Table 5
Interpretation of the values used in AHP's pair-wise comparison matrix to determine weights for the different criteria of a decision problem

Value of a_{ij}	Interpretation
1	Criterion i and j are of equal importance
3	Criterion i is weakly more important than criterion j
5	Experience and judgement indicate that criterion i is strongly more important than criterion j
7	Criterion i is very strongly or demonstrably more important than criterion j
9	Criterion i is absolutely more important than criterion j
2,4,6,8	Intermediate values—for example, a value of 8 means that criterion i is midway between strongly and absolutely more important than criterion j

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Appendix A. Interpretation of values in pair-wise comparison matrix

In Saaty's AHP, a pair-wise comparison matrix is used to determine weights for the different criteria. In such a pair-wise comparison matrix, the entry in row i and column j indicates how much more important criterion i is than criterion j. 'Importance' is to be measured on an integer-valued 1–9 scale. The interpretation of the values is described in Table 5 [12].

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