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Large-scale offshore sand extraction: What could be the results of interaction between model and decision process?

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Abstract

The Netherlands is considering large-scale offshore sand extraction to meet the increasing demand for building sand, as the current supply of sand from land is insufficient. To develop a well-considered management policy to address this problem, knowledge about future morphological changes offshore caused by such an extraction is necessary. Such knowledge is not yet available. To support decisions about large-scale sand extraction, we developed a morphological model, which indicates possible effects of such extraction. However, because no field data is available, we cannot meet the requirement of decision makers to validate this model. Therefore, its results are controversial and difficult to use in decision-making. In this study, firstly we evaluate whether validation of the model would help the decision-making process about large-scale sand extraction? Secondly, we explore how we can use the invalidated model results in decision-making. And finally, we explore how to improve both the model and the use of the model without validation.

Our opinion is that validation of the model will not solve the problem that decision makers deal with, and that although invalidated, decision makers can use the model results by using them as early warning signals. Interviews with the key players, to define the willingness to use the model results for decision-making, lead to useful recommendations to improve the model. These interviews were the first step of constructive technology assessment (CTA), which focuses on broadening the design and implementation process to stimulate the integration of societal criteria in the development of the model. Besides, these interviews appeared to have a positive influence on the willingness of the key players to use the model for decision-making. In general, we conclude that CTA, modulating the

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interaction between model and decision process, is a useful method for model makers that can help to make their models useful tools for decision-making.
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1. Introduction

In The Netherlands, we are facing an increasing demand for building sand and a depletion of inland sand sources. Building sand is required for large infrastructure projects, such as the creation of new land to compensate for the lack for space. Examples of such projects are Maasvlakte II (a large-scale land-reclamation project near Rotterdam Harbour) and Flyland (island-airport in the North Sea). Besides, sand is needed for several smaller infrastructure purposes, such as constructing roads and railways. Also, beach nourishment requires increasing amounts of building sand because of the rising sea level. These are the main reasons for considering large-scale offshore sand extraction at sea in The Netherlands [1].

To help understanding possible changes in morphology due to large-scale sand extraction, the University of Twente developed a model to forecast the behaviour of a large-scale sand extraction pit and its surrounding area in time and space [2]. The model aims to support decision processes about the long-term morphological effects of large-scale sand extraction offshore by providing information about the morphological impact [1]. The first results of the model show that creating such a pit has long-term morphological implications, for both the pit itself and the surrounding area. The pit itself deepens, whereas around the pit a sandbank-like pattern emerges, spreading at a constant rate of tens of metres a year [2]. Often, field data is used to check the quality of the model and to obtain recommendations to improve the model. In this case, reliable field data to verify this specific morphological model are not available and cannot be obtained in the near future. However, this is the case for almost every large-scale morphological model predicting human impact. Therefore, the results of the model are controversial and according to policymakers and administrators therefore difficult to use as a basis for decision-making.

Due to the fact there is no field data available to validate the model, we have to face the following problems to achieve the original aim of the model:

- the model cannot (optimally) support the decision process because the model information is considered to be unacceptably uncertain;
- the model cannot be improved by using field data.

We maintain that although invalidated, the morphological model to forecast the behaviour of a large-scale sand extraction pit and its surrounding area in time and space [2] can add value to the decision-making processes. However, we do realise that using invalidated models is not without risks.

To improve the model and to further develop the knowledge about the morphological impact of large-scale sand extraction, we have to look for alternatives to using field data. Therefore, the scientific challenges of this paper are:

- to evaluate whether validation of the morphological model can change (the role of the model and model information in) decision-making processes about large-scale sand extraction;

- to explore how decision makers can use the present model results in decision processes;
- to explore how the invalidated model can be improved both scientifically and for its use in decision processes without using field data.

To achieve these aims, we have used theories that originate from the social sciences, namely (constructive) technology assessment ((C)TA) and early warning, which we applied for the case of large-scale offshore sand extraction.

1.1. Organisation of the paper

The paper is organised is as follows. Section 2 describes background information; the decision-making process, the sand extraction model and the use of scientific information in decision processes (models in particular). Next, in Section 3 we evaluate whether validation of the model helps decision makers. In Section 4, we discuss how the current model results could be used in decision processes. Section 5 explores the use of the social science to improve the model. The modulation of interactions between the model and decision process (CTA) is presented as an alternative way of improving the model. The next sections present the results of this study, followed by discussion and conclusions.

2. Large-scale sand extraction and decision-making

2.1. The decision process around large-scale sand extraction

There is no dedicated decision process (Appendix A) for large-scale sand extraction offshore. It appears that large-scale sand extraction offshore is a sub-aim that arises in several decision processes having a different purpose for the required sand. The purpose of the sand is related to the required type of sand, which determines the location and the type of extraction. The latter two influence the morphological effects of large-scale sand extraction predicted by the model that is the subject of this study. We conclude that the decision process for large-scale sand extraction involves different decision processes as a way or sub-aim to reach a higher aim (see Fig. 1).

Decision processes about large-scale sand extraction are carried out within the limitations of the existing policy, plans or legislation. During this study, the regional extraction plan for the North Sea RON [3] was being reconsidered. The new RON [4]

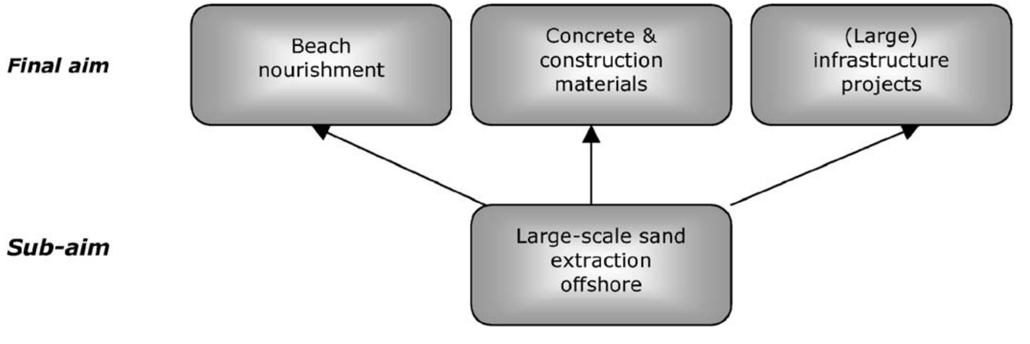

Fig. 1. Illustration of the purposes of the sand that require large-scale sand extraction offshore.

allows for extraction deeper than 2 m below the local bed under certain restrictions. This is based on studies [5] which showed that a deep sand extraction does not necessarily lead to undesirable effects. In the new RON [4], the Ministry of Transport, Public Works and Water Management decides whether sand extraction is permitted and the correct interpretation of the existing plan is very important.

2.2. Sand extraction model

We introduce an analytical sand extraction model by Roos et al. [2]. The starting point of the model (see Appendix C) is the hypothesis that the development of patterns in the seabed is the result of self-organisation in the linked system of tides and the seabed [6]. The hypothesis assumes that due to the water motion near the bed, sediment is transported (bed load transport), which changes the bed. The new bed topography will change the water motion, so starting the cycle all over again.

The first results of the model show that creating a large-scale sand extraction pit may have long-term morphological implications, for both the pit itself and the surrounding area. The behaviour of the pit depends on the shape of the pit: different geometries are possible to extract a fixed amount of sand. For pits with horizontal dimensions in the order of kilometres, the pit itself deepens, whereas around the pit a sandbank-like pattern emerges (see Fig. 2), spreading at a constant rate of tens of metres per year [2]. Sensitivity analysis has shown that the main problem of the model is the large uncertainty in the sediment transport, which results in an uncertainty in the time-scale of the bed evolution [1].

In the case of offshore large-scale sand extraction in the North Sea, no field data about offshore large-scale pits are available nor will be available in the near future. It will probably take at least 25 years to monitor such large-scale processes to obtain useful field data to be able to validate the model. Field data about small-scale sand extraction pits is available, but cannot be used to validate the model to forecast behaviour of a large-scale sand extraction pit. This conclusion is derived from the modelling study of Hulscher [7],

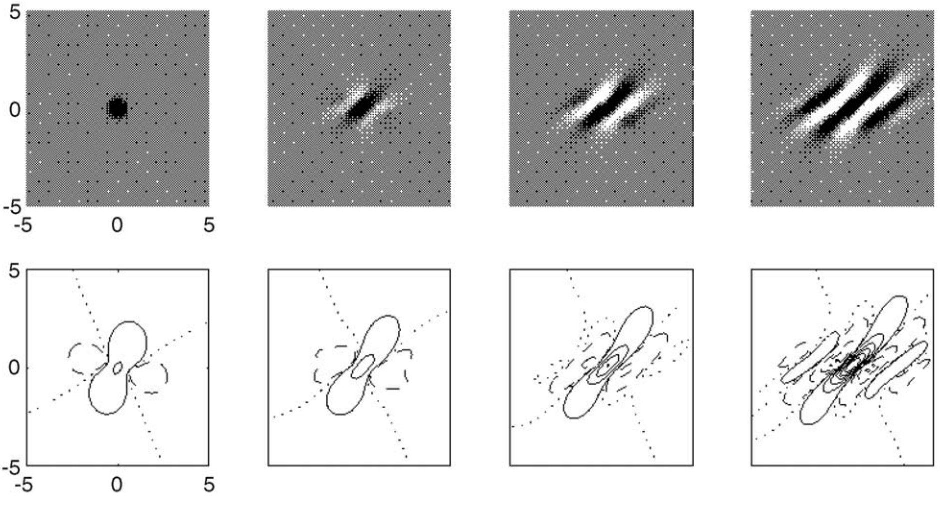

Fig. 2. The evolution of a sand extraction pit and the emerging sand bank-like patterns [2].

which showed that the morphodynamic processes applicable for small and large bedforms (i.e. pits) are very different. The results of this study are confirmed by an expert-judgement study of Dijkman et al. [8].

2.3. The use of scientific information in decision processes

To take decisions related to large-scale sand extraction offshore, scientific knowledge is required to forecast future effects of large-scale sand extraction. Such information sources are based on:

- reality (field data, experiments, etc.),
- theory (models, hypotheses, etc.).

The first type of information is a reflection or mirror of what has already happened and is retrospective in character. Real field data are measurements obtained and if the instruments are reliable, this data is considered to be reliable. Therefore, it is hard to ignore field data: to query field data, parties involved in the decision process (actors) can only point at the inaccuracy of the measured data, or at their irrelevance in a certain context. The second type of information aims to be predictive and, in general, focuses on understanding the responsible processes rather than the outcomes. Models are a simplification of reality, have a predictive value and may use field data as a starting point. Due to this predictive character, information produced by models always contains (large) uncertainties. If there is no field data available to validate the model, which is the case when new or innovatory activities take place, these uncertainties are hard to quantify. Therefore, the model results not only contain large risks, they are indeed uncertain [9]. In Table 1, we distinguish different types of uncertainties [10,11].

In this study, we do not discuss the topic of uncertainty itself, but assume it to be part of the term *invalidated*. Interviewing possible users of the model showed that the main argument for not using the model as a decision support tool is the fact that the model is not validated. Here 'invalidated' is defined as 'without being verified and/or calibrated using field data concerning large-scale sand extraction'. Decision makers require a sound basis for taking decisions and consider the analytical model to be unacceptably uncertain to be able to use it for decision-making. This pressure for certainty includes a preference for 'solid facts' rather than theories and models. 'Sound science' appears to be interpreted as 'empirical science' in the sense of direct observation rather than models and statistical

Table 1
Types of uncertainty

Van Asselt and Rotmans [10]	Hoeksema and Smidt [11]
Inexactness (Funtowicz and Ravetz, 1990; Zimmerman, 1996)	Gap in knowledge
Lack of observations/measurements	Gap in information
Practically immeasurable	Gap in prediction method
Conflicting evidence (Zimmerman, 1996)	
Reducible ignorance (Funtowicz and Ravetz, 1990; Wynne, 1992)	
Indeterminacy (e.g., Wynne, 1992)	
Irreducible ignorance	

analysis. Such a standard would make it impossible to prepare for environmental harms in advance [12]. Furthermore, empirical science appears to risk overestimation of the quality of the model. Previous research [13] has shown that validation of morphologic models using field data is not straightforward, so it remains unclear when a model is really validated.

3. Can a validated model change the role of the model in the decision process?

Summing up, the previous paragraph, a basic problem in decision-making is about how to deal with uncertainties or invalidated models. Both model makers and decision makers dislike these uncertainties and they want to eliminate uncertainties in the model. However, we expect their motivations to be rather different. In general, model makers feel the need to eliminate uncertainties out of scientific motivation, whereas decision makers ask to eliminate uncertainties to minimise risks. In decision processes dealing with many conflicting interests, controversies about model results are likely to appear. Therefore decision makers require a strong basis for taking decisions. From this view, it is clearly understandable that decision makers require validated model results and that they focus research on reducing uncertainties by validation. But, does this tactic really solve the problem decision makers deal with in decision-making about large-scale sand extraction? We believe that it does not.

Firstly, we state that even if field data would be available, validation using field data would only reduce part of the uncertainty. Uncertainty related to the system's unpredictability, called 'conflicting evidence, reducible ignorance, indeterminacy and irreducible ignorance ' by van Asselt and Rotmans [10] or 'gap in knowledge and prediction method' by Hoeksema and Smidt [11], will still be present. These uncertainties can never be eliminated completely, because validation has a retrospective bias. Uncertainties that will remain, are still expected to be emphasised or covered up in decision-making. The response to uncertainties is strongly dependent on social aspects such as the position and interest of the actor. In the case of decision processes about large-scale sand extraction, there are many different actors with different interests are at present and thus controversies about the model results can be expected, as long as uncertainties exist.

However, the most important reason why validation cannot help the decision maker is related to the vicious circle decision makers deal with, illustrated in Fig. 3. To obtain a well-calibrated and validated sand extraction model, implementation of the risky event 'large-scale sand extraction offshore' is necessary. The social costs of 'learning' by implementation appear by trial and error and could be considerable. Also, often it is hard to repair and change the new situation, because the technology is already firmly embedded in sectors, institutions and practices [14]. So we conclude that a validated model can only exist after the decision to extract large amounts of sand offshore. The problem is that such 'learning' may cause considerable damage to society and this is what decision makers want to prevent by using a model. Besides, we have not even mentioned time. Decision makers now have to take decisions about large-scale sand extraction and they cannot wait 10–25 years to obtain morphological field data. Also the calibration and verification process of a model takes a long time.

We close by saying that learning by implementation of large-scale extraction pits is no solution for decision makers, as we assume that decision makers want to anticipate

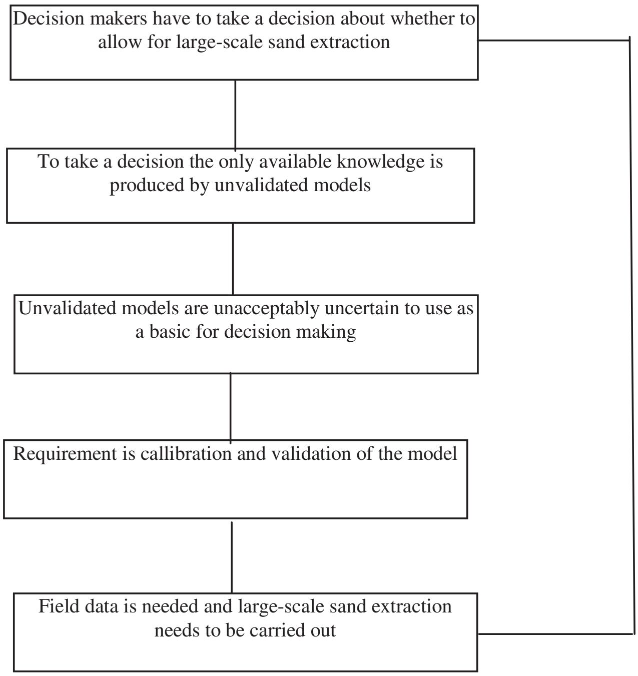

Fig. 3. Illustration of the dilemma the decision makers have to deal with.

possible effects with the help of models. At the moment, knowledge about the effects of large-scale sand extraction offshore to assess large-scale sand extraction can only be obtained by using predictive but invalidated models.

4. How can decision makers use the model results?

4.1. Model results as early warning signals in decision-making

In this paragraph we discuss how we can use the invalidated morphological model as a tool to anticipate on possible effects of large-scale sand extraction in decision processes about large-scale sand extraction. Considering the fact that the only available scientific information comes from models and that validation cannot help decision makers, there are only two options left for decision makers:

1. an assessment based on interests only (without the use of model (results);
2. an assessment based on the existing knowledge, i.e. invalidated models such as the model that is subject of this study.

Although the model is not validated, it does indicate possible (positive and negative) morphological effects of large-scale offshore sand extraction and at an early stage. Therefore, we state that although invalidated, it is preferable to take into account the model results because it prevents decision-making based purely on interests. A way to deal with results of the invalidated model is by using them as early warning signals of possible undesired behaviour of large-scale offshore sand extraction to policymakers, administrators and society. The role of models in early warning can be illustrated by the ozone layer debate in the 1970s [15], in which a model about the impact of cfc on the ozone layer turned into an early warning. By regarding the model results as early warning signals, the invalidated model about large-scale sand extraction is able to support the decision processes. An example of such an early warning signal could be a sandbank-like pattern that may emerge around the pit (see Fig. 3), which could disturb the seabed-ecology. By considering early warning signals seriously, one is able to anticipate. An example of such anticipation is by changing the strategy of the extraction, for example the angle between the extraction pit and the tidal velocity, to minimise possible negative effects.

5. Interactions between model and decision process as an alternative to improve the model

5.1. CTA to improve the quality of the model

By using the model results as early warning signals, the model has become a technology assessment (TA) tool for decision makers. This brings us to the idea of studying TA to find out whether this theory can be useful to improve both the model and the use of the model.

TA as a tool for policy analysis and policy support is based on the changes that took place in the 1960s and 1970s. TA aims to determine the advantages and disadvantages of a new technology of an early stage to adjust the development, design or application of the technology or to find alternatives. All aim to minimise the undesirable effects and maximise the desirable effects [16]. However, the disadvantage of TA is that it is hard to predict all the effects in advance. To compensate for the limitations of TA, CTA has been developed.

CTA is based on the insights obtained by Technology Dynamics. Technology Dynamics assumes an interaction between technology (here a model) and the social surrounding of this technology (here a decision process). In this case, the interaction would mean that the model has an indirect impact on decision processes about large-scale sand extraction, which will cause changes in this decision process. In turn, these changes will influence the model development and so on. An illustration to show that the scientific discussion is inextricably bound up with the social dynamics is the following. Positions and interests of actors may play an important role in the way research agendas are set through the commitments and problem definitions these actors introduce [17]. In turn, these research agendas and problem definitions determine the development of scientific information and design process of models. CTA focuses on broadening the design and implementation process to stimulate the integration of societal criteria in the development of a technology to improve the technology [16]. Furthermore, CTA emphasises ongoing improvement. An important effect of the implementation of CTA is acceptation of the technology. Besides acceptation, the CTA characteristics are anticipation and social learning and reflexivity. The last two are actually effects of anticipation and play an important role during the modulation of interactions between model and decision process. By considering the development of the morphological model as a technology, we are able to apply the concept of the technology dynamics and especially CTA.

We conclude that design processes of models developed for being used in decision-making call for a wider approach to be optimally successful; one which takes both scientific and social aspects into account. CTA is such an approach, and therefore we have applied CTA for the case of large-scale offshore sand extraction. So in the case of large-scale sand extraction, CTA aims to modulate the interaction between the morphological model and the decision process by the anticipation of possible impacts of the model on the decision processes and so on. This interaction process is characterised by reflexivity and social learning towards both the model and the decision process and during the interaction recommendations will be made. We should remark that interactions early in the decision process may be especially important. Also, a restriction to be able to apply CTA is that one of the actors is willing to use the model results to start the interaction between model and decision process.

5.2. How to determine the willingness to use the model results as early warning signals?

An important question to be answered is whether one is willing to use the model results as early warning signals. It is important to indicate the willingness to determine the potential success of the model to support decision makers. If it appears that none of the actors involved in the decision process is willing to use the model results as early warning signals, then we should realise that motivation for further model development would be little more than scientific curiosity.

To determine whether the involved actors are willing to use the early warning signals derived from the model that is the subject of this study, we use the concept of the 'Fork-model' described in Fig. 4. This model distinguishes three main paths actors are expected to follow.

The non-embracing path on the left shows the behaviour of an actor having a sceptical attitude. Strong arguments are required to convince the actor to take the early warning signals seriously. Conversely, the actor that follows the embracing path is willing to undertake actions based on the early warning signals and does not put any restrictions on using the early warning signals, because he wants to be proactive. If the embracing path is followed, the role of models can be strongest. However, this is an extreme point of view. The 'learning' attitude is a compromise between the two extremes, based on increments of precaution. If at all possible, in this path the element of learning comes first and also learning from models. Which paths actors finally follow depends on both the social aspects (such as the interest and position of the actor) and the scientific quality of the early warning signals. In this study, for the most important actors, we defined the attitude

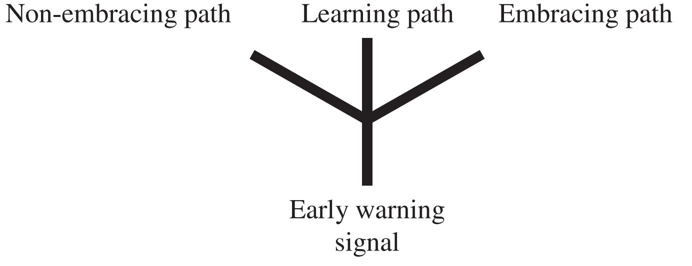

Fig. 4. 'Fork' model (Rip, personal communication, 2001): possible attitudes towards scientific information (derived by models).

towards the model results and the potential of the model to be able to support decision makers by doing interviews and studying available literature and other relevant information resources. For the methodology followed in this research, a priori we assume that at least one of the main actors is willing to use the model results as early warning signals because actors having conflicting interests are at present involved in decision processes about large-scale sand extraction. However, this assumption should be verified later on.

5.3. Using controversies as an informal way of CTA

The existence of controversies about the model results is a characteristic that can be used in a positive way to improve the model. Controversies about model results in a decision process create an optimal situation for receiving feedback about the model and this feedback can be used to obtain recommendations for further research and can benefit the quality of the model [17]. However, a requirement to reach this situation is that actors having different interests are all engaged in the decision process.

6. Results of study

6.1. The willingness of the actors to use the model results as early warning signals

To define the willingness to use the model results in decision-making processes, we first made an inventory of the actors involved in decision processes about large-scale sand extraction. To define the involved actors, we first have to define 'decision process' (Appendix A) and took into account the following aspects:

- the decision process about large sand extraction exists of several different decision processes (see Section 2);
- in all different stages of each decision process, different actors can be/are involved;
- different actors can be involved directly and indirectly, depending on the stage of the decision process.

A list of actors directly involved in large-scale sand extraction decision processes is summarised in Appendix B.

In this study, we choose to interview only the main actors (see Table 2) involved in large-scale sand extraction decision processes as a first start for interaction between the design process of the model and the decision process (CTA). We choose to interview governmental organisations, a dredging business and an environmental organisation according to the framework of perspectives designed by Rotmans and van Asselt [18]. This is because we expect these three actors to have different perspectives,[1] which is likely to lead to different acting and thus a different attitude towards information.

The interview questions, interviewed persons are listed in Appendix D. The information obtained through the interviews is used to label the actors, so as to determine the willingness to use the model results in the decision-making process. The willingness of the

[1] A perspective is a coherent and consistent description of the perceptual screen through which (groups of) people interpret or make sense of the world and its social dimensions, and which guide them in acting [18].

Table 2
Relevant information about the interviewed actors

Organisation	Ministry of Transport, Public Works and Water Management	Dredging Company	Environmental Organisation
Perspective[a]	Hierachist	Individualist	Egalitarian
Actor type	Demander North Sea manager Knowledge producer and adviser	Sand extractor Representative Knowledge producer	Protector
Persons interviewed	3	4	1
Order of employees NL	10^4	10^3	10^1

[a]According to typology by Rotmans and van Asselt [18], which is based on insights derived from anthropology and cultural theory, philosophy of culture, ecology and environmental ethics.

Table 3
Attitude of the interviewed actors towards early warning signals

Name of the Organisation	Ministry of Transport, Public Works and Water Management	Dredging Company	Environmental Organisation
Attitude	Learning	Non-embracing/learning	Embracing
Unequivocable distinctions	Quite clear	Complex	Clear

actors to use the model results is labelled by considering their statements during the interviews, and using other information (official reports, information from the internet, etc.). We will define this labelling more explicitly in Appendix E. The labels found are shown in Table 3. Their attitudes towards early warning signals are based on limited information. Therefore, we have introduced a kind of uncertainty margin; a comment to explain whether this label was complex or clear to determine. In case of the environmental organisation, the attitude towards early warning signals was clear as all sources led to the same result (learning attitude). We conclude that it is worthwhile to improve the model as at least two actors in the decision process are willing to use the model results as early warning signals or are willing to learn from them.

6.2. *Results of the interaction process*

During this study and previous studies, interaction between the design process of the model and the decision process (CTA) has been initiated. Research of Healey et al. [19] shows that science has its greatest influence early in policy development. So interaction between design process of the model and the decision process from an early stage already, increases the chance that science can play an effective role in the decision process. Appendix F gives an outline about this interaction. In this paragraph we present the main results and recommendations of the interaction process for the model (design process).

6.2.1. *Results for the model*

We found that all the actors are sceptical about the fact the model predicts that large-scale sand extraction pits will become deeper (see Section 3). On the generation of the sandbank-like pattern, they do not have an opinion. They can imagine that the shape and position of the pit influences the morphological development. All the actors think the model should be extended with wind-waves. Therefore, it is worthwhile to study how this limitation may influence the results.

The most powerful actor—the Ministry of Transport, Public Works and Water Management—does not have enough confidence in the Roos et al. model [2] to pass over the uncertainties of the model and to use it for decision-making. The fact the model is not validated is the main reason for not using the model, because it implies large uncertainties. All interviewed actors propose that model improvement should include field data. The lack of observations and field data to validate models complicate the advising of policymakers or administrators and the taking of decisions.

During the interviews, it was suggested comparing the model results with those of the Delft 3D model as an alternative for validation. Clearly, actors seem to accept the numerical model Delft 3D more than that of Roos et al. [2] because they have longer experience of it. Actors state that if both model results are similar, this will contribute to their confidence in both models. However, although comparison does give an indication of the quality of the model, both models are still in one's infancy.

As the use of invalidated models is not unusual (see also Section 1), we could question whether lack of validation is indeed the main reason for not (yet) using the model that is the subject of study. Research has shown that the use of models and model results is also influenced by the trust in the model designer [15]. Moreover, the experience and authority of the model designer and the trust in science in general are important [15]. The results of the interviews confirm that the status of the model designer is indeed important.

6.2.2. *Recommendations for model improvement*

Recommendations to check the quality of the model are:

- Check whether the model is able to produce established effects such as migrating sand pits in a river and present the results.
- There should be a detailed comparison between the different models to understand why the differences in results occur and what are the effects of model assumptions. The best way to compare is by modelling the same case and presenting the model and model results on a comparable basis as done in De Vriend et al. [13].
- Check the model results by using a more accepted model: Delft 3D.
- Consider an experimental extraction (step-by-step approach) for providing field data to improve models.
- Next to an experimental extraction, one could also make a small-scale laboratory model to obtain 'field data'. An advantage of such a model in time scales is usually smaller. A disadvantage is that obtained field data may not be representative of the real scale.
- Check the model results by using (experimental) field data, but decide in *advance* the acceptable level of deviation between the field data and model results, which will allow the model to be considered 'validated'.

As all the different actors are sceptical about the fact that the pits are becoming deeper, it is important to focus on this during further research. Especially the limits of the model related to time need further investigation; that is, what is the maximum developed pit depth?

- Include non-linear terms in the equations. If the current model will be extended to a 3D model, the model may be used to model a deep extraction.
- The results should be explained better (why pits deepen).

Neglecting wind waves should be reconsidered and be based on stronger arguments for which further research is required:

- Study at which North Sea locations waves may have an effect on the seabed.
- Talk to field experts like fishermen and shippers to get an impression about which processes may be important.

Presentation of the results:

- The length scale of the model is kilometres. This is unusual and therefore it should be emphasised better when presenting results.
- Quantification of uncertainties, possibly using a probabilistic approach for input parameters.

Check the model theories:

- If there will be an experimental extraction, one should think about what should be measured to obtain useful information to check the model. Therefore the assumptions and hypotheses should be made explicit.
- As it is unlikely that in the near future useful field data can be obtained, think about other ways to validate the model.
- Look for parameter change within a shorter timescale, to indicate whether certain assumptions or hypotheses of the model are correct.

Linking to important aspects in decision process:
Safety

- Study the assumption that the coastal zone stops at a waterdepth of 20 m.

Ecological

- Explore in what way the results of the model can be used as an input for ecological models. The ecological match can be realised by also talking to North Sea experts, ecologists and other scientists that develop ecological models.
- Explore what information ecologists need and find out whether the model can be useful to obtain this information. For example: 3D modelling is probably required, as ecologists are interested in the local velocity near the bed and not a depth-averaged velocity.
- Think about if and what ecological conclusions can be drawn from the current model results.

6.2.3. Financial

- Modellers should check which pit dimensions (length, width and depth) match the dimensions dredging ships can dredge in one go. This minimises costs related to dredging. This may be taken as first constraint, after which optimalisation with respect to the strategy with the least harming morphological effects can be carried out.

7. Discussion

Although decision makers require validated models, using invalidated models for decision-making is not unusual. Up till now, decisions on large-scale human interference in coastal areas have been taken without validated knowledge on future morphologic changes. In the past, we have discovered morphological changes as a result of human interference that has not been forecasted. So morphology of coastal systems is a complex discipline that is still in its infancy. This is also illustrated by the study of De Vriend et al. [13], which shows that different morphological models produce conflicting model results. Consequently, validation and the forecasting capacity of models become an issue [20,21].

We conclude that the results of the morphological model can be used as early warning signals in the decision process about large-scale offshore sand extraction. Furthermore, we conclude that by using the model results as early warning signals in decision processes, an interaction between model and decision process will be initiated, which will benefit both the quality and usefulness of the model. However, we did not discuss whether the model requires a minimum quality to enter the decision processes as early warning signals and what this quality should be. We do suggest a minimum quality, otherwise just any idea can enter the decision process. We suggest that the minimum quality should be: whether the model is more or less accepted by other scientists. This can be measured by whether the papers and articles explaining the model are accepted in congresses and scientific magazines. The model of large-scale offshore sand extraction is accepted in the journal Reviews of Geophysics, 41(2) [22].

As validation is impossible at the moment, we have suggested an alternative to improve the model: CTA. CTA focuses on quality control of the design processes and assumes that by interaction and modulation of the design process the quality of the model can be improved. So it assumes a relation between design process and product. A good design process does often lead to a good product. However, we should realise that there are exceptions to this rule. Nevertheless, we do believe that here interactions between model and decision process help to improve both the quality and usefulness of the model.

We are able to apply CTA to the case of large-scale offshore sand extraction because we consider the design process of the morphological model as a technology. This leads to a slight difference: the model about large-scale sand extraction does not have any effects on society as technology does, but the knowledge and information produced by the model (although they are speculative) have effects on the decision process.

We explained why taking into account social aspects during the design process of the model could be useful. However, we also understand there is some danger in taking into account social aspects: losing objectivity. Therefore, we see an important responsibility for model makers to be critical towards the feedback concerning the model and decision process and understand the exact reason why certain feedback is given. However, we do formulate restrictions towards introducing the model into decision processes, which should guarantee criticism: the requirement of scientific acceptation and the fact that controversies should be at present in the decision process. In this study, we assumed that controversies were present because the key players had different interests. So, it is likely that controversies will be present but we did not explicitly investigate this and so recommend doing this in the next study.

Finally, we appreciate that the results of this study were based on limited information. Especially the fact that just three key players were interviewed is a significant limitation. Nevertheless, we think that the choice of these three actors, who represent three perspectives, is able to give a good indication of various perceptions possible about model and decision process. However, we are aware about the uncertainty of the results of the interviews. Also we can discuss the results of interviews. We realise that it is very important which person is interviewed, as within one organisation two different persons can give different information or (even very!) different opinion. It appeared to be difficult to find persons that are able to answer questions about both decision processes and the model. This phenomenon is termed compartmentalisation. Compartmentalisation is a feature of many large organisations. Compartmentalisation is related to the structure, size and character of the organisation. For example, the environmental organisation is a flat organisation, having the smallest number of employees, who are extremely motivated and believe in the ideal they aim for. It appeared that compartmentalisation was smallest in this organisation. Besides, what type of answer can be expected is related to the character and/or function of the person, i.e. generalist or specialist. Furthermore, we are aware that in each interview, the atmosphere is different and questions are asked in a different way, and that this could affect the answers. In order to obtain representative information, we interviewed a larger number of persons when the organisations were larger (see also Table 1) and also included information from other sources (such as the internet, literature).

8. Conclusions

This research focuses on the use of a new model [2] in decision-making processes for offshore large-scale sand extraction. The aim of this research is firstly to evaluate whether validation of the model helps the decision-making process about large-scale sand extraction. Secondly, we explore how we can use the invalidated model results in decision-making. Finally, we explored how to improve both the model and the use of the model.

Our opinion is that validation of the model will not solve the problem that decision makers face. Firstly, we state that validation would only reduce part of the uncertainty because it has a retrospective bias. The remaining uncertainty is still expected to be emphasised or covered up, depending on the position and interest of an involved actor. This will complicate the decision process in the same way as it does right now. Also, we state that it is impracticable to meet the requirement for a validated large-scale sand extraction model because to obtain appropriate field data, large-scale sand extraction has to be implemented. We assume that decision makers do not want that, because they want to anticipate possible harms and using models should help them with that.

However, although invalidated, decision makers can still use the model results as early warning signals. Using the model results as early warning signals is a way to include science in the decision process, which otherwise is only based on social aspects. However, if used we need to assure correct use of the model results in decision-making. A way to deal with this is by applying constructive technology assessment (CTA): modulating the interaction between the model design process and the decision process. To anticipate the possible response of actors to the model, we distinguish three main paths in which actors involved in the decision process may respond to early warning signals: the learning path, the embracing path and the non-embracing path. Which path an actor will follow and whether they are willing to use the model results as early warning signals, is rather related to social aspects than the scientific quality of the model. By exploring the social context of large-scale sand extraction and interviewing the key players, we found that these have varying learning, embracing and non-embracing attitudes towards the model results. From these results, we also conclude that at least one of the key players is willing to use the model results, and therefore the model has a potential for being used and the interaction between model and decision process starts from here.

Interviews with the key players, defining the willingness to use the model results for decision making, led to some useful recommendations to improve both model and decision process. Also, they were the first step of the interaction between model and decision process about large-scale sand extraction. Besides, these interviews appeared to have a positive influence on the willingness of the key players to use the model for decision-making.

Finally, we conclude that CTA, modulating the interaction between model and decision process, is a useful method for model makers that can help to make their models useful and used tools for decision-making.

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Appendix A. : Definition of decision process

We specify the definition of the decision process. Teisman [23] defines a decision process as a sequence of decisions taken by different actors to realise a conversion of ideas to actual societal changes. According to Hoogerwerf [24] decision processes are the result of societal forces, which at the same time cause new societal forces. The relation between these societal forces consists of stabile relations (patterns) and more temporal relations (processes). The processes have several characteristics [24]. Firstly, there is an interaction between factors that are part of the process, e.g. interaction between actors but also interaction between power of the actor and information. Secondly, the process is a succession of events, which has a recognisable development. Consequently, they are dynamic. Due to recognisable development, one can speak about stages in the decision process [24], these are summarised below.

(1) Agenda building
(2) Policy or decision preparation

(3) Policy or decision making
(4) Realisation of the decision or policy
(5) Evaluation
(6) Feedback
(7) Policy termination or revision of the decision.

The decision process takes place in a network of actors that participate during the decision process. The network is defined as the changing patterns of relations in between mutual dependent actors, that establish around policy problems which form, maintain or change due to a sequence of interactions in the decision process [25]. In this network, actors keep up long relation patterns. However, not all relations in such a network have to be activated constantly. The activated part of the network is called the arena [23]. The stages Hoogerwerf [24] distinguishes are sub-decision processes, whose boundaries in time are characterised by a decision. These sub-decision processes match with what Teisman [23] calls an arena. A decision in a certain arena may affect other arenas. Actors participate in different arenas, but may also decide to drop out, for example because they do not have an interest anymore in the next arena.

Appendix B. : Actors involved in the decision process about large-scale sand extraction

The main actors directly involved in large-scale sand extraction decision processes are the following:

- Demander of sand (concrete and construction industry, initiators of large infrastructural projects like 'Gemeentelijk havenbedrijf Rotterdam', the coastal manager of the North Sea: DNZ, Ministry of Transport, Public Works and Water Management: RWS).
- Manager of the North Sea (DNZ: Regional Department North Sea of the Ministry of Transport, Public Works and Water Management).
- Protector of the North Sea (environmental agencies: 'de Noordzee').
- Sand extractor (sand extraction companies like 'Royal Boskalis Wesminster n.v.').
- Knowledge-producing institutes (RIKZ: the National Institute for Coastal and Marine Management, which is a specialist research department of the Ministry of Transport, Public Works and Water Management, Universities, Engineering and Consultancy Agencies).
- Users of the North Sea (owners of pipelines, cables, fishermen).

Appendix C. : Model equations

Water motion model:

$$\frac{\partial(\varsigma - h)}{\partial t} + \frac{\partial}{\partial x}[(H + \varsigma - h)u] + \frac{\partial}{\partial y}[(H + \varsigma - h)v] = 0, \tag{4.1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial \varsigma}{\partial x} - r\frac{u}{H - h + \varsigma}, \tag{4.2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + fu = -g\frac{\partial \varsigma}{\partial y} - r\frac{v}{H - h + \varsigma}, \tag{4.3}$$

where (u, v) is the depth averaged water velocity in the (x, y) direction, ς the watersurface, h the seabed, H the waterdepth, r the linear friction coefficient and f is the Coriolis parameter

Sediment transport model:

$$\frac{\partial h}{\partial t} + \vec{\nabla} \cdot \vec{S}_b = 0, \tag{4.4}$$

$$S_b = \alpha |\vec{u}|^b \left\{ \frac{\vec{u}}{|\vec{u}|} - \lambda \vec{\nabla} h \right\}, \tag{4.5}$$

where h is the seabed, $\vec{S}_b$ the sediment transport, (u, v) the depth averaged water velocity in the (x, y) direction, α the sediment parameter which is a constant and b is the exponent in transport formula, which controls the amount of sediment transport. The power of transport is set at 3.

Sand extraction pit:

$$\hat{h}_i(x, y) = -\mathrm{e}^{-(c_1 x)^2 - (c_2 y)^2}, \tag{4.6}$$

where $\hat{h}_i$ is the initial shape of the sand extraction pit and c_1 and c_2 the constants which determine the dimensions of the Gaussian shape in the x and y direction.

Appendix D. : 'The Interview'

D.1. The interview questions

These questions are the basic questions that have been asked during the interviews. However, in each interview these questions are asked differently and specially adapted to the interviewed actor and circumstances.

D.2. The Model

Aim of the model is to predict qualitatively the behaviour of the pit and its surrounding area. The model cannot be used quantitatively. The model predicts that:

- Large-scale sand extraction pits will become deeper and do not fill up like field data about small-scale pits show.
- Around the pit a sandbank-like pattern emerges, spreading at a constant rate of about tens of meters per year.
- The shape of the pit (long or circular and the orientation to the dominant direction of the tidal current are important for the morphological behaviour of the pit.

During the interview we will explain and the most important assumptions, the scope of the model and the meaning of the model results.

IDEAS/OPINION ABOUT:

- THE RESULTS OF THE MODEL
- THE TRANSLATION OF THE RESULTS
- POSSIBILITIES AND RESRICTIONS OF THE MODEL/STERNGTHS AND WEAKNESSES

- THE USE OF THESE MODEL RESULTS IN DECISION PROCESSES
- DOES THE MODEL (RESULT) PROVIDE YOU AS A POTENTIAL USER USEFUL INFORMATION? WHY?
- IS THE FACT THAT THE MODEL IS NOT VALIDATED (THE UNCERTAINTY) A PROBLEM FOR YOU FOR USING THE MODEL?
- DOU YOU OFTEN USE THE HELP OF MODELS?
- HOW DO YOU DEAL WITH INVALIDATED MODELS?
- DO YOU THINK VALIDATION IS POSSIBLE IN THIS CASE?
- IDEAS ABOUT:
- DEFINITION OF VALIDATION?
- WHEN IS A MODEL RELIABLE?
- ALTERNATIVE WAYS OF VALIDATION?

D.3. Scientific information and models in decision-making

No field data are available about offshore large-scale sand extraction pits. A few models are available, but all rely on theory and hypothesises, that cannot be checked in the nearby future.

IDEAS ABOUT:

- THE USE OF DEVELOPING MODELS
- THE AVAILABILITY OF SCIENTIFIC INFORMATION
- ROLE OF SCIENTIFIC INFORMATION IN DECISION PROCESSES
- HOW IS IT DEALED WITH UNCERTAINTY IN DECISION PROCESSES

D.4. Sand extraction in the North Sea

In The Netherlands, the societal pressure to extract sand offshore increases. We are encountered with an increasing need for filling sand and a depletion of inland sand sources. Filing sand is needed for creation of new land to compensate for the lack for space: large infrastructure projects like Maasvlakte II (large-scale land-reclamation project near Rotterdam Harbour), Flyland (island-airport in the North Sea) and for several smaller infrastructure purposes as the construction of roads and railways. Besides this, increasing amounts of filling sand are needed for beach nourishment because of the rising sea level.

The possibilities to extract sand have been researched for several years/decades already (from 1980 ‘plan of Waterman’). The last decade, this topic got more attention and serious plans to extract large amounts of sand offshore were released.

IDEAS ABOUT:

- THE ORIGIN OF THE DISCUSSION AND DECISION PROCESS ABOUT LARGE-SCALE SAND EXTRACTION
- THE NECESSITY TO EXTRACT SAND FROM THE NORTH SEA. TO CHANGE THE REGIONAL PLANS, POLICY AND LAW
- THE EFFECTS OF LARGE-SCALE SAND EXTRACTION IN THE NORTH SEA AND WHETHER THIS WILL CAUSE PROBLEMS (FOR OTHER USERS OR USER FUNCTIONS)
- DO YOU PREFER A CERTAIN EXTRACTION STRATEGY? WHY?

D.5. The decision process

As a large part of the amount of filling sand needed, for large-scale infrastructural projects, the decision process about large-scale sand extraction will be tied with the decision process about the necessity of these projects. The extraction of concrete and construction industry sand and filling sand require different strategies for extraction, which probably also makes a difference for decision-making.

YOUR IDEAS ABOUT IT

Probably many different actors participate in decision processes about (or related to) large-scale sand extraction. All participants represent a different interest and bring forward information and knowledge to substantiate their opinion:

- HOW IS IT DEALED WITH DIFFERENT ACTORS AND POSSIBLE CONFLICTING INTERESTS?
- WHAT IS YOUR CONTRIBUTION TO THE DISCUSSION ABOUT LARGE-SCALE SAND EXTRACTION?
- DOES SCIENTIFIC INFORMATION PLAY AN IMPORTANT ROLE? WHICH OTHER FACTORS ARE IMPORTANT?
- WHAT TYPE OF INOFRMATION DO YOU USE TO SUBSTANTIATE YOUR POINT OF VIEW?
- DO YOU THINK YOUR POINT OF VIEW IS BEING HEARD (SERIOUSLY)?
- WHICH OTHER MINISTRIES OR ORGANISATIONS AND COMPANIES ARE INVOLVED IN DECISION PROCESSES?
- WHAT IS THEIR ROLE?
- WHAT IS THEIR INTEREST AND CONTRIBUTION TO THE DISCUSSION?
- DO YOU THINK THERE IS A DOMINANT POINT OF VIEW AMONG THE DIFFERENT ACTORS INVOLVED IN DECISION PROCESSES?

D.6. The interviewed persons

- manager of the North Sea at the DNZ, is interviewed both as a ‘manager of the North Sea ‘ and as a ‘demander for sand for beach nourishment’;
- two scientists of the RIKZ. They are interviewed as ‘knowledge producers’;
- director of the North Sea Foundation. He is interviewed as a ‘protector of the North Sea’;
- (Project) managers of the Royal Boskalis Westminster n.v. They are interviewed as a representative (secretary) of the Dutch Association of Sand Extraction Companies and as sand extractors;
- employees of ‘Hydronamic’, which is the engineering agency of the Royal Boskalis Westminster n.v. They are interviewed as a sand extractors and knowledge producers.

Appendix E. : Labelling the actors

E.1. Ministry of Transport, Public Works and Water Management

This is an organisation that follows the learning path. Aim of the Ministry of Transport, Public Works and Water Management is to consider all the different aspects of large-scale sand extraction offshore and then to take a well-considered decision that is best for the Dutch society. To be able to take such a decision, an open attitude is required. We experienced such an attitude during the interviews, although we recognised the attitude stronger in the coastal manager (DNZ) than the National Institute for Coastal and Marine Management (RIKZ). The reason for this difference can be found in the role these different departments of the Ministry of Transport, Public Works and Water Management have. DNZ states that 'information does not need to be complete but sufficient', whereas we think the RIKZ does not take any risk in advising and strongly holds on to validation of the models with field data before using them. During the interviews, DNZ stated that they are willing to use the model results when he has to permit for sand extractions. The motivation is that it is not wise not to use the current scientific findings, when the other option is using nothing.

E.2. The sand extraction company

This is an organisation that follows a path that is in between the non-embracing path and the learning path. During the interviews, the project managers stressed that the model and its results were not that interesting for sand extraction companies. They state that especially for RWS this information would be useful. The company explains that in general, they do not do research about effects of sand extraction themselves. Only if the results of the research that is used to take decisions goes against their intuition, they do research themselves. Although the model is not of direct use to them, they appear find it worthwhile to arrange a meeting with 'Hydronamic' (the Dutch Engineering Agency of The Company) to discuss the model. So from this point of view, they are interested in the model. In the beginning 'Hydronamic' was quite sceptical about the model, but after some discussion, their scepticism decreased. They did want to be informed about the progress we make. For the company it is interesting to know what is the state of the art, it enables them to anticipate on these researches when necessary. Furthermore, these types of models could bring on new ideas about what is the best way (economical and ecological) to extract sand. The company explains that this model can be interesting, if it brings them any benefits. This is not necessarily (direct) economical benefit. When the model provides an extraction strategy that is better for ecology, they are also interested because it gives them a good reputation.

E.3. The environmental organisation

This is an organisation that follows the embracing path. During the interviews she even said literally that she would use the model results and how she uses them. The analysis of the interviews and other information led to the same conclusion. The environmental organisation 'De Noordzee' is an organisation that prefers to leave the North Sea untouched, because she thinks it is an important environmental area that needs to be protected. So in principle she opposes any action that may affect the North Sea and this is always their first dedication in a decision process. However, she realises that sometimes compromises should made. Therefore, the environmental organisation has a critical attitude during the whole process and picks up all types of information that may give knowledge about effects to make sure that the best possible decision will be made, regarding the North Sea. Therefore, the environmental organisation is willing to pick up the information produced by the developed model, which illustrates that there may be other long-term effects than have been expected for so far. She does not mind about the fact that the model is not validated because she does not think it is their task to validate the model, their task is just to make sure that all existing information is considered and taken seriously. However, as these signals may support their interest, she would have preferred a validated model because and then the model results would be a stronger argument. However, as plausibility is important to be taken seriously, she does make demands on early warning signals, i.e. she needs to be scientific. However, for them this does not mean that she should be validated.

Appendix F. : Outline of interaction between model and decision process

During this study and previous studies, a first start is made to include social aspects in the design process of the model, which can be considered as the first steps to implement CTA (see Fig. F1). Previous studies, steps A and B, are characterised by an increased extension of including social aspects and actors. However, these first steps did already lead to some useful recommendations and were used to determine the research agenda

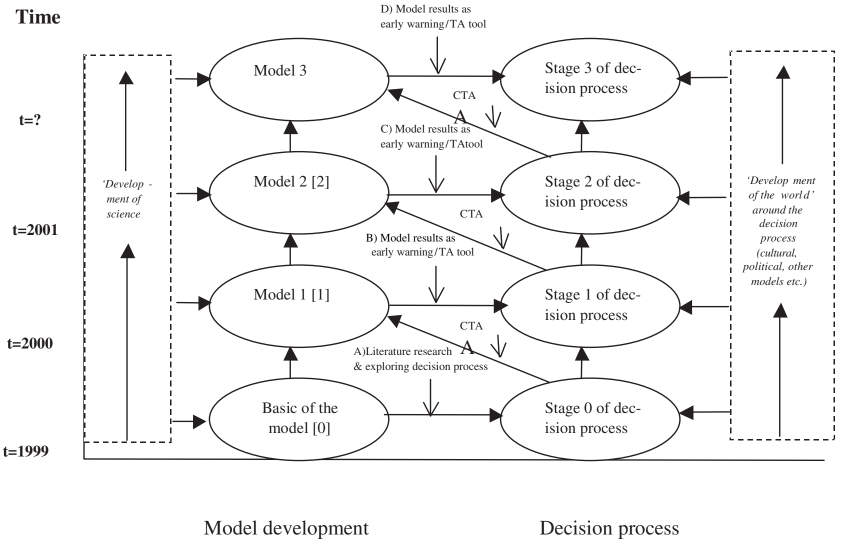

Fig. F1. Interacting between model and decision process by implementation of CTA. (A) Model 1 [1] is designed after exploring decision processes about large-scale sand extraction and the Dutch sand market by a doing study which includes literature research and interviews with RIKZ and the DNZ. The results of this study are used in the design process of the model and are the first step of the CTA approach. (B) Model 2 [2] is developed using the results of new interviews with RIKZ and the DNZ and the recommendations of the Master Thesis of Peters [1]. The fact that the results of Model 1 of Peters [1] could not be translated back from the Fourier Space into 'normal 'space was a huge problem, because the results were difficult to interpret and it was an enormous limitation for the use of the model. The model of Roos et al. [2] is a model, which is user-friendlier. (C) Model 3 is to be developed; guideline for the development of this model are the recommendations obtained by this study. During this study interviews with RIKZ, DNZ, an environmental organisation and an extraction company were performed. (D) In 2002–2003 the next step is further exploration of decision processes about large-scale sand extraction in a Ph.D. project.

of the model designers. As a result of this approach, possible users (RIKZ and DNZ) knew of the existence of the model (even before model 1 was finished) and they were interested in its further development. Furthermore, the model makers knew the need of decision makers and knew which recommendations to improve the model should have priority. Step C is realised during this study and the most extensive step to implement CTA for so far.

During step C the main actors and their characteristics, interests and opinion are explored and analysed by means of interviews with actors. These interviews were also used to explore the social context of the model. During these interviews, it turned out that by asking questions during the interviews some of the actors obtained new insights and ideas. This might be because of the fact that due to the interviews, actors are forced to think about matters that they might not ever think about. Furthermore, it appeared that explanation and discussion during the interviews had a positive contribution to the willingness to use the model (results). Another direct impact is that by doing these interviews, we were able to understand the weaknesses and the strengths of the mode. Furthermore, these interviews provide insights in the social context about large-scale sand extraction. This enables us to determine and understand the attitude of the different actors towards the model, which is necessary to assess their criticism towards the model. This information can be used to improve the model and it also enables us to anticipate on the social surrounding (decision process) in which the model should be able to survive, to be able to support decision makers. Note that, apart from these impacts, the interviews also influence future actions of actors. By doing interviews, we inform actors on the model.

Since actors know the existence of the model and what the controversies are at present, it is likely that the model results are being used to derive arguments from and this development will result into feedback on the model and can be seen as an informal way of Technology Assessment. As a result of step C recommendations for both decision process and model are derived and these can be found in the next paragraphs. The next step (D) in Fig. F1 will be an extension of this study. The most important aim of the next study will be to explore the social dynamics of decision processes about offshore large-scale sand extraction. This will give insights in the way the results of the model influence decision processes about offshore large-scale sand extraction and the development and priority of research agendas.

References

[1] Peters BGTM. Large-scale sand extraction offshore, the modelling of large-scale sand extraction pits, M.Sc. Thesis, Civil Engineering, University of Twente, 2000.

[2] Roos PC, Hulscher SJMH, Peters BGTM, Németh AA. A simple morphodynamic model for sand banks and large-scale sand pits subject to asymmetrical tides. In: Ikeda, S. (Ed.), RCEM 2001, 2nd IAHR symposium on river, coastal and estuarine morphodynamics, Obihiro, Japan; 2001. p. 91–100.

[3] RON, Regionaal Ontgrondingen Plan Noordzee. Policy document, Ministry of Public Works, Transport and Water Management, 1993.

[4] RON 2, Regionaal Ontgrondingen Plan Noordzee 2. Policy document, Ministry of Public Works, Transport and Water Management, 2001.

[5] Hoogewoning SE. Fysische effecten van zeezandwinning (in Dutch). The Hague, The Netherlands: National Institute of Coastal and Marine Management/RIKZ; 2000.

[6] Hulscher SJMH, De Swart HE, De Vriend HJ. The generation of offshore tidal sand banks and sand waves. Continental Shelf Research 1993;13(11):1183–204.

[7] Hulscher SJMH. Tidal-induced large-scale regular bed form patterns in a three-dimensional shallow water model. Journal of Geophysical Research 1996;101(C9):20,727–44.

[8] Dijkman MJ, Wiersum BS, Zitman TJ. Risico-analyse morfologische effecten Maasvlakte II en gerelateerde zandwinning (in dutch). Ministry of Public Works, Transport and Water Management; 1999.
[9] Otter HS, Capobianco M. Uncertainty in integrated coastal zone management. Journal of Coastal Conservation 2000;6:23–32.
[10] van Asselt MBA, Rotmans J, Uncertainty in integrated assessment modelling, climatic change. Dordrecht: Kluwer Academic Publishers; 2002. p. 1–31.
[11] Hoeksema HJ, Smidt JT. Milieu effectrapportage: omgaan met leemten in kennis. Milieu 1995;10(3):156–62.
[12] Rip A. Contributions from social studies of science and constructive technology assessment, ESTO Project on Technological Risk and the Management of Uncertainty. Commissioned by the Forward Studies Unit, European Commission. Enschede: University of Twente; April 1999.
[13] De Vriend HJ, Capobianco M, Chesher T, De Swart HE, Latteux B, Stive MJF. Approaches to long-term modelling of coastal morphology—a review. Coastal Engineering 1993;21(1–3):225–69.
[14] Collingridge D. The social control of technology. London: Frances Pinter (Publishers); 1980.
[15] Rip A. Expert advice and pragmatic rationality. In: Stehr Nico, Ericson Richard V, editors. The culture and power of knowledge. Berlin and New York: De Gruyter; 1992. p. 357–73.
[16] Schot J, Rip A. The past and future of constructive technology assessment. Technological Forecasting and Social Change 1997;54:251–68.
[17] Rip A. Controversies as informal technology assessment. Knowledge 1986;8(2):349–71.
[18] Rotmans J, van Asselt MBA. Perspectives on a sustainable future. International Journal of Sustainable Development 1999;2(2).
[19] Healey MC, Hennessey TM. The utilization of scientific information in the management of estuarine ecosystems. Ocean and Coastal Management 1994;23(1994):167–91.
[20] De Vriend HJ. Long-term morphological prediction. In: Seminara G, Blondeaux P, editors. River, coastal and estuarine morphodynamics. Berlin: Springer; 2001. p. 163–90.
[21] Capobianco M, De Vriend HJ, Stive MJF, Southgate H, Jimenez J, Larson M, et al. Large-scale coastal evolution towards a robust model-based methodology. Journal of Coastal Research 2001 22pp.
[22] Roos PC, Hulscher SJMH. Large-scale seabed dynamics in offshore morphology. Modeling human intervention. Reviews of Geophysics 2003;41(2):1010.
[23] Teisman GR. Complexe besluitvorming: een pluricentrisch perspectief op besluitvorming over ruimtelijke investeringen(in Dutch). The Netherlands: VUGA, s-Gravenhage; 1995. p. 293.
[24] Hoogerwerf A. Overheidsbeleid, een inleiding in beleidswetenschap (in Dutch) vijde druk: Samson; 1978. p. 417.
[25] Klijn EH, Teisman GR. Beleidsnetwerken analyse en management: een theoretische beschouwing over analyse en management van beleidsprocessen in complexe beleidsstelsels (in Dutch). Paper accepted for 'Netwerkconstituering en netwerkmanagement', Politicologenetmaal, 4 en 5 juni 1992 te Soesterberg, The Netherlands, 1992. 21pp.