Abstract

The limits of coastal engineering may be reached in several ways. This paper concentrates on three limits of engineering reached at the project approval stage. First, we identify two types of approval processes – called here traditional and contemporary. The paper describes the traditional process, its advantages (projects are approved) and its obvious deficiencies in evaluating environmental impacts. Then it analyses the contemporary process in some detail and identifies from experience where the process fails, how the process might be improved and how engineers can contribute to the process to improve the likelihood of project approval.

Traditional approval processes often result in daring, experimental designs, which test the limit of existing coastal science and engineering knowledge. Contemporary project approvals, on the other hand, require assessments of impacts with such accuracy that they constitute a second test of the limits of present knowledge in science and engineering. The measurements and calculations for such impact assessments contain substantial uncertainties and therefore the assessment becomes necessarily a combination of objective input (hard numbers) and subjective input (experience). Because the numbers alone cannot provide the complete assessment, the public or project opponents can easily say that the studies are worthless. Any legal process also has great difficulty understanding uncertainties. This results in a third limit to engineering discussed here; the fact that many projects are delayed, postponed or cancelled, either because of the uncertainties in the results or because the contemporary approval process provides too many opportunities for opponents to block the project.

Introduction

Kamphuis (2000) describes the “ideal design sequence” shown in Figure 1. However, any such design, no matter how good, can only take a project so far. The project must also be approved (Figure 2) and that is essentially the topic of this paper.
First, two basic axioms on economics and the environment are introduced. These are often misunderstood in practice.

**Axiom 1:** Approval decisions are always made within some economic framework. Although approval decisions are often concerned with the environmental aspects, such as impacts, all approval decisions will be made against the background of the overall economics. For example, if a positive decision will result in a loss of jobs, the final decision will likely be negative.

**Axiom 2:** The ideas (ideals) of environment and the economy are generally in opposition to each other. The historical development and change of the relationship between economy and environment is not a simple progression. It could be represented by a pendulum (Figure 3a). The position of the pendulum at any time, relative to the economy and environment extremes, depends on the political climate of the day (Kamphuis, 2000).
Approval Processes

We identify two types of approval processes, which are denoted as traditional and contemporary. In the traditional approval process, the authority for approval is vested with a small group (usually government for coastal projects). This authority’s thinking is aligned with the engineering – in fact, it generally commissions the work and it is interested in seeing the project successfully completed. Because of the concentrated focus of this approval procedure, “secondary problems” may not receive the attention they should and normally the environmental implications of the project are not studied well enough. The project is usually approved for its economic benefit, and ecological and environmental damage is possible. In the more modern versions of the traditional approval process, there is usually some commitment to mitigate whatever significant environmental damage occurs.

In this paper we invent the term GAMSI decision (Go Ahead and Mitigate Significant Impacts) for this type of decision.

The traditional approval process finds itself close to the economy limit the economy-environment pendulum, as in Figure 3b.

In the contemporary approval process, the authority for approval is also vested with a small group (usually government for coastal projects) and the authority’s thinking is usually aligned with the engineering. The authority is interested in seeing the project successfully completed; however, if a government has changed during the approval process, the authority may not be interested in completion of the project. In a democratic
society, all citizens have a voice; otherwise the politicians will not be re-elected. In such a political system, approval is contingent upon input from “stakeholders” – a diverse group of people, consisting of representatives of governments, owners, affected individuals and groups, and all individuals or groups who think they might possibly be impacted. The approval process becomes much more complicated, because of the many conflicting voices. At most, only some of the stakeholders are in line with the project and/or the engineering and there is often considerable interest within the stakeholder group in blocking the project. Environmental impacts are no longer considered “secondary problems” in this contemporary process; in fact the process prides itself on its focus on the environment and sustainability. A project may show economic benefit, but that alone no longer guarantees approval. Approved projects will normally generate minimum ecological and environmental impact. The contemporary approvals process comes quite close to the environmental limit of the pendulum swing (Figure 3c).

An in-between approval process that is based on relatively equal consideration of the economy and the environment appears to be very difficult to achieve. Either the decision is mostly economic (perhaps with a nod to the environment), made by a small power group, or if the environment is considered, including stakeholder involvement, the pendulum normally swings very far toward the environmental limit of the pendulum.

One final introductory note regarding environmental impacts: Who determines significance of an impact? It should be the decision-making body that defines and determines significance, but for the contemporary process, there will be an extensive (often contentious) input from the stakeholders specifically on this point. This makes decisions much more difficult, since individual and collective perceptions of significance are far apart.

**Example 1: Traditional Approval - Islands in the Canadian Beaufort Sea**

Three examples will now be given. The first two will discuss traditional approvals, their advantages and disadvantages, to set the stage for an example and a detailed discussion on contemporary approvals. The first example, of the traditional approval procedure, concerns artificial drilling islands built in the Canadian Beaufort Sea in the 1970s and 1980s for exploration of oil. An example is shown in Figure 4. Tarsuit is a caisson-retained mass of dredged fill, placed on top of a large base of dredged material, but many islands also simply consisted of a very large mound of dredged granular material extending above the water surface. The projected lifetime of the islands was less than one year. The economic interest in constructing these islands was high. The region was remote and there was little organized opposition to the projects, which meant that there was only limited stakeholder involvement.
Figure 4  Tarsuit Island  a) in open water – note the very high and steep breaking waves, b) in winter – note the ice ridges resulting from the moving ice, c) ice ridges
The Arctic area, however, has severe construction limitations. The islands would be locked in moving ice for nine months of the year, and there was no rock available for scour protection. This ruled out conventional drilling methods, pushed the existing limits of engineering knowledge and called for entirely new, innovative design methodologies. New methods were developed so that drilling could proceed through the nine months of winter, rather than only through the three summer months. The large ice forces were resisted by shear through the large masses of granular material contained in the islands. Ways were found to make beneficial use of the ice (as a vertical load to increase shear resistance of the island against ice action and as an outer breakwater against wave action). The drilling islands were designed to function for one winter season only and when the ice moved out, they were simply sacrificed to the waves. The one exception was Tarsuit Island. It was decided to keep this island over one summer and two winters. Figure 4a shows it in its summer season. All known environmental precautions were taken during construction and de-commissioning of these islands.

The new design methodology made the islands relatively safe in the winter but very vulnerable in the short open water season after the end of construction and before freeze-up. Although testing showed that these islands could only survive for hours during storms (except for Tarsuit), the owners gambled that no inconvenient major storms would occur in this narrow window.

The net results of this traditional approval process were:
- The decisions were GAMSI – with many unknowns.
- Limits to existing engineering knowledge were encountered, providing an opportunity and necessity to develop new, innovative design methodologies,
- Many islands were built,
- Impacts from these islands on the environment were eventually found to be limited.

The obvious issues about this traditional approval were:
- The islands were designed for a very hostile environment with new, largely experimental design methodologies
- Any short period of open water could lead to destruction of the island
- The ice forces and the shear resistance through the soil of the island were difficult to determine accurately, making island stability calculations quite uncertain,
- This is very cold water, which means that any oil spill would potentially take decades to a century to clear.

**Example 2: Traditional Approval - Reconstruction of the Dubai Shoreline.**

The second example of a traditional approval process is the reconstruction of the Dubai shoreline. Figure 5 shows a satellite photo of the initial palm island (Palm Jumeira) under construction. The background in Figure 5 is essentially the total Dubai shoreline. With the exception of the large Jebel Ali and Dubai ports, the existing infrastructure
consisting of fishing ports and beaches can hardly be seen in the figure. Thus the island design is on a totally different scale than the rest of the shoreline. Figure 6 shows one such beach to give an idea of what hardly shows up in Figure 5. But Palm Jumeira is a prestige project of high national and economic interest and the decision was made to go ahead with its construction - a traditional approval.

Figure 5  Palm Jumeira (Ref: Palm Island website)

Figure 6  Part of Jumeira Beach
Since Palm Jumeira is only the first of several large island projects under development, it is clear that the actual decision was much broader than simply an approval for Palm Jumeira. It has, in effect, been decided that it is in the national interest to re-engineer the entire Dubai shoreline. This is clear from Figure 7, presented in another paper at this conference (Mohammad, 2005). It shows other projects either planned or under construction, and the possible expansion of Jebel Ali Port on a similar scale, also presented at this conference, (Driscoll et al., 2005) is not even shown on Figure 7.

Figure 7  Future Dubai shoreline (Ref: Mohammad, 2005)

These constructions are on such a grand scale that they are beyond the scope of present coastal engineering practice. Entirely new methodologies are needed to build these projects, and to manage this new shoreline and the changed environments it produces. This project pushes the limits of coastal engineering as we know it today. The relatively straight, open Dubai shoreline dominated by small craft harbours and beaches will be replaced by a shoreline consisting of very prominent headlands, containing extensive, shallow bays with economically and environmentally sensitive shores and beaches.

The net results of this project are:

- A GAMS1 decision – with many unknowns,
- Limits to existing engineering knowledge were reached, providing an opportunity and need to develop new, innovative design methodologies,
- Prestigious and exciting projects of great economic importance are being built,
- A large experimental laboratory was created for serious research on dredging techniques, management methods, impact and mitigation,

Some of the obvious issues are:

- These are very large structures very close to shore,
- The existing littoral processes will be disrupted – in fact the coast will be changed from an open littoral zone to pocket shores enclosed by headlands going far out to sea,
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- The impacts of these projects on the existing shore are not clearly known and are likely to be large; mitigation will be difficult and will need to be very innovative.
- Water quality in very warm, shallow water will be a concern.
- Migration of young fish will be disrupted.
- The concept of a totally re-engineered shoreline will need clear cut, integrated planning to optimise the new projects while continuing to care for the original Dubai coastal environment and its existing infrastructure.

Example 3: Contemporary Approval – Proposed Island Airport and Proposed Port Expansion in the Netherlands.

Figure 7  Design alternatives for proposed island airport (Ref: Flyland, 2002)

The two projects discussed together as Example 3 are similar in scope. The first is a proposed airport island 13 to 30 km off the Dutch coast (Figure 7). Studies were initiated to define the alongshore and offshore location, the size (400 – 8100 ha), the shape and the land connection (bridge or tunnel). This was set up as a thoroughly modern design study. Several alternatives for the island, the borrow areas and the land connection were investigated and all impacts were carefully analysed.

An abbreviated list of the types of impacts investigated (Flyland, 2002) follows:

- **Near field**
  - **Borrow area**
    - Bottom disturbance (loss of biomass),
    - Anaerobic conditions in the deep borrow pit.
  - Island
    - Bottom disturbance (loss of biomass),
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- New flora and benthic communities develop on the new shore and around the island,
- Impact on fish, birds and mammals.

  - Far Field
    - Both during and after construction
    - North Sea (relatively close)
      - Impact of silt on primary production
      - Subsequent impacts on plankton, then fish, then birds.
    - Wadden Sea (further away)
      - Impact on biodiversity and habitat in this very productive tidal area
  - Coast and Dunes
    - Impact of changes in wave climate on salt spray and hence on vegetation
    - Impact on ground water levels

  - Ecology
    - Both during and after construction
    - Fish
      - Impact on production, breeding and nursery areas
      - Impact on transport of fish larvae
    - Birds
    - Mammals

  - Uses by Man
    - Both during and after construction
    - Safety of the existing shore
      - Erosion
      - Damage to structures
      - Coastal resilience
    - Recreation
      - Water quality
      - Foam formation
      - Beach width and quality
    - Fisheries
    - Navigation
      - Shipping
      - Maintenance of channels and harbours
    - Infrastructure (cables, pipelines, etc.)

These impacts are obviously part of major impact chains. Examples of primary and secondary impact chains are shown in Figure 8.

This study and the impact assessments pushed the limits of knowledge of engineering and ecology. In any such investigation, however, there are uncertainties in the measurements and calculations. These uncertainties increase as the studies become further removed from the site and further down the impact chains. Such growth of uncertainties is shown schematically in Figure 9.
Figure 8  Impact Chains – (a) Primary  (b) Secondary
After very extensive technical study, the island airport was judged not to be economically justified (by the Dutch government). The technical studies were therefore suspended and the approval process did not really come into play. However, an expansion of the Port of Rotterdam was planned in a similar North Sea environment (Figure 10). The methodology for this project could therefore build upon the earlier airport studies. This time all the studies deemed necessary were completed. Although uncertainties in the results (Figure 9) did not allow all processes to be completely understood, the potential impacts were judged not to be significant, and it was decided to go ahead with the port expansion and to mitigate all unforeseen significant environmental impacts. Another GAMS decision, but this time it is much closer to the environmental limit of the pendulum in Figure 3.

The decision led to objections from individuals and advocacy groups that were apparently not present at the table during the approval process. They simply introduced new, possible far field impacts. An appeal was made to the Supreme Court and the decision to go ahead was reversed because the newly raised issues were deemed not to have been studied sufficiently. This has led to a stoppage of the project and another loop of very detailed studies. Procedurally, the Supreme Court decision was correct – the significance of those new possibilities should have been studied. But technically the new, more detailed studies will also contain large uncertainties. The answers may be scientifically

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1 The Dutch “Raad van State” is not exactly a Supreme Court. It is a body consisting of lawyers, judges and other citizens that monitors the quality of government decisions. But its decisions, like those of the Supreme Court are binding and cannot be appealed.
better, but will only provide slightly better insight into the biological, ecological and social issues. In the end another GAMSI decision will need to be made – slightly closer to the environment limit of the pendulum in Figure 3. And what then? Can other issues be introduced that require further study?

Figure 10  Proposed expansion of the Port of Rotterdam (Ref: Port of Rotterdam website)

The net results for the Rotterdam port expansion are:

− A GAMSI decision was made with small unknowns,
− The impact study tested the limits of both engineering and science – even the best technology results in large uncertainties, particularly further away from the project and further down the impact chains (Figure 9),
− The decision was reversed because of insufficient study,
− More expensive studies have been started that are unlikely to add to real knowledge.

The obvious issues are:

− After a decision was made, it was possible to introduce new issues and on the basis that these new issues had not been studied sufficiently the project was postponed.
− The same can in principle be repeated after the new studies are completed
− Large, state-of-the-art, expensive technical studies of very complex processes can simply be set aside through a possibly poorly informed non-technical procedure or through reaction to political and/or social pressure,
− A project of great economic importance has been delayed.

Analysis of the Contemporary Decision Making Process

A contemporary decision making process may be visualized by combining Figures 2 and 9. This is shown in Figure 11.
The stakeholders come from widely varying backgrounds. They may exhibit very different individual perceptions and aversions of risk. They are also free to pursue personal and organizational biases. With respect to uncertainties, they expect science and engineering solutions to be *pure* (perfect); they do not expect nor want uncertainties. They can regard results that are not pure (numbers that are not hard) as useless in decision making and use that argument to suit their private purposes.

To improve its chance of success, the author’s experience shows a number of possibilities. Stakeholders meetings are necessarily an exercise in education, diplomacy, bargaining and goodwill. They need strong leadership and may be helped by a facilitator who is conversant with all the viewpoints. The aim of the decision process should always be clear. The studies should provide an integrated evaluation of the impacts and required mitigations. A clear decision must be made based on this evaluation.

Experience also has shown that all stakeholders should be present at the table from the beginning of the discussions. All possible concerns should be opened up for discussion and study. There should also be thorough discussion at stakeholders meetings of the expected uncertainties of the studies and how the results are to be used. Individual perception and aversion to risk should be discussed as well as inherent biases. It should be clearly decided that no participant has a veto over the decision. And it should be clear that any decision will be a GAMSI decision, which will contain some unknowns generated by the large uncertainties in the studies.

Finally, an integrating evaluation policy must be formulated. Evaluation of all the impacts and their significances should be thoroughly transparent. Evaluations should be expected to be both objective (using hard data and results) and subjective (based on
experience and judgment). Consequences of all impacts must be weighted to provide an integrated evaluation of overall risk and damage.

Any decisions should be clear and when they are made, a fair but forceful leadership must not react to last minute changes of mind or to new advocacy groups that object to the final decisions, even though they did not participate in all the stakeholder discussions. The whole approval process will be cumbersome and will require much bargaining within the stakeholders and decision makers. An awareness of “win-win” solutions needs to be cultivated, based on the recognition that no-one wants to lose and that there are no perfect solutions, just optimum solutions. Participant must be prepared to trade in expectations and biases to reach such optimum solutions.

At the end, in spite of the best efforts by the stakeholders and the decision makers, and no matter how close any GAMSI decision is to the environmental limit of the pendulum of Figure 3, the project may still end up in litigation. Opposition to the decisions may come from stakeholders that do not agree, from groups breaking away from the stakeholders, or from totally new opponents. Usually the opponents’ purpose of the litigation is to stall (or perhaps even stop) the project. Hence any decisions made must stand up in court and will need to be defended there.

Engineers can contribute greatly to the success of such a decision-making process in several ways. They will do the studies, designs and construction, but should also be vitally involved in the stakeholders meetings (to explain their design process and to advise the stakeholders). Engineers may also directly advise the decision makers. In particular engineers are aware that the numbers provided by the studies contain large uncertainties. They realize that impact assessment and risk analysis require both the (objective) mathematics and (subjective) judgment. They know that risk analysis, etc. are only tools to help make decisions; they are not substitutes for good science and clear thinking, but extend them. This knowledge needs to be clearly communicated by the engineers to the stakeholders and decision makers. Engineers also have a unique opportunity to act as facilitators; they are probably most familiar with most of the issues. In order to function as facilitators, however, they need to cultivate the trust of all sides.

Conclusions

Three limits to coastal engineering were identified and discussed. Project innovation and need for accuracy in impact studies both push the limit of technology. The third limit to coastal engineering is a socio-political one: projects are perceived by stakeholders and the courts to have been insufficiently studied and are therefore delayed or postponed.

The traditional approach has resulted in many successful projects and has provided opportunities to push the technological envelope to develop new methods. However, in many cases, environmental risks were consciously accepted. Because that has resulted in some environmental disasters, because shorelines are coming under ever-greater population pressure, and because there is a great increase in public interest in the
In principle this contemporary approach should work to everyone’s satisfaction. However, it opens the door to abuse primarily by advocacy groups, intent on stopping the project for private reasons. Their opposition draws the approval process out unnecessarily and then, when decisions are finally made it is still possible to postpone the approvals through litigation. As a result the contemporary project approval process is seriously flawed, because it often becomes mired down and projects are postponed temporarily or permanently, ostensibly because the studies were not conclusive enough as a consequence of uncertainties in the measurements and studies.

Thus, in short, the traditional approach has lead to completed projects that might impact the environment; the contemporary approach’s focus on the environment and public participation has lead to a very difficult process, often followed by litigation and regularly resulting in stalled or even postponed projects. Obviously neither approval process is satisfactory.

The solution is hinted at in the text above. For the traditional approach, a modern variation is mentioned, where significant impacts are mitigated. This decision-making variant was called a GAMSİ (Go Ahead and Mitigate Significant Impacts) decision. The decision in the contemporary approval process example for the Port of Rotterdam expansion was also GAMSİ. Essentially the final decisions for both approval processes are some form of GAMSİ. They are similar, except that the impacts are generally more carefully studied in the contemporary process than in the traditional process and as a result there are fewer unknowns when the decisions are made.

For the traditional approval process the remedy is simple. It needs to pay (much) more heed to the environmental consequences of the designs in order to push the GAMSİ decision in the direction of the environmental limit of the pendulum in Figure 3.

For the contemporary approval process, everything appears to be done right, technically and procedurally. The environmental impacts are studied to the limit of our knowledge, but the process often ends up in stalemates, litigation and project postponements. The solution to this is much more difficult. Experience suggests that if a number of criteria are met, these problems might be reduced or avoided.

− Stakeholder meetings should have a very strong leadership,
− All possible impacts should be opened for discussion,
− All stakeholders should be present from the beginning of the discussions,
− In addition to points relevant to the particular project, the discussions should also cover:
  o Uncertainties to be expected, as in Figure 9,
  o The necessity to use both objective and subjective information,
  o Risk perception of individuals, and integration of risk,
  o Inherent biases of individuals,
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- No-one has a veto,
- There are no perfect solutions, just optimum solutions,
- The inevitability of GAMS decisions in the end
  - Decision making should be as thorough and transparent as possible,
  - Decisions should be clear,
  - The system should integrate all the concerns into the best possible decisions.
  - All decisions must be defensible in the courts.

Engineers can/must play a major, multi-faceted role in such any decision-making process. They are needed first to provide the best possible designs and impact studies, blending uncertain numbers with experience and judgment. Then they need to communicate their knowledge clearly and advise stakeholders and decision makers, who do not necessarily understand the technical jargon nor uncertainties. Finally, they need to be prepared to defend their designs and give expert evidence in court.

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References

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