ABSTRACT
Dredging work allows removing sediments, which are deposited on the seabed, and which can prevent the traffic of ships. This operation poses the problem of the transfer of and what to do with the products to be evacuated, while taking into account the economic factors and the environmental aspects to protection of the environment. This problem concerns fine sediments (grains size < 63µm): dredging sands are mainly non-polluted, and are used in the building domain. For the Small Island Developing States network this aim is very important.

The environmental evaluation process, reinforced by the study of impact on the environment within a framework of information and participation of the actors involved enables orientation towards an iterative and negotiated approach corresponding to a social logic. Multi-criteria analysis encourages the process of evaluation of solutions or alternative variants within a political context of durable development.

Research underway aims at making available to the numerous participants an operational tool for piloting dredging operations that corresponds to the best techniques and tackles the problem of what to do with the products.

General Terms
Environment, Technology & ICT

Keywords
Marine sediments, dredging operation, decision-taking.
3. APPLICATION TO THE DREDGING OPERATION

3.1 Presentation of the study
This present study concerns dredging of the depths of the fishing basin located at the entrance of the town and of the Eastern Harbour in Dunkerque. The silting-up observed and the development of drafts in both the fishing and pleasure fleets create navigation difficulties that are also linked to tidal conditions.

3.2 Data and constraint
The data collected comprises the following information: bathymetric maps and dredging clearances, characterisation of the sediments and eco-toxicological studies, existing structures and eventual obstacles, meteorological and hydrological conditions, marine traffic and navigation.

The main project execution constraints concern: access to the site in function of the structures, realisation of the works in function of natural conditions, respect of the regulations in force concerning protection of the environment, minimising of site expenses.

In situ sampling was carried out in the works area so as to analyse the level of presence of contaminants in the sediments to be dredged. These sediments are mainly fine with a proportion of particles smaller than 63 µm, equal to 86.4 % (average value issue to tests on five samples, by laser diffraction). Analyses by the Pasteur Institute indicate the presence of heavy metals, PCBs, PAH, TBT, DBT, and MBT.

The toxicity tests (embryonic development of bivalves) indicate very weak concentrations in sediments (from 0.09 to 0.51 g/l) compared to the CE50 corresponding to a rate of abnormal larvae of 50%. Toxicity of sediments is said to be high when the CE50 is reached with a concentration in sediment of 5 g/l.

3.3 Potential actions
The various potential actions proposed are distinguished by the choice of equipment, methods of depositing and treatment of the materials:

n°1 : Dredging by bucket chain dredger equipped with an anti-turbidity tunnel and secure on-land depositing at the Eastern Harbour (Dutch Dredging process - Holland),

n°2 : Dredging by stationary dredge, dehydration of the sediments, pre-treatment of the water and evacuation of the materials to an approved dump (Extract process – France),

n°3 : Dredging by scraper dredger equipped with a watertight scraper and liberating of the sediments in an interior tidal basin in a wet dock for progressive filling-in,

n°4 : Dredging by running suction dredge, without discharge of mixture, hydraulic backflow, treatment by phosphatation and calcination and on-land depositing for reuse (Solvay process, Bertin technology, Novosol).

3.4 Choice of assessment criteria
The five criteria retained concern the technical, environmental, economic, health and social aspects.

Each criterion or sub-criterion is the subject of an assessment grid with the help of a notating system. All the assessments are noted on a scale of numerical values to avoid any discrimination between “objective” and “subjective” criteria. For all the criteria, the highest note corresponds to the worst assessment.

Criterion 1 (C1): technical aspects
This criterion groups several sub-criteria: the type of material to be extracted and deposited (table 1), the meteorological and hydrological conditions, the dredging clearance and machine manoeuvrability, on-site execution time linked to machine production.
Criterion 2 (C2): economic aspects
This criterion groups several financial items: the mob/demob cost of the equipment, the dredging, transport and depositing expenses, the cost of treating the polluted sediments, the cost of setting-up on-land depots for secure storage.

The increasing notes are in accordance with the global amount of the expense; the note attributed to the least expensive action is the unit; the note increases by one point per 75K Euro bracket.

Criterion 3 (C3): environmental aspects
This criterion groups several sub-criteria drawn up during the environmental assessment:

The increase in turbidity (Floating Material at the bottom). The global assessment of the sub-criterion is carried out by simple stacking,

The level of variation in dissolved oxygen. The global assessment of the sub-criterion is carried out by simple stacking,

The risk of percolation or diffusion in the land or aquatic milieu,

The level of variation in chlorophyll (a),

Assessment of environmental practice,

The level of noise pollution from site machines. The global assessment is carried out by simple stacking,

The level of visual and olfactory pollution linked to the colour of the water, the aesthetics of the site and to smells due to presence of gases in the silts.

Criterion 4 (C4): health aspects
This criterion also groups several sub-criteria: the risk linked to the toxicological level (embryo-toxicity test on bivalves) [Ifremer, 1999]. This assessment applies to the final toxicity at the time of deposit of the products, the level of risk of exposure of human beings through the food chain.

Criterion 5 (C5): social aspects
This criterion groups several sub criteria, regarding the acceptability with regard to: regulations in force, local politics, navigational and recreational activities, residents and associations in the field of protection of the environment.

The “social aspects” criterion is a subjective criterion that represents the opinion of various authorities which must be integrated in the project negotiation.

<table>
<thead>
<tr>
<th>Table 2. Assessment sub criterion 1</th>
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</thead>
<tbody>
<tr>
<td>Turbidity and floating material (FM)</td>
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<td>Duration</td>
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<td>Note</td>
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<tr>
<td>Range</td>
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<td>Note</td>
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<tr>
<td>Intensity (FM)</td>
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<th>Table 3. Assessment sub criterion 1</th>
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<tr>
<td>Toxicological level (measure of percentage of anomalies in the development)</td>
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<td>Toxicity</td>
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<td>Note</td>
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<th>Table 4. Assessment sub criterion 1</th>
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<td>Acceptability with regard to the regulations</td>
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<tr>
<td>Regulation</td>
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<td>Note</td>
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</table>

3.5 Project assessment proposal

The assessment notes for each potential action for each criterion are obtained by simple stacking of the notes attributed to each sub criterion under consideration.

Assessments of the criteria for each action are assembled in the assessment matrix, a double-entry table in which each line represents an action and each column a criterion. The global note is attributed to each criterion and corresponds to an aggregate data that corresponds to the detailed assessment of the sub criteria under consideration.

The criteria are classified by decreasing order of preference according to the rows method by weight per participant (we have deliberately limited the number of participants to 3). Each participant has his set of distinct weights of criteria; this choice corresponds to the will not to aggregate the weightings and to respect personal points of view, the aim being, however, to find results in agreement with the participants’ preferences.

The assessment matrix represents assessments of potential actions and the weighting adopted by the participants according to the various criteria retained.

<table>
<thead>
<tr>
<th>Table 5. Multi-participant assessments matrix</th>
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<tbody>
<tr>
<td>Potential actions</td>
</tr>
<tr>
<td>C1</td>
</tr>
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<td>1</td>
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<td>5</td>
</tr>
<tr>
<td>9</td>
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</table>
4. TREATMENT AND RESULTS

4.1 Choice of the initial parameters

The ELECTRE III model requires the choice of three thresholds for each criterion:

The indifference threshold \((q)\) is the widest preference variation judged to be compatible with the indifference.

The preference threshold \((p)\) is the widest preference variation judged to be unconvincing of a strict preference.

The veto threshold \((v)\) is the smallest variation between the performances of two potential actions above which the user estimates that it is no longer possible to accept that the worst of the two actions be globally considered as at least as good as the best, even if its performances on the criteria are all better (inter-criteria parameter).

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
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<tbody>
<tr>
<td>q</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<td>p</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
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<tr>
<td>v</td>
<td>5</td>
<td>25</td>
<td>8</td>
<td>3</td>
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4.2 Robustness analysis

The robustness analysis has been limited to weighting by the participants.

4.3 Interpretation of the results

The sensitivity analysis carried out on the weighting by the participants confirms the strong stability of action 4, systematically classified first whatever the weighting given by the participants to the criteria under consideration.

The consensual recommendation is finally given to action 4: “dredging by running suction dredge, without discharge of mixture, with hydraulic backflow, treatment of the sediments by phosphatation, calcination and on-land depositing on the PAD site”.

5. CONCLUSION / PERSPECTIVES

Simultaneous integration of the technical, economic, environmental and social aspects in the study for the potential choice of the best actions should enable better association of the various participants through personalised weighting of the criteria.

This study constitutes a case of applying a multi-criteria method where the iterative choice of the various parameters and thresholds encourages the sensitivity analysis necessary for verifying the stability of the recommendations and enlightenment of the various participants in the understanding of the results.

The multi-criteria analysis enables the deciding parties to qualify their decision while reducing the risks of conflicting situations and also seeking the solutions that correspond to the best compromise for all interested parties.

However, it must again be emphasized that to create several criteria is to admit that a decision must inevitably be the result of a compromise between several conflicting aims and that the participants do not always have the same vision of this compromise [Maystre et al, 1994].

6. REFERENCES