Ranking many harbour projects

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Harbours are more important in Iceland than in most other countries, being an island in the middle of the North Atlantic Ocean, and since 50% of Iceland’s export is fish and fish products. The paper describes a multi criteria method that has been developed for ranking harbour project proposals. The transportation authorities currently use the method as the basis for selecting projects for public funding.

The method differs from other Multi Criteria Decision Making methods in a few ways, e.g. in that a ranking index for a project is obtained by multiplying two numbers, each being a weighted mean of a set of indicators. The indicators play the roles of the criteria but are inherently different. One of the sets of indicators is based on standards that are set for each class of harbours.

**Keywords:** Government; Public expenditure; Multi-objective; Multi Criteria Decision Methods; Ranking
1 INTRODUCTION

The population of Iceland is 280 000. The size of the island is 103 000 km², however the exclusive fishing zone provides 758 000 km² of working area for the more than 1000 fishing vessels. Fishing is the backbone of the Icelandic economy and more than 50% of Iceland’s exports are fish and fish products. Thus, harbours are crucial elements of the transport infrastructure in Iceland.

The annual catch amounts to 2 million tons. This can be compared to the 2.5 million tons, which is the estimated transport on Icelandic roads (exclusive urban areas). The catch is landed in 50 harbours around the island. The location of the main harbours and the amount of landed catch is shown on figure 1. The import, which is 2.5 million tons, is mainly through Reykjavik harbour. More than 60% of the population lives in the Reykjavik capital area.

Each year some improvements are made in most of the harbours in Iceland. Among the reasons for this are increased size of fishing vessels and environmental aspects. The harbours are considered to be part of the transport infrastructure which the government and municipalities are jointly responsible for. Thus, the government funds between 60 and 95% of the cost of most of the projects, the percentage depending mainly on the type of project.
The process of making decisions about harbour improvements is as follows:

1. Every second year municipalities send project proposals to the minister of transport. These projects are intended to improve harbours, however not to build new harbours. In total, the cost of the proposed projects is usually about double of what the government is willing to spend.

2. The next step is that the Icelandic Maritime Administration (IMA) ranks the projects, and makes a plan for the two next years and a preliminary plan for the third and fourth year.

3. This plan is sent to the minister of transport, which usually makes some changes, and then a bill for a construction plan for the next four years is sent to the parliament.
4. The parliament’s transport committee usually makes some changes to the plan (members of parliament fighting for their clients or region) and finally the parliament confirms the construction plan.

In 1998 IMA and the Institute of Economic Studies at the University of Iceland, jointly developed a new method to rank the suggested harbour improvement projects. One of the authors participated actively in developing this new method. The method was used by IMA in the autumn of 1998 and only some minor changes were made before the parliament confirmed the construction plan. In short, this turned out to be an example of a successful operations research (OR) project in the sense that the users, i.e. the decision makers, were very satisfied with applying the method and with the final results, and actual and important governmental decisions were based upon the results of the OR-model.

The next section of the paper discusses evaluation of public transport projects. Operations Research methods have contributed significantly to this field, in particular the Multi Criteria Decision Making (MCDM) methods discussed in section 3. This is natural as governmental decisions are frequently characterized by a number of different goals, views and concerns. In some cases the MCDM methods are used to create a ranking of alternatives. Our method for ranking projects for public funding is introduced in section 4. More details of the method are presented in section 5. Finally, section 6 includes conclusions and discussion points.
2 EVALUATION OF PUBLIC TRANSPORT PROJECTS

In the last decades there has been a clear development in many countries towards more thorough evaluation of public transport projects, as well as many other forms of public money spending. Among reasons for this are the still growing public sector, privatisation, increased democracy and the opening of government affairs. One of the last trends is the increased emphasis on environmental issues.

Scientists, consultants and public servants have been involved in the development of methods to evaluate public projects, and hopefully increased the quality of public decision-making processes.

Cost Benefit Analysis (CBA) is probably the most used numerical method for evaluation of public transport projects. Assuming that all costs and benefits can be estimated on a monetary scale, the CBA gives information about the "benefit that accrue to the society per dollar invested"\(^1\). CBA has many forms such as Net Present Value and Benefit Cost Ratio.

In some cases the CBA is decisive of which projects are funded. An example is the government funding of road projects in New Zealand\(^2\). In other cases, CBA is performed for all project proposals but the decision is based on other aspects as well. An informative example of this is given by Odeck\(^1\). In our case CBA is not applicable since it is practically impossible to estimate the benefits on a monetary scale.

Among evaluation methods that are increasingly being used to evaluate public projects are MCDM methods. The method presented in this paper falls into that category and these methods are discussed in the next chapter.
Many other methods are being used to evaluate public projects. In some of them a special attention is given to multiple criteria although the methods does not fall into the group of MCDM methods. One of them is the Strategic Choice Approach\(^3\), which was initially mainly applied in the context of land use planning (often including road construction) but has since then been used for all kind of problems.

It is also important to remember that decisions about public transport problems are political decisions. Arguments regarding justice, old promises or political vision might be the ground for decision rather than some analysis. Politicians (the parliament) can transfer their decision making power to the administration (ministers) and that power can further be transferred to social servants. Regardless of who makes the final decision, social servants usually make some analysis, sometimes with help from consultants or academia.

There are three basic problem situations when public projects are evaluated, although there are mixtures of these basic situations and other problem situations:

- Should a given project be carried through or not? This could be a question of whether to build a new airport or not. Sometimes the question might be *when* rather than *if* the project is going to be carried through. The decision depends on whether the benefits (in a general meaning) of a project are sufficiently much higher than the costs (in a general meaning) of the project.

- Which one project, of several alternatives, should be selected? The different alternatives might for example be different locations for a fire station or different variants of a new airport.
What projects, of many possible projects, should be selected? This problem is the so-called “limited budgeting problem”. Many projects are competing for a limited amount of resources, usually monetary funds. The decision makers have to select projects to be carried through such that the total cost is within the given limits. Sometimes the projects are (mainly) independent and then, the projects are given priority (formally or informally) and those with highest priority are carried through. This is the case in our study. In other cases the projects are interdependent and then the problem is different in nature.

3 MULTI-CRITERIA METHODS

In contrast to Cost Benefit Analysis, the Multi Criteria Decision Making methods take different criteria into account without measuring all criteria on a single scale, i.e. the monetary scale. A great number of MCDM methods have been developed and some of them have been used for the evaluation of public transport projects.

The interested reader is referred to other literature for overviews of multi-criteria methods\(^4\)\(^5\) and \(^6\). Here, we discuss shortly some issues relevant to the application of MCDM methods for evaluation of public transport projects.

Common to all of the MCDM method is that several criteria (objectives, goals, attributes) and several alternatives are defined. In most methods numbers are generated which measure how good each alternative is for each criterion. In some cases, e.g. in outranking methods like ELECTRA\(^5\) this might be done indirectly. We will call these numbers
“scores”. Also, in most methods weights are generated that indicate the different importance of the criteria.

The MCDM methods fall mainly into two categories depending on how the scores are generated. In the first category pairwise comparisons of the criteria, and then of the alternatives against each criterion, play a key role. In the second category the scores for a given alternative are obtained (more or less) independent of other alternatives with direct assessment. Our approach falls into this category.

The Analytic Hierarchy Process, AHP\(^7\) and \(^8\), which is a popular and widely used method, is a good example of the first category. Here we will only mention one application described in a paper by Liberatore et al\(^9\). The title of the paper, "The Evaluation of Papers (or How to Get an Academic Committee to Agree on Something)", indicates that the decision-making situation is in many aspects very difficult, as is also the case in our situation. In our case pairwise comparison is not considered to be practical, mainly because of the vast number of alternatives, but also due to the numbers of criteria and their nature (indicators rather than objectives).

Since the scores are intrinsically of different nature for different objectives (e.g. number of jobs, cost and usage of water) but the methods involve summing of the scores, some sort of “value functions” are needed. Often the value functions take value on the scale 0 to 1 or 0 to 100. We have used the scale 0 to 10. The value functions can be linear functions (as in our case) or nonlinear.

In fact, only few real life cases, where MCDM methods are used to evaluate transport projects, are reported on in the literature. As one example, a model, based on the ELECTRA method, was used within the
Ontario Ministry of Transportation and Communications, to derive priorities for over 200 major capital projects.¹⁰

4 A NEW RANKING METHOD

In this chapter we describe the background, development and the basis of a new ranking method. In the next chapter we give more details of the method. In section 6 we discuss the method further and draw some conclusions of its application.

In 1994 to 1997 IMA (Icelandic Maritime Administration) made significant progress in developing standards for harbours, by developing variables (measurements) for several aspects of harbours and making numerical evaluation of improvement projects. The intention was, among other things, to improve the basis for ranking project proposals. These numbers and expert evaluation was the basis of the ranking in 1996.

In 1997 IMA started to develop an Excel model to help ranking harbour projects. The work was based on a similar work in Norway in the late eighties (Ref?) where several indicators were defined which contribute to the final grading of the projects. Most of the indicators would either measure a kind of cost-efficiency or the (relative) importance of the harbours.

In 1998 the Institute of Economic Studies at the University of Iceland worked with IMA on the research project discussed in this paper. The objective of the research project was to make the ranking method more objective and consistent and less subjective, in some sense. The objective also was to increase the acceptance level of the ranking.
Early in the process, it was decided to build as much as possible on earlier work. By that way we would maximise the possibility of “political acceptance” (it is easier to accept something that looks similar to something you know) and to maximise the possibility of a finishing the project in just a few months.

The task at hand is to rank 100-200 project proposals for harbour improvements. The construction plan (list of funded projects) for the next four years (updated every second year) is then based upon the ranking. In this case cost-benefit analysis was not considered to be suitable but the problem situation seemed to lend itself to the use of some variant of MCDM method. Still, in this case it is not possible to use some of the “standard” MCDM methods, or a modification of one. The main reason is that it is not possible to define criteria of the nature that is normally assumed. This is discussed further in section 6.

The objectives of the ranking were not well defined – and can probably never be well defined. The main objective can be interpreted as spending the taxpayer’s money wisely. It is not clear what that means and, in fact, a part of the work was to make that more clear.

The approach we took is basically a simple one. A total index for a project \( \text{TOTAL}_j \) is the product of two numbers for that project, one is a measurement of the importance of the harbour \( \text{IMPORTANCE}_j \) and the other is a measurement of the improvement caused by the project \( \text{IMPROVEMENT}_j \). In some sense, IMPROVEMENT is an indicator for efficiency or outcome, whereas TOTAL is an indicator for effectiveness.

\[
\text{TOTAL}_j = \text{IMPORTANCE}_j \times \text{IMPROVEMENT}_j
\]
Each of the two numbers is a weighted mean of several indicators, which take values on the scale 0-10. The next section discusses these indicators.

The logic of the multiplication can be explained by the following:

- If harbour A is twice as important than harbour B then a project improving harbour A will score twice as much as a similar project improving harbour B.
- Also, if a project i will improve a harbour twice as much as project j (in the same harbour or a similar harbour) then project i will score double as much as project j.

The importance of a harbour has many attributes or facets. One facet is the harbour as an prerequisite or enabler of some jobs. The more people that work in the fishing sector, the more important is the harbour for the community. Since some fish is transported between harbours before being processed and since there are many jobs related to fisheries (services) it is impossible to define one measurement for this aspect. Hence, several indicators are used.

Another facet is the community as a whole. A harbour in a town with a population of 500, of which 100 work in the fisheries sector, is more important than a harbour in a town with a population of 5000, of which 100 work in the fisheries sector.

One aspect seems to be missing, namely the cost of the project. This aspect is in fact taken partly into account in IMPORTANCE and partly in IMPROVEMENT as described in the next section.
5 DETAILS OF THE METHOD

As said before, the total index is a product of two numbers, TOTAL = IMPORTANCE * IMPROVEMENT. We will now discuss these numbers in some detail.

IMPORTANCE is a weighted mean of eight indicators and IMPROVEMENT is a weighted mean of 16 indicators. The nature of the indicators is somewhat different in the two cases, as should be evident from the following text. Each of the indicators takes a value between 0 and 10 and, hence, also IMPORTANCE and IMPROVEMENT take values on the scale 0-10.

Each indicator (taking a value between 0 and 10) is a function (value function) of a measurement. The value function is simply such that the project with highest score on the measurements gets 10 for the value of the indicator and other projects gets value in proportion. (This is referred to as a “local scale” in B1.) Let IND$_j$ be the value for the indicator for project j and ME$_j$ be the value of the corresponding measurement for project j.

Step 1: Get the value of ME$_j$ for all j  
Step 2: Find the maximum value and call it ME$_{max}$  
Step 3: Define IND$_j$ = 10 * ME$_j$ / ME$_{max}$

6 THE IMPORTANCE OF A HARBOUR

The importance of a harbour is of course difficult to define accurately or measure objectively and is thus highly subjective in nature. Although each of the indicators is highly debatable as a measurement of the
importance, the people involved in the decision process have expressed their feeling that together they tell much about the importance.

In 1997 the IMA had developed measurements for IMPORTANCE. These were used with some small changes in this work. These are grouped in three classes and are listed in table 1. The weights given for a measurement is used for corresponding indicators when they are weighted together.

It could be argued that the first group of measures, i.e. the Benefit-Cost aspects, hardly measure the “importance of the harbour”. The cost of the project enters as a numerator and thus IMPORTANCE is project dependent. However, as have been pointed out, the cost of the project is taken into account partly in IMPORTANCE and partly in IMPROVEMENT in this way. One might say that these measurements measure the “relative importance of the harbour”.

An example of a change made in 1998 is that for some measurements the average of the last two years is used instead of only using the last year.

Table 1: Measurements for IMPORTANCE. (The indicators are functions of the measurements.)

<table>
<thead>
<tr>
<th>Benefit - Cost aspects (50 %)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of jobs in fishing sector / Cost of project</td>
<td>17 %</td>
</tr>
<tr>
<td>Value of landed fish / Cost of project</td>
<td>17 %</td>
</tr>
<tr>
<td>Amount of landed fish / Cost of project</td>
<td>17 %</td>
</tr>
<tr>
<td>Employment aspects (25 %)</td>
<td></td>
</tr>
<tr>
<td>No. of jobs in the fishing sector</td>
<td>5%</td>
</tr>
<tr>
<td>Amount of landed fish</td>
<td>10%</td>
</tr>
<tr>
<td>Fish processing measure (10 %)</td>
<td>10%</td>
</tr>
<tr>
<td>District policy (25 %)</td>
<td></td>
</tr>
<tr>
<td>No. of jobs in fishing / Total no. of jobs</td>
<td>12.5 %</td>
</tr>
<tr>
<td>Isolation of town</td>
<td>12.5 %</td>
</tr>
</tbody>
</table>
7 THE MEASURE OF HARBOUR IMPROVEMENT

The basis of the measurement of harbour improvements is definitions of standards for several aspects of the harbours. Six different standards – out of 10 defined - were used in this work. These standards are for:

- Depth of harbour (25 %)
- The utilisation of piers for shelter (15 %)
- The utilisation of piers for landing (25 %)
- Size of turning area (10 %)
- Maintenance (15 %)
- Facilities (10 %)

The harbours are grouped in four classes, mainly depending on the size of fishing vessels using it, and the standards are different for the different classes.

Three different measurements are used for the first five of the standards (all but facilities). In the case that the standard is fulfilled before (the project) then all these numbers are 0. In the case that the standard is not fulfilled then the three numbers are based on:

- Difference from the standard (relative difference)
- Part of the difference that the project will fix
- Part of the difference that the project will fix / the cost of the project

The difference from standard is in some cases a quantitative measurement, e.g. of a depth, but in other cases an expert judgement. The same is true for the part of the difference that the project will fix. (The cost of the project is a given number.)
As an example assume that five projects for increasing the depth of harbours are proposed. All projects are in harbours where the standard says 10 m but the actual depth is different. The effect of the projects is as follows:

- Project I: 6m -> 7m
- Project J: 6m -> 8m
- Project K: 9m -> 10m
- Project L: 9m -> 12m
- Project M: 10m -> 12m

Project M will score 0 because the standard is already filled. Projects K and L should score the same, if the cost is same. One of the measurements takes the cost into account. Project J means greater step towards the standard than project I and one of the measurements covers that. Projects I and K means the same size of step, but since the situation is worse in I, the score will be higher.

For project I, in the example, the difference is (10-6)/10 = 0.4. The project will increase the depth to 7 m and thus the improvement score is (7-6)/10 = 0.1.

As said before, the 16 indicators are value functions of the 16 measurements and IMPROVEMENT is a weighted average of the indicators.

8 DISCUSSION

Only few papers have reported on real life applications of Operations Research to the problem of ranking public project alternatives. This paper reports on an application where a Multi Criteria Decision Making
method was developed and used to rank many harbour improvement alternatives.

In our case it was considered to be impractical to use one of the standard approaches to develop a hierarch of criteria, and perhaps use some of the standard MCDM software. We will first discuss the main differences between our method and the standard approach and then discuss the main characteristics of the problem situation that can explain why we chose our unique development of criteria.

The main differences of our method from conventional MCDM approaches:

- The first level sub-criteria (IMPORTANCE and IMPROVEMENT) of our method are multiplied together, but not added together as is the standard way. Each of these two sub-criteria is then split into second level criteria in the standard additive way.

- The numerous criteria are not independent, and some are in fact highly dependent. For example, the number of jobs in the fishing sector enters three criteria. This is not seen as a problem or weakness since the meaning of the criteria is different from what is common. The meaning is more “indicators” than “measurements”.

The main reasons for not trying to use some conventional MCDM approach are the following:

- There are two main goals (objectives, views) that are conflicting (competing) in somewhat different way than is usually the case. More importantly, these goals are ill defined with unclear and
complex meanings. These goals are:

1. All Icelanders should have access to good infrastructure, e.g. harbours, independently of where they live (and of cost). The meaning of “good” is not defined and since there is always a lack of money, the infrastructure is far from being perfect and many harbours and roads need much improvement.

2. The taxpayers’ money should be used effectively and thus a cheap project should be prioritised before an expensive one if the effects are similar.

• The impacts of a given project on the two main goals are impossible to estimate with such certainty or accuracy that it could be useful. For example, a harbour improvement project might open up some possibilities. Only in few cases is it almost certain that the possibilities will materialize, but in most cases it is very uncertain.

• Neither of the two goals can be split into sub-goals in the usual way.

• Our method is based on a work that the different stakeholders were familiar with and, because of that, they found it relatively easy to accept our method.

• In a typical MCDM application, each decision maker spends much time on evaluating how much each alternative scores on each criterion. In our case, the decision makers are the members of parliament but the social servants at the IMA do the initial ranking. Thus it would not be practical to make the members of parliament make the evaluations, especially since the evaluations are rather technical. In fact, developing the criteria is more a technical work than decision-evaluation work.
The difficulty of estimating the effects can be explained further. One of the main characteristics of the fisheries is frequent change. In contrast, the traffic on a given road is stable (with fluctuations within the day and the week and even the year) and future traffic can be forecasted relatively accurately. Forecasting the fleet that will be using one of the small or medium size harbours 5-10 years from now is extremely difficult and 50% increase or decrease is not unlikely. Also, the fleet is a combination of different vessels and the combination and the use of vessels might change.

The essence of OR is to improve decisions which can both mean that decisions are better, in some sense, or that the decision making process is improved, for example made shorter, more transparent or more democratic. One of the most realistic measures of the quality of a method or a solution is the satisfaction of those involved. In that sense, the quality of the method described in this paper is high, because the decision makers were very satisfied with applying the method and with the final results, and governmental decisions were based on the results of the method in real life.

Since real life problem situations are of very different nature and peoples experience, knowledge and interests are different, it is not easy to say what the MCDM world can learn from this application. We have two suggestions:

- Perhaps too much emphasis is put on the additive model of sub-criteria? Would it be reasonable in many cases to multiply the scores on some of the criteria?

- In cost-benefit studies the estimated benefits often are divided by the estimated cost. In a MCDM study the cost will be taken into
account in a totally different way. It will be treated as one of several dimensions (criteria) and weighted together with other criteria. Perhaps it would be possible and worthwhile to divide by the cost in some MCDM applications?
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