MULTI-CRITERIA SELECTION OF HYDRAULIC GATES

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ABSTRACT

Hydraulic projects like navigation locks, weirs and storm surge barriers are actions of great economical and other impact to large areas. They affect many people in many ways, varying from the safety of their homes to the nature of their income. Gate type selection is a crucial step in the very early design of such projects. The impact of gate type selection is often complex; and can be short-term (e.g. instant solution to a flood problem) as well as long-term (e.g. agriculture, ecology or even climatic changes). There are far-reaching consequences of choosing one gate type above another. One should, therefore, take account of all relevant interests, seeking a balance between them. The way to do it is to use multi-criteria assessment methods. This paper presents a review of hydraulic gate selection methods, as practiced nowadays in Europe.

Multi-criteria assessments enjoy growing interest of engineers, environmentalists, navigation experts and other professionals. An example is the inclusion of this subject in the PIANC 26 Work Group report (Rigo et al. 2006) of the Inland Navigation Commission. The first author of the current paper was the subject leader there; the second author was the work group leader. Additionally, some aspects of gate type selection made part of the doctoral thesis, defended in 2005 at the Gdansk University of Technology under the supervision of the third author of the current paper.

SOME HISTORICAL BACKGROUND

Roles of the main actors in gate type selection changed gradually throughout the ages, but one thing remained the same: Engineers were always thinking out solutions and analyzing their feasibility – and their clients were making final choices[1]. What differed from the current practice was a smaller depth of the analysis and a potentially less balanced (often arbitrary) selection. This did not prevent the appearances of many remarkable gate structures. E.g., the world first mitre gates were - in all likelihood - constructed in the 15th century's link of the Italian Navigilio Grande Canal to Milan. However, in terms of gate type selection, the only criterion that mattered there was the transport of marble for the Milan cathedral (Erbisti 2004). The medieval revival in Europe, gradually introduced more criteria. At least three of them – navigation (not only to build cathedrals), water supply and land safety – became a common practice. However, their relation to gate type selection was still a matter of the engineer's and his principal's personal view. In some countries

[1] Exceptions – like the czar Peter the Great who studied maritime engineering in the Netherlands and personally contributed to some projects in St. Petersburg; or George Washington, a surveyor and an engineer himself, who initiated some canal projects in the USA – serve to prove the rule.

(Netherlands, Flanders, later France) more people were involved in this selection than in the other (United Kingdom, Austria, Germany), but it did not always result in better-balanced decisions.

Technical drawings showing gate layouts and details appeared in the 17th and 18th century. A typical lock or barrier controlled the access to the city moats; and comprised outer, inner and toll gates. Toll charging was a cherished source of income for many small states of Germany and the Dutch provinces. Fig. 1 (Horst v/d 1736) shows that different gate systems were used for different purposes, proving that a kind of gate type assessment had already been performed.

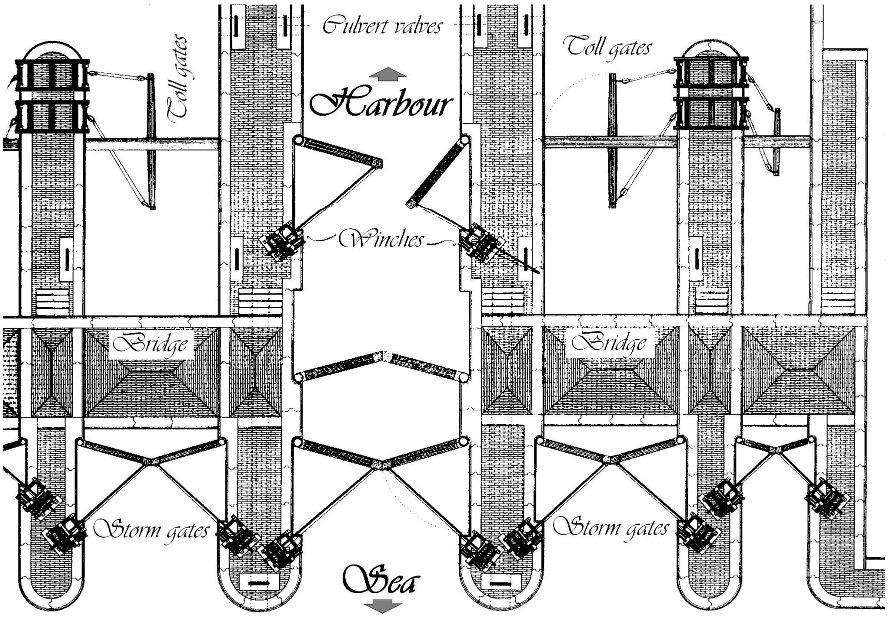

Fig. 1. Gates of the Sea Lock in Muiden (Netherlands), beginning of 18th century

The Industrial Revolution brought further changes. The French Revolution and the emergence of the United States gave voice to new social groups, while the industrialization lead by Britain and Germany resulted in large hydraulic projects. Many new gate systems were developed which gave more significance to the issue of gate selection. Although nobody spoke about the selection criteria yet, gate types were considered to have different advantages and disadvantages in various fields. Apparently, there was little consensus about it. Everybody had own preferences. At the end of 19th and the beginning of 20th century, advancing education and the emergence of technical literature began to stimulate some consensus. Engineering was not an elitist activity with the air of secrecy any more. The lead in this process belongs to two famous French schools, *Ecole des Ponts et Chausses* and *Ecole Polytechnic*, the British *Mechanics' Institutes* and the German *Technische Hochschulen* - not to minimize the other countries' educational institutions. Typical is the discussion at the *Technische Hochschule* in Hannover on the advantages and disadvantages of various gate systems, employing quite a wide range of criteria (Kulka 1928).

The multi-criteria analyses, as performed nowadays, were largely introduced after the World War II. The principal tendency's which stimulated it, were (and still are) as follows:

- growing urbanization and complexity of large infrastructural projects;
- emancipation of different social groups, interests, ideas etc.;
- call for transparency and balance in all projects affecting environment;
- demand for cost optimization and effective cost control;
- computerization, desire for programmable selection procedures.

ASSESSMENT IN QUALITQTIVE TERMS

Any multi-criteria analysis results, in general, in a matrix in which the considered options are evaluated with respect to some criteria. Completing the analysis means - simply speaking – giving values to the matrix elements and deriving the option total scores. The simplest way to do it is to use only qualitative ranking with no numerical values. Several gate type selections have been performed in this way. Below is an example of gate type assessment for a navigation lock, 18 m wide, on the Meuse in Lith, the Netherlands (Daniel 2000). In a pre-selection, four gate types were considered suitable for this project: two mitre gate options, vertical lift gate and a rolling gate (Fig. 2). The ratings in the selection matrix were as shown below (Table 1).

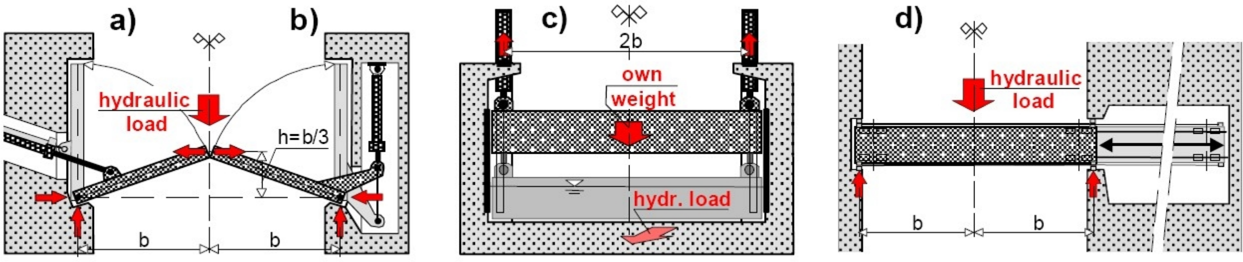

Fig. 2. Four gate types for the Princess Maxima Lock in Lith (details in the text)

Table 1. Simple (only qualitative) selection matrix for the gate types in Fig. 2

Criterion	Gate type			
	Mitre gate (a)	**Mitre gate (b)**	**Vert. gate (c)**	**Rolling gate (d)**
1. Total costs	+	+/-	+	--
2. Reliability	+	+	++	+
3. Navigation	+	++	-	+/-
4. Maintenance	+/-	+	+	-
5. Environment	+	+	+	-
6. Esthetics	++	+	--	+/-
Total score	**+**	**+**	**+/-**	**-**

Herein:

++ very good
+ good
+/- fair
- poor
-- bad

In this case, mitre gates (a) were chosen. Decisive were: unlimited overhead space, moderate costs and little objections against having drive cylinders above the lock chamber. Such analyses are, however, entirely based on arbitrary judgments of a person or a team, which makes them manipulative. As the matrix contains no numerical values, there is practically no way to verify the performance ratings. Nevertheless, the method can be sufficient in the situations like:

- When there is no time or money to perform a better, quantitative analysis. This is in fact a bad excuse; wrong gate selection always costs more. Yet, the client may have a different view in this matter, e.g. when the money does not all come from the same pocket.
- When the case is simple. It may be efficient then to make a quick, qualitative assessment, see the results and decide later whether more effort should be spent to the gate selection.
- When – to the contrary – the case is complex, no consensus has been reached using more sophisticated methods and there is a general impotence to get anything done.
- When the client has already made his choice and he does not really want to discuss it. Yet, he likes some kind of “educated justification” in case he should give an account of it. If this does not conflict with the engineer’s views, he may choose doing it.

QUANTITATIVE COSTS ASSESSMENT

Instead of qualitative ratings, one can fairly quantify gate performances in some criteria (e.g. costs in euros or dollars), less fairly in some other (e.g. navigation in time or ship passages) and ignore the not quantifiable ones (e.g. aesthetics). The problem that appears then is which measure should be leading the entire analysis and how to convert all criteria ratings to the same measure. A common approach is to choose costs as such leading measure. Project costs are always one of the most important and best quantifiable selection criteria. When the costs dominate the analysis, we will try to quantify the gate performances in as many criteria as possible in currency units. Some other criteria, e.g. maintenance or operation, can indeed be measured in currency units. An example of this approach is a study on the reconstruction options for the old weir on the Meuse in Sambeek (Pouw et al. 2000). Also here four options were considered suitable: vertical lift gate with a flap, sector gate, top hinged flap gate and bottom flap gate (Fig. 3):

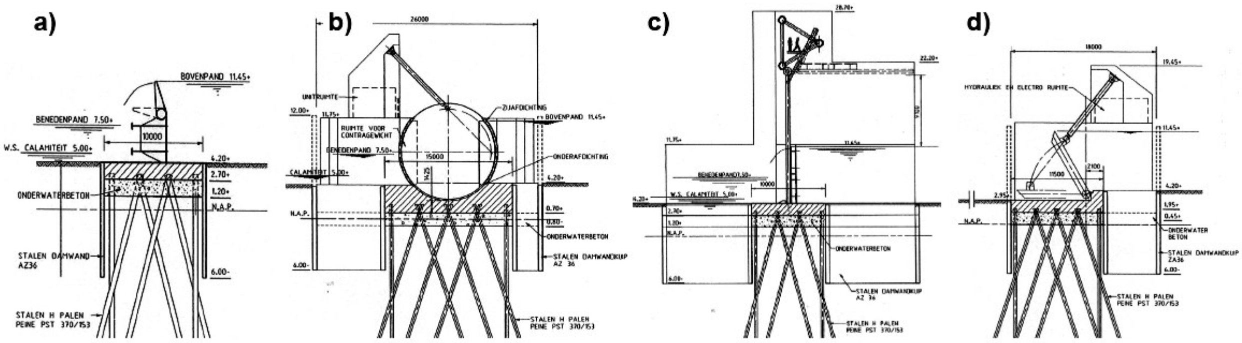

Fig. 3. Four gate types for a new weir on the Meuse in Sambeek (details in the text)

Table 2. Gate assessment in terms of costs for the reconstruction of the Meuse weir in Sambeek

Option **Criterion (€)**	**Vertical lift gate (a)**	**Sector gate (b)**	**Suspended flap gate (c)**	**Bottom flap gate (d)**
Construction	36,000,000,-	37,000,000,-	34,000,000,-	32,000,000,-
Maintenance:				
- per year	340,000,-	447,000,-	365,000	421,000,-
- capitalized	7,596,000,-	9,987,000,-	8,155,000,-	9,406,000,-
Operation:				
- per year	246,000,-	246,000,-	246,000,-	246,000,-
- capitalized	5,496,000,-	5,496,000,-	5,496,000,-	5,496,000,-
Totally (€)	**49,092,000,-**	**52,483,000,-**	**47,651,000,-**	**46,902,000,-**

The costs analysis resulted in the matrix as shown in Table 2. Here, a period of $\boldsymbol{n}$ = 50 years was assumed for capitalizing the maintenance and operation costs. In this period, an effective interest rate of $\boldsymbol{i}$ = 0,04 (4%) was assumed. The capitalized maintenance and operation costs $\boldsymbol{C_c}$ were derived from the estimated yearly costs $\boldsymbol{C_y}$ as follows:

$$C_c = \quad C_y \cdot \frac{1-(1+i)^{-n}}{1-(1+i)^{-1}} \qquad (1)$$

Although the measure (money) is verifiable and generally accepted in construction projects, this approach has still a number of disadvantages. The most important are:

- Not all criteria can be given a price. Environment, aesthetics, local effects (traffic, local economy, consumed land, social effects etc.) can hardly be measured in this way.
- Strictly financial assessment of maintenance and operation says little about e.g. inspection conditions, obstructions due to maintenance, ease and safety of operation etc.
- This approach tends to neglect or underestimate the third parties' costs, e.g. obstacles for navigation, impact on local traffic, agriculture, hindrance due to construction.
- Cost-dominated analyses tend to give everything a price. This may be morally or otherwise controversial[1)], e.g. with respect to human life, irreversible environmental damage etc.

Nevertheless, gate type assessments based on costs can successfully be used in the cases like:

- So-called "quick-scan assessments", which do not necessarily (anyway not immediately) lead to a project. This was in fact the case in the presented example.
- Gate assessments in which other than financial criteria are little relevant, e.g. projects in barely inhabited areas of small ecological significance.
- Situations, where gate type performances of in other than financial criteria differ little from each other. One should, however, be careful in classifying a project as such.

The presented case was rather simple. In more sophisticated assessments, costs are usually not defined deterministically, as here, but in a probabilistic way (means with standard deviations). Financial and other risks can also be quantified in that way. The space limit of this paper does not allow for a detailed discussion of these improvements, but they certainly deserve attention.

ASSESSMENT IN WEIGHTED CRITERIA

As mentioned, costs assessments neglect or underestimate some criteria. A method that does not do that should, therefore, introduce an own measure that is applicable to all criteria rather than "borrow" the measure of a single criterion. Such a method is the performance rating in weighted criteria. Usually, a rating scale from 0 to 10 points is assumed to quantify the gate performances in each criterion. Higher ratings represent better scores, although reverse systems (the higher, the worse) are thinkable as well. The rating takes place in one of the two following ways:

- For quantifiable criteria: Express gate performances in the quantity units of a criterion (e.g. money for costs, time for navigation etc.); choose a rating range covering the performance dispersion and convert the measured values to the ratings.
- For not-quantifiable criteria: Let a group of experts rate the gate performances subjectively; ask them to come up with a consensus or derive the mean scores.

Having done the ratings, one can not simply add them to each other because the importance of the criteria is not the same. In order to produce total scores, the relative importance of all criteria must be defined. This can be done using weight factors. The most convenient way is to assign the criteria weight factors in such a way that the sum of these factors equals 1.00. The total scores will then emerge in the same rating scale as the criteria scores, which helps to avoid confusion.

It is advisable to let a team of the project owner (possibly including local authorities and other parties involved) determine the criteria and their weight factors; and an independently acting team of professionals generate solution ideas and rate the gate performances. This decreases the risk of "dragging" the analysis towards the results that are favorable to individual team members. The communication between both teams is a sensitive mater: It must produce well-understood and workable criteria; but it should not allow for lobbying or other manipulating of each other.

An example is the gate selection for a new, double navigation lock between two lakes – the IJsselmeer and the Markermeer – which emerged from damming the Zuiderzee, a former internal Dutch sea. The lock was constructed in 2003 as a so-called *Naviduct*, lock on an aqueduct (Daniel et al. 2003). It combines lock and barrier functions, which is a common practice in the Netherlands and Belgium. The idea is that the gates perform locking under normal conditions. When a storm

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[1)] Giving no price to human life may also be controversial. It is not the authors' intention to issue moral judgments here.

surge approaches, the navigation holds up and the closed gates operate as a barrier, protecting land against inundation. Again, four gate types were selected for the final assessment: mitre gate (here with drive arms), single leaf gate, sliding gate and sector gate (Fig. 4).

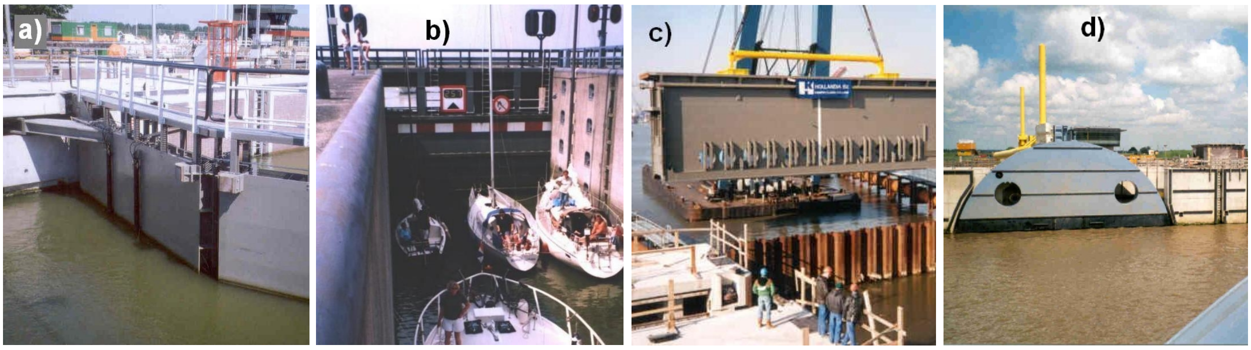

Fig. 4. Four gate types for the *Naviduct* in Enkhuizen (details in the text)

Table 3. Gate assessment in weighted criteria for the *Naviduct* in Enkhuizen

		Gate type			
Option / Criterion	**Weight factor**	**Mitre gates (a)**	**Single leaf gates (b)**	**Rolling gates (c)**	**Sector gates (d)**
1. Total costs	0.40	8	9	6	6
2. Operation	0.35	9	8	8	7
3. Local constraints	0.10	8	7	8	7
4. Navigation	0.10	8	7	8	6
5. Environment	0.05	7	7	6	7
Total score	1.00	**8.30**	**8.15**	**7.10**	**6.50**

The considered criteria and their weight factors are shown in Table 3. “Total costs” represent here the construction and the (capitalized) maintenance costs. “Operation” has been considered separately including financial and other issues. “Local constraints” cover the aspects like esthetics, required space, walkway passage, disturbance to radar communication etc. “Navigation” requires no comments. “Environment” is focused on environmental impact in the local sense (pollutions due to lubrication, painting, impact on wild life etc.) and in global sense (energy consumption, diverse emissions due to material winning, manufacturing etc.). Here, the costs and the operation criteria dominated the analysis, which is not necessarily advisable for other projects. The total gate scores $\boldsymbol{S_t}$ were obtained by adding the products of criteria ratings $\boldsymbol{S_i}$ and weigh factors $\boldsymbol{wf_i}$:

$$S_t = \sum_{i=1}^{n} S_i \cdot wf_i \qquad (2)$$

We see that mitre gates offered the best solution. This gate type has indeed been selected. More details about the completed project can be found in (Daniel & Vrijburcht 2004).

SENSITIVITY ANALYSIS

The method of weighted criteria is still vulnerable to arbitrary opinions. It remains difficult to set up an objective, traceable ranking system except for the costs related criteria. The weight factors remain an arbitrary choice as well. It is practically impossible to eliminate these arbitrariness, but it is possible to estimate its influence on the final results. A way to do it is the so-called “sensitivity analysis". We shall focus on the sensitivity to different assumptions of the weight factors, which is a crucial, numeric decision to be made. However, this does not cover the whole subject. One can also analyze the sensitivity to the assessment approach as such, i.e. to the way in which proper groups of interest are involved in the decision making process. Interesting examples in this field are the Belgian and French experiences with the so-called "concertation" method – a multi-criteria analysis for multi-actor decision-making (Hiver 2003).

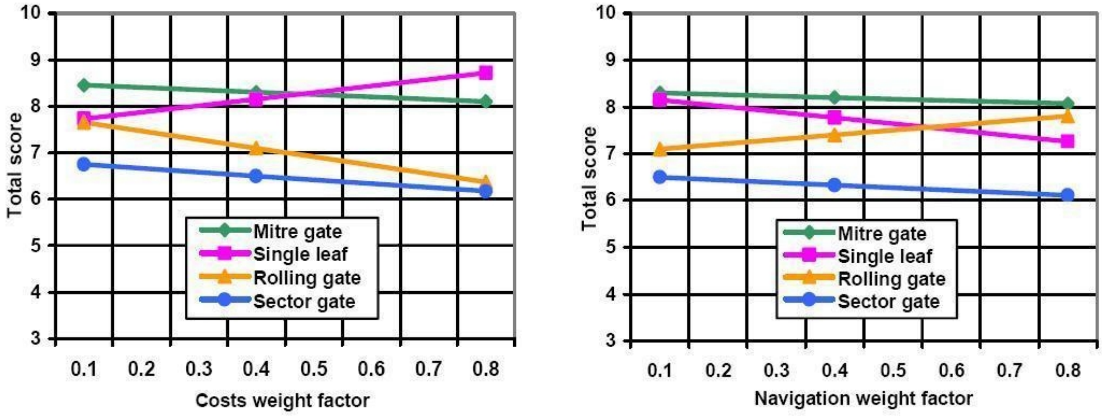

Fig. 5. Sensitivity graphs for the costs and navigation criteria in the *Naviduct* project

Let us assume that the client feels uncertain about the high weight factor of 0.40 for the costs criterion in the *Naviduct* project. He wants to know how much it maters if it assumes other values. In order to answer that, we now take other value – say 0.10 – for this weight factor, and divide the difference proportionally between the remaining criteria. The resulting weight factors are then: total costs 0.10, operation 0.525, local constraints 0.15, navigation 0.15, environment 0.075. The gate scores with these factors, and the gate scores from Table 3 define the linear functions of the total gate scores in relation to the weight factor for the costs criterion (Fig. 5 left). In the same way we can investigate the sensitivity to any other criterion, e.g. navigation (Fig. 5 right).

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