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Use of Pairwise Comparison Method in Road-and-Bridge Tenders

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Abstract. The paper is a brief presentation of the pairwise comparison (PC) method, implemented with the use of the Concluder, a modern tool for PC analysis which is being developed by Professor Waldermar Koczkodaj and which is used for comparing tenders in the road-and-bridge construction industry. The paper discusses the tender criteria which are adopted for tenders in this industry. It addresses the issue of developing the relevant weights while using one of the functions of the expert system, i.e. the function which relies on the opinions of the experts familiar with a given matter, who however not always present the same views. Once the experts' opinions have been collected, they can be "agreed" while using the PC method. Diversification of the criteria is particularly important from the point of view of improvement of the quality of the services offered by the road-and-bridge construction industry in Poland, since in to-date practice the price has been the only or the dominant criterion. The paper contains examples (in terms of numbers) of analysis of tender criteria where the price was not the only criterion, which is the starting point for further research.

1 Introduction

Is there any universal criterion that can be applied to assessment of multiple issues in so a diversified field as the construction business, especially bridge construction? Is there an optimum method of selecting the best solution? Even if we are not a fairy and are unable to foresee the best variant or find the best solution when it is not precisely defined, still we can use some approximation or a method which offers tangible solutions and enables finding a result in the form which is easy to compare, based on unambiguous assessment criterion, for example based on the weights of tender criteria. Should the price account for 60% of the assessment, with other criteria making up the remaining part, or should the price account for 50%, or should the split be still different?

This way we can express the advantage of one solution over another in a way which easy to comprehend for us without having to dismiss any solution or making "I think so" statements, which is often not so clear at first glance in the case of similar value solutions,

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which is often the source of our dilemmas. Is it worth investing in a better but more expensive product, or choose a cheaper one which will last shorter” How to select the tender criteria? The answer, in a mathematical form, can be provided by the pairwise comparison method (PC) or the consistency-driven pairwise comparisons method (CDPC) method which are globally known and applied, also in the construction business. Summing up, on the one hand we have the relevant method with many diverse applications, and on the other there are numerous issues which require solution. For example, adoption of multiple criteria in infrastructure-related tenders in Poland so as to improve the quality, which ultimately may result in better roads and bridges for us. The method can be also useful when operating and maintaining these facilities, e.g. for assessing their technical condition, etc.

2 Review of publications on the topic

There is quite a number of publications on the PC method, with new ones being developed all the time. The PC method finds use in many fields of life, however in the case of bridge construction the publications are not numerous since the issue was not examined extensively earlier. One of the early studies regarding use of computers and expert systems in bridge construction, e.g. [1] and [3], may provide some reference point here.

2.1 Expert systems

Expert (knowledge-based) systems can be helpful wherever the criteria are unclear by definition, because they cannot be measured, like e.g. how beautiful a bridge is, or when the criteria are difficult to assess due to diverse reasons, since we have no comprehensive information on a given facility (e.g. the technical condition is difficult to assess).

The assumptions underlying the expert systems are presented by the authors of [1] with a reference to publication [2]. The assumptions include in particular:

- development of decision variants when the information is not full, the analyzed problems are ambiguous, i.e. they have descriptive form, or they are based on contradictory information, or in other words they are poorly structured,
- ”work with a user in a dialog system,” which today we would term as an interactive system, with of course a user friendly interface.

The requirement for this is “broad” access by such a system to knowledge bases. In the general sense, the role of such a system is played by the Internet nowadays, but then thanks to the Internet such a system could contact dedicated database all over the world, or at least in Poland (e.g. in the scope related to bridge maintenance), which is an indirect assumption of a kind of data standardization, as the data must be “comprehensible” for the system.

According to the classical definitions [1, 2] every expert (knowledge-based) system consists of tree modules in principle:

- the knowledge base (the long-term memory),
- the inference procedure (the inference or control mechanism),
- the dynamic memory (the short-term memory),

as well as of the three additional factors which have proven very important in making systems more available and lasting, e.g. the possibility of expanding the knowledge, facilitation of explanations and a user interface.

Inference procedures make up the core or “the brain” of the system - this is where the experts’ experience is modeled and formalized in the computer program, the place where the know-how related to a given field is synthesized, tested and rendered available to a bigger group of users.

Today nobody questions the benefits of application of computers to bridge construction, and on the contrary computers are indispensable and no engineer is able to imagine working without a computer. Today an average smartphone has more computing power than the early supercomputers and one should expect the trend of growth of computing power to continue into the future, moving down to increasingly smaller devices.

But we face other problems – replacement of operating systems and software by newer versions, which translates into the way in which data is stored – the format of digital files as well as the physical capabilities of hardware in terms of its compatibility, e.g. today we would not be able to install old hard drives in the new hardware. At some point in time the systems and the data will require transformation to a new system, a new data carrier, else becoming practically useless.

Only the core – the inference procedure – will not change. In the algorithm-based systems there must exist the relevant algorithm, while the expert system requires that the knowledge of experts, i.e. the people who are highly experienced, be implemented while using a relevant tool. This is something that is "internal" with respect to the "external" computing power. Tested algorithms are not aging as compared to hardware. Thus, the ability to comprehend the methods and their theoretical development are of key importance, bigger even than the systems that support them or the programming language.

2.2 PC method

Pairwise comparison method is one of such tools. It enables inclusion of not very precise opinions or oral assessments and expressing them by means of "cold figures." The method will also make it possible to collect the experts' knowledge and arrange it into a hierarchical system of criteria with a defined measure and then, based on these criteria, to make decisions with even bigger precision [3].

Hence, everything relies on the opinions of a group of experts who have knowledge of a given matter though not always they share the same views. These opinions should be collected to obtain research material. Each team can have a different opinion and can analyze a problem in a different way, though we assume that the opinions will not differ significantly in the most important aspects. Even if that is the case, we can deal with it by appointing many teams. Once the opinions are agreed, we can obtain the criteria that are of interest for us in the form of a digital notation.

Can similar scaling of the technical condition of bridges be achieved? Such attempts were made by the Municipal Road Authority (ZDM) in Warsaw in whose case regular inspections of bridges were commissioned regularly since the year 2000 to assess the condition of the bridges. Classification of bridge facilities was developed this way and the worst ones, i.e. the ones which required immediate repairs or replacement, were named. This way the "ZDM black list," mentioned in [4], was created. It would be interesting to perform comparative analysis of this "black list" while using the PC method, or potentially to create such a list in the future. Would the result of the analysis be identical?

We also expect to obtain, with the use of the PC method, the new, improved assessment of the existing system of inspection and assessment of bridges which is currently used by the road authority, for example by the General Directorate for National Roads and Motorways. The research work which has been undertaken, and its results, can be interesting for many local road authorities and enable them to plan maintenance, repairs and budgets in a better, optimum manner thanks to access to an additional, digital "metric" of the condition and quality of these facilities. The existing system already provides numerous important information items which can be reanalyzed and interpreted in a new way.

The Instructions (related to on-going, basic and extended as well as detailed inspections include an assessment scale (from 5-adequate to 0-emergency) which is helpful when using the PC method, as well as the assessment methodology (in which the score is) the smallest value of the relevant arithmetical averages of the assessed elements [9]. Could this be done better with the use of another method?

The data collected this way can be used for carrying out a new, better in terms of quality, analysis and introducing the new scoring for the facilities based on the PC method, e.g. 100 [%] in the case of an ideal bridge which has just been built, 0% in the case of a total ruin, a bridge which is totally unfit, in whose case demolition is the only right solution.

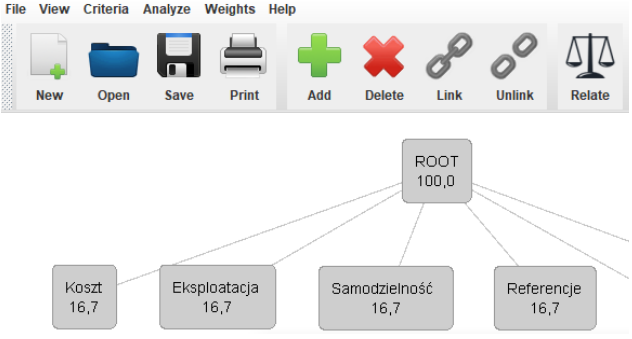

Fig. 1. An example of the graphical illustration of the decision-making criteria – a fragment of the home page of the Concluder software [7].

What methodology should be adopted and what will be the estimated result? What is the condition of majority of Polish bridges? In what range do they fit in? What criteria will be adopted by the team of experts?

3 Tender criteria

The Public Procurement Law (PPL) lists the exemplary evaluation criteria which can be used. According to section 2 of Article 91: *Tender evaluation criteria shall be price or price and other criteria linked to the subject-matter of the contract, in particular:*
1) quality, including technical parameters, aesthetic and functional characteristics;
2) social aspects, including social and occupational integration of persons referred to in Article 22.2, accessibility to disabled persons, and responding to user needs;
3) environmental aspects, including energy efficiency of the subject-matter of contract;
4) innovation aspects;
5) organisation, professional qualifications and experience of persons appointed to perform the contract, if they can have a significant influence on the contract performance quality;
6) after-sales service and technical assistance, delivery conditions such as delivery deadline, manner of delivery, and lead time or period of completion.

One should however underscore that the criteria must be related to the subject of an order/request, rather than to the characteristics of the contractor, which is covered in the wording of the Article 91, section 3 of the PPL Act (save for the scope of security which is associated with convoying of money and valuables as well as social welfare services – Article 5, section 1 of PPL Law) – especially the bidder's economic, technical or financial credibility. Order completion date as well as the anticipated time schedule are permitted to be used as criteria.

Let us however note that "the professional qualifications and experience of persons appointed to perform the contract" [5] can be a requirement in the tender process, however the rules of fair competition must be observed. This means that the qualifications of a contractor can be taken into account in a different way.

In accordance with the wording of section 8 of Article 91 of the PPL Act, the minister responsible for economy shall determine these criteria by means of a regulation. As long as such criteria have not been defined yet, intense discussions should continue in the bridge construction community to select the best possibility.

Examples of tender criteria, which are found in [6], are listed in Table 1. It is a proposal which is worth considering. However, our opinion is that there should be more proposals, and since we are not aware of any other, the authors have made the attempt to "mobilize: the community to voice their opinions on the matter. We did so by performing a survey during the 28th Bridge Seminar in Rosnówek near Poznań on 12 June 2018. In part 4 of the paper we quote some exemplary opinions of the participants of the survey.

Table 1. Criteria in a multi-criteria tender according to [6]

Item	Name of criterion	Weight [%]
1	Construction cost	15
2	Operating cost	15
3	Construction without sub-contractors	10
4	Number of references	10
5	Construction time	10
6	Warranty period	5
7	Equipment-related potential	5
8	Innovation	5
9	Professional qualifications	5
10	Professional experience	5
11	Working conditions	5
12	Activation of the disabled	5
13	Staff development	5
	TOTAL	100

Upon reducing the criteria from the Table 1 to the ones which relate only to the subject of the order, their number has decreased down to 6. (Table 2).

Table 2. Tender criteria restricted to the scope of the order only acc. to [6]

Item	Criteria/Conditions	Weight [%]
1	Construction cost	20
2	Operating cost	20
3	Non-use of sub-contractors	15
4	Number of references	15
5	Construction time	15
6	Warranty period	15
	TOTAL	100

One could ask – is it an optimum proposal? How do we know that the proposed weights should be "round" percentages? In real life we rarely come across such ideally equal values – thus an attempt to start the discussion and recalculate the values anew, with a bigger group of experts, where each expert can have his own opinion.

It would be helpful to carry out another, broader survey among engineers – specialists in infrastructural construction projects, including civil engineers constructing bridges, roads and railways, etc. This way experts in the field of transport infrastructure can contribute to solving the identified problem, though their opinions may vary.

4 An example

The discussion of the solutions which are based on our own criteria (different weights) is presented below. The Concluder program, a state-of-the-art tool for PC analysis which is developed by Professor Waldemar Koczkodaj [7], only serves the purpose of a computational tool. The essence of the process is to adopt own weights for the criteria by means of the PC method, by defining to what extent one criterion, e.g. the construction cost (the price), is more important than another one, e.g. warranty. Table 3 presents the opinions of the participants of the survey conducted in Rosnówek where the criteria were adopted based on [3], with the scale of 1-5 (where 1 means identical or unknown value, while 5 means absolute importance, the highest degree in which one criterion is preferred over another).

Table 3. Criteria and weights adopted by experts and their mutual comparison

Name of criterion no. 1	Weights adopted for comparison			Name of criterion no. 2
	Expert 1	Expert 2	Expert 3	
Construction cost	0.33	0.50	4.00	Operating cost
Construction cost	0.25	0.25	3.00	Non-use of subcontractors
Construction cost	2.00	0.25	2.00	Number of references
Construction cost	3.00	0.50	0.33	Construction time
Construction cost	3.00	0.50	3.00	Warranty period
Operating cost	4.00	0.33	0.50	Non-use of subcontractors
Operating cost	4.00	0.25	2.00	Number of references
Operating cost	3.00	1.00	0.33	Construction time
Operating cost	2.00	1.00	0.50	Warranty period
Non-use of subcontractors	3.00	1.00	0.50	Number of references
Non-use of subcontractors	3.00	2.00	0.33	Construction time
Non-use of subcontractors	1.00	2.00	2.00	Warranty period
Number of references	0.33	2.00	0.33	Construction time
Number of references	0.50	2.00	0.50	Warranty period
Construction time	0.50	1.00	4.00	Warranty period

Upon conducting the variance analysis – finding the relevant matrix coefficients, we have arrived at the final result in the form of relevant criteria weights. We have obtained results which will of course depend on the adopted assumptions (compliance matrix coefficients).

The above example shows that each expert made different assumptions! Fig. 2 shows the results obtained by the program. Expert 1 introduced himself as an architect/designer, while Experts 2 and 3 were both from the construction business, and still their opinions differed.

We will take the liberty to say that it was the first survey of this type in Poland and the results are very interesting. For this article we have selected several most diversified responses which show how differently a given issue can be viewed.

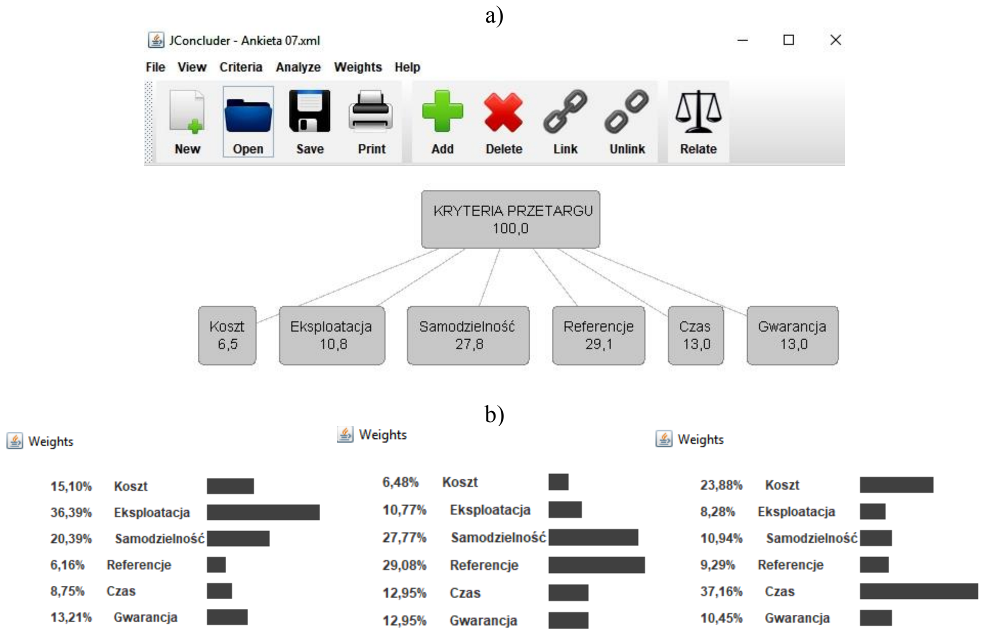

Fig. 2. Graphical illustration of the weights arrived at with the use of Concluder software [7]; a) exemplary, graphical presentation of the "criterion tree" of Expert 2.; b) percentage-based and visual weights of criteria (respectively) from Experts 1,2,3.

5 Conclusions and directions of further work

Figure 2 indicates that "unequal" results have been obtained. Such a result seems to be closer to reality. We experience this every day – rarely are things "precisely equal, while all equal divisions seem to be imposed. Is it possible to cut an apple in such a way that the two halves will weigh exactly the same?

Is the solution obtained this way right? Is it closer to truth? This is the starting point for further examination as to whether the weights of tender criteria are proper and a starting point for looking for practical use of the tool for other purposes, for example for resolving issues related maintenance and repair of bridge facilities. The survey gave very diversified results, hence the need for further in-depth research of the discussed issue. One should strive to obtain as many opinions as possible, so that it will be possible to examine "the entire" opinion of the civil engineering community, including the opinions of the bridge construction engineers, so as to adopt the best method of implementation of tasks/projects. This does not mean that one "uniform" opinion will be developed for the entire industry which will be suitable for "all occasions," though we think that this could be possible with the use of the PC method if a methodical approach was adopted. **It would rather be a matter of creating some guidelines for further tender procedures,** so as to have a richer selection of the tender criteria, leading to better choices than the ones made on the basis of the price criterion, as the only criterion – a prevailing practice nowadays. For full clarity it should be added that each individual tender can be governed by its own laws and the criteria that are suitable only for this specific tender could be selected! This analysis sets no limitations as to selection of the criteria and their weights but is intended to provide assistance – in the future no solutions may be imposed "upfront" since this would be contradictory to the spirit of the method.

Maybe some other criteria should still be added? If so, then what criteria? How many of them there should be? One additional hint, based on experience, comes to mind – there should not be too many criteria because that would not add clarity to the issue being resolved while extending the time of analysis and calculations. It is recommended that the number of criteria be restricted to around 7 [see 8]. Even if there are more criteria, it is probable that with high certainty we will be able to pinpoint several significant ones, while restricting the number of criteria without harming the precision of the findings. Or may be only three or four will suffice?

Summing up, an intense discussion is needed in the community as regards the selection of the criteria and their relevant weights in public tenders, which should lead to increased awareness of the decision-makers, and may be even to creation of some guidelines for tendering processes. The conducted survey is the first step in that direction. As many experts as possible should participate in the discussion so as to obtain a "reliable opinion" and so that adoption of the criteria and the decision regarding selection of the bidder in a tender be, as much as possible, "indisputable," as J. Rymsza put it [6], fair and the best from the point of view of Poland's public good that the engineers are trying to serve!

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