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Investment into New Technology under Uncertainty Conditions

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Abstract

The Republic of Croatia is undergoing a massive reconstruction of large infrastructure systems, specifically design and highway construction with accompanying service buildings. Hence the need for the foundation work for bridges, viaducts, overpasses, office and public service buildings on the soil of low stiffness, e.g. of inadequate bearing capacity. Various soil improvement technologies might enhance its bearing capacity, e.g. keep under control or reduce total and differential settlements. The paper presents methodology of the decision making on a probable purchase investment into a potential soil improvement technology on the example of a typical highway structure. Firstly, criteria are set on the basis of defined designers', investors' and wider community's interests according to which the rank list of foundation technologies would be made up using multi-criteria analysis of AHP method. Then, using the tree method decision and applying expected values criteria the decision on investment into soil improvement technology purchase will be reached. Providing that the decision on investment has been reached, the decision on the selection of a proposed technology by means of a decision tree will be made.

Keywords

Investment, Decision making, AHP, Decision tree, Soil improvement

1. Introduction

Due to the massive construction of infrastructure facilities, particularly highways, there is an increasing need for heavy structures' foundation work on the soil of low stiffness, e.g. of insufficient loadbearing capacity in the Republic of Croatia. Such a problem can be solved in several ways: by giving it up, by relocating it on the soil of better stiffness and loadbearing quality, by designing a foundation structure with respect to low stiffness and soil capacity, or by improving the soil. Solution making on the foundation mode in such situations depends on the systematic study of the whole series of impact indicators, adequacy and information quality, on the number of alternatives to be chosen, and on the use of adequate models and techniques for the selection of optimal, e.g. the most suitable alternative (Kovacevic *et al.*, 2006).

Giving up of a project is the most extreme case adopted only in case when geotechnical and economic analyses result in abandoning the project as the better solution than any attempt at founding the facility. With regard to the extraordinary significance of the highway network for the total economic development of the Republic of Croatia the abandoning of the project becomes replaced by the relocation to the soil of acceptable stiffness and loadbearing capacity, e.g. by replacing the existing soil with new, stiffer and more stable soil for the foundation work. The soil replacement up to relatively low depth is technically and economically possible. Providing that the bad soil reaches down to bigger depths the foundation structure should be either designed with respect to low stiffness and loadbearing capacity, or the soil should be improved. The traditional method of foundation work on the soil of low stiffness and of the low loadbearing capacity is the construction of drilled or driven concrete piles which take over the upper structure's load. The option is turning of the natural soil into a new material by various technological procedures of compacting and mixing of the existing soil with the new one. The soil improvement methods can contribute to soil's higher loadbearing capacity, e.g. to reduce and keep under control the total and differential settlements, and reduce the time needed for deformations to turn up. Further they can contribute to lower soil permeability, and completely remove the water from the soil by constructing inner drainage systems and thus increasing the erosion stability (Mitchell and Jardine, 2002).

The design, construction and maintenance of highways and accompanying facilities in the Republic of Croatia is run by state owned companies acting as investors on the behalf of the state. The investor invites tenders and lets the designer to complete a design. Taking into account stability, e.g. stiffness and loadbearing conditions the designer chooses the foundation technology or the method. It often happens that the designer engineer designs a very expensive and slow technology, not owned by tendering companies. In case they win a tender they purchase the equipment, estimating it convenient in some way.

The design engineer's selection, along with the selection of the foundation technology depends on the project financing model. In case the project is being financed according to the concession model shared mostly by private investor, then the private investor is going to choose a designer with best references, and the one who will protect the investor's interests to the highest extent.

If the project is going to be financed totally or for the major part from the state budget, the state chooses company for the project realization. In that case the company takes the investor's role, and the designer is chosen by participating in a public tender. The investor is practically not able to influence the designer's foundation method in Croatia. According to the Law on public purchase the investor invites tenders, and the company with a required experience in foundation design, and with the lowest price wins a tender. In this way the company experienced in only one technology often wins, without knowledge of new and current design technologies, but offering the lowest price for the design itself. The project could be the cheapest, but the construction might be the most expensive of all, the terms longer and the environmental impact more inadequate than the one offered by other technologies. The investor does not posses any instrument of bringing the designer to consider other technologies, e.g. to adjust to the interests of broader community. Moreover, the investor can not influence the selection of the same company for the next project, as the company in question will have even more references and the lowest price of design.

The paper suggests the approach that would overcome mentioned problems in a certain way. According to it, for each tender the investor makes a team consisting of investors' representatives, leading design engineering companies and representatives of broader community. They define together the interests of all interested parties. The resulting criteria are going to be set in order to define the list of foundation technologies shortlisted by multi criteria analyses. Upon making the foundation technologies list public, the tender and the designer are obliged to be experienced in all suggested technologies. Further, the investor can add a bonus into the contract, the amount of which is proportional to the selected technology on the rank list.

The designer is always expected to select the top ranked technology. Therefore, the problem of the best method selection should be solved, and not the problem of ranking the methods. The latter would be a wrong approach. There are additional criteria, defined standards contained in many cases in practice, which foundation structure has to satisfy, and which could eliminate any foundation method not noticeable in the pre-tender phase.

2. Criteria for Making the Foundation Technologies Rank-list

Within the team which ranks the foundation technologies there are interests groups of different, and often not overlapping concern. Frequently, the interests are totally opposed. A designer is focused on designing a safe and stable foundation structure with the least possible degree of settlement for the future building with the highest possible loadbearing capacity. With technologies of soil improvement and various technological procedures of compacting and mixing the existing soil with the new one, the natural soil is turned into a new material. In other words, natural or artificial materials are being mixed into the soil, which can to a higher or lesser degree pollute the environment. At this point the broader community turns up to find its interest, particularly if the soil improvement can make an impact on the ground water resources. The investor's position is the most precarious one. The company carrying out the project has been established by the Government, which is supposed to take care of the community's matters, e.g. of the environmental concerns, as they represent issues of the national priority. On the other side, since each construction disaster can result in terrible consequences the Government is interested in design and construction according to the safest and highest standards. Besides the political responsibility, there exists also the legal issue. What is more, the project is being financed from the state budget, so that the design's price, e.g. the good management of the voters' means is the Government's primary concern. The last but not least, the construction of large infrastructure projects influences the Government's rating with voters to a large extent. Therefore, the promised completion of several projects is of immense importance for the Government's credibility.

According to above mentioned items the criteria for the foundation technologies ranking are the following:

1. The lowest price
2. Shortest terms
3. Increase of the soil stiffness
4. Increase of the soil's loadbearing capacity
5. The least environmental impact

3. Foundation Technologies

The following foundation technologies can be shortlisted when the established criteria are considered:

1. A deep soil vibratory compaction,
2. Deep soil mixing,
3. Jet grouting,
4. Stone columns and
5. Concrete piles

The technology of *deep soil vibratory compaction in incoherent and mixed soils* is concerned with rearrangement of soil particles, increasing thus the soil density, e.g. compaction, the angle of inner friction, and the modulus of compressibility (Brown, 1977).

The technology of *deep soil mixing* is carried out by mechanical engines for mixing the soil where the binding agent is being mixed into soil, and elements of different shapes and configurations are obtained, whose minimal depths has to be 3 m to name the method the deep mixing (Moseley, 1993).

In the technology of *jet grouting* a certain volume of soil is being turned into an earthen mortar. The soil structure is being broken by means of highly forceful liquid jets. At the same time, the soil particles are being mixed with the cement suspension and fill the designated area. A diameter of the demolishing jet action in the soil ranges up to 2,5 m, depending on the soil type, carrying out of the procedure and the applied liquid (Shibazaki and Ohta, 1982).

In the technology with *stone columns* in coherent and mixed soils, the piles made of gravel or granulated stones are constructed by driving and vibration taking over additional loads. Such granulated material embedded by means of the vibrator has greater stiffness and yields larger shear resistance along with adjacent soil (Wats, 2000).

The traditional foundation method on the soil of low stiffness and insufficient loadbearing capacity is the construction of *concrete piles* taking over the upper structure's load. The columns are constructed by piling and driving or on the site in pre-prepared drillholes. Concrete piles take over the load like the columns when their base stands on the solid ground and with their resistance to jacket and bottom if they do not reach the bedrock (Bell, 1993).

4. The Foundation Technologies Ranking List

The multi criteria analysis - AHP method will be used for setting up the rank-list of foundation technologies in this paper (Saaty, 1980). The major reason for the selection of this method accounts for the need to incorporate subjective estimations and objective facts into a logical hierarchical frame, which will enable a decision maker to adopt an intuitive and sound approach to quantify the significance of each decision element through the comparison process. (Saaty, 1995; Ceric, 2003).

4.1. Hierarchical Structure

The model consists of the goal, five criteria and five alternatives. The goal is to set a rank-list of foundation technologies. The criteria are: the lowest price, the shortest terms, the maximal soil stiffness increase, the maximal increase of soil's loadbearing capacity, and the least environmental impact. The alternatives to the foundation method are the following: deep soil vibratory compaction, deep soil mixing, jet grouting, stone columns and concrete piles.

4.2. Criteria Comparison with Regard to the Goal

The estimations of the criteria significance regarding the goal are the most dubious issues of the study in total. At this level we should adopt to investor's, designer's and the community's interests. The obtained relative significance of criteria regarding the goal largely depends on specific investor and designer. If the analysis result would be acceptable for the whole Croatian construction industry the round tables should be organized for the all prominent investors, designers and representatives of the Ministry of Environment Protection and non-governmental taking part. The paper brings the estimations on the basis of the author's experience and her consultations with designers and investors' representatives by using the Saaty's scale.

4.3. Alternatives' Comparison Regarding the Criteria

The alternatives comparison regarding the criterion: *Price* was established in this paper on the basis of obtained information from the investor on the unit price of a square meter of the soil improvement for all the methods on the soil of similar physical and mechanical properties.

The comparison of alternatives with regard to the criterion: *Terms* – the criterion is obtained here on the basis of terms estimation of foundation work for a type structure and by setting the duration of the methods into interrelation.

The comparison of alternatives with regard to the criterion: *Stiffness* – is obtained on the basis of information on measuring the degrees of stiffness increase of completed structures for all the methods on the soils of similar physical and mechanical characteristics.

The alternatives comparison in relationship to the criterion: *Loadbearing* basis here on obtained information on measuring the loadbearing increase degrees of completed structures for all the methods on the soils of similar physical and mechanical characteristics.

The alternatives comparison in relationship to the criterion: *Environment* basis on the use of the Saaty's scale.

4.4. The Synthesis of the Comparison Results and Formation of Foundation Technologies Rank List

Fig. 1 shows the results of multi-criteria analysis, e.g. the rank list of foundation methods by using the Expert Choice ver. 11.0 of the inc. Pittsburgh company, Pennsylvania.

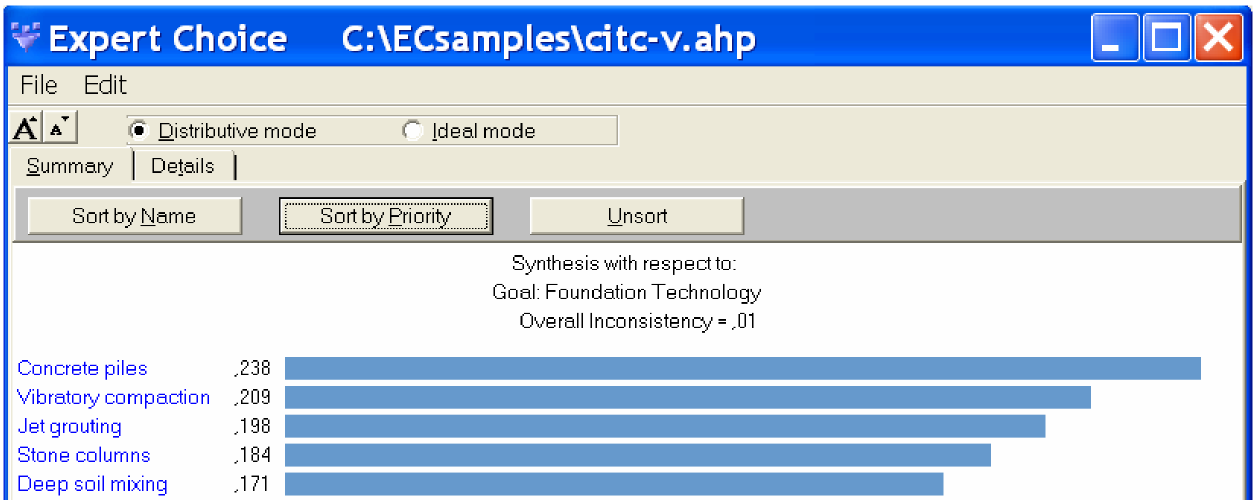


Figure 1: Foundation Technology Rank List

The following rank list of soil improvement methods was obtained:

1. Concrete piles - 23,8 %
2. Vibratory compaction - 20,9 %
3. Jet grouting - 19,8 %
4. Stone columns - 18,4 %
5. Deep soil mixing - 17,1 %

5. Investment into New Technology – Decision Making Tree

Upon the publication of the multi-criteria analysis results, e.g. the rank list of foundation technologies on poor soil for the highway construction requirements and accompanying business and service facilities, the prominent performer of geotechnical works wants to make decision on investing into the purchase of new equipment for foundation. The performer is ready to invest into undertaking specialist investigation work related to soil stiffness, as it often happens that the soil conditions can be highly inadequate for foundation work. It leads eventually to a design solution requiring considerable additional work, and therefore more profit. Providing that the performer is ready for investment, he has to decide on the listed foundation technologies' equipment purchase.

The decision on the equipment purchase is to be made for one of 5 offered foundation technologies: Vibratory compaction, Deep mixing, Jet grouting, Stone columns and Concrete piles. The decision tree will be the basis of making the decision (Figure 2).

Multi-criteria analysis resulted in the rank list of foundation technologies with the accompanying weighted share for each method. They can be taken as probabilities that any of those technologies would be chosen by a designer and accepted by the investor. This is a real estimation as the weighted share sum is equal to 1, and with regard to satisfied interests of both a designer and an investor, it can be expected that the certain technology will be chosen according to that probability.

Upon the author's consultations with the designers the current practice in Croatia confirmed that additional specialist investigation works estimated at 5.000,00 € for such a type structure in 70 % of cases results in increased amount of works for circa 20 %, and in 30 % cases with an increase for even 30 % of works.

The requirement for a work increase for circa 20 % corresponds approximately to an increase of weighted share of the *Stiffness* criterion from the AHP analysis for some 5 % at the expense of other criteria. New weighted shares of the foundation technologies which can be taken as new probabilities are determined by the sensitivity analysis. Therefore, it can be concluded with the 0,7 probability that investigation works can lead to new probabilities.

The work increase requirement for some 30 % corresponds approximately to the increase of weighted share of the *Stiffness* criterion from the AHP analysis for some 15 % at the expense of other criteria. New weighted shares of the foundation technologies which can be taken as new probabilities are determined by the sensitivity analysis. Therefore, it can be concluded with 0,3 probability that investigation works can lead to new probabilities.

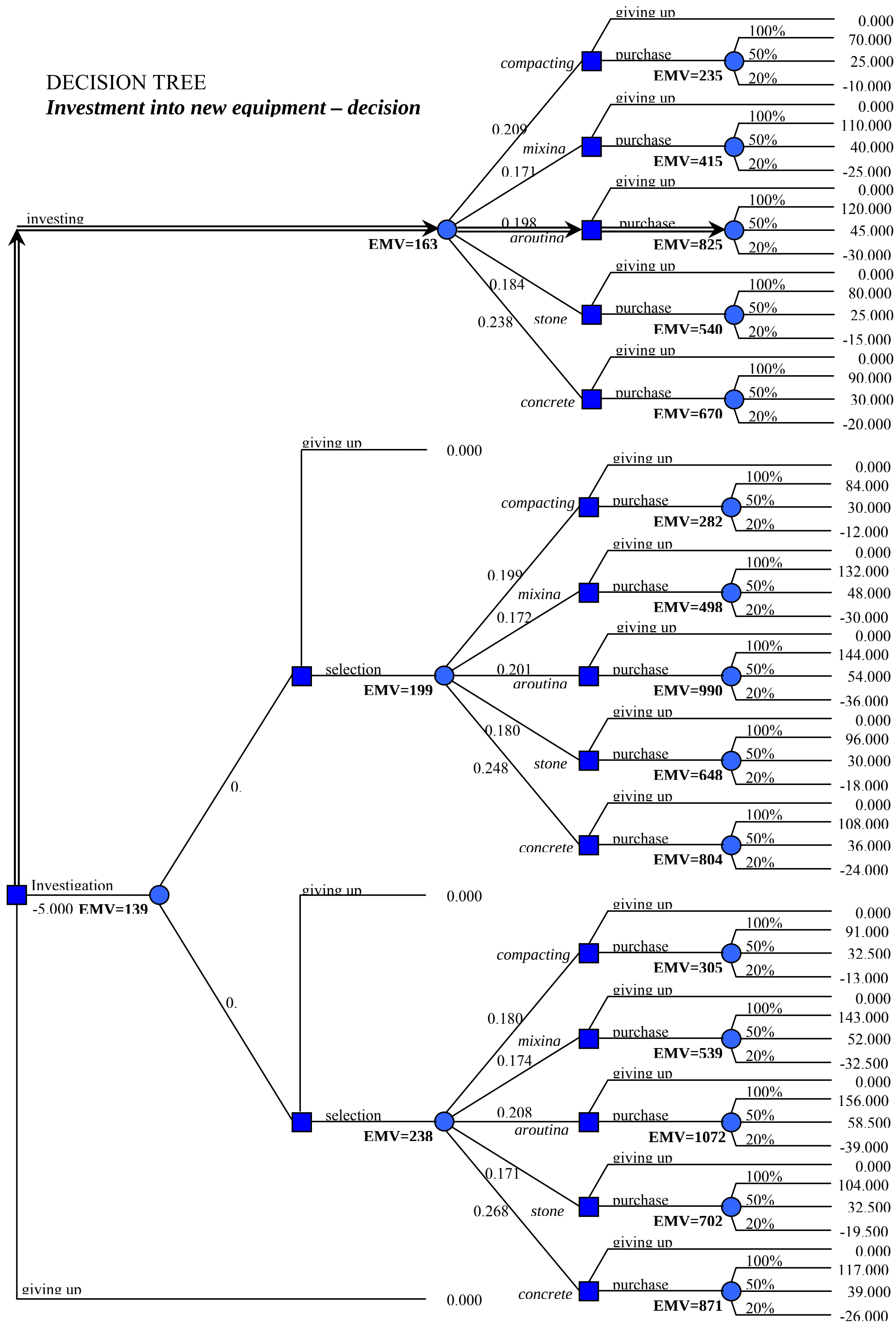
In order to select individual foundation methods an analysis was carried out for the profits which can be obtained by applying relevant technologies. For a typo structure to which the multi-criteria analysis was applied and upon available information, the differences of revenue and expenditures were calculated in cases that the equipment operates with 100 %, 50 % and 20 % of capacities. The security point is approximately 30 % of machines exploitation. The full capacity is achieved when the machine is run and serviced by well trained and experienced workers, when spare parts are ensured, materials such as gravel and cement are continuously available, and there are no unpredictable negative surprises. It was found out that the greatest profit (150.000,00 €) can be achieved by the full exploitation of Jet grouting. However, when it is poorly used it leads the greatest loss (-30.000,00 €).

The previous experience confirmed that the application of different technologies and probabilities resulted in machines being used with different capacities. It is therefore highly probable (0,7) that concrete piles will operate with 100 % capacity, as it is the traditional and the best run technology with good logistics and a high number of experienced workers on the market. The lowest probability (0,2) is that the Vibratory compaction will operate with 100 % capacity as this technology is relatively little used on our market without enough experienced workers.

Such a situation represents a classical problem of decision making in uncertainty conditions, e.g. in risk conditions. The decision alternatives are known, and with a certain degree of probability the results, e.g. outcomes of each alternative are known. A highly complex textual description of a decision context could be clearly shown by means of a decision tree (Cockett, 1990). Figure 2 shows a decision tree, payment tree, probability, back calculation and made decisions. The criterion of expected value is applied with decision making. The decision was made that the geotechnical company is investing into new technology without additional investigation works. It is going to purchase equipment for the jet grouting.

DECISION TREE

Investment into new equipment – decision



6. Conclusion

A high construction intensity of infrastructure facilities, particularly highways in the Republic of Croatia, determines the foundation of heavy structures on the soil of low stiffness, e.g. insufficient loadbearing capacity due to the soil composition. The decision making on the foundation technology in such situations requires the consideration of investor's economic interests, designer's expert interests and environmental issues as the paramount interest of the whole society.

For this reason it is necessary to make a rank-list of foundation technologies for the typo facilities by using the multi-criteria analysis AHP method. Providing that the geotechnical company makes a decision to invest into any of the listed technologies, it can do it by using the decision tree method and applying the criteria of expected value. As the decision alternatives are already known, taking into consideration a certain probability and selection consequences of each alternative, there appears a classic problem of decision making under uncertainty, e.g. risk conditions.

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