

PAPER • OPEN ACCESS

Selection of Construction Products Suppliers According to the Condorcet Criterion

To cite this article: Michal Tomczak *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 112068

View the [article online](#) for updates and enhancements.

Selection of Construction Products Suppliers According to the Condorcet Criterion

Michał Tomczak ¹, Sławomir Biruk ¹, Piotr Jaskowski ¹

¹ Department of Construction Methods and Management, Faculty of Civil Engineering and Architecture, Lublin University of Technology, Nadbystrzycka 38 D, 20-618 Lublin, Poland

m.tomczak@pollub.pl

Abstract. The continuous growth of competition on the construction market results in the fact that construction companies are forced to keep searching for solutions facilitating the building process and construction logistics. In the recent decades, one of the most fascinating ideas which enable a real improvement in the aspect of a company's competitiveness on the market is supply chain management. It has undergone a transformation from fragmented actions to integrated operations intending to optimize the flow of physical resources and information. The first step towards the application of the modern logistics tools is the selection and evaluation of entities involved in a cooperation within the supply chain framework. The selection of reliable partners to supply a construction site or a building company may reduce the operational costs, minimize inventory and improve timeliness as well as the quality of offered services. Any mistakes made in the process of supplier selection may lead to issues such as supply delays, difficulties in keeping contract deadlines and even complete failure of a project or bankruptcy of a construction company. An 18th century criterion for the selection of the most preferable candidate developed by Nicolas de Condorcet is commonly accepted owing to its fair rules of choice (anyone who defeats most of their competitors in a direct confrontation wins). Due to its democratic approach, most criteria decide as to the selection of the winner. Should the choice of a winner or establishing a Condorcet ranking from the perspective of the social choice theory prove impossible, the selected candidate ought to be as much similar to a winner in the Condorcet sense as possible. The theory was developed in order to facilitate the selection of the most suitable candidate in the election, however it may also find application in the selection of a supply chain elements evaluated with the use of multiple criteria. There are a number of decision-making methods which fulfil the Condorcet criterion. They vary in their computational complexity and may provide different final order. The intention of this paper is to review the methods which may offer support while selecting the most preferable supplier of construction products.

1. Introduction

Despite the growing popularity and significance of the problems connected with supply chain management, including the selection of construction products suppliers, there is still much difficulty in the implementation of the modern supply chain management methods in construction [1–3]. Moreover, in construction, the conditions related to the selection of suppliers are more complex than in other fields of economy [4–6]. The main difficulties encountered in the selection of construction products suppliers involve the following construction-related particularities: uniqueness of design projects, condition diversity of each project, changeability of a construction product localization, product specifications,



which are often beyond the ordering party's control, diversity of needed products, plenitude of suppliers and relations between them, difficulty in estimating precise supply times in a longer time perspective [1], [2], [4], [7-10].

Due to the fact that the selection of a construction products supplier needs to reconcile a number of conflicting, commensurable, ordinal and cardinal objectives, the task is usually considered a multi-attribute decision-making (MADM) problem [11–13]. MADM problems are usually described using discrete decision variables – modelling the selection of a finite number of decision variants. Arrow and Raynauld [14] presented an analogy between the discrete multiple criteria decision-making methods and the social choice theory (SCT). The place in the ranking of variants prepared for individual criteria with the use of SCT may be equated with voters' choices. The SCT methods do not require grade quantification, which is particularly important in the case of immeasurable (qualitative) criteria [15], [16]. The SCT methods fulfilling the Condorcet criterion are commonly accepted owing to their democratic and fair selection way, and thus they may constitute an interesting option to use for the purpose of selecting construction products suppliers.

This paper has been arranged in the following way: the next chapter covers the overview of the literature related to the selection process of a construction products supplier; chapter 3 discusses the selection methods fulfilling the Condorcet criterion. Chapter 4 presents an example of the selection process of a construction aggregate supplier for a road construction company using various methods fulfilling the Condorcet criterion, while chapter 5 offers the conclusions.

2. Approaches to supplier selection

The literature related to the selection of construction product suppliers can be divided into two basic categories: the publications dealing with the identification of assessment criteria for construction products suppliers and the papers concerning multi-attribute methods supporting the optimum selection of suppliers [17].

Selection of a products supplier is a complex problem, therefore it ought to take account of many varied assessment criteria. A number of researchers indicate that the assessment criteria for suppliers should be adapted to the policy, strategy or business objectives of a company [18]. In spite of this, there are continuous attempts at determining the universal factors affecting the selection of the optimum suppliers. Originally, the most commonly enumerated assessment criteria included quality, price, timeliness of deliveries or a supplier's capacity [17]. Currently, when selecting suppliers, it is increasingly common to apply the following criteria: payment conditions, lead time, delivery performance/flexibility, quality of services and the products, guarantee conditions, delivery reliability, technical expertise and reputation of the supplier, performance history of the supplier, technical capability, communication with the supplier [19–30].

As it was mentioned before, the problem of the selection of construction products suppliers is complex and multifaceted. In order to resolve it, techniques of varied precision levels and complexity are used. Reviewing the most common techniques used to solve the problem being discussed, it is possible to divide them into three basic groups: the first one including the low precision and complexity methods, the second one composed of the medium precision and complexity methods and the third group, which includes the highest precision and complexity methods [31].

The first group includes such methods as: The Scoring Model (SM) or the Categorical Methods (CMs). The simple SM combines the criteria weights with the supplier rankings according to a given criterion and indicates the supplier with the highest overall score. CMs divide suppliers into different valuation categories on the basis of the historical data or a decision-maker's experience [31].

The second group of methods includes such techniques as: The Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP) and Data Envelopment Analysis (DEA). For the selection of construction suppliers, Cengiz et al. [17] used the ANP method, Shramm and Morais used the SMARTER (Simple Multi-Attribute Rating Technique Exploiting Rating) method [23], while Estehrdian et al. [32] used the AHP and ANP methods. For the purpose of increasing the procurement of construction material effectiveness, to select a supplier, Safa et al. [25] enhanced the Integrated

Construction Material Management (ICMM) model by means of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Finally, Yazdani et al. [13] combined the DEMATEL (DEcision MAKing Trail and Evaluation Laboratory) method with the QFD (Quality Function Deployment) method. It provided a straightforward solution to apply consumer-dependent weighting method for decision criteria, which plays a fundamental role in circumstances where the satisfaction of external stakeholders and customer enters the decision process. The preparation of a supplier ranking, however, is carried out with the use of (COMplex PROportional ASsessment).

The third group of methods may include such approaches as: the Fuzzy Set Theory, the Grey Theory or the Mathematical Programming [31]. The fuzzy approach to construction products supplier selection was used by Shahvand et al. [18] creating a fuzzy expert system based on linguistic evaluations given by the experts. In the system which they created the suppliers were evaluated in three main categories: quality, cost and timeliness of historical deliveries, while the system itself was being successfully applied in three construction companies for two years. To resolve the problem being discussed, Polat et al. [20] adopted an approach combining fuzzy AHP with fuzzy TOPSIS – criteria weights are determined by a decision-making team on the basis of the fuzzy AHP method, while supplier rankings and the final selection of the optimum one is created with the use of the fuzzy TOPSIS method. Wang et al. [5], in turn, combined the AHP method with the Grey Relational Analysis (GRA) for the purpose of selecting construction products suppliers and subcontractors and creating Resilient Construction Supply Chain. In their approach, the criteria weights are determined by means of AHP, and then they are used to calculate the grey weighted correlation coefficient. In this concept, the higher the grey weighted correlation coefficient is, the closer a candidate is to an ideal supplier, and thus is more preferable.

3. Condorcet criterion compatible selection methods

The identification of the most suitable construction products supplier may be described as a problem of choosing the best option out of a set of decision variants $A = \{a_1, \dots, a_n\}$ evaluated by means of a mutually independent, mostly additive, criteria set $C = \{c_1, \dots, c_m\}$. In the selection process, it is necessary to assume a primitive notion that a *decision-maker's preference* is expressed by the *preference relation* $\succ \subset A \times A$ also called the *pre-order relation* [33]. Such a relation should fulfil the reflexive condition:

$$\forall a_i \in A \quad a_i \succ a_i, \quad (1)$$

and the transitive condition:

$$\forall a_r, a_s, a_t \in A \quad a_r \succ a_s \wedge a_s \succ a_t \Rightarrow a_r \succ a_t. \quad (2)$$

The pre-order relation determines a *indiscernibility relation*:

$$a_r \approx a_s \Leftrightarrow a_s \succ a_r \wedge a_r \succ a_s, \quad (3)$$

as well as a *strict order relation*:

$$a_r \succ a_s \Leftrightarrow a_r \succ a_s \wedge \sim (a_s \succ a_r). \quad (4)$$

In the 18th century, Nicolas de Condorcet formulated a principle which stated that the best solution is the one that is highly preferable in pairwise comparisons, that is $a_{rj} \succ a_{sj}$ ($r \neq s$), to all the other decision variants in a higher number of criteria. According to Condorcet, the worst solution is the one which loses against all the other variants. The final arrangement $a_1, a_2, \dots, a_n$ fulfils the Condorcet criterion if each solution a_r is preferable to a_s while ($r < s$). In Condorcet's approach, it is assumed that all partial arrangements (criteria, voters) have equal significance (meaning). In the case when the

criteria weights are w_j different ($w_j \in \{0,1\}, \sum_{j=1}^m w_j = 1$), the Condorcet principle may be modified in the

following way: the best solution is the one that pairwise compared with all the other decision variants is highly preferable for the criteria whose total weight is higher than 0.5.

From the perspective of the social choice theory, a winner, a loser and a Condorcet arrangement does not always exist [15]. In such a case, the revealed decision variant should be as similar to a Condorcet's winner as possible.

The Dodgson and Young's algorithms are based on the Condorcet principle and they always determine a Condorcet's winner in the first place, provided that one exists. Establishing a Dodgson and Young's arrangement is an NP-hard problem [34], [35]. A Young's number is a maximum number of partial arrangements, which must be taken account of in order for the solution to become a Condorcet's winner. The alternative with the highest Young's number wins. The following symbols are introduced: $a_r \in A$ is the solution for which a Young's number is determined, $x_j \in \{0, 1\}$ is a binary variable $\forall j (j = 1, 2, \dots, m)$ and $x_j = 1$ if, and only if, the criterion j is taken into account while determining the Young's number for a_r . The constant $e_{rj}^i \in \{-1, 1\}$ depends on the partial arrangement and $e_{rj}^i = 1 (r \neq j)$ if in the arrangement according to the criterion j the solution a_r is better than a_i . The determination of the Young's number for a_r is performed by solving a linear binary programming problem, in which the objective function (5) maximizes the number of the partial arrangements which must be considered for the offer a_r to become a Condorcet winner – according to the following expression [15], [34]:

$$\max Y(a_r): Y(a_r) = \sum_{j=1}^m x_j, \quad (5)$$

with the constraints:

$$\sum_{j=1}^m x_j \cdot e_{rj}^i \geq 1, \quad \forall a_i \in A \setminus \{a_r\}, \quad (6)$$

$$x_j \in \{0, 1\}, \quad j = 1, 2, \dots, m. \quad (7)$$

The shift of the solution a_r in the arrangement for the criterion j of the $k (k \in \{0, 1, \dots, n-1\})$ positions results in the fact that the number of advantages of a_r over $a_i \in A \setminus \{a_r\}$ increases by $e_{ijk} = \{0, 1\}$. $d_i(a_r)$ is the minimum number of criteria where a_r must gain advantage additionally in order to gain advantage over $a_i \in A \setminus \{a_r\}$ in the final arrangement. If a_r is preferable to $a_i \in A \setminus \{a_r\}$, then $d_i(a_r) = 0$. The minimum number of shifts in the arrangements for criteria that secures a victory for the solution a_r in the Condorcet sense is called a Dodgson's number $D(a_r)$ [15]. Dodgson described only the selection method for the best solution [36]. A Dodgson's winner is the offer with the lowest value $D(a_r)$. For the solution a_r , the number may be determined by solving the following linear binary programming problem [15], [37]:

$$\min D(a_r): D(a_r) = \sum_j \sum_k k \cdot x_{jk}, \quad (8)$$

$$\sum_k x_{jk} \leq 1, \quad \forall j, \quad (9)$$

$$\sum_j \sum_k e_{ijk} \cdot x_{jk} \geq d_i(a_r), \quad \forall a_i \in A \setminus \{a_r\}, \quad (10)$$

$$x_{jk} \in \{0, 1\}, \quad \forall j, k. \quad (11)$$

The binary variable x_{jk} assumes the value 1 if in the partial arrangement of the criterion j a shift of the offer a_r by k positions is made. The objective function (8) minimizes the number of shifts in the partial arrangements. The boundary set (9) enables only a single shift of the solution a_r in each partial arrangement. The boundary set (10) ensures that the offer a_r becomes the winner in the Condorcet sense [15]. In order to calculate a Dodgson's number, a simple greedy algorithm was prepared [38]. A Dodgson's number may also be calculated using, for instance, a dynamic programming algorithm [15].

Benham [39] proposed a simple winner-finding procedure based on the Condorcet principle. The candidate that scored the lowest number of the first places in the partial arrangement for the criteria is eliminated from the set and the winner is searched for in the new set reduced by one solution. The procedure is repeated until the final winner is indicated [15].

In the Köhler method [15], [40] an outranking matrix $A = [a_{rs}]$ (a square matrix of order n) is created first. The element a_{rs} determines the number of criteria for which the offer a_r is preferable in comparison to a_s . In the step k of the algorithm the minimum and then the maximum value is selected for each row. In the case of equal values, one of them is selected arbitrarily. The offer corresponding to the selected value is placed in the position k of the final ranking. The column and the row corresponding to the selected offer are deleted and a new comparison matrix of the $n-1$ rank is created and then used in the step $k+1$ of the algorithm. The process is repeated until the final ranking is revealed [15]. If a Condorcet's winner exists, then it is always placed in the first place of the preference order by the Köhler method algorithm. If, however, a Condorcet's arrangement exists, then the arrangement determined using this method is compatible with it.

The Arrow-Raynaud's method does not always place a Condorcet's winner in the first place of the preference order, but it makes it possible to identify the loser in the Condorcet sense. The elimination of variants may be used for a preliminary selection of offers and it may lead to a reduction in the number of the considered variants. The Arrow-Raynaud's algorithm [15], [40], [41] is based on the iterative selection and elimination of the variant which is the most disadvantageous among those that have not been placed in the preferential order due to an outranking relation. In each iteration, the highest values in the rows are selected, and then the lowest of them is placed in the $(n - k + 1)$ place in the preference order. In the case of equal values, one of them is selected arbitrarily. The row and the column corresponding to the chosen solution are deleted, and the procedure is repeated until the final arrangement is revealed [15].

The Slater method [42] is based on finding a minimum number of arcs in a tournament $T = (A, E)$ (A – a set of solutions – graph nodes, $E \subset A \times A$ – a set of outranking relations – directed graph arcs), whose direction needs to be changed in order to obtain a transitivity relation (a linear arrangement of variants). The Slater's order minimizes the distance between the final arrangement and the partial arrangements according to the majority principle. Several Slater's arrangements may exist, but in each of them the Condorcet's winner is the Slater's winner [15], [43]. The determination of a Slater's arrangement is an NP-hard problem equivalent to the classic *Minimum Feedback Arc Set in Tournaments* problem [15], [44], [45]. A Slater's arrangement may be found by solving the following linear programming problem [46]:

$$\max: \sum_{(i,j) \in E} w_{ij} x_{ij}, \quad (12)$$

$$x_{ij} + x_{jk} + x_{ki} \leq 2, \quad \forall i, j, k, \quad i, j, k \in A, \quad (13)$$

$$x_{ij} + x_{ji} = 1, \quad \forall i, j \quad (i \neq j), \quad (14)$$

$$x_{ij} = \{0, 1\}, \quad \forall i, j. \quad (15)$$

Weight of arc w_{ij} takes value 1 if, and only if, $(i, j) \in T$; otherwise it takes value -1. The binary variable $x_{ij} = 1$ when $(i, j) \in T$ and takes value 0; otherwise, it maximizes the number of arcs used from the tournament to transform it into a linear order. The condition (13) eliminates directed cycles of length 3 in the tournament, set of constraints (14) and (15) result in the fact that only one directed arc joining two different nodes exists [16], [46].

There exist many more approaches fulfilling the Condorcet criterion, for instance that of Kemeny who maximizes the concordance of all partial arrangements with the final arrangement (a final ranking for which the sum of its distances from the partial arrangements is minimum is looked for), [15]. An interesting concept – called the Condorcet east reversal system – was presented in the works [16], [47].

4. Example

The decision-making methods fulfilling the Condorcet criterion were applied to the selection of an aggregate supplier for a construction company from the road construction industry. Six potential candidates were evaluated regarding five equivalent criteria: total cost (c_1), payment conditions (c_2), lead time (c_3), delivery performance/flexibility (c_4), guarantee conditions (c_5). The decision-maker prepared partial arrangements of potential suppliers for the individual criteria:

$$c_1 : a_1 \succ a_2 \succ a_4 \succ a_5 \succ a_3 \succ a_6 ,$$

$$c_2 : a_1 \succ a_4 \succ a_2 \succ a_6 \succ a_3 \succ a_5 ,$$

$$c_3 : a_4 \succ a_2 \succ a_5 \succ a_1 \succ a_6 \succ a_3 ,$$

$$c_4 : a_2 \succ a_4 \succ a_1 \succ a_3 \succ a_6 \succ a_5 ,$$

$$c_5 : a_1 \succ a_4 \succ a_6 \succ a_3 \succ a_5 \succ a_2 ,$$

For the partial arrangements determined in this way, there is a preference order of suppliers, compliant with the Condorcet principle: $a_1 \succ a_4 \succ a_2 \succ a_6 \succ a_3 \succ a_5$.

Let us assume that the partial arrangements (for another group of the evaluated suppliers) takes the following form:

$$c_1 : a_1 \succ a_2 \succ a_4 \succ a_5 \succ a_3 \succ a_6 ,$$

$$c_2 : a_6 \succ a_2 \succ a_4 \succ a_1 \succ a_3 \succ a_5 ,$$

$$c_3 : a_4 \succ a_2 \succ a_5 \succ a_1 \succ a_6 \succ a_3 ,$$

$$c_4 : a_5 \succ a_6 \succ a_3 \succ a_1 \succ a_4 \succ a_2 ,$$

$$c_5 : a_6 \succ a_4 \succ a_1 \succ a_3 \succ a_5 \succ a_2 ,$$

The outranking graph T (so-called tournament) for the above partial rankings was presented in the figure 1.

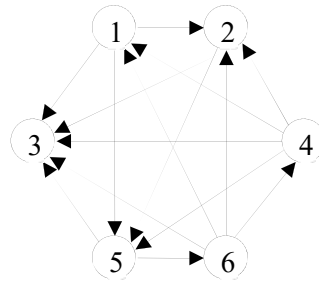


Figure 1. An outranking graph (example)

For the partial arrangements determined by this method, there is not a Condorcet's winner. The supplier a_3 is the loser in the Condorcet sense (loses in the majority of criteria against the other suppliers). It is impossible to indicate the final ranking of the remaining suppliers.

Young's numbers for the individual suppliers equal respectively: 1, 3, -, 3, 1, 3. For example, the supplier a_6 is positioned as the first in the ranking only for the criteria c_2 and c_5 . In the rankings for the remaining criteria that supplier is ranked lower than the supplier a_5 . Therefore, the maximum number of criteria (Young's number) which may be taken account of in order for the supplier to become the winner in the Condorcet sense is a_3 . According to this approach, the best suppliers are the suppliers a_2 , a_4 , a_6 .

Dodgson's numbers for the individual suppliers equal respectively: 2, 3, 8, 1, 5, 1. According to this approach, the best suppliers are the suppliers a_4 , a_6 . In the case of the supplier a_6 , it wins against the other suppliers (except the supplier a_5) in at least 3 partial rankings. Shifting it by one position (Dodgson's number) in the ranking for the criterion c_4 will result in the fact that it will gain advantage also over the supplier a_5 and will become the winner in the Condorcet sense.

When applying Benham's approach, depending on what choice of deleted solutions of the same number of the first positions in the arrangements according to the individual criteria was made, supplier solutions a_5 , a_6 are found as the best. The Arrow-Raynaud method made it possible to identify the supplier a_3 as the loser in the Condorcet sense. The Slater method delivered the following ranking of suppliers: $a_6 \succ a_4 \succ a_1 \succ a_2 \succ a_5 \succ a_3$.

Based on the obtained results, the supplier a_6 , identified as the winner in all the applied approaches should be recognized as the best supplier.

5. Conclusions

Construction materials constitute a major part of costs in construction projects. A lack of necessary product of a proper quality and sufficient quantity in the right time is the most frequent cause of delays in the realization of construction projects [20]. The selection of an inappropriate construction products supplier may lead to a failure in keeping realization times or even a failure of the entire project, and it seems to be one of the crucial problems faced by construction site managers and the management staff of a construction company. Moreover, the selection of a supplier in the construction industry is influenced by a number of factors that are difficult to identify and describe, which makes it significantly harder to resolve the problem. Owing to the character of the problem, construction products supplier selection is mostly perceived as a multi-attribute decision-making problem and it is solved by means of various methods of varied accuracy and complexity levels. It appears that the use of the social choice theory in the construction products supplier selection problem may be remarkably interesting due to the lack of necessity to express the partial grades in a quantitative way. In this theory, there are plenty of voting methods fulfilling the Condorcet criterion, which vary in their computational complexity and may lead to determining different final arrangements.

Acknowledgments

This work was financially supported by Ministry of Science and Higher Education in Poland within the statutory research number S/63/2018.

References

- [1] M. Tomczak, Problems in logistics of small and medium-sized construction companies,” *TTS Tech. Transp. Szyn.*, no. 10, pp. 637–645, Oct. 2013. (in Polish)
- [2] A. T. Nursal, M. F. Omar, and M. N. Mohd Nawi, “Criteria Requirement for IBS Vendor Selection,” *Int. J. Supply Chain Manag.*, vol. 5, no. 2, pp. 108–114, Jun. 2016.
- [3] P. Jaśkowski, A. Sobotka, and A. Czarnigowska, “Decision model for planning material supply channels in construction,” *Autom. Constr.*, vol. 90, pp. 235–242, Jun. 2018.
- [4] D. Seth, V. K. Nemani, S. Pokharel, and A. Y. A. Sayed, “Impact of competitive conditions on supplier evaluation: a construction supply chain case study,” *Prod. Plan. Control*, vol. 29, no. 3, pp. 217–235, Feb. 2018.
- [5] T.-K. Wang, Q. Zhang, H.-Y. Chong, and X. Wang, “Integrated Supplier Selection Framework in a Resilient Construction Supply Chain: An Approach via Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA),” *Sustainability*, vol. 9, no. 2, pp. 1–26, 2017.
- [6] A. Sobotka, P. Jaskowski, and A. Czarnigowska, “Optimization of Aggregate Supplies for Road Projects,” *Procedia - Soc. Behav. Sci.*, vol. 48, pp. 838–846, 2012.
- [7] M. Tomczak and P. Jaśkowski, “Application of type-2 interval fuzzy sets to contractor qualification process,” *KSCE J. Civ. Eng.*, pp. 1–12, Jan. 2018.
- [8] E. Radziszewska-Zielina, “Methods for selecting the best partner construction enterprise in terms of partnering relations,” *J. Civ. Eng. Manag.*, vol. 16, no. 4, pp. 510–520, 2010.
- [9] Ł. Rzepecki, “Multi-criteria evaluation of logistic systems for construction supply,” *Autobusy Tech. Eksploat. Syst. Transp.*, vol. 17, 2016 (in Polish)
- [10] P. Jaśkowski, “Methodology for enhancing reliability of predictive project schedules in construction,” *Eksploat. Niezawodn.*, vol. 17, 2015.
- [11] M. K. Ghorabae, M. Amiri, E. K. Zavadskas, and J. Antucheviciene, “Supplier evaluation and selection in fuzzy environments: a review of MADM approaches,” *Econ. Res.-Ekon. Istraživanja*, vol. 30, no. 1, pp. 1073–1118, Jan. 2017.
- [12] K. Govindan, S. Rajendran, J. Sarkis, and P. Murugesan, “Multi criteria decision making approaches for green supplier evaluation and selection: a literature review,” *J. Clean. Prod.*, vol. 98, pp. 66–83, Jul. 2015.
- [13] M. Yazdani, P. Chatterjee, E. K. Zavadskas, and S. Hashemkhani Zolfani, “Integrated QFD-MCDM framework for green supplier selection,” *J. Clean. Prod.*, vol. 142, pp. 3728–3740, Jan. 2017.
- [14] K. J. Arrow and H. Raynaud, *Social Choice and Multicriterion Decision-Making*. MIT Press, 1986.
- [15] S. Biruk, “Analysis of the methods of selecting suppliers in accordance with the condorceta rule (in Polish),” *TTS Tech. Transp. Szyn.*, no. 12, pp. 1786–1790, 2015.
- [16] S. Biruk and P. Jaśkowski, “Selection of subcontractors using ordinal ranking methods based on Condorcet approach,” *Bud. Arch.*, vol. Vol. 15, no. nr 4, 2016.
- [17] A. E. Cengiz, O. Aytekin, I. Ozdemir, H. Kusan, and A. Cabuk, “A Multi-criteria Decision Model for Construction Material Supplier Selection,” *Procedia Eng.*, vol. 196, pp. 294–301, Jan. 2017.
- [18] E. Shahvand, M. H. Sebt, and M. T. Banki, “Developing fuzzy expert system for supplier and subcontractor evaluation in construction industry,” *Sci. Iran. Trans. Civ. Eng.*, vol. 23, no. 3, p. 842, 2016.
- [19] A. Fallahpour, A. Amindoust, J. Antuchevičienė, and M. Yazdani, “Nonlinear genetic-based model for supplier selection: a comparative study,” *Technol. Econ. Dev. Econ.*, vol. 23, no. 1, pp. 178–195, Jan. 2017.

- [20] G. Polat, E. Eray, and B. N. Bingol, "An integrated fuzzy MCGDM approach for supplier selection problem," *J. Civ. Eng. Manag.*, vol. 23, no. 7, pp. 926–942, Oct. 2017.
- [21] G. N. Aretoulis, G. P. Kalfakakou, and F. Z. Striagka, "Construction material supplier selection under multiple criteria," *Oper. Res.*, vol. 10, no. 2, pp. 209–230, Aug. 2010.
- [22] C. Ho and P.-M. Nguyen, "Supplier evaluation and selection criteria in the construction industry of Taiwan and Vietnam," *Inf. Manag. Sci.*, vol. 18, no. 4, pp. 403–426, 2007.
- [23] F. Schramm and D. C. Morais, "Decision support model for selecting and evaluating suppliers in the construction industry," *Pesqui. Oper.*, vol. 32, no. 3, pp. 643–662, Dec. 2012.
- [24] E. Plebankiewicz and D. Kubek, "Multicriteria selection of the building material supplier using AHP and fuzzy AHP," *J. Constr. Eng. Manag.*, vol. 142, no. 1, p. 04015057, 2015.
- [25] M. Safa, A. Shahi, C. T. Haas, and K. W. Hipel, "Supplier selection process in an integrated construction materials management model," *Autom. Constr.*, vol. 48, pp. 64–73, Dec. 2014.
- [26] A. H. I. Lee, "A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks," *Expert Syst. Appl.*, vol. 36, no. 2, Part 2, pp. 2879–2893, Mar. 2009.
- [27] E. Radziszewska-Zielina, "Fuzzy control of partnering relations of a construction enterprise," *J. Civ. Eng. Manag.*, vol. 17, no. 1, pp. 5–15, Apr. 2011.
- [28] M. Tomczak, "The decision-making model of deliveries carried out by the distribution center for the needs of small and medium-sized construction companies," *Logistyka*, no. nr 3, pp. 6358–6366, 2014 (in Polish)
- [29] P. Jaskowski, A. Sobotka, and A. Czarnigowska, "Decision model for selecting supply sources of road construction aggregates," *Eng. Econ.*, vol. 25, no. 1, pp. 13–20, 2014.
- [30] M. Tomczak and Ł. Rzepecki, "Evaluation of Supply Chain Management Systems Used in Civil Engineering," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 245, no. 7, p. 072005, 2017.
- [31] D. Masi, G. J. L. Micheli, and E. Cagno, "A meta-model for choosing a supplier selection technique within an EPC company," *J. Purch. Supply Manag.*, vol. 19, no. 1, pp. 5–15, Mar. 2013.
- [32] E. Eshtehardian, P. Ghodousi, and A. Bejanpour, "Using ANP and AHP for the supplier selection in the construction and civil engineering companies; Case study of Iranian company," *KSCE J. Civ. Eng.*, vol. 17, no. 2, pp. 262–270, Mar. 2013.
- [33] T. Trzaskalik, *Multi-criteria decision support*, 1st ed. Warszawa: Polskie Wydawnictwo Ekonomiczne, 2014.
- [34] I. Caragiannis *et al.*, "On the approximability of Dodgson and Young elections," *Artif. Intell.*, vol. 187–188, pp. 31–51, Aug. 2012.
- [35] U. Endriss and R. de Haan, "Complexity of the Winner Determination Problem in Judgment Aggregation: Kemeny, Slater, Tideman, Young," in *Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems*, Richland, SC, 2015, pp. 117–125.
- [36] D. Black, *Theory Committees and Elections*. Cambridge: Cambridge University Press, 1958.
- [37] J. Bartholdi, C. A. Tovey, and M. A. Trick, "Voting schemes for which it can be difficult to tell who won the election," *Soc. Choice Welf.*, vol. 6, no. 2, pp. 157–165, Apr. 1989.
- [38] C. M. Homan and L. A. Hemaspaandra, "Guarantees for the success frequency of an algorithm for finding Dodgson-election winners," *J. Heuristics*, vol. 15, no. 4, pp. 403–423, Aug. 2009.
- [39] J. Green-Armytage, "Four Condorcet-Hare Hybrid Methods for Single-Winner Elections," *Voting Matters*, vol. 29.
- [40] Z. F. Lansdowne, "Ordinal ranking methods for multicriterion decision making," *Nav. Res. Logist. NRL*, vol. 43, no. 5, pp. 613–627, Aug. 1996.
- [41] G. Munda, *Social Multi-Criteria Evaluation for a Sustainable Economy*. Berlin Heidelberg: Springer-Verlag, 2008.
- [42] P. Slater, "Inconsistencies in a Schedule of Paired Comparisons," *Biometrika*, vol. 48, no. 3/4, pp. 303–312, 1961.

- [43] O. Hudry, “On the Difficulty of Computing the Winners of a Tournament,” *Ann. LAMSADE*, vol. 6, 2006.
- [44] P. Festa, P. M. Pardalos, and M. G. C. Resende, “Feedback Set Problems,” in *Handbook of Combinatorial Optimization*, Springer, Boston, MA, 1999, pp. 209–258.
- [45] I. Charon and O. Hudry, “A branch-and-bound algorithm to solve the linear ordering problem for weighted tournaments,” *Discrete Appl. Math.*, vol. 154, no. 15, pp. 2097–2116, Oct. 2006.
- [46] N. Sukegawa and S. Mizuno, “Redundancy of the Transitivity Constraints in the Ordering Problem.” Department of Industrial Engineering and Management, Tokyo Institute of Technology JAPAN Technical Report No. 2014-2, 2014.
- [47] H. Nurmi, “Settings of Consensual Processes: Candidates, Verdicts, Policies,” in *Consensual Processes*, Springer, Berlin, Heidelberg, 2011, pp. 159–177.