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Research paper

Modelling the impact of electronic auction on the tender procedure for the construction of railway infrastructure with the Bayesian networks

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Abstract: The numerous overruns of the investor's budget during tenders for the construction of railway infrastructure in Poland resulted in the widespread use of a new procedure for awarding public contracts – electronic auction. This procedure has many advantages and potential risks. One of the biggest benefits for an investor is the potential gains from reducing bids. Contractors competing against each other allow for the achievement of optimal prices for the planned construction investment. However, this may cause the originally calculated risks, should they materialize, lead to significant budget overruns. This, in turn, may imply further negative consequences, including exceeding the assumed investment deadlines. The article presents a method of modeling the influence of an electronic auction on a tender procedure with the use of a Bayesian network. Data from completed tender procedures announced by the PKP Polskie Linie Kolejowe S.A. were used to build the network. The created network was then validated, verified and calibrated using new data from 8 tender procedures.

Keywords: Bayesian networks, electronic auction, public procurement, railway works

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1. Introduction

The implementation of large infrastructure projects in Poland, financed from the public, state budget, is associated with the application of the regime of the Public Procurement Law [1]. The most important regulations include: detailed procurement procedures, including provisions on supplies, services or works. The content of the act also takes into account the provisions of EU directives that specify the manner of spending funds from the EU budget [2]. Procedures included in the statutory provisions also constitute guidelines according to which the tender procedure should be conducted.

Participation in the tender procedure for construction works is a widely described and discussed phenomenon. Among the many topics, there are, among others, issues related to modeling the contractor's participation in the tender procedure. The work [3] presents three selected multi-criteria methods of supporting the decision on participation or non-participation in the tender procedure, taking into account 15 defined tender criteria. A different approach is presented in [4], where the decision to participate in the tender procedure for construction works was made on the basis of the model of neural networks. Also noteworthy is the contractor's support method based on fuzzy logic methods, presented in [5].

Until the amendment to the PPL Act in 2016, the basic procedure for awarding contracts for construction works under the "National Railway Program until 2023" (KPK) was an open tender [6]. This trend changed when in 2016–2018 many of the tendering procedures were not resolved due to exceeding the investor's budget [7]. In order to solve the problem, it was decided to use an electronic auction, which was carried out after the completion of the evaluation of the submitted bids as part of the standard tender procedure.

The electronic auction is successfully used in the implementation of various construction projects around the world [8,9]. Its use is widely discussed, and the purpose of research is, inter alia, ways to optimize the process or estimate the effects of electronic auctions on key aspects of the tender procedure [10]. Along with the development of the use of electronic auctions, both the investor and contractors must properly adapt to the new procedure, as well as choose an adequate strategy for participation in the tender. Discussion of many key issues, including a review of the techniques used so far to process electronic auctions, is presented in [11].

Use of electronic auction in newly announced tender procedures by PKP PLK S.A. resulted in the occurrence of previously unheard of circumstances. Some of them will be discussed in this article. In order to demonstrate the impact of the use of electronic auctions on the most important aspects of the tender procedure, a dedicated Bayesian network was created, containing the most important information influencing the tender procedure. It was also decided that inference based on the created network should be done with the definition of several key input parameters describing the planned construction investment. It may allow for the analysis of the tender procedures completed so far, as well as for making decisions based on the defined input parameters of the network.

2. Stages of the tender procedure for construction works

The provisions of the PPL Act require appropriate preparation and implementation of a tender procedure for construction works. The public investor (contracting authority) should make every effort to ensure that the procedure ensures fair competition and equal treatment of all contractors. If it does not infringe the public interest, the procedure is public and information about the procurement is available to all parties [1]. Tender procedures for construction works for investments covered by the KPK must also meet the internal regulations of PKP PLK S.A. [12] and the requirements of the act on rail transport [13].

Immediately before announcing the public contract, the investor specifies a number of information related to the conducted procedure. The most important ones include: investor's name, contact persons, procedure, value of the contract, estimated duration of the contract, contract description, terms of participation, as well as the date of contract settlement. The tender announcement is published in the national public procurement bulletin and its EU equivalent [2].

Having a complete set of information on the tendering procedure, contractors prepare an offer, which they prepare to the best of their knowledge, based on the available tools, experience and executive potential. The description of the contract should be unambiguous, however, in case of doubts, it is possible to ask questions. After preparing the offer, the contractor submits it to the contracting authority and waits for information from the so-called opening envelopes. This is the moment when the contracting authority discloses data on bids submitted by all contractors. They usually contain information on the price and other tender criteria. After opening the envelopes, the contracting authority commences a detailed examination of the offers in order to determine compliance with the applicable legal regulations.

If none of the offers has been excluded as a result of the examination of the offers, all of them are subject to evaluation in terms of the accepted tender criteria. From among the submitted offers, the one with the most favorable evaluation is selected. It is then chosen as the most advantageous. The contractor who submitted the most advantageous offer is invited to sign a contract with the contracting authority. The award of a public contract is tantamount to concluding a contract.

Bearing in mind the above, it can be stated that the tender procedure consists of several consecutive stages, which may differ depending on the chosen method of conducting the tender. A typical tendering procedure for an open tender is presented in Fig. 1 [14].

The Act [1] also provides for the possibility of appealing against the identified actions (eg. rejection of the offer), requesting clarification of the provisions or carrying out specific actions again. The legislator also foresaw a situation in which it is not possible to select the best offer and the tender procedure should be canceled. One of such premises is exceeding ' the investor's budget or an abnormally low price [15].

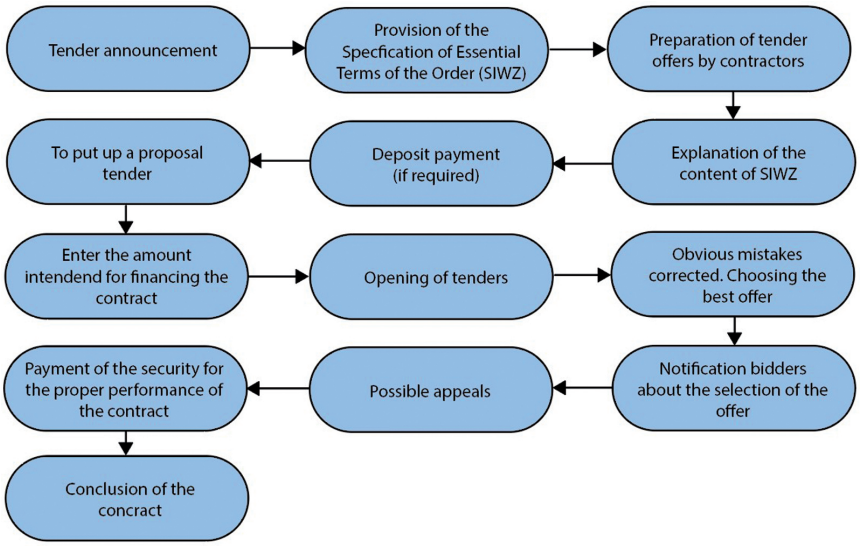

Fig. 1. Tender procedure diagram for open tender

3. Electronic auction mechanism

As already mentioned, the most commonly used procedure for awarding a public contract for construction works under the KPK is open tender. It has many advantages, including, first of all, the competitiveness of the procedure for all its participants. Despite the high attractiveness of tender projects announced by PKP PLK S.A. they often exceed the planned investor's budget [16,17]. This entails the risk of the procedure being canceled, the entire procedure being repeated and, as a result, not meeting the assumed financial targets and those included in the entire program.

The amendment to the PPL Act in 2016 [1] abolished the maximum amount thresholds for the use of electronic auctions. This allowed for its use in public contracts for high-value construction works, including those announced by PKP PLK S.A. After numerous annulments of tender procedures in 2016–2018 [7], the investor decided to make the electronic auction universally applicable for all orders planned under the KPK.

The use of electronic auction is preceded by a standard open tender procedure. If, after the bid examination stage, at least two non-rejectable bids are found, the contracting authority may conduct an electronic auction. It aims to obtain new, reduced prices or new values for predetermined tender criteria [1]. Electronic auction may only refer to the price or any tender criterion defined at the stage of announcing the procedure.

Conducting an electronic auction is preceded by inviting all contractors whose bids have not been rejected. Along with the invitation, the contracting authority specifies all the details of the auction process: date, number of participants and the rules of its conduct. The IT system is also presented along with its user manual.

The auction is conducted in one or more stages. Each of the contractors may follow the status of their offer items on an ongoing basis, in particular information on the obtained offer score in relation to the others. Until the auction is closed, contractors may submit the so-called increments, i.e. new bids taking into account the conditions of the auction. The submission of a bid increment is effective only if it is more advantageous than the currently most advantageous bid. The auction ends when no new increments are made within the set deadline or after the end of the last fixed stage [1].

Conducting an electronic auction allows you to obtain a new, most advantageous offer. It is treated as binding and used in the further stages of the tender procedure described earlier.

4. Characteristic of tender procedures

To create the database, information from 36 completed tender procedures for construction works commissioned by the company PKP PLK S.A., the date of publication of the announcement was from 27/12/2019. until 10/12/2021. Tender procedures covered investments carried out in the "design & build" and "build", and the contractor of which was selected in accordance with the rigor of the Public Procurement Law. All analyzed projects were also part of the KPK [6].

Each tender procedure was described with the help of key parameters and the dates of each stage of the tender procedure were characterized. The obtained information made it possible to determine: the implementation formula, the investor's budget, the contract completion date, the value of the offers from the envelope opening stage, the value of the most advantageous offers (before and after the electronic auction), the duration of the entire tender procedure, as well as savings resulting from the auction.

All analyzed tendering procedures were commissioned under the open tender procedure. 26 of the planned investments will be implemented in the design and build formula, while the remaining 10 in the build formula. One criterion was specified for 29 tender procedures – the price. The others had different criteria: the length of the guarantee for the works performed or the shortening of the deadline. The share of these criteria was different, but the price criterion in any of the analyzed tender procedures was not lower than 60%. However, in 33 out of 36 tender procedures the share of the price criterion was at least 80%. The investor's budget for the announced tender procedures ranged from PLN 5,425,669.00 to PLN 598,275,331.49. The duration of the projects differed for the analyzed set of tender procedures and ranged from 9 months to 39 months, counted from the date of signing the contract with the contractor.

5. Building a Bayesian network

The "Stanford activation protocol" [18] based on the logical connection of events taking place in the analyzed process, as well as their combination into one system. Then, for individual events, possible variants were defined and the probability of their occurrence was

determined. The classical definition of probability was used to determine the probability of event variants, according to the Eq. (5.1) [19].

$$R = f(PC) \tag{5.1}$$

where: R – Risk, P – The probability of a certain event occurring, C – Consequences of the event on final result of the project implemented.

In order for the created tool to be as effective as possible, it was decided to distinguish between the investments being the subject of the tender procedure and to define the measurable effects of the electronic auction. It was decided to define construction projects due to three different criteria: the formula of implementation, the value of the investor's budget and the contractual duration of the investment. In the case of receiving an electronic action, the following parameters were proposed: duration of the procedure, the final best offer, savings after applying the auction, and the value of the savings. As a supplement to the correct mapping of the tender procedure, information on the use of electronic auctions in the analyzed tenders was proposed, along with clarification whether the original bids submitted in the procedure were within the tender budget. The properties (events) of the discussed process, defined in such a way, constituted nodes of the Bayesian network, which were then connected with each other. The topology of the Bayesian network is presented in Figure 2.

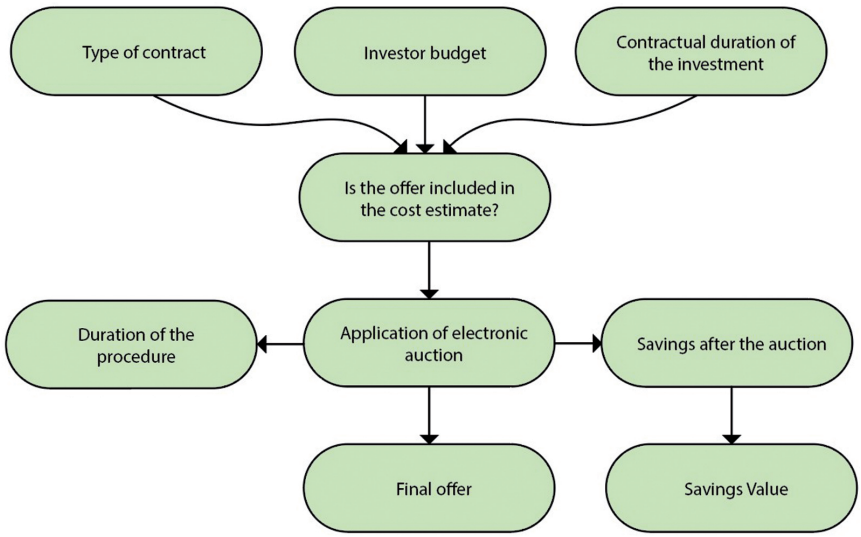

Fig. 2. Created Bayesian network topology

Each of the defined nodes of the Bayesian network contained predefined variants, reflecting the key information influencing the tender procedure. The selection of event variants was based on the author's own experience related to the engineering practice to date. The variants included in the nodes of the Bayesian network were collected and presented in tabular form in Table 1.

Table 1. Variants of Bayesian network nodes

Node name	Node variant
Type of contract	• Build; • Design and Build.
Investor budget	• Up to PLN 25 million • From PLN 25 million – PLN 125 million; • Over PLN 125 million.
Contractual duration of the investment	• Up to 15 months; • From 15 to 24 months; • More than 24 months.
Is the offer included in the cost estimate?	• Yes; • No.
Application of electronic auction	• Yes; • No.
Duration of the procedure	• Up to 180 days; • From 180 to 240 days; • From 240 to 365 days; • More than 365 days.
Final offer	• Over 100% of the investor's budget; • From 90% to 100% of the investor's budget; • From 80% to 90% of the investor's budget; • From 70% to 80% of the investor's budget; • Less than 70% of the investor's budget.
Savings after the auction	• Yes; • No.
Savings value	• None; • Up to 10% of the submitted offer; • From 10% to 20% of the submitted offer; • From 20% to 30% of the offer submitted; • More than 30% of the submitted offer.

Defined events, specific combinations of these events, as well as the proposed variants made it possible to formulate the complete topology of the Bayesian network under construction. After its definition, the event probabilities and conditional probabilities were introduced. For this purpose, the data obtained from 36 completed tender procedures, discussed in the previous part of the work, were used. For each event variant, the probabilities of their occurrence were defined, and for related events, the conditional probabilities. GeNie software was used to build the Bayesian network [20].

In line with the assumptions made, a Bayesian network was built to model the impact of the electronic auction on the tender procedure under the investment for the KPK. The network with the general scenario is presented in Figure 3.

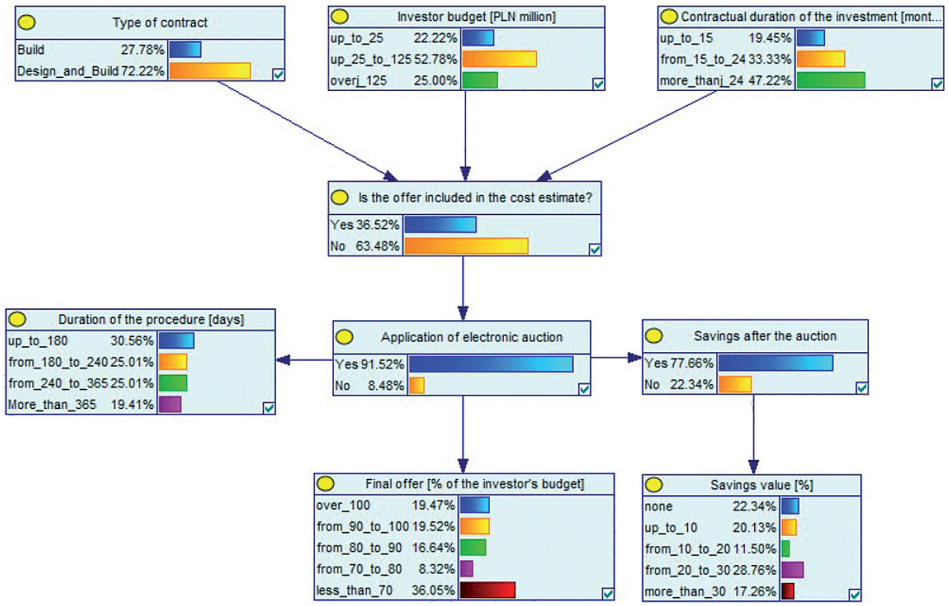

Fig. 3. Bayesian Network – impact of electronic auction

The developed Bayesian network allows for the observation of certain general relationships describing the analyzed tender procedures. Among the planned investments to be completed, 72.22% are projects in the design and build formula, while 27.78%

in the formula build. More than half of all analyzed tender procedures (52.78%) have an investor budget in the range of PLN 25 million to PLN 125 million. On the other hand, the contractual duration of the planned investments was most often defined as over 24 months. This duration was determined for 47.22% of investments from among the analyzed tender procedures.

For 63.48% of the tendering procedures, an offer within the investor's budget was not obtained. Taking this fact and other conditions into account, it was found during the analysis of the contract documents that an electronic auction was additionally used for 91.52% of tender procedures. In the case of 77.66% of the auctions, savings were achieved compared to the originally proposed cheapest offer from the envelope opening stage. The most common savings were from 20% to 30%,and the probability of its occurrence was estimated at 28.76%.

At the same time, after taking into account the information on the course of the electronic auction, data was obtained on the most advantageous offer selected by the investor. Among the analyzed tender procedures, the most probable was the acquisition of the most advantageous offer, falling below 70% of the investor's budget. The probability of this event was 36.05%.

The last element of modelling the impact of an electronic auction was the introduction of information on the duration of the entire tendering procedure (from the announcement

of the tender procedure to the signing of the contract). Like the data related to the selection of the best offer, the duration of the tender procedure could depend on the occurrence or conduct of an electronic auction. Among the proposed options, the most likely was the completion of the tender procedure within 180 days of its announcement. The probability of this event was 30.56%.

The created Bayesian network was cross-validated 10 times with the use of information from the created database [21]. In order to determine the quality of the developed classifier, ROC curves (Recevier Operating Characteristic) [22] were used, determined for two key network nodes, ie "Application of electronic auction" and "Saving value". An exemplary ROC curve for the selected variant in the node is shown in Figure 4.

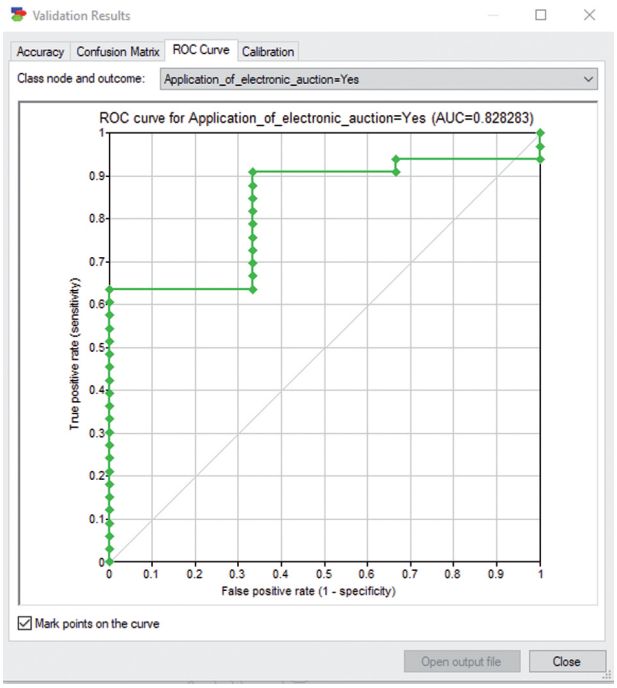

Fig. 4. ROC curve for the "YES" variant in the "Application of electronic auction" node

ROC curves were created for all variants of selected network nodes, and then the value of the AUC parameter was estimated for each of them [23]. The obtained values of the AUC parameter were summarized in tabular form and compared with the reference prediction values proposed in [24]. The results are presented in Table 2.

Additionally, the Accuracy, representing the accuracy of prediction during cross-validation [23]. In the case of both analyzed network nodes, this parameter was 0.958. Based on the adopted criteria, i.e. the quality of prediction based on AUC and the accuracy measure, it was found that the assessment of the network performance is satisfactory and can be used in practice.

Table 2. The quality of the prediction of the created network

Node name	Node variant	AUC value	Prediction quality
Application of electronic auction	Yes	1	Perfect
	No	1	Perfect
Savings after the auction	No	0.828	Good
	No	0.828	Good

Inference based on the Bayesian network can take place using the introduced event scenario or on the basis of the so-called general scenario [18]. Defining an event scenario is associated with the definition of event variants along with the introduction of known probability values of individual variants (e.g. a situation where the implementation formula, investor budget, etc. is known). It is usually a situation in which some information about the studied phenomenon is available, which can be unequivocally entered into the network. The remaining dependencies, introduced at the stage of building the Bayesian network, remain unchanged and are determined on the basis of conditional probabilities.

The second way of inference is to base your beliefs on the so-called general scenario. In this case, the Bayesian network allows for the acquisition of typical information, shaping the prediction based solely on the knowledge obtained from previous tender procedures.

The selection of inference with the use of the proposed model depends on the information that is possessed by decision-makers at the selected stage of the tender procedure. When preparing the investment for implementation, it will not be possible to determine detailed data, therefore the general scenario will be used to make decisions. While specifying the key parameters of the planned investment (e.g. investor's budget, implementation formula, etc.), it will be possible to apply an appropriate scenario reflecting the existing situation. The quality of the prediction will depend on the adopted scenario. Defining the event scenario will lead to better opinions and predictions based on more precise input data.

6. Network verification and calibration

The dynamics of construction processes, including the analyzed phenomenon of electronic auction in tender procedures commissioned by PKP PLK S.A., requires constant observation and the introduction of possible changes to the created models supporting decision-making. Similarly, the proposed Bayesian network should be verified or updated (conditional probability calibration) based on new data from subsequent investments or tender procedures. For the purposes of this work, the network was updated and verified using information obtained from 8 previously unused tenders, commissioned by PKP PLK S.A.

All tenders were conducted in accordance with the rigor of the PPL Act, were part of the KPK program, and were characterized by conditions similar to those of the 36 tenders used to build the Bayesian network. Selected tendering procedures were announced in the period from May 31, 2019 to May 12, 2021. The investor budget of the new tenders ranged

from PLN 30,576,986.58 to PLN 1,586,927,200.04. Five out of 8 procedures concerned investments carried out in the "design and build" formula, while the remaining 3 were carried out in the "build" formula. For all 8 tenders, the price criterion accounted for at least 60% of the total proposed tender criteria. The time of the investment implementation differed depending on the planned investment and ranged from 16 months to 221 months.

The network verification consisted in re-validation with the use of new data, as well as the determination of ROC curves, AUC values and the accuracy parameter [23]. Due to the smaller data set, in order to verify the created network, a 4-fold cross-validation was performed. The obtained data was collected in tabular form. The results are presented in Table 3.

Table 3. Bayesian network verification

Node name	Node variant	AUC value	Prediction quality
Application of electronic auction	Yes	1	Perfect
	No	0*	–
Savings after the auction	No	1	Perfect
	No	0*	–

*The classifier did not match any element to the proposed variant.

Based on the determined values of the AUC parameter, a peculiar case of prediction of network variants was obtained. For all tender procedures, the network correctly predicted all the actually achieved variants. Additionally, in each of the 8 tenders there was only a situation in which an electronic auction was used, and also after its completion, savings were achieved. Such a state did not allow for the estimation of the predictions for the variants "NO" in both analyzed network nodes: "Application of electronic auction" and "Saving after auction".

As a supplement to the considerations, the value of the accuracy parameter was determined. In the case of the analyzed 8 new tender procedures, the accuracy was estimated at the level of 0.8125. Based on the adopted criteria, it can be concluded that the quality of prediction in the case of the "YES" variant for both analyzed network nodes is excellent, while in the case of the "NO" variant, further research related to the verification of the network should be carried out, supplemented with further tendering procedures, containing different situations related to the conduct of an electronic auction.

A characteristic feature of Bayesian networks is their easy updating based on new data (calibration). It was decided to use the information obtained from 8 tender procedures to calibrate the probabilities in all nodes of the network. Out of several possible network training methods, the "EM" (Expectation-Maximization) algorithm implemented in the software used was selected [20,25]. It was also assumed that the previously entered data (36 tender procedures) are important in terms of updating probabilities in nodes, and a certainty value equal to the number of tender procedures was proposed. For such assumptions, one network calibration cycle was carried out. Figure 5 shows the Bayesian network after calibration.

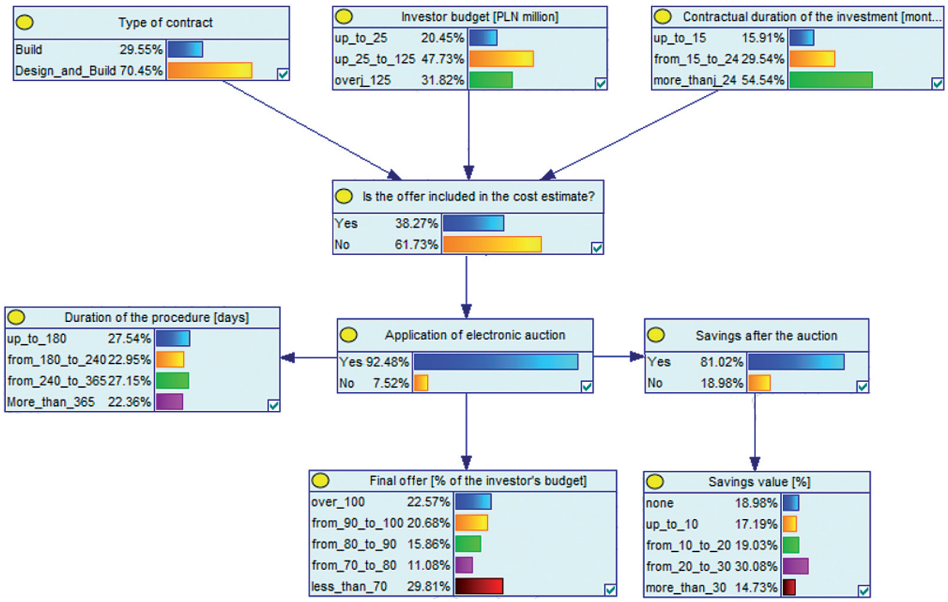

Fig. 5. Bayesian network after calibration with new data

The network update changed the probabilities of all variants in the defined network nodes. The changes in the probability values ranged from –6.24 pp. (variant "below_70" in the "Final offer" node) to 7.32 p.p. (variant "above_24" in the node "Contractual investment duration"). Additionally, the detailed analysis presents in Table 4 changes in probabilities for two key network nodes, "Application of electronic auction" and "Savings after auction".

Table 4. Probability value update after network calibration

Node name	Node variant	Probability value [%]	
		Base network	Calibrated network
Application of electronic auction	Yes	91.52	92.48
	No	8.48	7.52
Savings after the auction	Yes	77.66	81.02
	No	22.34	18.98

Data from 8 new tender procedures increased the probability of using electronic auction (from 91.52% to 92.48%) and obtaining savings as a result of its conduct (from 77.66% to 81.02%). Correspondingly, updating the network reduced the probabilities for the opposite ("NO") variants in both analyzed nodes.

7. Conclusions

The phenomenon of electronic auction in tender procedures conducted under the KPK is very common nowadays. Understanding this mechanism and the consequences of its application may allow for rational management of the entire process. The proposed Bayesian network, which is a very useful and easy-to-use tool, can be used to model the impact of an electronic auction on the tender procedure [18]. As presented in this paper, a great advantage of this solution is the possibility of introducing scenarios corresponding to the actual situation prevailing during the tender procedure. The quality of the decision support tool will depend on the information you have.

The data set (36 completed tender procedures) allowed to build a complete network. Additionally, in order to be practical, the network has been validated, verified and calibrated based on data from new, 8 completed tender procedures. Despite the peculiar case of network verification (related to the occurrence of one event scenario), the correct prediction quality was found. The probabilities were also updated using the EM algorithm.

Verification of the network is extremely important, especially in the context of the current opinions of industry circles [17], which indicate that the use of auctions may cause many negative phenomena. Among the short-term effects, among others, unrealistic market rates for building services and materials, undercutting margins or lack of risk calculation in the bids submitted. What may affect the financial liquidity of suppliers or subcontractors. In the case of long-term effects, the emphasis is primarily on the possibility of terminating contracts with contractors, which will lead to repeated tender procedures and, consequently, increase costs and extend the entire KPK. Therefore, it is extremely important to get to know also those aspects of electronic auctions not directly resulting from the use of a different procedure. The originally planned savings in the case of using electronic auction may lead to higher long-term costs, which will exceed the possible profits (savings) of the adopted mechanism of conducting the tender procedure. The more that the dominant tender criterion is a price criterion.

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Modelowanie wpływu aukcji elektronicznej na postępowanie przetargowe dotyczące budowy infrastruktury kolejowej przy użyciu sieci bayesowskiej

Słowa kluczowe: sieci bayesowskie, aukcja elektroniczna, zamówienia publiczne, roboty kolejowe

Streszczenie:

Liczne przekroczenia budżetu inwestorskiego podczas przetargów na budowę infrastruktury kolejowej w Polsce spowodowały powszechne zastosowanie nowego trybu udzielania zamówień

publicznych – aukcji elektronicznej. Ta procedura ma wiele zalet i potencjalnych zagrożeń. Jedną z największych korzyści dla inwestora są potencjalne zyski, wynikające z zmniejszenia ofert. Oferenci konkurując wzajemnie pozwalają na osiągnięcie optymalnych cen dla planowanej inwestycji budowlanej. Jednak to może spowodować, iż pierwotnie kalkulowane ryzyka w razie urzeczywistnienia się, doprowadzą do znacznych przekroczeń budżetu. To z kolei może implikować dalsze negatywne konsekwencje, w tym przekroczenie założonych terminów inwestycji. W artykule przedstawiono metodę modelowania wpływu aukcji elektronicznej na postępowanie przetargowe z wykorzystaniem sieci bayesowskiej. Do budowy sieci wykorzystano dane pochodzące z zakończonych postępowań przetargowych ogłaszanych przez spółkę PKP Polskie Linie Kolejowe S.A. Stworzona sieć została następnie poddana walidacji, zweryfikowana i skalibrowana z wykorzystaniem nowych danych, pochodzących z 8 postępowań przetargowych.

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