

Application of BN in Risk Diagnostics Arising from the Degree of Urban Regeneration Area Degradation

Magdalena Apollo, Beata Grzyl, Emilia Miszewska-Urbańska

Department of Metal Structures and Construction Management
Gdansk University of Technology, Faculty of Civil and Environmental Engineering
Gdansk, Poland
[magdalena.apollo@wilis.pg.gda.pl](mailto:magdalen.apollo@wilis.pg.gda.pl)

Abstract—Urban regeneration as a complex project, generates many extremely specific threats affecting the increase of investment risk. Its unique nature causes that probability parameter, normally applied in the process of risk quantification, is extremely difficult to estimate. Due to lack of historical data urban regeneration related activities are therefore associated with uncertainty.

According to the authors, a useful tool for resolving the above issues may prove to be Bayesian networks (BN). Beliefs based on expert knowledge should be considered as a subjective measure, nevertheless BN also allow to combine this information with objective results of conducted research.

The authors built a model representing various urban regeneration risk areas, where the analysis covers degradation of the urban regeneration area. The article also presents selected parameters allowing for diagnostics of technical condition of buildings, road pavement and underground infrastructure in the area of urban regeneration.

Keywords—*bayes methods; condition monitoring; degradation; urban areas.*

I. INTRODUCTION

The Polish experience in urban regeneration, i.e. restoration of degenerated urban areas, indicates that such enterprises are risky from the investor's point of view [4]. Despite that urban authorities continue to undertake such projects since in many cases a decisive impact have factors of social nature. Due to fact, that when assessing economic effectiveness of the activities related to urban regeneration projects, the typical indicators are not fully justified, in practice there is a clear need for the risk assessment for the projects of the above nature (urban regeneration investment risk - RIR). BN prove to be a good tool to assess this type of complex investments, because they factor in relations between various elements of the project, creating a network of interdependencies.

The article points out the possibility of using BN to evaluate technical condition of facilities existing in the urban regeneration area, and as a consequence to determine the level of investment risk [9]. The basis of estimates of the technical condition were the actual observations within urban regeneration project conducted in Gdansk in 2009-2012. The

authors analyse selected parameters (symptoms) allowing for diagnostics of the technical condition of buildings, road pavement and underground infrastructure. Therefore, in the situation, when the complete technical documentation is missing there is a chance for the indirect estimation through observations introduced into the symptom variables. In authors' opinion this approach can be especially useful at the preparation stage of urban regeneration project when investor has to make decisions based on limited information.

A special kind of BN has been constructed in order to represent RIR. Object-oriented Bayesian network (OOBN) reflecting various urban regeneration risk areas, has been divided into 8 parts presenting various groups of threats. Analysis contained in the paper covers only degradation of urban regeneration area, which is defined as one of substructures (objects) of the global model. The aim of the article is to determine the extent and size of the impact of the technical condition of buildings, road pavement and underground infrastructure on the risk level resulting from the urban regeneration area degradation. In the course of study one has used literature analysis, consultations with experts as well simulations conducted in AgenaRisk software, including sensitivity analysis [7].

II. RESEARCH MODEL

The global OOBN model, being a representation of risk factors and groups of risk factors generating RIR was built in AgenaRisk software [13]. This model accounts for risk factors identified during expert polling as having significant impact on potential increase of cost, due to additional works required to complete the project. Apart from risk factors, in line with methodology of constructing a BN, it includes nodes representing background variables, symptom variables, problem variables and intermediate ones. Background and symptom variables when populated with information about actual project conditions allow to update assessment of real risk level in a given project. Data necessary for qualitative analysis (relations between specific objects and risk factors), as well as quantitative analysis of the network (*a priori* probability, node probability tables - NPT) was obtained during consultations with experts.

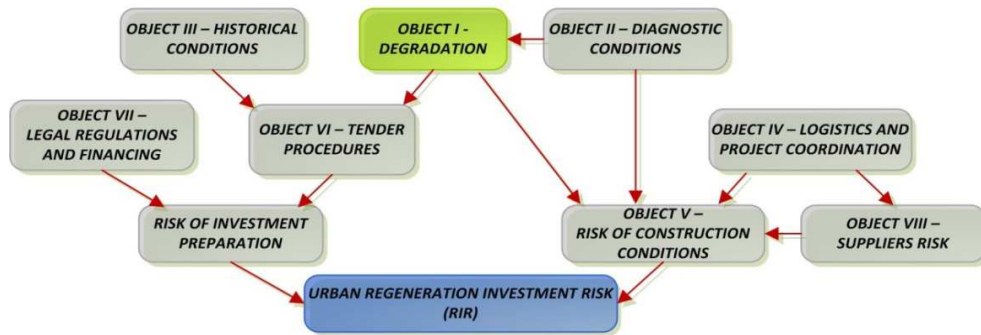


Fig. 1. OOBN structure – global approach (risk arising from urban regeneration area degradation marked in green).

According to the idea of building OOBN [8], identified risk factors have been grouped into 8 thematic substructures presenting different areas of RIR (Fig.1). This paper covers only a part of wider analysis. The considerations in terms of diagnosis of technical condition relate to buildings, road pavement and underground infrastructure (Fig. 2).

III. ANALYSIS OF THE PARAMETERS USED IN THE MODEL

A. Assessment of the Technical Condition of Buildings

Diagnosis of technical condition of buildings located in Gdansk-Letnica was based on general criteria of assessment of the technical condition of the building elements, which also apply to assessment of the building as a whole (Table I; author’s research based on [5, 10, 11, 14, 15]). In accordance with the above, 4 conditions of the variable *technical condition of buildings* have been considered as per Table I.

High number of factors impacting the diagnosis of technical condition of buildings makes it impossible to account for all of them, especially in the initial stage of the project analysis. Specific indicators (such as service limit state, ultimate limit state, etc.) corresponding to the properties of specific construction element are also not analysed in the model, only the general characteristics of the object are taken under consideration. In order to build the network a simplified set of key (in author’s assessment) parameters has been used, that represent the average condition of buildings in a given urban regeneration area.

Symptom variables (indicators of technical condition) include:

- *visible deflection of structural elements* (displacements of construction especially important in case of wooden construction; possible state of the variable: *Yes/No*),

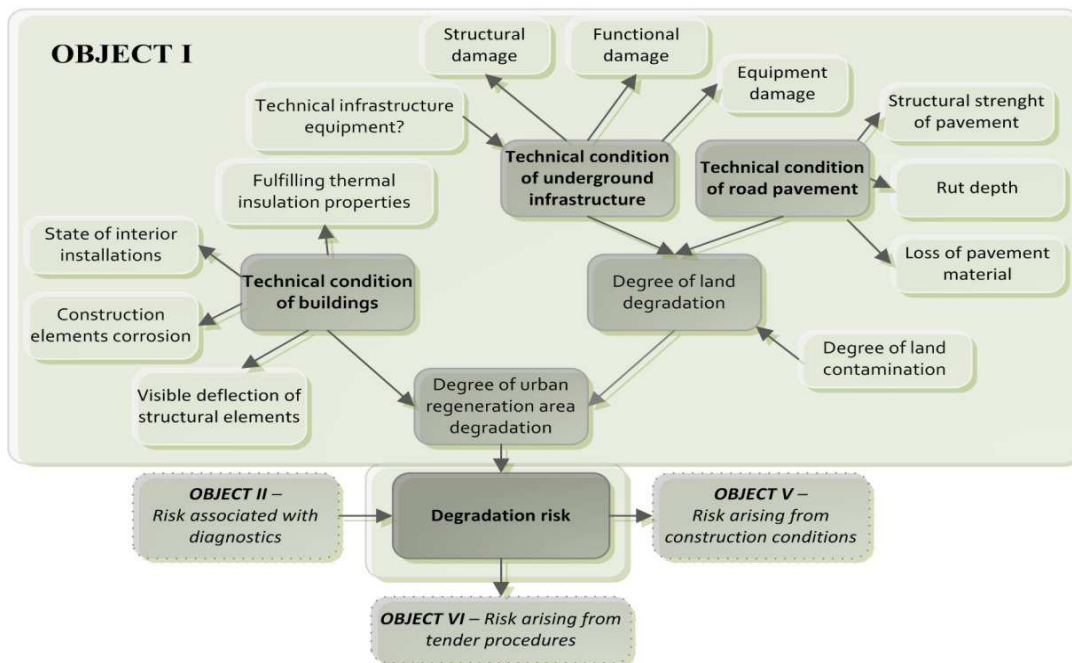


Fig. 2. Bayesian network covering the issue of urban regeneration area degradation.

TABLE I. CLASSIFICATION OF THE TECHNICAL CONDITION OF BUILDINGS (BASED ON [5, 10, 11]).

Technical condition	Technical damage [%]	Criteria of assessment
very good	0-10	building in good condition, maintained, without signs of wear and tear and damage
good	11-25	building shows no significant signs of wear and tear, but specific parts may require maintenance
medium – satisfactory	26-60	building condition is satisfactory, but a renovation is recommended; in case of damage of >51% a complete general renovation may be required
bad - emergency	61-100	building is severely damaged; a complete renovation is required, especially if damage is over 70% (then demolition is recommended)

- *construction elements corrosion* (relevant mainly for steel, wood and concrete; corrosion, erosion, moisture, biological damage etc; possible state of the variable: *Low/Medium/High*)
- *state of internal installations* (possible state of the variable: *Good/Bad*)
- *fulfilling thermal insulation properties* (for example heat transfer coefficient; possible state of the variable: *Yes/No*).

pavement, technical condition of underground infrastructure and degree of land contamination.

1) *Assessment of technical condition of road pavement*

The parameters reflecting technical condition of road pavement were defined based on the instruction [12]. According to [12] in determining the technical condition of the road pavement, it is necessary to:

- evaluate bearing capacity (assessment of the level and shape of surface deflection under pressure or sizing the damage),
- measure the rut depth,
- assess the pavement damage (calculation of the loss of chippings grains and e.g. asphalt mixture in the upper part of pavement).

B. *Degree of Land Degradation*

Assessment of the degree of land degradation directly depends on the factors related to infrastructure decapitalization and pollution of former industrial areas. The degree of land degradation is assessed through the technical condition of road

TABLE II. CLASSIFICATION OF ROAD BEARING CAPACITY BASED ON THE EXPECTED DURABILITY TIME [6].

Bearing capacity classes	Definitions of bearing capacity classes (expected expiration time)
A/B	18 years; pavement of class A should have bearing capacity close to new pavement (20 years)
B/C	8 years; length of the class C corresponds to typical inter-renovation period (the need for repairs coincides with expiration of pavement durability and structural overlay)
C/D	2 years; pavement in class D requires immediate intervention; 2 years is the period sufficient to conduct research and preparing renovation before expiration of durability

TABLE III. CLASSIFICATION OF THE TECHNICAL CONDITION OF ROAD (BASED ON [12]).

Technical condition	Assessment criteria
good	Class A
satisfactory	Class B; the road does not require renovation, but a regular review of technical condition is recommended as well as preventative maintenance
unsatisfactory	Class C; pavement requires renovation
bad	Class D; pavement requires immediate emergency renovation

TABLE IV. EVALUATION CRITERIA OF PAVEMENT RUTTING [12].

Pavement class	Assessment criteria
A	rut depth less than 10mm
B	rut depth 11÷20mm
C	rut depth 21÷30mm
D	rut depth more than 31mm

TABLE V. EVALUATION OF SURFACE DEFECTS ACCORDING TO THE CRITERIA INDICATING THE NEED FOR PREVENTION WORK (BASED ON [12]).

Classes	Assessment criteria
I	closed surface, without damage and losses
II	surface closing maintenance recommended
III	surface closing maintenance is necessary to extend the durability of pavement in sufficient technical condition
IV	pavement degraded so much that surface closing maintenance is ineffective

As much as measurements of the rut depth and assessment of damage to the surface allows directly to qualify the road pavement into one of previously defined classes, the classification of bearing capacity depending on the remaining durability of the pavement is not so straightforward. According to [6] the idea of bearing capacity of pavement in road construction is ambiguous. It can be however evaluated based on time remaining until the loss of bearing capacity (Table II).

In general, the indicated parameters (Table II, III) allow for the mathematical point scoring, constituting the basis for identifying the renovation needs of road infrastructure. Within this paper the above parameters can be used to diagnose overground infrastructure in the context of technical condition of pavement, as classified in Table III. Values of the parameters (states of symptom variables) allowing to describe the technical condition of road pavement as per Tables II, IV and V.

2) Assessment of underground infrastructure technical condition

The key task in the context of assessment of technical condition of underground infrastructure is its complete survey, giving the full picture of existing and potential threats. It is crucial to identify and classify damages to the underground infrastructure, which according to [1] include:

1. Construction damages:

- defects and damages of the material used to construct the line, as well as defects in pipeline connections;
- gaps in the joints in masonry and prefabricated objects, in connections to cubature objects;

- overly dislocated or misshapen construction elements of the object;
2. Functional damage – hydraulic limitations, caused by too small capacity of the network;
 3. Equipment damage:
 - damages to internal insulation of the object caused by chemical corrosion;
 - damage to additional equipment, e.g. rungs or a fittings installed in the network.

The above groups of damage require the analysis of risk level they generate, which is conducted based on qualifying criteria: bearing capacity, environmental and hydraulic (explained wider in [1]). For the purposes of the constructed model, diagnostics of technical condition of underground infrastructure is conducted by simplifying the above classification of damages and qualifying criteria. It is assumed that the above diagnostics is based on symptom variables (*structural damage, functional damage, equipment damage*), defining the possible states of those variables as: *large, medium and low*. As a result observation of those variables allows representation of the actual technical condition of underground infrastructure.

Apart from the symptom variables, technical condition of underground infrastructure depends directly on the causal relation with the node *technical infrastructure equipment*, which should be considered as the background variable. Lack of equipment, in relation to classifying the technical condition and criteria of assessment provides information about fulfilling (or not) requirements of the some technical condition.

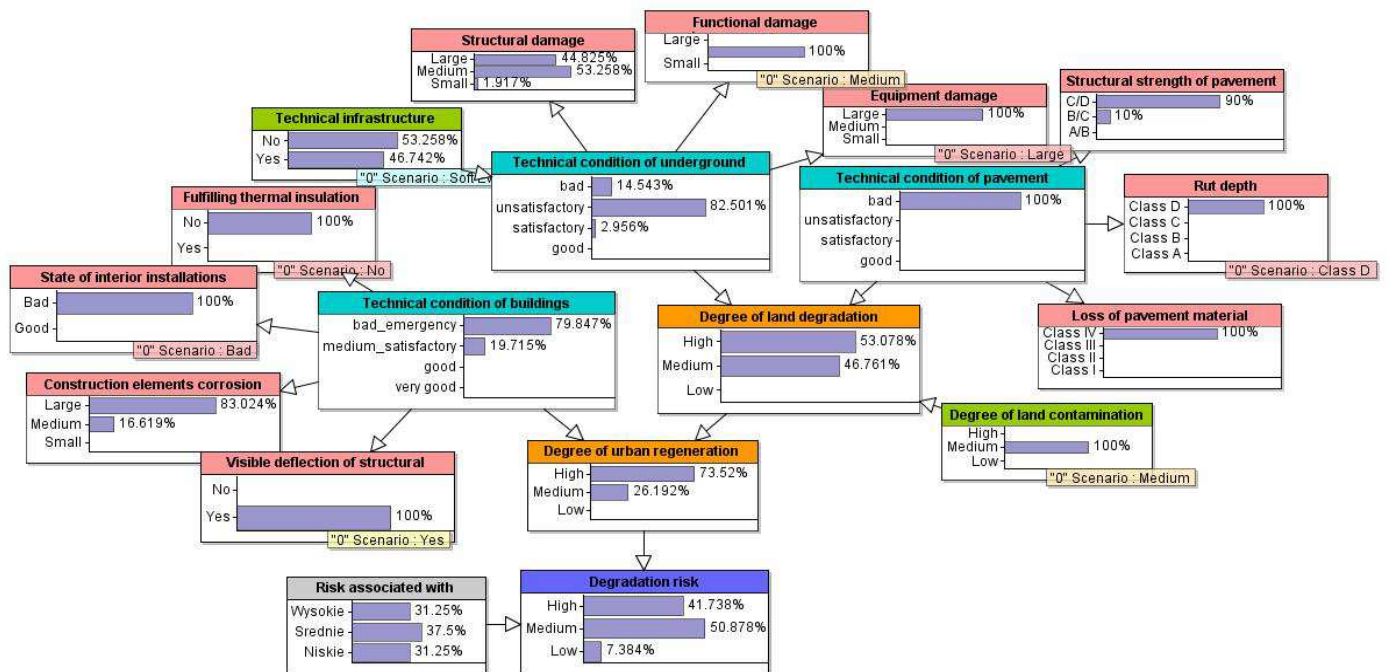


Fig. 3. Simulation of risk level resulting from urban regeneration area degradation.

The node allows input of information about the actual infrastructure of the urban regeneration area. Assuming logical values *yes/no* there is possibility of representing the percentage ratio of the area covered by the network to the area without it, with default values defined as equivalent (50% 'yes' and 50% 'no').

IV. RESULTS OF CONDUCTED SIMULATIONS

Due to high level of uncertainty related to urban regeneration projects, BN are particularly useful at the initial and preparation stage of the project. In case when the direct assessment of technical condition of construction element (building) e.g. through technical expertise, cannot be conducted, BN allow to indirectly estimate it through observations input into the symptom variables [3]. This approach has been used in the simulation conducted.

In the analysis the idea of *soft evidence* has been applied, which denotes a situation when we are not able to introduce the observation as a specific state of the variable (so called *hard evidence*). The use of soft evidence allows defining the ambiguity in the input observations, through assigning independent values of probability to specific states of each variable.

The observations input into the model allowed to diagnose technical condition of the buildings (probability of 79.85% for state: *bad_emergency*), road pavement (100% for state: *bad*) and underground infrastructure (82.50% for state: *unsatisfactory*). Those results were confirmed by the actual state setting the risk of urban regeneration caused by degree of area degradation at medium level (probability of occurrence 50.88%) trending to high (41.74%). It is accepted that such high risk should be addressed by the borough in the preparation of the project and by the investor in the realization phase in order to reduce the risk level. What is more the risk should be monitored especially in the context of updating the symptoms. The use of sensitivity analysis, based on Tornado

diagrams, additionally allowed to identify the impact of the abovementioned technical conditions on the risk level resulting from the degree of urban regeneration area degradation (Fig. 4).

V. CONCLUSIONS

The presented model allowing assessment of risk stemming from the degree of urban regeneration area degradation, allows for an individual diagnosis of technical condition of buildings, road pavement and the underground infrastructure in the situation when direct assessment of technical condition is not possible. In cases where technical condition is known the symptom nodes can be skipped in further analysis and one can input only the observed technical conditions.

It should be mentioned that the process of constructing a BN is not limited to connecting the nodes and objects with causal relations. The key subject is the expert knowledge that is input as observations to the specific variables (respectively *a priori* probability and node probability tables). Credibility and objectivity of the network models depends mainly on the correctness of assigning the levels of the abovementioned probabilities by independent experts, who based on their own experience assess the relation strength between variables.

References

- [1] T. Abel, "Ocena stanu technicznego oraz badania trudno dostępnych obiektów podziemnej infrastruktury sieciowej," Inżynieria Bezwykopowa, vol.6, 2012 (in Polish).
- [2] M. Apollo and M. Kemblowski, "Modelowanie ryzyka przy pomocy sieci zorientowanych obiektowo," Materiały budowlane, 2016 (in Polish).
- [3] A. C. Constantinou, N. Fenton and M. Neil, "Integrating Expert Knowledge with Data in Bayesian Networks: Preserving Data - Driven Expectations when the Expert variables Remain Unobserved," Expert Systems with Applications 56 / 2016.

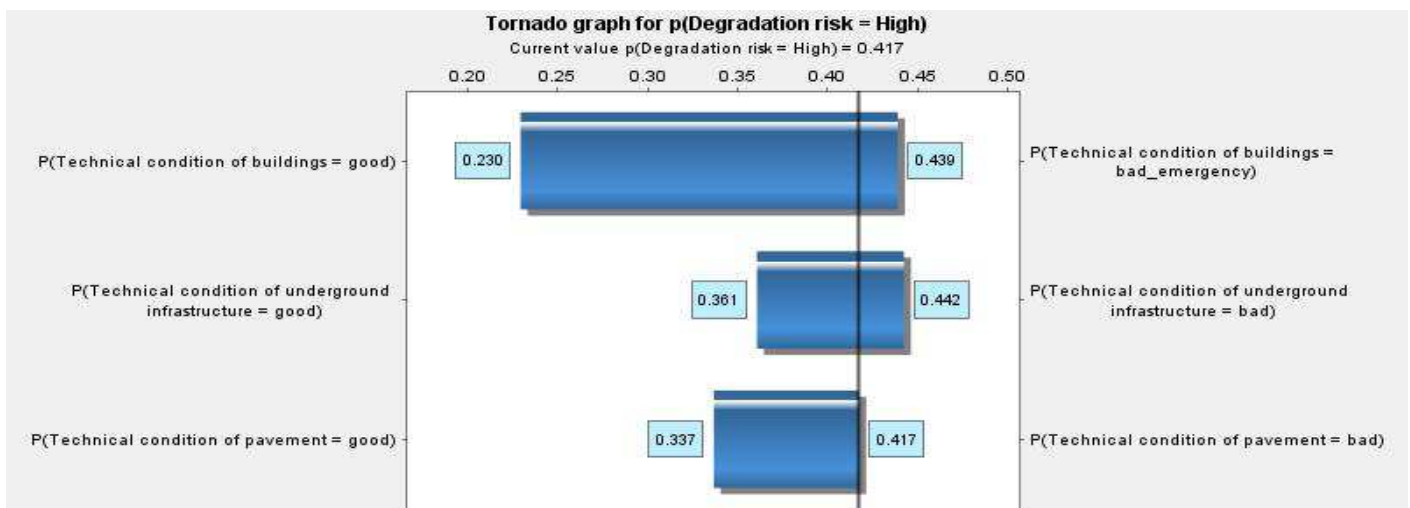


Fig. 4. Tornado graph for the target node: *Degradation risk* (state of the variable: *High*) taking into account the set of evidences presented on Fig.3.

- [4] M. Apollo and E. Miszewska-Urbańska, "Podejmowanie decyzji w warunkach niepewności przy użyciu sieci Bayesa – przykład zastosowania," *Logistyka* vol.6, 2014 (in Polish).
- [5] A. Jakubczyk-Galczyńska and R. Jankowski, "Traffic-induced vibrations. The impact on buildings and people," *Environmental Engineering. Proceedings of the ICEE* vol.9. Vilnius Gediminas Technical University, Department of Construction Economics & Property, 2014.
- [6] A. Janowski, J. Sarbiewska and M. Klatka-Gigiel, *Opracowanie metodyki sieciowej oceny nośności nawierzchni na podstawie pomiaru ugięć pod obciążeniem dynamicznym*, GDDKiA, Warszawa, 2008 (in Polish).
- [7] R.S. Kenett and S. Ron, Bayesian network: Theory, applications and sensitivity issues. *Encyclopedia with Semantic Computing and Robotic Intelligence* vol.01, I.01/2017.
- [8] U. Kjaerulff and A. Madsen, *Bayesian Networks and Influence Diagrams. A Guide to Construction and Analysis*, Springer Science+Business Media, LLC, 2008.
- [9] A. Madsen, F. Jensen, M. Karlsen and N. Soendberg-Jeppesen (2014) "Bayesian Networks with Function Nodes," in: van der Gaag L.C., Feelders A.J. (eds) *Probabilistic Graphical Models, PGM 2014, Lecture Notes in Computer Science*, vol. 8754. Springer, Cham
- [10] K. Michalik, "Diagnostyka, badanie i ocena stanu technicznego budynków cz. 1," *Materiały dydaktyczne Wyższej Szkoły technicznej w Katowicach*, 2013 (in Polish).
- [11] L. Niedostatkiewicz and M. Niedostatkiewicz, "Aktualny stan techniczny i uwarunkowania eksploatacyjne obiektów budownictwa mieszkaniowego i użyteczności publicznej," FRIL, Gdańsk, 2005 (in Polish).
- [12] *Ocena stanu technicznego nawierzchni dróg powiatowych na terenie powiatu kołobrzeskiego*, Dokument ZDPK. Kołobrzeg, 2011 (in Polish).
- [13] *Oprogramowanie AgenaRisk. Bayesian Network and Simulation Software for Risk Analysis and Decision Support*.
- [14] M. Rokieli and C. Magott, "Diagnostyka w renowacji budynków cz. 2," *Inżynier Budownictwa*, 2011 (in Polish).
- [15] *Ustawa z dnia 7 lipca 1994 r. Prawo budowlane. Tekst ujednolicony z dnia 19.08.11.* (in Polish)

