Multi-disciplinary Lego-bricks: building an integrative metamodel for policy analysis by using Bayesian Networks

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Summary

Bayesian networks (BNs) are often praised on their easy to update -characteristic. This is commonly understood as either updating the conditional probability tables when new data or knowledge appears or updating our prior knowledge by setting some of the variables to a "known" state. In addition to that, BNs are relatively easy to update in a sense that the structures can be modified to answer different research questions. In many cases, selected nodes and their defined mutual dependencies can be detached from the original model and linked to another BN as such. It is also possible to integrate whole BNs as submodels to larger entities – metamodels, which are useful e.g. for policy analysis where alternative management actions affecting different parts of the system should be evaluated and compared. We present a process of building a cross-disciplinary BN for minimizing the ecosystem risks caused by the increasing oil transport in the Gulf of Finland (GoF), North-Eastern Baltic Sea. This integrative metamodel enables searching for the best management actions in the light of current knowledge and uncertainties.

Introduction

During the past dozen years, Bayesian networks (BNs) as method have gained popularity in the fields of environmental risk assessment and management. This is understandable, as BNs do have several characteristics valuable for that type of research. They are found to be interactive tools that can help in managing and analyzing complicated problems that no human brains alone can handle. They can also help us to assess the gaps in our knowledge and value of new information. Instead of just single-scenario answers, they also provide syntheses for the sets of scenarios, by weighting the most probable, but still taking into account the possibility of the rare combinations. We present a BN for the analysis of alternative management actions to minimizing the ecosystem risks caused by the increasing oil transport in the Gulf of Finland (GoF), North-Eastern Baltic Sea. This model integrates the work of researchers of several fields – ranging from accident modellers to statisticians, economists, geographers and biologists. This model is developed as part of the EU-funded project MIMIC - Minimizing risks of maritime oil transport by holistic safety strategies.

Materials and methods

For analyzing the question about the best actions for minimizing the oil transportation induced risks for the ecosystem in the GoF, the following sub-questions needed to be first answered:

1. What are the current (2010) and likely future (2020 and 2030) maritime traffic and oil transportation densities in the GoF? (Brunila &Storgård, 2013)
2. How do the tanker accidents (collisions and groundings) arise? (e.g. Hänninen et al. 2012)
3. Given the tanker accident, how the bunker oil leakages arise? (e.g. Goerlandt et al., 2012)
4. Given the leakage, how much oil we can assume to be recovered (in random conditions)? (Lehikoinen et al. 2013)
5. Given the amount of oil not recovered, how large proportion of the coastal line would likely be polluted?

6. Given the extent of the damage, how much harm is caused to different groups of organisms? (Lecklin et al. 2011)
7. How could we manage different parts of this system? What are the costs and utilities related to the actions?

For integrating the gathered knowledge into a single BN, several methods have been applied, such as:

- Adding BNs as sub-models
- Cutting suitable modules from existing BNs (and sometimes also updating them)
- Populating probability tables (PTs) by using data, statistics and literature reviews
- Populating PTs by running existing models
- Including the variability arising from the parallel models and multiple experts

Results and discussion

Bayesian Network consists of two central elements: the graphical presentation of the causalities in the system analyzed and the PTs behind the variables. Updating the existing (prior) knowledge with new observations is the central idea of the Bayesian logic. In practice, for a BN this usually means either updating the PTs when new data or knowledge appears or updating our prior knowledge of the system by setting some of the variables to a "known" state when running the network and then studying the resulting (posterior) distributions of the other variables. In addition, we have found BNs to be relatively easy to update in a sense that their cause-effect structures can be modified to answer different research questions.

It is important to notice that the main purpose of this model is not to predict the consequences of one single oil accident but to find the most cost-effective measures to decrease the environmental risks of the oil transportations. The resulting output quantities, such as the theoretical amount of oil ending up to the ecosystem yearly or the monetary value of the oiled coastline are abstract but they can still be used as criteria for the decision ranking.

We have found BNs to be a workable method for formalizing and integrating different types of knowledge into the same analysis. We have also learned that in addition to suitable methodology, development of interdisciplinary interaction skills and practices are prerequisites for a successful integrative modelling project. Interdisciplinarity can be seen as a learning process that takes place not only between disciplines and types of knowledge, but also between individuals (Haapasaari et al. 2012).

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