Bayesian influence diagrams as integrative modeling tools in cross-disciplinary and multi-risk decision analysis: two applications for the Gulf of Finland

Annukka Lehikoinen [1,4], Maria Hänninen[2,4], Jenni Kuronen[3,4], Inari Helle[1] & Sakari Kuikka[1,4]

1 University of Helsinki – Dept. of Biol. & Env. Sci. / Fisheries and Environmental Management group
2 Helsinki University of Technology – Dept. of Applied Mechanics / Marine technology
3 University of Turku – Centre for Maritime Studies
4 Kotka Maritime Research Centre

Maritime traffic, including the oil transportations, in the Gulf of Finland (GoF) is predicted to rapidly increase in the near future. This will add on the risks directed towards the ecosystem, not only through direct pollution risk arising from the increasing amount of oil transported but also via amplifying accident risk arising from the increasing total amount of vessels navigating in the GoF.

A multi-disciplinary probabilistic (Bayesian) modeling approach SAFGOF (Klemola et al. 2009) to be developed during 2008-2010, will be presented, combining the latest statistics and alternative future maritime traffic scenarios with technical accident and human error models. Bayesian influence diagram (BID) is used to integrate different kinds of probabilistic models and knowledge. Oil accident probability distributions in certain accident prone “hotspot” areas (Kujala et al. 2009) in the GoF are modeled given the uncertain future traffic development and a selection of alternative management actions. The spatial harm (given a probabilistic accident scenario) is evaluated from the viewpoint of biodiversity (threatened populations). The aim is to develop a first version of an advisory risk assessment and decision support tool for governmental decision makers. Probabilistic decision analysis enables realistic assessment of the relative efficacy and robustness of alternative actions under uncertainty related to the different parts of the problem field.

The SAFGOF BID structure includes decision variables defining the future maritime traffic scenario for year 2015 (Kuronen et al. 2008), alternative accident probability management actions (preventative risk management) (see Kuronen & Tapaninen 2009) and alternative oil recovery design solutions (secondary risk management). The decision variables are providing input both to traffic pattern variables and directly to the sub-models of different accident types and factors. Accident types modeled are collisions and groundings. Separate sub-models for geometric (Ylitalo et al. 2008) and causation (human factor) probabilities (Hänninen 2008) are included.

If a tanker collision or grounding happens, the spill occurrence and size are dependent on variety of factors, e.g. the size and speed of the tanker as well as the magnitude of damage to the hull, arrangement of the tanks, height of the oil column in the tanks, oil type etc. In the case of a realized oil accident, effective oil combating plays a major role in minimizing the negative impact of oil on the vulnerable ecosystem of the GoF. As current oil combating is mainly based on mechanical recovery, the efficiency depends not only on the arrangement, amount and capacity of existing recovery vessels in relation to the accident location but also environmental conditions and oil type (Helle 2009). In the model presented, own sub-models for both leak size (given the tanker size and type of the accident) and oil recovery efficiency (given e.g. the recovery design solution, accident location and weather patterns) are included as well.

The final product of the leak size and recovery efficiency sub-models (given the accident scenario) is variable (final amount of) *"Oil in water"* producing the probability distribution for the amount of oil that will be washed ashore. The oil drifting model SpillMod (Ovsienko 2002) is used for producing scenario-specific probability maps to evaluate the magnitude and spatial distribution of the Finnish coastal areas that are in greatest risk to be oiled.

The concept of risk contains both the probability of a certain event and the magnitude of harm caused if it becomes true. The magnitude of harm or utility is always somewhat subjective a question thus being problematic to be defined unambiguously. Protection of the biodiversity and threatened species is an international objective regulated and supported by several laws, acts and conventions. Thus, evaluation of the harm caused by a random oil accident in the GoF is, in the current model approach, based on the mapped knowledge on spatial distribution of the detected threatened species occurrences on the coastline (OILECO software; Kokkonen et al. 2010). For each occurrence, indexes of conservation value and recovery potential (resulting from multiple criteria, such as exposure and mortality indexes, IUCN and directive statuses of the species etc.), are defined. The "harm-value" of each SpillMod map cell is determined by summing up the products of these two indexes for each of the occurrences within the area. The higher the value in a cell, the greater the harm caused in the case that this particular cell would be contaminated by oil.

Finally, the integrative BBN model, scenario-specific oil drifting maps and the OILECO software are integrated to run as one risk model calculating the expected risk (ER) in each of the SpillMod cells given future traffic growth scenario and other decisions / choices of the model user. As ER values of all the cells will be summed up, we end up to a single total risk value for the GoF that summarizes the probabilistic information from multiple models and spatial distribution of both oil contamination probability and harm into one value. As such this value does not tell us much, but it is rather meant to be compared with the end results of the other scenarios. By comparing the total risks of alternative scenarios, it is possible to evaluate the effectiveness of different preventative management actions and oil recovery design solutions against each other. This can be done e.g. by choosing certain future growth scenario and / or accident location as starting points for the analysis or in the light of overall uncertainty concerning the future development and the place where the accident happens. This also provides for assessing the robustness of the ranking order of management actions when the uncertainty in certain part of the model is manipulated – something which can also be utilized for directing the future research work most cost-effectively.

When evaluating the likely consequences of various oil accident scenarios, it is noteworthy that several human-driven pressure factors are continuously changing the ecosystem of the GoF. Recovery potential of stressed system is not comparable to that of healthy one, and more irreversible losses are likely to occur. An integrative Bayesian multi-risk decision analysis model under development in the BONUS+ project IBAM will be shortly illustrated as well. The model integrates oil spill risk management results of SAFGOF -model with four other themes: harvesting (fisheries and hunting), eutrophication and climate change.

Remarkable uncertainties are related to each of the components of both models: the future development of maritime transportations, the effect of the management actions, the processes and factors leading to human error, the severity of a possible accident and the biological consequences as well as the response of the ecosystem taking into account the synergies of multiple pressures. Bayesian networks as method help in providing a realistic picture of the accuracy of current knowledge, and are easy to update in the light of new evidence or more developed sub-model versions. Results can be given in a graphic form that is relatively easy to understand. This provides a good base for planning of future actions, although careful orientation to the underlying ideology and discussion on the acceptable risk levels are first demanded to avoid gratuitous misconceptions. The magnitude of increasing knowledge and more holistic understanding on the system should not be undervalued either.

References:

Helle, I. (2009): Modelling the effectiveness of oil combating from an ecological perspective – a Bayesian network approach for the Gulf of Finland. MSc thesis, Helsinki University of Technology, Faculty of Engineering and Architecture, 98 pp.

Hänninen, M. (2008): Analysis of human and organizational factors in marine risk modelling - Literature review. Faculty of Engineering and Architecture, Department of Applied Mechanics, TKK-AM-4, 51 pp. Available online at: http://www.merikotka.fi/safgof/Hanninen_2008_Analysis.pdf

Klemola, E., Kuronen, J., Kalli, J., Arola, T., Hänninen, M., Lehikoinen, A., Kuikka, S., Kujala, P. & Tapaninen, U. (2009): A cross-disciplinary approach to minimizing risks of maritime transport in the Gulf of Finland. World Review of Intermodal Transportation Research 2(4), p. 343-363.

Kokkonen, T., Ihaksi, T., Jolma, A. & Kuikka, S. (2010): Dynamic mapping of nature values to support prioritization of coastal oil combating. Environmental Modelling & Software 25,p. 248-257.

Kujala, P., Hänninen, M., Arola, T. & Ylitalo, J. (2009): Analysis of the marine traffic safety in the Gulf of Finland. Reliability Engineering and System Safety 94(8), p. 1349-1357.

Kuronen, J., Helminen, R., Lehikoinen, A. & Tapaninen, U. (2008): Maritime transportation in the Gulf of Finland in 2007 and in 2015. Publications from the Centre for Maritime Studies, University of Turku A45, 110 pp. Available online at: http://www.merikotka.fi/julkaisut/Kuronen_Maritime_transportation_2008_v2.pdf

Kuronen, J. & Tapaninen, U (2009): Maritime safety in the Gulf of Finland – Review on policy instruments. Publications from the Centre for Maritime Studies, University of Turku A49,86 pp. Available online at: http://www.merikotka.fi/safgof/Kuronen_Tapaninen_SAFGOFWP6.pdf

Ovsienko, S. (2002): An updated assessment of the risk for oil spills in the Baltic Sea area. 77 pp. Available online at: http://www.helcom.fi/stc/files/shipping/RiskforOilSpillsReport2002.pdf

Ylitalo, J., Hänninen, M. & Kujala, P. (2008): Accident probabilities in selected areas of the Gulf of Finland. Faculty of Engineering and Architecture, Department of Applied Mechanics, TKK AM-6, 49 pp. Available online at: http://www.merikotka.fi/safgof/Ylitalo_2008_Accident.pdf