Twelfth Annual Conference of the Australasian Bayesian Network Modelling Society (ABNMS)

December 9-10, 2020

Wednesday 9th December 2020

(8:30 - 9:30) Plenary Session

(8:30) Bayesian Network Clinical Decision Support Systems for COVID-19

Tom Snelling[a], *Steven Mascaro*[b]
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COVID-19 emerged in late 2019 and has rapidly developed into a global pandemic. While caused by the same family of viruses that cause the common cold, COVID-19, for many individuals, can be far more severe. It has a fatality rate estimated at approximately ten times that of seasonal influenza and there are possibly long term consequences for recovered cases. COVID-19 has had a profound impact globally, with close to 1.5 million reported deaths to date, as well as broad impacts on health services, non-COVID patients, the economy and society more generally. Researchers around the globe have moved rapidly to address the varied challenges posed by COVID-19, with much research into testing, prevention and treatment. Several programs are aiming to collect high quality data on its epidemiology and clinical features.

Early in the pandemic, our group turned its focus to using our existing modelling approaches for infectious disease to create models of COVID-19 that could support clinical decision making, understanding and research. We organised a series of expert workshops and 1-on-1 sessions around biological processes and systems that we suspected to be heavily influential of COVID-19 outcomes. Through these workshops, we developed a variety of expert models on different facets of the disease. This included a model of the testing process, including factors that affect testing accuracy and the chances of false negatives and positives; models of body systems, particularly pathophysiology of the respiratory, cardiac and vascular systems, and the mechanisms by which COVID-19 can affect their normal function; and models of the progression of COVID-19 and the development of complications.

From early on, it became evident that many of COVID-19's central mechanisms were highly novel and unlike other respiratory infections, particularly in producing severe disease. This

includes the manner of the virus's spread in the respiratory tract and involvement of other organ systems, including the key role of the vasculature and its inner lining, the endothelium. We have regularly updated our models in the light of emerging information about the virus, via our workshops and from a rapidly expanding global literature. Access to clinical data has proven surprisingly slow and difficult given the urgent global context, so our models have thus far been parameterised based on estimates adapted from published reports and expert input, with data based parameterisations and evaluations still in progress. Nonetheless, we believe these models already provide useful insights into key aspects of COVID-19, and will soon be capable of supporting the decision making around the diagnosis and prognosis of COVID-19 in a transparent, justifiable and intuitive manner. We expect to demonstrate the proof-of-concept for our approach can be applied to other decision-making problems in health and medicine.

(9:30 -10:30) Environmental applications I

(9:30) To All The Bayesian Networks I've Loved Before

Bruce G. Marcot,
USDA Forest Service

Like a living organism, Bayesian network (BN) modeling has evolved over time to become increasingly refined in its structures and functions, to grow new applications, and to become increasingly symbiotic with other fields of study. In this talk, I recount the way that my own work with BN models has progressed and matured along a set of 7 modeling-consideration themes of: the basis of Bayesian thinking, increased scientific rigor, ties to network theory, the value of uncertainty in decision advisories, methods of calibration and validation, emergence of machine learning, and integration with other modeling constructs. I briefly display and explain operational and applied examples or two for each theme, and suggest to where the field may evolve to next.

(10:10) The long and winding road (to better management of roadside vegetation)

Kate Parkins, Brett Cirulis, Trent Penman, Tim Gazzard, Chris Medlin, Julian Madigan.
The University of Melbourne

Wildfires are increasingly resulting in the loss of life around the world and these patterns are shifting under changing climates. Many of these lives are lost as people try to escape from the fire, becoming trapped by the fire itself or fallen trees. Roadside vegetation has been identified as an area of concern for local communities, fire management authorities and emergency services particularly on days of high fire danger. Many roadside vegetation patches have environmental significance as they represent remnant vegetation in an otherwise cleared landscape. Inappropriate fire regimes in these areas will result in significant ecological change.

Roadsides are managed for a range of different values and risks, posing a complex and challenging task for land and fire managers. Management of roadsides from a bushfire

prevention capacity is further complicated by the multiple agencies that are responsible for managing these landscape features. In this study, we used multiple methods to gain a better understanding of how we can manage roadside vegetation for meeting multiple objectives. Consideration was given to: reducing the risk of ignitions; the use of roads as strategic fire breaks to disrupt the spread of fire; facilitation of safe access and egress; and protection of high conservation value native vegetation on linear reserves. A series of structured decision-making workshops identified a range of community values and potential management scenarios, with access and egress identified as the greatest concern for land managers, emergency services and community members. Using an expert elicitation approach, we developed a Bayesian Network structure to quantify the risks associated with roadside vegetation in a fire context. The results from this project will help inform better management of existing roadsides and guide future plantings and modification of roadside vegetation.

(11:00 -12:00) Environmental applications II

(11:00) Forecasting volcanic eruptions from observational data

Annemarie Christophersen, *Yannik Behr, Craig Miller and Rob Buxton*
GNS Science

In New Zealand, GNS Science through the GeoNet Programme is the official source of geological hazard information. GeoNet organises the volcano monitoring team and oversees the employment of instrumentation to continuously monitor New Zealand's active volcanoes, collect and archive observational data. For life-safety assessments for fieldwork on volcanoes, the volcano monitoring team regularly estimates probabilities of an up-coming eruption for active volcanoes. However, the team has limited quantitative models to estimate the probability of eruption.

Bayesian Networks (BNs) have been applied successfully to model multiple data streams for eruption forecasting and volcanic hazard and risk assessment, but they are not widely employed in volcano observatories. For some years, we have been exploring the usefulness of BNs for probabilistic eruption forecasting in New Zealand. In many cases, volcanic eruptions are preceded by magma rising to the surface and on its way interacting with surrounding rocks and fluids. These interactions lead to earthquakes, tremor, the release of magmatic gases, and surface deformations.

Here we build a simple BN to forecast the probability of eruption for Mount Ruapehu from two key observational data, the eruption catalogue and the temperature of the crater lake. Temperature measurements started in the 1950s and were initially done manually and only every few weeks to months since they involved climbing the mountain. Since 2009, temperature data are transmitted every 15 minutes from a sensor in the lake. Given the slow changes in crater lake temperature over time, we have extrapolated earlier data to daily

measurement. Averaging more recent measurements per day, we have more than 24,000 daily data points between March 1950 and June 2020, during which time 369 discrete eruptions occurred, many in a period of enhanced activity between 1995 -1996. The latest eruption was in 2007.

Since 2008, there are continuous digital volcanic tremor measurements and since 2003 about 100 volcanic gas measurement at irregular interval. These additional data in conjunction with expert elicitation can be used to further inform the eruption probability.

The BN model for different forecast intervals is available on a web browser to members of the volcanic monitoring team to inform the regular expert elicitation of eruption probabilities.

(11:20) Spatial patterns in landscape features drive vertebrate diversity

Annalie Dorph, *Trent Penman, Matthew Swan, Julian Di Stefano*
The University of Melbourne

Understanding the relationships between landscape characteristics and biodiversity can help ecologists to assess the impacts of environmental change and inform management actions. Yet, research into the influence of landscape spatial pattern from disturbance processes, such as fire and land use change, relative to other environmental patterns is limited. We used Bayesian networks in two independent studies of mammal and reptile communities within Victoria, Australia to link species richness responses to spatial pattern from ecological and disturbance sources. Mammals responded most strongly to variables measuring productivity, fire, habitat structure and elevation. Reptiles were most strongly influenced by land use and habitat structure, while fire had little effect. This research highlights the importance of integrating multiple sources of spatial pattern to measure the effect of environmental variables on both reptile and mammal richness.

(11:40) Development of a Bayesian Network of estuarine ecosystem health

R. Bulmer, F Stephenson, J Hewitt,
NIWA

New Zealand estuaries face multiple interacting stressors at a range of scales. While environmental managers may have limited ability to affect the pace of global climate change, significant drivers of stress in New Zealand are potentially within management capacity to address, such as sedimentation, nutrient inputs and urban contaminants. However, understanding the interactions among these stressors is a key research need for effective management. Following workshops attended by a range of experts, NIWA researchers developed a Bayesian network to model estuarine ecosystem functioning in response to

multiple interacting stressors under a variety of different management scenarios. Outputs from this model were used investigate characteristics and values of estuarine coastal zones, including the ecosystem services they provide and their vulnerability to anthropogenic disturbance and climate change. Exploration of scenarios within a BN provides important and cost-effective information which compliments other tools for effective estuarine and coastal zone management in New Zealand.

Thursday10th December 2020

(8:30 -10:30) Defence and industry applications

(8:30) QGeNIe: A Link Between Qualitative and Quantitative Bayesian Networks
Marek J Druzdzel
Bialystok University of Technology

Qualitative Bayesian networks have seen little use in practice since they were proposed around 30 years ago. One reason is that while they significantly reduce the knowledge engineering efforts, they typically derive only weak results. For example, models capturing only signs of influences are often unable to derive the sign of change, as multiple paths of opposing sign will lead to an undetermined sign.

In this talk, I will describe QGeNIe, a qualitative user interface to quantitative Bayesian networks. QGeNIe minimizes the number of numerical parameters to just one probability per node and one per arc, both elicited graphically. While it relies on a quantitative Bayesian network engine (SMILE), it shows posterior marginal probabilities by colors. QGeNIe has two important practical applications: (1) an instant gratification interface for asking "what if" questions in group decision making sessions, and (2) rapid model construction, as a prelude to building quantitative networks.

(8:50) Analyzing GIS Data with Bayesian Networks using HUGIN Software
Anders L Madsen
HUGIN EXPERT & Aalborg University

In this presentation, we will show how to analyze GIS data with Bayesian networks using HUGIN software. HUGIN software is a commercial general purpose tool for developing Bayesian networks and influence diagrams. Recently, an open source plugin was developed to facilitate the use of Bayesian networks and influence diagrams with HUGIN software in QGIS. The presentation will use two different examples to demonstrate how to analyze raster GIS data using the QGIS plugin and how to analyze vector using HUGIN Graphical User Interface in combination with QGIS.

(9:10) Bayesian Network Modelling for Military Utility Assessment of Direct Energy Weapon within Future Tactical Land Warfare

Thang Cao[a], Steven Mascaro[b], Minh Tuan Nguyen[a] and Jason Alvino[a]

[a]Defence Science Technology Group, Edinburgh, Australia

[b]Bayesian Intelligence Pty Ltd, Melbourne, Australia

Defence Science and Technology Group (DST) is investigating future concepts of use (CONUSE) and operational characteristics of Directed-Energy Weapons (DEW) within tactical land warfare with a view to inform decisions on priority areas for further investment in DEW technologies. In this paper, we focus on the application of High-Energy Laser (HEL) and High Power Radio Frequency (HPRF) weapons within a future combat team. CONUSE, which we define as novel operational applications of specific technologies, were developed by a previous study and include options such as: large, medium and small HPRF, HPRF Active Denial; high, medium and low power HEL, HEL retro and HEL UAV etc.

Using a combination of Bayesian Network (BN) Modelling, Multi-Criteria Decision Analysis (MCDA) and Multi-Objective Evolutionary Algorithms (MOEA), we have developed a quantitative approach for the Military Utility Assessment (MUA) of DEW technologies for future combat teams. In this context, we define MUA to be the evaluation of the relative contribution that DEW technologies contribute to the effectiveness of the future combat team across a relevant scenario space. BN Modelling is employed to model the probabilistic effects of blue force DEW technology options and CONUSE on red force fighting capability and to estimate MUA for each DEW technology/CONUSE option or combinations thereof. The military utilities considered in this paper are based on the operational effectiveness metrics of the combat team such as: mission success, survivability, lethality, discrimination and operational cost. MCDA techniques are employed to aggregate multiple utilities based on the elicited Decision Makers (DMs) preferences. Finally, DEW options are ranked and prioritised by maximised expected utility and aggregated utilities. Moreover, MOEA is adopted to remove the subjectivity of the elicitation process in quantifying DMs' preferences, and to heuristically search for the 'best' combination of DEW/CONUSE options.

(9:30) Quantifying Catastrophic Bushfire Consequences

Ian Fitzpatrick; Kate Parkins[1]; Brett Cirulis[1]; Trent Penman[1]; Veronique Florec[2]; and the Project IGNIS team.*

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This project was completed in collaboration between the Energy Industry, BNHCRC, the University of Melbourne and the University of Western Australia).

Understanding the vulnerabilities to energy networks from bushfires is essential for the development of strategies and initiatives aimed at building and sustaining resilience in the

energy sector. In particular, the ability to predict where the highest risks are to (and from) the network and surrounding assets is important for determining where management actions can be implemented in an attempt to reduce those vulnerabilities. The IGNIS project was developed to demonstrate the value of combining bushfire modelling with economic analysis through a Bayesian Network approach to estimate risk exposure of network assets. We developed a standardised methodology for assessing potential costs to electricity networks from major bushfires by combining fire behaviour simulations, economic analyses and Bayesian Network decision analyses. A series of case studies from south-eastern Australia were used to test the effectiveness of the methodology, and its ability to capture regional variations in topography, land use, and economic assets.

(9:50) Bayesian analysis to inform technology selections for a multi-agent system

Maggie Tong, Maria Kapsis, Andrew Coutts, Greg Newbold, Nikoleta Tomecko
Defence Science and Technology Group

Versatile swarm-like multi-agent systems are increasingly being explored for varied applications due to their ability to use the power of numbers to deliver desired effects, and reduce development costs due to their modularity. Examples of such systems include heterogeneous UAV swarms or vehicle fleets. To develop such a system, many choices need to be made about technology inclusions, with the overall performance of the system contingent on not just individual technology choices, but also diverse interdependencies between the technologies. The number of possible technology combinations grows exponentially with the number of potential technology options, such that evaluating the system against multiple operational use cases becomes a complex problem. In the initial concept development phase, it is not feasible to undertake detailed modelling and analysis of all possible concepts and technology combinations for all operational scenarios. This means that often, decisions about the technology choices to progress to detailed analysis or even product prototyping are made without any systematic analysis at the scoping stage.

In this paper, we describe how a Bayesian approach can be used at this initial phase to inform technology selections. A Bayesian influence network can be constructed and populated using subject matter expertise to represent the relationships between technology choices at the lowest level, and track how they impact mission-level performance metrics, all the way to top-level measures of operational effectiveness. This allows technology combinations to be ranked by a metric that considers the effectiveness of the whole system in each scenario being analysed.

The advantage of this approach is that the Bayesian network provides a framework to aggregate the wide range of subject matter expertise into a performance metric that accounts for the impact of each technology choice on different aspects of system performance and the interdependencies of those choices. By using this Bayesian approach, the most promising technology combinations can be identified to progress further to higher-fidelity modelling and analysis. This closes the gap in the analytical chain and ensures that operational effectiveness is considered from the initial concept development and technology scoping phase.

(10:10) Modelling the Force: A BN Approach to Support Decisions on Army Force Structure

Denis Shine, Thang Cao and Julia Piotto
Defence Science and Technology Group

Structuring the Australian Army to best meet its competing priorities and manage its stressors represents a challenging problem for decision makers. The Army system is highly complex and interdependent, with subsystems of individual and collective training, equipment acquisition, platform maintenance, recruitment, retention and operational readiness. These systems inter-operate with a readiness rotational system where at any point elements of the Army are at different levels of readiness to deploy. Modifying this system has significant first and second order effects which must be considered when making organisational change decisions.

Recently, Army sought analysis from LCA examining the impact of organisational change options to the Army system. To achieve this, we developed and populated a decision support model with an underlying architecture combining Utility and Bayesian Network approaches. Two rounds of stakeholder engagement workshops were conducted; first to elicit the network structure, with particular focus on the most important influencing factors; second to elicit the conditional probability tables and comparative assessments required to examine the trade-offs of the options. Results from this study provided broad insight into these options which is currently informing Army decision making.

(11:00 -12:20) BN Developments

(11:00) Dynamic Bayesian network inferencing for non-homogeneous complex systems

Paul P.-Y.Wu[1], M. Julian Caley[1], Gary A. Kendrick[2], Kathryn McMahon[3], Kerrie Mengersen[4]
1. Queensland University of Technology, and Australian Research Council Centre of Excellence in Mathematical and Statistical Frontiers, Brisbane, Australia
2. University of Western Australia, Crawley, and Western Australia Marine Science Institution, Perth, Australia
3. Edith Cowan University, Joondalup, and Western Australia Marine Science Institution, Perth, Australia
4. Queensland University of Technology, and Australian Research Council Centre of Excellence in Mathematical and Statistical Frontiers, Brisbane, Australia

Dynamic Bayesian networks (DBNs) provide a versatile method for predictive, whole-of-systems modelling to support decision makers in managing natural systems subject to anthropogenic disturbances. However, DBNs typically assume a homogeneous Markov chain which we show can limit the dynamics that can be modelled especially for complex ecosystems that are susceptible to regime change (i.e. change in state transition probabilities). Such regime changes can occur as a result of exogenous inputs and/or because of past system states; the latter is known as path dependence.We develop a method for non-homogeneous DBN

inference to capture the dynamics of potentially path-dependent ecosystems.The method enables dynamic updates of DBN parameters at each time slice in computing posterior marginal probabilities given evidence for forward inference. An approximate algorithm for forward–backward inference is also provided noting that convergence is not guaranteed in a path-dependent system. We demonstrate the methods on a seagrass dredging case-study and show that the incorporation of path dependence enables conditional absorption into and release from the zero state in line with ecological observations. The model helps managers to develop practical ways to manage the marked effects of dredging on high value seagrass ecosystems.

(11:20) BARD: an online tool to support groups collaboratively build BNs

Ann Nicholson
Monash University

In many complex, real-world situations, problem solving and decision making require effective reasoning about causation and uncertainty. However, human reasoning in these cases is prone to confusion and error. Bayesian networks (BNs) are an artificial intelligence technology that models uncertain situations, supporting probabilistic and causal reasoning and decision making. However, to date, BN methodologies and software require significant upfront training, do not provide much guidance on the model building process, and do not support collaboratively building BNs. BARD (Bayesian ARgumentation via Delphi) is both a methodology and an application that utilizes (1) BNs as the underlying structured representations for better argument analysis, (2) a multi-user web-based software platform and Delphi-style social processes to assist with collaboration, and (3) short, high-quality e-courses on demand, a highly structured process to guide BN construction, and a variety of helpful tools to assist in building and reasoning with BNs, including an automated explanation tool to assist effective report writing. The result is an end-to-end online platform, with associated online training, for groups without prior BN expertise to understand and analyze a problem, build a model of its underlying probabilistic causal structure, validate and reason with the causal model, and use it to produce a written analytic report. Initial experimental results demonstrate that BARD aids in problem solving, reasoning and collaboration.

(11:40) Combining expert elicited judgements for BNs

Kerrie Mengersen
Queensland University of Technology

Many Bayesian Networks are quantified using information from users' opinions. While there is a substantial literature on this quantification for one user, there is still some debate about how to represent opinions from multiple users. In this presentation, I will discuss some of our research in this area and the case studies that have motivated this research. Two models are considered. The first is a measurement error approach that is argued to address the issues associated with current methods of combining opinions such as the absence of a coherent probability model, the loss of the conditional independence structure of the BN and the provision of only a point estimate for the consensus. The second is an item-response model that accounts for the

relative ability of the contributors. The associated case studies are wayfinding in airports and conservation of threatened habitats.
This research has been undertaken in collaboration with a range of colleagues who will be acknowledged in the presentation.

(12:00) The role and challenges of expert elicitation in blockchain technology

Sandra Johnson
PegaSys / ConsenSys

The Blockchain community is unfamiliar with probabilistic models, such as Bayesian network models. The preferred strategy to explore new concepts is running experiments on test networks and simulating different scenarios with the aid of various machine learning approaches such as reinforcement and deep learning. Therefore, quantifying a model partially with expert knowledge increases potential scepticism of the proposed approach. Against this backdrop, eliciting information from experts for a BN model provided some novel challenges and insights. Expert elicitation has evolved over the years to equip facilitators with a good selection of strategies, and in this talk I share my elicitation journey with the Ethereum community and the unique insights gained into the fascinating world of blockchain technology.