Due Date: *Friday, January 21st at 11:59pm*

Faculty Name: Piotr Szczurek

Department: ECaMS

Research Project Title: Combating Vaccine Hesitancy with Artificial Intelligence

Research Project Summary (Please provide an overview of your project -- this will be shared with students as a project description; maximum 500 words):

This project proposes the development of a decision network that would compute the expected utility of getting vaccinated. Decision networks are heavily studied in the field of artificial intelligence (AI) in order to design agents that make optimal choices in uncertain environments. Our network would be based on real-world data about vaccine effectiveness, the spread and health effects of COVID, and other factors. Such a network would provide people with the ability to set their beliefs about the truthfulness of the data, and their values, and determine the optimal actions based on their individual situation. We hope that by providing people the ability to see how uncertainty changes their optimal decision, they will be more comfortable in making decisions based on data, and possibly, be less hesitant to get vaccinated.

This project would involve studying AI methods, and researching data about various factors related to vaccine hesitancy. The student would use either software like Netica or programming in Python to develop and validate a decision network model. This model would then be analyzed for sensitivity of various factors and value-of-information. The results would document the effect these factors have on optimal vaccination decisions.
In the space below, provide a **Project Description** of your research project in 6 pages or less that includes the following:

- **Introduction and Background**
  - Broader impacts on field of study and undergraduate research
  - Specific aims and goals of the project

- **Proposed Research Plan**
  - Preliminary results (if applicable)
  - Experimental design and methodology
  - Instrumentation required and accessibility
  - Expected outcomes and how you will determine success

- **Mentorship Plan**
  - The role of the student in the proposed research plans
  - Plans for engaging with the student throughout the research process
  - How you will hold your student accountable for completing the proposed work
  - Plans for developing specific skills and techniques during mentorship

- **Proposed Timeline that includes Aims and/or Goals**

- **References** (not included in the 6 page limit)

- **Budget up to $500** (not included in the 6 page limit)

  *Only include supplies that are absolutely necessary for completing the proposed work (supplies which you do not currently have access to through your department).*
Project Description

I. INTRODUCTION AND BACKGROUND

Since their discovery, vaccines have been responsible for limiting or even eradicating many human diseases [1]. The most famous example is that of smallpox, which has been essentially wiped out once people were sufficiently vaccinated [2]. However, since their introduction, people have had doubts about their effectiveness and possible short and long-term side-effects that might affect them [3]. This has led to vaccine hesitancy that has recently come to light due to the COVID pandemic. This hesitancy has potentially increased the death and hospitalization rates of COVID patients and kept the pandemic going for much longer than would have otherwise [4].

The hesitancy problem has been very divisive [5]. Those that encourage vaccines do not understand why someone would choose not to be vaccinated, while those unvaccinated most likely wonder the same about those that get the shot. Both groups attempt to convince the others and try to support their claims with various information and data, some of which may be erroneous and lead to wrong conclusions. In many cases, people tend to simplify the problem to make it seem as though their viewpoint is the only one that is rational. However, such an approach is only going to lead to further divisions and will not reduce the hesitancy problem.

Although studies identified many possible factors for vaccine hesitancy ([3], [6], [7]), two factors seem to be most important. The first is that people may not find the vaccine valuable for them. This could be due to questions about vaccine effectiveness or the potential severity of the disease for them and the people they care about. The second, is that they fear either short or long-term side effects from the vaccine itself. The common approach by politicians, scientists, and other vaccine supporters is to show data from scientific studies about the severity of the disease and the efficacy and safety of the vaccines. To supporters, the data clearly shows that one should get vaccinated and that whomever refused must be irrational. While some individuals may have problems understanding data and scientific conclusions, there does not seem to be a lack of seemingly intelligent people who refuse to get vaccinated. However, the one factor that vaccine supporters commonly overlook is uncertainty. There is inherent uncertainty in every scientific study and one must take that into account when making rational decisions. Hiding uncertainty is commonly done to simplify the problem, so that the answer appears simple. Yet this can be perceived as a coercive tactic by those hesitant to vaccines and thus exacerbate the problem further.

This proposal aims to address this issue by first acknowledging that uncertainty exists at every decision point and that making rational decisions needs to take this into account. However, making decisions under uncertainty is known to be a hard problem that may be hard to solve with mental calculations [8]. The claim is that what is needed is to develop a decision support system, based on expert knowledge and best available data that allows people to see how their decisions will be impacted by their beliefs and values. Such systems have been well-studied within the field of Artificial Intelligence (AI) and many approaches have been created over the years. These include rule-based expert systems, knowledge-based logical agents, machine learning models, Bayesian networks, and others [8]. In particular, Bayesian networks work well for problems involving uncertainty, because they can be used to create a descriptive model of an agent’s behavior ([9], [10], [11]).

A Bayesian network is a directed acyclic graph, in which nodes represent random variables, and arcs represent the fact that one variable is conditioned on another. Each node contains a conditional probability table (CPT) that encodes how one variable influences another. This network allows for modeling a problem involving many uncertain factors in a compact way. This is typically done by introducing conditional independence assumptions that limit the network complexity while still representing the full joint probability distribution. Using this Bayesian network and known probabilistic inference algorithms, any probability query about the model can be answered. A Bayesian network can also be augmented to add action and utility nodes to create a decision network, sometimes called an influence diagram [12]. These decision networks allow one to set their beliefs and examine how that changes optimal decisions. To make rational decisions, these networks will also force people to quantify their values, in particular, the values of their lives and others, and through this process and the results they will see from the decision network, it might force them to change their beliefs and be more comfortable with data supporting vaccines.

A. Specific Aims and Goals of the Project

The main goal of this project is to develop a decision network that allows to set beliefs and utility values, and computes the optimal rational decision under such settings. The network will be developed from researching latest data on factors that influence vaccine decisions, including vaccine effectiveness for different groups of individuals, the virus lethality and spread factors, vaccine safety data, and others. These different factors would be connected to form the Bayesian network, which would produce probabilities that will represent the belief states of the intelligent agent. These would influence the expected utility of two actions: get vaccinated, or stay unvaccinated. The secondary goal of this
project is to use the developed decision network to study how the optimal decision depends on various factors, utility settings, and beliefs. For example, we can have a factor that represents the belief that data from a scientific study is valid, and then attempt to find the inflection point of that belief at which the optimal decision changes. This would allow us to better understand the factors that influence those who do not want to get vaccinated, which may lead to a prescriptive solution that addresses the hesitancy problem.

B. Broader Impacts on Field of Study and Undergraduate Research

Achieving the outcomes of this research has the potential to address the vaccine hesitancy problem that has been a big issue in the COVID pandemic. By developing a system that would allow one to see how their decisions vary with their beliefs and values, we may be able to change the minds of certain individuals and help support scientists in their communication with the public about vaccines. More broadly, this methodology can be used to help support decision making in other issues, such as climate change. By giving people a model in which they themselves can see the numbers and how uncertainty can affect results, they feel more in control about making a decision, instead of feeling like they are pressured to a particular viewpoint. For the student, this research would provide an opportunity to study their own decision making and problem solving, and help them to think critically about real-world problems. It would also help them in understanding concepts from computer science, data science, and mathematics, and how they can be applied to an important issue.

II. PROPOSED RESEARCH PLAN

A. Preliminary Results

This would be a new study and based on my research, it would be a novel contribution. While Bayesian networks and influence diagrams have been used in the past for a variety of applications (see [8]-[12]), there has been no attempt to my knowledge at implementing an influence diagram for vaccine decisions. The closest work has been done by Mayfield, et al. [13], where they build a Bayesian network for risk assessment of the AstraZeneca COVID-19 vaccine. However, their work does not implement a decision network, that is, it does not consider how a person values their health and that of others. They also do not consider the person’s beliefs in the data themselves, which is a common issue with those that are vaccine hesitant. Therefore, this project will provide a completely novel contribution to existing work on this subject, although it will build on the Bayesian network knowledge provided in [13].

B. Experimental Design and Methodology

The project will be divided into two parts. In the first part, the student will work on developing the decision network. This will involve first researching literature on vaccines, the COVID pandemic, and human decision making. Sources of data would be researched and examined for possible use in the model. Afterwards, we would attempt to identify factors that would affect a person’s vaccination decision. These factors would then be formed into a Bayesian network that represents the interaction among different variables. The network would then be trained with the gather data using gradient descent or other similar methods. Finally, the resulting Bayesian network model would be compiled and validated against several scenarios. Once this is done, we would add the action and utility nodes to transform it into a decision network. The utility values would be parameters of the system, so that we could examine what happens as person’s values change. In the second part of the project, the decision network would be used to perform sensitivity analysis on different factors to find the impact they make on the optimal decision probabilities. We would also perform a value-of-information analysis to see if increased certainty of certain factors allows for different behavior among vaccine hesitant individuals.

C. Expected Outcomes and Success Will be Determined

It is expected that we will have a developed decision network, which will be parameterized by beliefs and utility values. We will be successful if such a model can be validated against existing data. For example, we can try to use the network to determine the probability that individuals of certain characteristics, such as age, are likely to get vaccinated, and compare that against what we see in the real-world.

III. MENTORSHIP PLAN

The student will be responsible for the following:

- Researching the relevant literature
- Learning about Bayesian networks, utility theory, and influence diagrams
- Using software like Netica or Python packages to implement the decision network
- Collecting data from various sources
- Performing statistical analysis of the results and validating the model.
- Experimenting with the resulting model and performing sensitivity and value-of-information analysis.
- Writing up and presenting the results

Students will have to document their work in a written report and meet with me on a regular basis (usually twice a week) to discuss results and plan future work. They will be required to produce specific deliverables for each portion of the project. Depending on their background, they may first need to study and do some research on Bayesian networks and utility theory. I will be able to provide them the necessary resources and teach them whatever they need, since I cover these topics in my AI courses. I expect that to take up to two weeks. The student would then attempt to build the network by first researching data sources and articles on vaccines, the pandemic, and human decision making. At the same time, we would work together to identify potential factors and their interactions, which would eventually form the Bayesian network. After the research is done (est. about two weeks), data would be gathered to train and validate the network. This may require some experimentation, so it may take another week. Then, we would augment the network with action and utility nodes and test it against various scenarios. In the last few weeks, the student would perform sensitivity analysis and value-of-information analysis and document the results.

IV. Timeline and Goals

Weeks 1-2: Learning about required methods (Bayes nets, utility theory, etc.).

Weeks 3-4: Review existing literature and identifying data sources. Simultaneously, determine factors and their relationships.

Weeks 5-6: Train the Bayesian network and validate results. Then add action and utility nodes to make a decision network.

Weeks 7-8: Validate and experiment with the decision network model. Perform analysis and document results.

Weeks 9-10: Continued evaluation of results and experimentation. Write final report. Work on presentation of results.

REFERENCES


Description of any additional funding you will be using for your proposed research (Doherty Grant, Lasallian Research Grant, External Research Grant, etc.) and how it will be used in this project.

Criteria for student applicants (Please report minimum criteria you will expect from student applicants, such as coursework that must be completed prior to starting work on this project):

Prior coursework involving probability theory and/or statistics is recommended. Python programming experience would be helpful, but not required.
As a faculty mentor, you will be required to participate as a leader for one of the weekly student seminars. This will be a 60-minute presentation at 9:00 am. Please indicate topics of interest from the themes listed below, or suggest an additional topic, that you might enjoy presenting.

_____ Ethics in Research

_____ Literature Search and Library Resources

_____ Scientific Method and Problem-Solving Skills

_____ Presentation Skills

_____ Data Analysis and Data Management

_____ Technical Writing

_____ Resume Writing and Marketing YOU

_____ Preparing for Graduate School

_____ Interview Skills

_____ Mock Presentation Supervisor (Practice for Symposium)

_____ Other (Please Describe) _____________________________________________
The James Girard Summer Undergraduate Research Program (SURE) is designed to support the execution of this proposed project by the faculty mentor and a single undergraduate student. After review of faculty proposals, selected projects will be advertised to Lewis University students, and all interested undergraduates will then be required to apply into the program, denoting the project for which they would like to be considered. Student applications will be reviewed for completeness by the program director and then forwarded to the appropriate faculty mentor for final selection of a candidate. Faculty may submit up to 2 projects for funding through the program. Although faculty mentors may also mentor additional students in the summer not funded through the program, the weekly program events and presentations will be exclusive for students in the program.

By submitting this application, you are agreeing to the following responsibilities of a SURE Faculty Mentor:

- Working closely with your student to ensure a worthwhile educational experience. Regular interactions with your student are an expectation (a minimum of once a week, but more frequently is encouraged). Interaction with other mentors and students is strongly encouraged
- Participating in the welcome and orientation day
- Leading at least one of the weekly workshops for the entire group of participants
- Writing at least one blog related to your area of expertise for the program website
- Participating in the Summer Research Symposium

This application will be reviewed by a faculty panel for acceptance into the program; determination of selected projects will be communicated after review. Project descriptions will then be made available to Lewis University undergraduate students, who can apply to the program and specific projects online via our website. Student applicants will be matched with mentors using a selection process where mentors rank interested students based on their applications and students rank projects based on their interests.

Any questions and all completed applications should be sent to Brittany Stephenson (SURE Director) at bstephenson@lewisu.edu.