



Decision Support

Predicting adolescent social networks to stop smoking in secondary schools



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ABSTRACT

Social networks are increasingly being investigated in the context of individual behaviours. Research suggests that friendship connections have the ability to influence individual actions, change personal opinions and subsequently impact upon personal wellbeing. This paper explores the effect of individual friendship selection decisions, and the impact they may have on the overall evolution of a social network. Using data from a large smoking cessation programme in secondary schools, an agent based simulation aiming to predict the evolution of the adolescent social networks is created. The simulation uses existing friendship selection algorithms from link prediction literature, along with a new approach to link prediction, termed PageRank-Max. This new algorithm is based upon the optimisation of an individuals eigen-centrality, and is found to be more successful than existing methods at predicting the future state of an adolescent social network. This research highlights the importance of eigen-centrality in adolescent friendship decisions, and the use of agent-based simulation to conduct behavioural investigations. Furthermore, it provides a proof-of-concept for targeted interventions driven by social network analysis, demonstrating the utility of using emerging sources of social network data for public health interventions such as with tobacco use which is a major global health challenge.

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1. Introduction

Investigation into individual behaviours in relation to social networks has experienced substantial growth in recent years. This is in part due to the availability of social network data as a result of social networking sites such as Facebook, Twitter and Google+, and the computing advancements that allow for the exploration of such large data sets (Kwak, Lee, Park, & Moon, 2010; Mislove, Koppula, Gummadi, Druschel, & Bhattacharjee, 2008; Salter-Townshend, 2012).

This paper is concerned with the individual decisions that cause social network evolution in adolescents, which is applied to data from a large smoking cessation programme in secondary schools. Smoking is a major global health challenge and tobacco use is said to kill 6 million people worldwide per year (World Health Organisation, 2015). More than 5 million of those deaths are the result of direct tobacco use while more than 600,000 are the result of non-smokers being exposed to second-hand smoke. Secondary schools are a common point at which people start smoking with, for

example, two-thirds of smokers in the UK starting before the age of 18 (Action on Smoking & Health (ASH), 2016). Quitting smoking is notoriously difficult; among all current U.S. adult cigarette smokers, nearly 7 out of every 10 (68.8%) reported that they wanted to quit but were so far unable to do so (Centers for Disease Control & Prevention, 2016). Smoking increases the risk for serious health problems, many diseases, and death (Centers for Disease Control & Prevention, 2014).

The theory of friendship decisions amongst adolescents has been widely researched, with factors such as proximity (Festinger, Back, & Schachter, 1950), reciprocation (Parker & Seal, 1996) and similarity (McPherson et al., 2001) discussed as important. Often studies such as these are based on qualitative evidence, with scientific experts drawing conclusions based on retrospective analysis. Our research discusses the development of an Agent Based Simulation (ABS) model which allows for the testing of behavioural theory relating to friendship. Through the use of specifically selected algorithms, drawn from the link prediction literature, a predicted future state of a social network can be made. The predicted future social network may then be compared with the real social network for accuracy, with conclusions drawn around the implemented behavioural theory.

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Simulation provides a tool to explore the evolution of a system, scrutinise theory and evaluate potential outcomes. Within the domain of OR, simulation is a core tool utilised for research – lending itself to applications such as manufacturing, defence and healthcare (Pidd, 2004). ABS is a particular paradigm of simulation, which aims to take an individualistic view of system evolution (An, 2012). ABS is a micro-simulation technique, modelling the individual behaviours of specific objects in a system to understand the emergent global phenomena (Niazi & Hussain, 2011).

ABS investigations related to social networks have covered a variety of topics. Epidemiology in particular has adopted ABS techniques to explore the spread of infectious diseases through networks, including HIV spread in Amsterdam (Mei, Sloot, Quax, Zhu, & Wang, 2010), Influenza in a metropolitan social network (Mao, 2014) and H1N1 on a Chinese university campus (Mei et al., 2010). ABS has also been used in the investigation of network structure, as opposed to its effects, although the number of papers in this area is far fewer. Pujol, Sanguesa, and Delgado (2002) uses agents to extract reputation in a social network topology, Han, Zhao, Hadzibeganovic, and Wang (2014) explores hierarchical geographical network structures and Bernstein and O'Brien (2013) uses ABS to generate 'realistic' social network data sets; however, these studies do not utilise empirical social network data. Given the individual perspective of ABS, and the ability to quantify the impact to a system as a result of the interactions of constituent parts, ABS appears an appropriate method to explore the behavioural factors influencing the evolution of adolescent social networks.

The motivation to adopt a quantitative simulation-based research approach to adolescent friendships, as presented in this paper, is that it appears to be an unexplored niche in social network literature. More specifically, the ability to implement link prediction methods in an ABS framework for adolescent social networks, provides a novel contribution to the literature. Furthermore we provide a proof-of-concept for targeted interventions driven by social network analysis, demonstrating the utility of using emerging sources of social network data for public health interventions.

This research also contributes to the growing body of work in Behavioural Operational Research (BOR) which is defined as the study of behavioural aspects related to the use of OR methods in modelling, problem solving and decision support (Hämäläinen, Luoma, & Saarinen, 2013). BOR may broadly be considered within three categories: behaviour in models (methods), behaviour with models (actors) and behaviour beyond models (praxis) (Franco & Hämäläinen, 2017). Our work is firmly grounded in incorporating behaviour within models (methods). Furthermore, as comprehensive reviews of the application of OR to healthcare (Brailsford, Harper, Patel, & Pitt, 2009; Hulshof, Kortbeek, Boucherie, Hans, & Bakker, 2012) reveal, relatively little prior consideration has been devoted to behavioural aspects in this field. Hence this paper also aims to demonstrate the use of BOR for healthcare applications.

The remainder of the paper is structured as follows. In Section 2 we introduce the data from the smoking in schools programme. Section 3 outlines the chosen network structures utilised within this research, whilst link prediction methods are introduced in Section 4. The developed ABS is described in Section 5. A new method for link prediction, *PageRank-Max*, is proposed in Section 6, validated in Section 7, and compared against the other methods in the results in Section 8. Conclusions are made in Section 9.

2. Case study

There are significant global challenges to reducing smoking from a public health perspective. The World Health Organisation (WHO) has created the Tobacco Free Initiative (TFI) which aims to "reduce the global burden of disease and death caused by tobacco, thereby protecting present and future generations

from the devastating health, social, environmental and economic consequences of tobacco use and exposure to tobacco smoke" (World Health Organisation, 2016). Many of the TFI's actions are aimed at adolescents given that this is a common time in life at which people start smoking. It is therefore vital to intervene at this age given the addictive nature of tobacco and the longer-term health effects.

Our conceptual approach to the problem is in predicting social networks to help with more targeted interventions to reduce the uptake of smoking amongst adolescents. The case study data is taken from "A Stop Smoking in Schools Trial" (ASSIST) and explores the effects of social networks upon attitudes toward adolescent smoking, with a view to inform potential cessation proliferation methods. Formed through a joint venture between Cardiff University Institute of Society, Health and Ethics and The Department of Social Medicine at the University of Bristol, UK, ASSIST was designed as a peer-led intervention, formulated around the 'Gay Hero' work of Kelly et al. (1992). Schools from across the West of England and South Wales were recruited to the study, through stratified randomisation, following a cohort of Year 8 students (12–13 year olds) over the course of a three and a half year period (Holliday, 2006).

Three waves of social network data were collected at one year intervals for 18 schools in the study. Each participant was asked to name up to six other students with whom they shared a friendship. From this data, a school based social network may be constructed, describing friendship evolution over the course of the study. The students' ability to only identify up to six friendships may be considered a limitation of the study; however, the work of Kirke (1996) and Pearson and Michell (2000) suggest that friendships ranked below the top six connections do not carry equal significance. Additionally, the average number of friendship nominations in the data across the three time points was calculated as 3.8 (T_1), 4.3 (T_2) and 3.8 (T_3) – suggesting students often did not opt to maximise their number of friendship nominations. Given the objective of this research is to predict social network structure to identify future influence, the friendship nomination limit is unlikely to substantially impact the conclusions of this research.

From the 18 schools, 12 are classified as control and 6 as intervention. Identified socially prominent individuals in adolescent social networks within the intervention schools were given training to diffuse a 'stop smoking' message to their peers (Audrey, Cordall, Moore, Cohen, & Campbell, 2004). An example of the data from one school may be observed in Figs. 1 and 2 demonstrating the evolution of the social network over time (friendship network at year 1 and 2 for Figs. 1 and 2 respectively).

Figs. 1 and 2 show network patterns and evolutions that were seen in many of the control schools. That is, over time the prevalence of smoking increases and that smokers tend to cluster together as friends. The findings of Campbell et al. (2008) suggest a reduced smoking prevalence in intervention schools in the early stages of the trial. Overall, the researchers concluded that ASSIST was a success, providing a cost-effective method for increasing adolescent smoking cessation (Hollingworth et al., 2012).

3. Network structures

This section introduces the essential graph theoretic and network science definitions that are used to inform the research in the development of the ABS (Section 4). As our study is concerned with the investigation of social networks, and ultimately the development of a new algorithm to predict social network evolution, the relevant metrics to analyse and interpret network structures are required.

An undirected *Graph* is defined as a pair $G = (V, E)$ of sets such that E is a subset of the unordered pairs of V , where V is the set

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