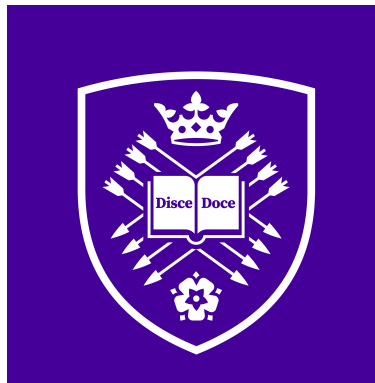


University of Sheffield

# Complex Systems Modelling of Alcohol-related Health Inequalities



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Interim Report

*in the*

Department of Automatic Control & Systems Engineering

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# Chapter 1

## Introduction

Although global alcohol consumption rates have fallen since 2010, in 2016 43% (2.348 billion) of the global population had consumed alcohol in the past 12 months, with the European region having the highest rate of consumption at 59.9% (449 million) of the total population ?. Alcohol is among the leading causes of premature deaths worldwide, with alcohol being attributed to 3 million deaths per year ?. Alcohol is also the most significant risk factor for those aged 15-49 ?. This is also an age range where people are most economically active, hence the economic consequences are significant.

Alcohol is well known to have both immediate and long-term adverse health effects ?. There is some conflicting literature on whether there is a safe level of alcohol consumption, with some studies showing that there is no safe level of alcohol consumption and others showing that participants with light alcohol consumption had lower risk of cancer and death than those who abstained ??.

The **AHP!** (**AHP!**) describes a phenomenon in which those with higher **SES!** (**SES!**) experience less overall alcohol-associated harm even when consuming greater amounts ?. The **AHP!** can be demonstrated both globally and locally, hence is a phenomenon which occurs across scales ??????. Although the underlying causes of the **AHP!** are still unknown, some hypotheses have been proposed as potential explanations, such as low **SES!** individuals having less access to healthcare and heavy drinkers becoming more prone to falling down in their **SES!** ?. The conventional approach to addressing public health issues is presupposed on changing the actions of individuals, which negates the social and economic context in which people live ????. These approaches have so far come up against policy resistance, suggesting an approach considering a wider societal context may be useful in understanding and solving the **AHP!**. **FCT!** (**FCT!**) is a social theory which recognises the health-related ramifications of differential access to physical and social resources, and has been proposed as a potential social theory to explain the **AHP!** ??.

**ABM!** (**ABM!**) is a technique used successfully in public health modelling, most notably during the COVID-19 pandemic ?. Some **ABM!**s have been used in the context of alcohol in public health ?. This dissertation project will look to build an **ABM!** through the lens of **FCT!** to see whether the **AHP!** can be explained through **FCT!**.

Intro  
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## 1.1 Aims and Objectives

### 1.2 Aims

The **AHP!** is a phenomenon in which those with higher **SES!** experience less overall harm from alcohol consumption over their lifetime than those with lower **SES!**, despite consuming greater quantities of alcohol. **ABM!** has been used to try to understand the paradox within a framework informed by a social theory known as **FCT!**. This project aims to replicate an existing **ABM!** and critically explore the extent to which it can reproduce the **AHP!**.

### 1.3 Objectives

#### 1.3.1 Core Objectives

1. Understand the **AHP!**, **FCT!** and the wider context of ABM's within public health research.
2. Develop **UML!** (**UML!**) design documents to represent the existing **FCT!**-based ABM.
3. Use the **UML!** design to develop a replica ABM in **RHPC!** (**RHPC!**).
4. Develop a range of experiments to explore the ABM and its dynamic behaviour.
5. Implement experiments and analyse the ability of the **ABM!** to reproduce the **AHP!**.

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#### 1.3.2 Stretch Goals

6. Critically appraise the **ABM!** as an adequate representation of **FCT!** within the context of **AHP!**.
7. Propose modifications or enhancements to the **ABM!** already in use to better represent **FCT!**.

#### 1.3.3 Work Done

#### 1.3.4 ODD

The **ODD!** (**ODD!**) protocol is a standard protocol used to describe how a particular **ABM!** works ?. Boyd produced an **ABM!** to analyse whether **FCT!** could describe the **AHP!** ?. This dissertation takes inspiration from Boyd's work and seeks to replicate and extend the model, and explore the fundamental behaviours. The full **ODD!** will be given in the final dissertation; the initial overview and design is given below.

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## Overview

The model proposed takes mechanisms present in **FCT!** and looks to explore the model output space with the intention of model exploration. The agents in the model live in an environment determined by a **DQ!** (**DQ!**). The agents are exposed to alcohol harm through drinking at a rate linked to their individual propensity to drink. The event generator periodically broadcasts events to a random number of agents events that help agents avoid alcohol harms. The level to which agents can decode the information is in part determined by **FCT!**-related parameters. Events are stored by the agent and each tick the agent will attempt to solve an event they've not yet solved. Agents have the capacity to share a successful adaptation to the event information with an agent within their social network once per tick.

### 1.3.5 Software Design

**UML!** is an approach to software design which presents many benefits in the development of **ABM!**s ?. Class diagrams, which are used to describe the behaviour of and relationship between entities in a model, are said to be among the most important model to design in the development of **ABM!**s ?. Figure ?? shows the current **UML!** diagram that follows the **MBSSM!** (**MBSSM!**) framework but re-contextualises the example model given in the paper to account for only **FCT!** in terms of social theories. There has been an extension to the **MBSSM!** example with the inclusion of a social network and environment classes, and the exclusion of mediator classes. Further details will be discussed in the final dissertation.

### 1.3.6 Experiment Conceptualisation

Table ?? shows a number of experiment concepts that has been reduced in the interest of keeping within the report requirements. The most important experiment that will be conducted is parameter space exploration through **LHS!** (**LHS!**), a technique used to generate a set of parameters for this purpose. This is intended to demonstrate the general behaviour of the model and give insight into expected and unexpected behaviours. Other experiments, such as those related to **FCT!** and **AHP!** give credibility to the model. Finally, an interesting experiment would be to look at which **FCT!**-related parameters lead to the greatest harm, giving scope for further research and potential development for the model.



## Fundamental Cause Theory ABM Class Diagram

Sebastiano Zuddas | December 3, 2022

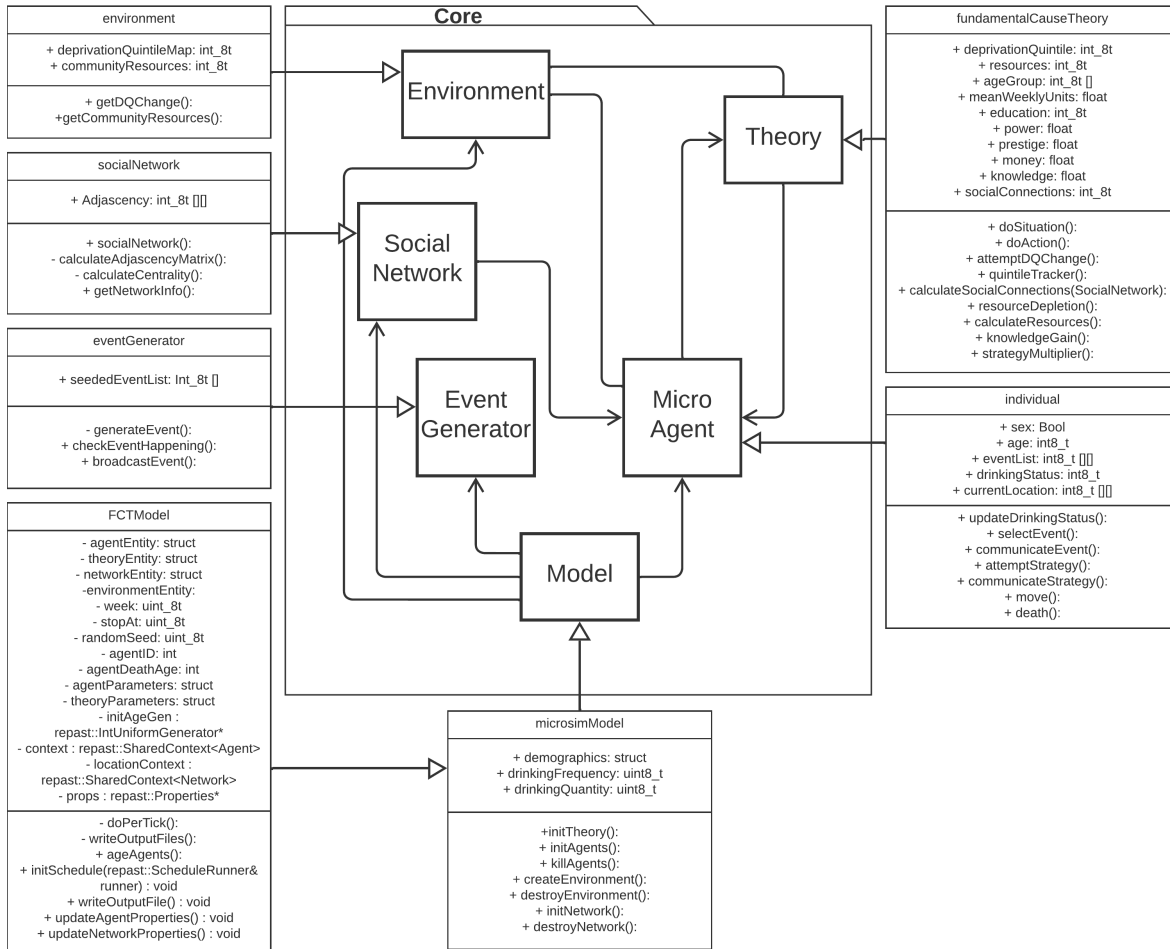


Figure 1.1: A class diagram of the proposed ABM

| Experiment  | Method   | Expected Impact   |
|---|--|---|
| Exploration of the parameter space.                       | Using <b>LHS!</b> .  | Demonstrate general model behaviour.  |
| Can <b>FCT!</b> be shown?                                 | Preventability shifts, manipulated preventability.                       | Validation of <b>FCT!</b> working in the model.                                     |
| Can <b>AHP!</b> be shown?                                 | Changing the extremities of available community and individual resources | Further evidence that <b>AHP!</b> can be explained through <b>FCT!</b> .            |
| Which <b>FCT!</b> parameters relate most to alcohol harm? | Test extremities of each <b>FCT!</b> parameter.                          | A certain combination of parameters will lead to the most harm for all individuals. |

Table 1.1: Table showing initial experiment concepts.

## 1.4 Project Management & Self Review

### 1.4.1 Gantt Chart & Amendments

The full pre-amendment Gantt chart can be found [here](#). The full post-amendment Gantt chart can be found [here](#).

Figure ?? shows the amended Gantt chart for Semester 2. Amendments were made to extend the time allocated to the development, validation and appraisal of the **ABM!**. This was done to allow more than enough time to iron out related development problems related to making the model work in conjunction with surrounding software. There will be iterative development processes performed during the model development, firstly focusing on developing core aspects of the **ABM!** such as the agents themselves and their interactions with the environment and event generator. Gradually, development will expand to include the more complex features, such as the social network, as well as make the **ABM!** work with other software such as MATLAB to process inputs and outputs.

### 1.4.2 Self-Review

Overall the project has seen good progress since the start of the semester. There has been excellent supervision and support on behalf of my supervisor.

The research aspect of the project proved relatively challenging as there were many new concepts to learn in a field in which I had no expertise (public health). Nonetheless, I feel I have gained a relatively good understanding of the topics related to public health given the **ABM!** is the core focus of the project. There was less difficulty in apprehending concepts related to **ABM!** as it is a topic in which I was formally taught in the semester and had done some previous work on.

There have been technical difficulties in using software and installing the various dependencies related to **RHPC!** both on my laptop and in the Linux remote server ?. This led to programming being slower than intended, and is a sign that work will have to be done over Christmas in order to compensate. The issues presented a challenge in understanding various computing concepts that were previously unknown to me, but they've extended my understanding of how computers work more generally. They are now mostly resolved and programming work can progress but there are still some issues that when overcome will lead to a more streamlined development process.

## Chapter 2

# Literature Review

### 2.1 Alcohol Harm Paradox

The **AHP!** has emerged from a collection of literature, where the association of alcohol harms with **SES!** was first formalised by Smith et al. in 2014 ?. Health inequalities have been apparent in almost all civilisations to date, and have even been shown to emerge as a result of being low status in the animal kingdom ??. The question becomes why in a modern society with relatively widespread access to healthcare and health information is **SES!** still a key determining factor in someone's health? And what are the other risk factors that determine the difference in health outcomes in the context of alcohol consumption?

The Global Status Report on Alcohol 2018 by the **WHO!** (**WHO!**) points numerous times to **SES!** being a key determining factor for differential outcomes in alcohol harms. On a global level, with Europe and North America having the highest alcohol consumption rates, low and lower-middle-income countries experience the highest levels of harm related to alcohol ?. Even within the bounds of the global regions declared by the **WHO!**, the **AHP!** was still apparent ?. It is, therefore, appropriate to state that the **AHP!** is a phenomenon that occurs across scales.

Boyd et al. conducted a systematic literature review which looked for explanations of the **AHP!** ?. The fact this was conducted in 2022 implies that the **AHP!** is still not well understood. Boyd notes a significant gap in the literature surrounding the **AHP!** is the lack of research surrounding social and economic causes. A number of reports from the UK demonstrate and investigate the **AHP!** ?????.

Research by Bellis et al. acknowledges the **AHP!** and reasons that individual-based actions such as smoking and diet choices alongside less access to healthcare resources may lead to the **AHP!** ?. Research performed by Baldwin et al. suggested five hypotheses for the existence of the **AHP!** ?. Baldwin then tested three of these including under-reporting of alcohol use, drinking patterns between **SES!** groups and compounding effects of other health determinant factors such as diet and physical activity. Baldwin did not test differences in access to health services between different **SES!** groups or whether the **AHP!** could be explained by individuals with problematic alcohol habits moving into lower **SES!** positions as a result of their consumption. Baldwin finally points towards a lack of published evidence that looks at the underlying mechanisms behind the **AHP!**.

Lit rev( range of possible methods to be used. Supports the decisions that you make. Gaps in state of the art. Shortcomings of existing methods. Be critical of literature. [discuss systems modelling approaches]. Consider the clarity of ideas. Clear structures → targeted writing.

A theme in the literature is the lack of access to healthcare in low **SES!** communities as a leading contributing factor behind the **AHP!**. This can be linked to the inverse care law - first noted in 1971, and a well known problem in public health ?. The literature to date attributes the **AHP!** to a variety of causal mechanisms alongside differential access to healthcare. It is clear that there are multiple factors contributing to the **AHP!**. Although certain individual behaviours are thought to contribute towards the **AHP!** the literature in general misses the broader social and economic context. This is peculiar considering the **AHP!** is inherently a social problem.

There is literature proposing complex systems approaches could be used to investigate health disparities, which would address the lack of social and economic context in the **AHP!** literature ??. Particularly, Boyd et al. suggest four health inequality theories could be used to investigate the **AHP!**, one of which is **FCT!**, which is what this dissertation will focus on modelling?.

## 2.2 Fundamental Cause Theory

First noted by Link et al. **FCT!** proposes that socioeconomic conditions are the underlying causes of disease, under the precipice that negative health outcomes cannot be resolved solely by addressing the direct mechanisms associated with the disease itself ?. It recognises that, for example, a person with an **AUD!** (**AUD!**) will struggle to resolve the issue through individual action if the social and economic resources available to them are low. By contrast someone with access to healthcare, money, knowledge, a supportive community and holds a position of high prestige in society is more likely to overcome adverse effects of **AUD!**.

There are two ways to test whether **FCT!** can successfully explain a phenomenon ?. First is the “preventability shifts approach”, which looks at exposure to different diseases over time as well as the capacity to cure said diseases. When the capacity to cure a disease increases, if low **SES!** individuals are seen to have a higher mortality rate then **FCT!** can be used to explain the phenomenon. The second is the “Manipulated preventability approach” where given a sample of a population when interventions are performed on a random set of individuals but require resources to benefit from the interventions, if differential health outcomes are observed based on access to resources then **FCT!** can be used to explain the phenomenon.

**FCT!** has seen success in explaining neighbourhood disadvantage and differential outcomes from both mental and physical health issues ????. For hard-to-cure diseases **FCT!** is less effective in predicting health outcomes ?. This suggests that **FCT!** cannot explain all health outcomes in society, but can be used to attribute differential health outcomes for individuals with different **SES!** for curable diseases. Common diseases of the liver are largely curable or preventable, and liver damage is often linked to alcohol consumption. Common advice given to either prevent or aid the recovery of liver diseases is to abstain from or reduce alcohol consumption ?.

Boyd et al. ? note that **FCT!** is not apparent in **AHP!** literature and argues that individual-based methods for understanding the **AHP!** are limited as they fail to account for the socio-economic context in which people live. This was the original motivation behind the research done by Link ?. **FCT!** seems to be useful social theory to help unravel the **AHP!** due to the strong link between **AHP!** and **SES!**.

## 2.3 Agent-based Models

### 2.3.1 Relevance to Public Health

**ABM!**s give researchers and policymakers the capacity to model how *local interactions* lead to the emergence of complex, large-scale behaviour ?. **ABM!**s have had success in explaining social phenomena such as segregation ?. One of the more recent applications of agent-based modelling in public health was during the COVID-19 pandemic, where **ABM!**s were used to evaluate and justify stay-at-home orders ?.

A scoping literature review was conducted by McGill et al. which looked for literature which used complex systems approaches in exploring alcohol related harms, some of which included **ABM!**s ?. Some **ABM!**s focus on alcohol consumption among young and college-aged people ?????, whilst others investigate more general populations ??????. Certain **ABM!**s focus on alcohol consumption during events where alcohol is consumed, such as nights out or parties with the intention of finding ways to reduce alcohol related violence ??????. There are also some **ABM!**s prioritising intervention strategies ????????? and some prioritising understanding behavioural mechanisms ??????????. There is notable overlap between **ABM!**s which look at behaviour and intervention strategies, as often understanding of behaviour is needed before the appropriate strategies can be employed. The models which are based on real-world data are initialised based on data sets from the US, UK, The Netherlands and Australia, hence there is a bias towards analysing populations from more advanced economies.

A common theme in the literature is to help shape types of interventions to curb the negative effects of alcohol by attempting to outline the mechanisms related to problematic alcohol consumption. Many of these models focus on the direct harms associated with events related to alcohol consumption such as alcohol related violence, trips and falls and vehicle-related accidents. No **ABM!**s mentioned in McGill's review focus on **SES!** or the **AHP!**. This may suggest that **ABM!** as a technique may not be suitable for investigating the **AHP!**, but other computational complex systems approaches, such as dynamic systems modelling, fail to capture the complexity involved where there are multiple interacting agents such as in a population.

A framework developed by Vu et al. presents a method with which **ABM!**s can be built to analyse social theories by modelling the underlying theory mechanisms ?. Vu refers to this framework as **MBSSM!**, which allows developers to create agent based models to model macro-micro, micro-micro, micro-macro interactions. **MBSSM!** has since been used to develop the **MUP!** (**MUP!**) policy in Scotland ?. Boyd et al. state that with the advent of **MBSSM!** twinned with the interest of policymakers to use **ABM!**-based tools, it is an appropriate time to investigate the **AHP!** through **ABM!**s ?.

Summarising, there is a clear gap in the **AHP!** literature, which has failed in finding the underlying causes of the **AHP!** due to the reliance on individual-based interventions. **FCT!** presents a new theory to investigate the **AHP!**, proposing that **SES!** and the difficulties and lack of resources that accompany being low **SES!** lead to the differential outcomes in alcohol harms described by the **AHP!**. **ABM!**s have seen success in public health modelling and in finding intervention strategies for dealing with alcohol related harms and **ABM!** seems like an appropriate technique to investigate whether **AHP!** can be explained through **FCT!**,

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pages)

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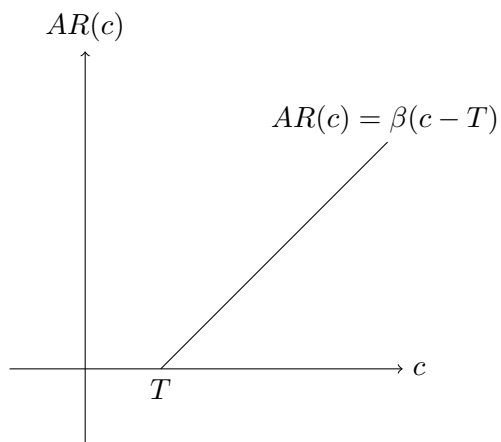
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which to  
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especially since the development of the **MBSSM!** framework.

## Chapter 3

# Development & Methods



**Figure 3.1:** *Absolute risk as a function of consumption*

The absolute risk of alcohol consumption is used to model mortality in the model, and is explained through equation ??

reference  
this from  
Jens paper

$$AR(c) = \begin{cases} 0 & \text{if } c \leq T \\ \beta(c - T) & \text{otherwise} \end{cases} \quad (3.1)$$

## Chapter 4

# Results



## Chapter 5

# Discussion

## Chapter 6

# Conclusions

# Appendices

# Appendix A

## Gantt Chart Amendments

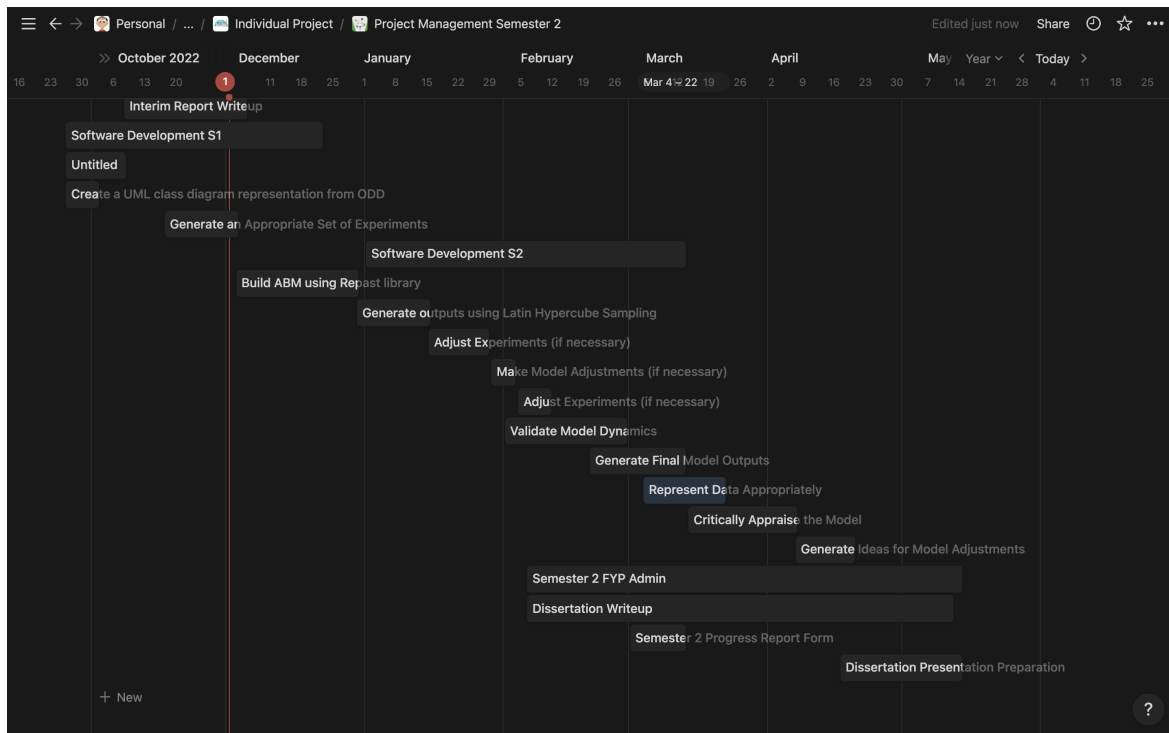


Figure A.1: The semester 2 Gantt chart.