Delivery of Patient Centred Care - System Modelling

Cardiff University
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1 Abstract

This report documents the completed work to perform a problem analysis through system modelling, which built a model and simulation to help pinpoint the problem zones & bottlenecks in the healthcare system of Type 2 Diabetes. The main aim was the creation of qualified and quantified models, from the System Dynamics methodology, which helped understand the complex Type 2 Diabetes system. Using online data and statistics ensured an ethically handled project without the danger to mistreat sensitive data.

Throughout the project there have been regular progress checks with the supervisor and advisor to demonstrate the system modelling approach and creation. The problem exploration of the fields of Diabetes and System Dynamics kick-started the project, which leads to creating two models (qualified and quantified), as well as a simulation to allow results experimentation through user interaction functionalities to perform a what-if analysis. Upon completion of the project, future directions in regards to finding and testing policy actions/interventions were discussed.

With the evaluation of the models and simulation, the project was deemed an overall success with a couple of time optimistic future steps to address. The evident COVID-19 pandemic brought strains into the management to input data, however with adjustments the functionality of the models and simulation work correctly whilst still allowing continuous improvement and broadening, as well as to move to interventions testing.

2 Acknowledgments

I would like to thank my supervisor, Martin Caminada, for supporting me throughout this project, providing me prompt constructive feedback and guidance, as well as giving me the space to surprise him with the field of System Modelling. I greatly appreciated working with him during my Year in Industry, as well as on my Individual Final Year Project.

I would also like to thank my technical advisor, Catherine Teehan, for introducing me to System Modelling and its potential in the current healthcare sector, as well as other fields. She reserved additional time and effort to help me throughout the project, for guiding me through the approach of tackling the chosen problem, ensuring the methodology is on the correct track, also providing constructive feedback when in need.

Furthermore I would like to thank my family and friends, who have supported me for the past semester with their encouragements, listening and overall help.

Ultimately I would like to shine some light on NHS Wales for all the incredible efforts they are doing to handle the current COVID-19 pandemic, as well as all its other healthcare work.

3 Acronyms

ABM = Agent-Based Modelling
CATWOE = Customers, Actors, Transformation, World View, Owners, Environment
CLD = Causal Loop Diagram
SD = System Dynamics
SSM = Soft System Modelling
NHS = National Healthcare Service
UK = United Kingdom

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5 Introduction

5.1 Sketch The Problem

It is no surprise that in today's world we aim to achieve our best, continuously innovating and improving. Yet, the higher the population the more we must provide for every individual, with health being the epicentre. The entity of a human being relies on being healthy, therefore being able to function in this world. This is the preliminary area of interest for this project, analysing the ways to improve health and more specifically diabetes, which will be explained to a more detailed scope.

The extremely real and problematic COVID-19 pandemic outbreak that has taken over the world shows great relevance of how people living with existing medical conditions such as diabetes can be at higher risk. The statistics prove that Diabetes is the second most dangerous pre-existing medical condition to have if infected by coronavirus. It states, "for a patient with [Diabetes], the risk of dying if infected by COVID-19 is [9.2%]" (Coronavirus Age, Sex, Demographics (COVID-19) - Worldometer. 2020).

The current operating healthcare system of the UK is the National Health Service, also known as NHS. One of the main problems NHS is experiencing is that "4.7 million people in the UK have diabetes", of which "about 90% of people with diabetes have Type 2" (Facts & Figures. 2019). This means that roughly 1 in 16 people in the UK have diabetes, which is a continuously increasing statistic. With such risks and consequences that come from having and not managing diabetes, it is important to tackle the problem and aim to eliminate such medical conditions.

5.2 The Aim

The aim of this project is formed around the management and efficient use of data. The goal is to perform a problem analysis through system modelling, which will aim to build a model and simulation to help pinpoint the problem zones & bottlenecks in the healthcare system of Type 2 Diabetes. Through every beginnings of a project, one must analyse where the problem lies and identify what is keeping it from reaching its ultimate goal state. For this reason, pinpointing the problem zones in this project is the first crucial step for NHS Wales to analyse what is keeping them from their ultimate goal of eliminating Type 2 Diabetes.

As the long-term goal, this starting project of problem analysis would aid to, optimise aspects of the limited resources of NHS Wales, and ultimately towards elimination and reduction of Type 2 Diabetes. The elimination concept conveys the message to lower the prevalence of a medical condition, lower the number of its patients and bring it closer to eradicating it. Through identifying the problem zones, NHS Wales could decide to use the suggested zones to manage more efficiently. To give an example of this, if one of the identified problem zones is the 'delivery frequency of diet and physical activity education courses' then NHS Wales could improve their current Type 2 Diabetes management and choose to implement new methods to overcome this, for example, to 'implement more frequent and engaging education courses'. By the end of the project I aim to help NHS Wales optimise the stated long-term goal with the data model within the scope of Type 2 Diabetes. In the near future, NHS Wales could use the same approach and solution to address other medical conditions.

5.3 The intended audience

Moving on from the aim, once the project is completed the beneficiaries would primarily be NHS Wales staff that is looking to optimise its limited resources and better manage Type 2 Diabetes. The long-term beneficiaries would be the Type 2 Diabetics and Pre-diabetics, as the long-term aim is to better manage their care and eliminate more pre-diabetics to develop onto being diabetics. The domino effect of such improvements would also positively impact the whole country, as healthcare entities would have more available resources to provide to people in other needs, citizens would be more likely to wait less time to be treated, perhaps with higher precision. Ultimately countries might learn from each other to best tackle Diabetes, making this a worldwide domino effect.

5.4 Scope of the project

Unlike the identification of the intended audience, the scope is a part of the project that is being identified and discovered along its process. In this section, I will also address the ethical considerations of the project.

Primarily, as the project was investigating problem zones in Diabetes in NHS Wales, it narrowed down to a clearer focus with time. From the initial proposal on PATS, the idea was to perform data modelling to optimise limited resource use and provide recommendations for a more effective delivery of patient-centred care. Given that I am not a specialist on the health field, the large bonus was to have an individual like me investigate the presented problem. Without the existing knowledge, I will less biased to incline to the expert views, and therefore could add a 'fresh pair of eyes' into the problem.

With the introductory crash course on 'System Dynamics', I decided to focus the project on a specific medical issue. From recommendations from my technical advisor, Dr Catherine Teehan, I chose to narrow my scope to Diabetes, also know as Diabetes Mellitus.

After exploring the background research into the field, performing my planning and brainstorming (see *Section 11.1 Brainstorm Mindmap*), I split my focus to Type 1 Diabetes and Type 2 Diabetes. Soon into the brainstorming it became evident that tackling the whole of Diabetes did not have a solid, clear focus and it would mean going down two separate paths. After researching the prevalence of Type 2 Diabetes, the facts spoke for themselves that "Around 90% of people with diabetes have type 2 diabetes" (Facts & Figures. 2019). I made the next choice to formulate the scope of my project to be Type 2 Diabetes. As further shown (see *Section 9.2 Narrower Context: The Problem Definition*), "more than half of all cases of Type 2 diabetes could be prevented or delayed" (Facts & Figures. 2019) the opportunity and need to tackle this problem and start building a system model was evident and allowed me to narrow down such saturated research field. Ultimately this proved it would be a more realistic scope of the project, as Diabetes is already a very difficult and complex issue in the world already.

The brainstorming presented in *Section 11.1 Brainstorm Mindmap* allowed me to visualise the factors and risks identified with Type 2 Diabetes. Moreover my findings had led me to investigate the causal relation of Poverty to the result of being at higher risks and onset of Type 2 Diabetes (to be described in *Section 11 Implementation – Application of selected approach*).

Due to the nature of the project, it is vital to address the ethical considerations that come into scope. The evident collaboration between NHS Wales and I meant that I needed to ensure I was being ethically correct and working rightfully with provided data. From regular communications with the NHS Informatics team, they have confirmed that only anonymised data will be provided. The examples of the data requested were "total number of patients in Wales with type 2 diabetes", "% of pre-diabetes patients becoming diabetic", "number of type 2 diabetes patients considered obese", etc. After ensuring with my supervisor, I verified with the Cardiff University Ethics Committee and they confirmed their ethical approval as I was dealing with unidentifiable patient data.

5.5 Assumptions

The project is made on the assumptions that NHS Wales has the room for improvement, for me to find ways to better utilise the limited resources and provide recommendations for the scope findings.

Furthermore, the work is based on the assumptions presented online, from existing research and trends. In the project, I have assumed that the research online is both truthful and incorrect, therefore I have gathered the most frequent opinions or facts, and am assuming they hold the highest level of truth. This assumption is highly important for this project; because the world evolves around continuing research and opinions, where unlike viewpoints see the truth differently.

5.6 Success Criteria

To measure completion of the project, I have selected to plan success criteria, which will drive the singular objectives. Since the project is highly based on problem identification and modelling trends (qualitative & quantitative), it is important to create success criteria that will be specific to the project and its timeline.

In order to correctly measure the success criteria, and ultimately the success of the project I will use the guidance from Copper Project Management as presented in Figure 1 (PM 101 — How to Define Project Success Criteria? - Copper Project Management Software. 2018).

The success criteria
How it will be measured
How often it will be measured
Who will be responsible for measuring the criteria

Figure 1: How to document success criteria

By the end of the project, these are the success criteria that I will be responsible to measure, analyse and evaluate as results (to be described in *Section 13.1 Results*):

No.	Success criterion	How and how often it will be measured?
1	Appropriate approach and use of selected methodology, to full degree.	This will be measured throughout the project, whether the appropriate methodology aspects are selected. It will also be measured by Dr Catherine Teehan's feedback, due to her expertise in the field.
2	Qualitative model shows fair assumptions with proof to justify causality and polarity.	This will be measured through feedback at the end of the qualitative model creation, whether the assumptions are justified with highest truth degree and discovered loops are correctly visualised.
3	Quantitative model enables input of data, and visualises simulations through graphs.	This will be measured through feedback at the end of the quantitative model creation, whether the model visualises a graph trend from NHS Wales's data, enables user interaction.
4	Simulation shows the same trend (correlation) for different geographical data focus i.e. UK vs. Wales vs. different regions in Wales	This will be measured at the end of the simulation creation, whether the trend is consistent.
5	2 interventions/polices recommended through system modelling and simulation results = 2 recommendations provided to NHS Wales.	This will be measured at the end of the project; whether I found 2 interventions that would 'flatten the curve' of Type 2 Diabetes, presenting it in the Project Viva.
6	**[STRETCH]** Receive feedback from NHS Wales, whether any interventions are helpful to them and their future operations.	This will be measured at the end of the project, whether NHS Wales gives me (positive) feedback on the created models and interventions, with suggestions to continue the project for future use.

Table 1: Success Criteria

6 Background

6.1 Wider Context

Let me take you back a step and look at this project from a **bigger picture**. The world we, humanity, live in is continuously being moulded, modernised and enriched by us. We try to take control of the nature, our longevity and our happiness. Nevertheless, we are frequently reminded of what is out of our control and what life comes down to. It all comes down to health. Without it we cannot operate, as it is our living fuel. Health holds or should hold the highest value in our lives, and that is the reason why this project in the health sector is extremely relevant and important.

The COVID-19 pandemic has taken the world by a storm, causing great risk for people with pre-existing medical conditions, such as Diabetes (see Section 8.1). In the current situation, there have been worldwide adaptations to protect people from getting infected and spreading it onto the others. Yet, those living with Diabetes are experiencing even more stress and uncertainly around the unprecedented pandemic due to their condition. If the prevalence of such diseases were to be reduced, there would potentially be less strain on the people, on the healthcare systems, on the limited resources and more factors.

As explained, in the wider context Diabetes is a worldwide issue affecting "9.3% (463 million people), rising to 10.2% (578 million) by 2030" (Saeedi et al. 2019). To raise its detrimental outcome, "it is among the top 10 causes of death in adults." This project specifically is important to face because it aims to capture and explore causal factors influencing Type 2 Diabetes, with promising findings of interventions to be suggested to NHS Wales (see following *Section 9.2 Narrower Context: The Problem Definition*).

6.2 Narrower Context: The Problem Definition

From the brief dive into the wider context, I would now like to shift your mind to the opposite end, where we drill deeper and **define** the problem.

Diving deeper into the problem and its context, "more than half of all cases of Type 2 diabetes could be prevented or delayed" and usually "obesity is responsible for 80 to 85% of someone's risk of developing Type 2 diabetes" (Facts & Figures. 2019).

In order to look at the complex medical condition and map out the problem, I chose to use the CATWOE Analysis. This was introduced to me from the 'CM2107 System Modelling' module, where the holistic approach "asks you to look at an issue from six unique perspectives" (CATWOE Analysis. 2016). I considered all questions to guide my root definition (as presented in *Table 2: CATWOE Analysis*) and analysing the background context allowed my research to guide me in a variety of directions.

Root Definition element	Root Definition description	Identified definition
Customers	Who benefits from, or is affected by the system that is being defined?	Primary: Type 2 Diabetic patients, NHS staff. Secondary: NHS healthcare recipients.
Actors	Who make the system 'happen'?	NHS Wales & its users.
Transformation	What is the targeted conversion?	Identify problem zones in Type 2 Diabetes and help optimise finite resources.
World View	What is the underlying assumption and what makes this meaningful? What is the worldview?	A health system struggling with limited resources to manage growing amounts of data and then better serve its users. Focus group is Wales, however evidence on assumptions is from local and worldwide sources, and are made by a novice in the field.
Owners	Who controls the system and therefore can make it stop?	NHS Wales and the population are in control because they can either stop operating or patients can stop using the services.
Environment constraints	What influences the system but has no control over it? (I.e. political, economic, social, natural)	Education and wealth status in Wales, marketing and media (advertisement), climate of organisation (speed/delays), social pressures (consumption, habits).

Table 2: CATWOE Analysis

6.3 Background Research

6.3.1 Methodology Selection

The project proposal originated in NHS Wales Informatics Team, when they began their interest in Dr Catherine Teehan's work on system modelling and policy/intervention creations. After discussions with Dr Catherine Teehan and Dr Martin Caminada, a project that revolved around Data and System Modelling became of high interest to me. This was an aspect of Computer Science I have been very captivated to study and with the technical advise from Dr Catherine Teehan, I kept the right track into System Dynamics and its use for the project.

Foremost, the introduction and definition to System Dynamics is essential. As John Sterman states in his book 'Business Dynamics: Systems Thinking and Modeling for a Complex World', "System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modelling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations. Together, these tools allow us to create management flight simulators-micro worlds where space and time can be compressed and slowed so we can experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design structures and strategies for greater success." (Sterman 2000)

On the opposing viewpoint, SD is a top-down approach, whilst an alternative methodology, Agent-Based Modelling, is a bottom-up approach that is used when "agents are different" (Csala 2012), for example to model Epidemiology, Social Networks or War Simulation. This is the main difference in the two most commonly used System Modelling methodologies; where SD aggregates system behaviour, whilst ABM aggregates individual agent behaviour.

Predominantly, for this reason, the chosen methodology of System Modelling is System Dynamics because of its focus on system behaviour and relevant application of real-world complex systems, which is the case in this project. It offers to create mental models of global systems and their feedbacks, which ABM does not. As stated, System Dynamics "enables us to understand the structure and dynamics of complex systems" and with the real-standing issue of limited resources and complex prevention and prevalence of diabetes, it is the correct approach. Furthermore, it will lead me to define the problem using the CATWOE Analysis approach (see *Section 9.2 Narrower Context: The Problem Definition*), developed by Peter Checkland to facilitate Soft System Modelling (SSM).

The continuation step in the approach would begin the creation of qualitative models, also known as Causal Loop Diagrams (see *Section 11.2 Qualified Model - Causal Loop Diagram*) or Influence Diagram. Throughout the creation of CLD, it is vital to justify the polarity of relationships (see *Section 11.4 Table of Relationship Justifications*) and unit consistency. These models are storytelling and powerful, as they are made based on assumptions of creator and verified by justifications, conveying the behaviour of cause and the feedback of factors connecting to form loops. The CLD identified 2 types of feedback loops; "A feedback loop is called positive [reinforcing], indicated by a + sign in parentheses, if it contains an even number of negative causal links" and "a feedback loop is called negative [balancing], indicated by a − sign in parentheses, if it contains an odd number of negative causal links" (Kirkwood 1998). Reinforcing loops indicate the system to be 'out of control' as "change in one direction is compounded by more change" (Colleen 2016). On the other hand, balancing loops "counter change in one direction with change in the opposite direction. Balancing processes attempt to bring things to a desired state and keep them there" (Colleen 2016). This means that the goal of the system is to have a system 'in balance' where it is either moving to an equilibrium or in oscillation. The reinforcing loops show exponential growth and are telling signs that its factors and causalities need a policy action.

After the qualified model comes the quantified model, also known as Stock & Flow Model (see *Section 11.6 Quantified Model – Stock & Flow Model*). This next step in the methodology is the foundation that leads to simulations (see *Section 11.7 Simulations*), where instead of storytelling the high-level understanding, we go deeper into analysis and focus on specific differentiated parts of the system. This parts that need attention, usually would be the areas where our analysis and policy action will take place. As suggested by the name, the quantified model is split into Stocks and Flows. “Stocks are entities that can accumulate or be depleted, such as a bathtub, which fills with water from a faucet. Flows, on the other hand, are entities that make stocks increase or decrease, like a faucet or drain affects the level of water in a bathtub. Note that flows are the only variables that can change stocks” (Aronson and Angelakis 2016). They help you specifying the unit measures for the model, and adding data when creating simulations to show future and/or past trend.

The final methodology step is to run the simulations from created Stock & Flow model, which will show the necessary trends that will guide our understanding to find interventions/recommendations/policy actions. “Because system dynamics modelling packages use stocks and flows as their fundamental language, creating a stock and flow diagram makes it much easier to build a computer model of the system you are studying. Besides, the level of detail required for a good stock and flow diagram helps you specify the system with the exactness required by a computer model. Transforming a CLD allows you to experiment with different policies and discover counterintuitive dynamics” (Aronson and Angelakis 2016). These changeable simulations allow the observer to formulate how factors cause different graph behaviours, allowing for hypotheses and ultimately interventions.

6.3.2 Type 2 Diabetes

As the project is concentrated within the healthcare sector, it is significant to communicate to the reader what exactly Diabetes is and why it is an important medical issue to treat.

First, let me tell you a story.

We are either born with genetic disposition or adapt certain lifestyles, which can cause our body to dysfunction. Lets say I am a 40-year-old male and I have been through a major tragedy, the loss of my beloved son. I am not coping well with the tragedy and turn to comfort food, laziness and bad habits in my day-to-day life. For the next 2 years, I am eating too much pre-processed foods, not enough fresh fruits and vegetables and getting out of the house once a week.
Within those 2 years of unhealthy diet and physical inactivity, I gained 50kg (110lb) putting me into the overweight/obese scale. Throughout this time, the insulin that my pancreas in my body has been making, in order to help glucose be used as energy by my cells, starts to not respond, causing heightened blood glucose levels. Over time the blood glucose levels could spike so high that the organs within my body would be in overdrive and I would develop kidney failure, and be at risk of dying.

This is an extreme case I wanted to illustrate in your mind, yet highlight that the development and onset of diabetes can come from a variety of severities and angles. The diagnosis, prevention and treatment are extremely crucial in the world as it can cause deadly outcomes. For example, if I was to begin scaling onto the obese category and seen a specialist to alter my diet and physical activity, it would most likely prevent the development of diabetes.

On the theoretical margin, I would now like to share the research around the onset and what Diabetes actually is.

The onset of the body not making enough insulin or none at all comes from insulin resistance and pre-diabetes.
Insulin resistance occurs "when cells in your muscles, fat, and liver don't respond well to insulin and can't easily take up glucose from your blood". (National Institute of Diabetes and Digestive and Kidney Diseases 2016) Your body uses the pancreas to level out the insulin and as long as it can keep up, the blood glucose levels will remain normal. Pre-diabetes is caused by elevated blood glucose levels, which are "higher than normal but not high enough to be diagnosed as diabetes" (National Institute of Diabetes and Digestive and Kidney Diseases 2016).

Diabetes is a "disease that occurs when your blood glucose, also called blood sugar, is too high. Blood glucose is your main source of energy and comes from the food you eat. Insulin, a hormone made by the pancreas, helps glucose from food get into your cells to be used for energy. Sometimes your body doesn't make enough—or any—insulin or doesn't use insulin well. Glucose then stays in your blood and doesn't reach your cells." (National Institute of Diabetes and Digestive and Kidney Diseases 2016)

Furthermore, Diabetes can be categorised into different types. Most commonly this would be Type 1 and Type 2 (see *Figure 2: Type 1 and Type 2 Diabetes 'metaphor'*).

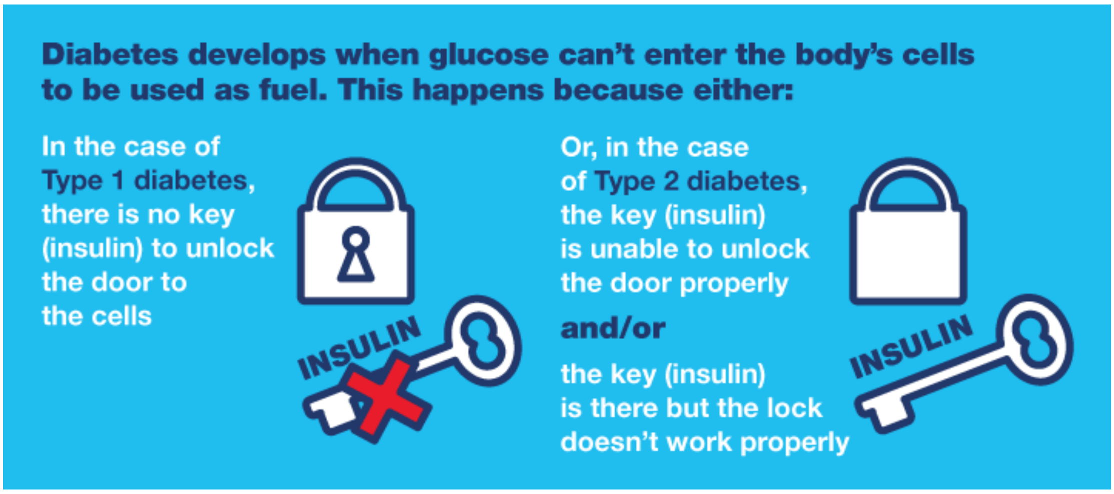

Figure 2: Type 1 and Type 2 Diabetes 'metaphor'
(Wye Valley Practice 2016)

The main difference between Type 1 and Type 2 is that Type 2 can be prevented, whilst Type 1 can be managed. Type 2 Diabetes has a high dependency on healthy lifestyle, in terms of diet and physical activity, which is controlled by the individual, yet affected by society, availability, education, awareness and more. The main similarity is that "no cure for diabetes currently exists, but the disease can go into remission. Even if a person maintains normal blood sugar levels for 20 years, a doctor would still consider their diabetes to be in remission rather than cured." (Johnson 2019) This article on MedicalNewsToday conveys the message that individual can go into remission from Diabetes, and that is down to their treatment and lifestyle, which will be investigated in this project (see *Section 10 Approach Selection*).

6.3.3 Poverty and how it is measured

I will be briefly expressing the background of poverty and how it is measured in Wales and the UK. This subject, as a chosen constant variable, is important to bring the notice to because it will be guiding the system modelling concerning Type 2 Diabetes.

Poverty is the state of lacking financial resources and support for the individual's or communities living conditions. The state is a continuously changing measure. The United Kingdom, specifically The Social Metric Commission (SMC), has recently adapted to a new measurement that "goes beyond a simple measure of people's relative income by taking into account core living costs such as housing, childcare and the extra costs of disability. It also accounts for people's wider resources, such as savings, in assessing whether they can be defined as in poverty" (The Guardian 2018). Wales, Scotland and Northern Ireland have retained to adapt to this new metric, and remain to measure "relative income poverty if they live in a household where the household income is below 60 per cent of the UK median household income" (StatsWales 2019).

From exploring the environmental constraints with Diabetes (see *Table 2: CATWOE Analysis* in *Section 9.2*), I let it guide me to the factor of Poverty in a MindMap (see *Figure 4: Mindmap of Type 2 Diabetes* in *Section 11.1*). Research conveyed a correlation between poverty and the prevalence of Diabetes in Wales, as Wales experiences "7.6% of the population aged 17 and over - the highest prevalence [of Diabetes] in the UK" (Diabetes in Wales. 2019) and the highest poverty measures (see *Figure 3: Poverty StatWales*).

			Year										
Indicator	Area		2006-07 to 2008-09	2007-08 to 2009-10	2008-09 to 2010-11	2009-10 to 2011-12	2010-11 to 2012-13	2011-12 to 2013-14	2012-13 to 2014-15	2013-14 to 2015-16	2014-15 to 2016-17	2015-16 to 2017-18	2016-17 to 2018-19
All individuals	United Kingdom		22	22	22	21	21	21	21	21	22	22	22
	United Kingdom	Wales	23	23	22	23	23	23	23	23	24	24	23
		Scotland	19	19	18	18	18	18	18	19	19	20	19
		Northern Ireland	19	21	(r) 21	21	20	21	21	20	20	18	19
		England	23	23	22	22	21	21	21	22	22	22	22

Figure 3: Poverty StatWales
(StatsWales. 2019)

This correlation has led me to focus my project on the primary causality of Poverty, given that it relates to a large multitude of factors such as availability of healthy diet, motivation for daily exercise, highest level of education and more.

6.3.4 Related Research

In every piece of work, it is critical to distinguish the nature of the work we are working on. It becomes imminent if one repeats something that has already been done, as stands the technological principle of 'reinventing the wheel'. This concept addresses the need to utilise existing research, data and knowledge, as there is so much information to choose from. Moreover, it becomes irrelevant and untrustworthy if one does not relate to, reference or counteract existing knowledge that is presented in the world.

This project varies to the more typical implementation problem and approach as it is based on System Modelling. Thus, for the final step of the background research and literature review, I will discuss an existing area of prior scholarship, which is a Journal of Public Health '*Understanding Diabetes Population Dynamics Through Simulation Modeling and Experimentation'* (Jones et al. 2006). It depicts the aim "to gain a better understanding of diabetes population dynamics" through "reporting results of simulation experiments with a system dynamics model developed to explore the past and future burden of diabetes."

On one hand, it is very applicable to mention the article due to its relevance of understanding diabetes. They identify the "growing health problem" to have "no quick or easy fixes" and the importance to tackle it by "addressing all major components together *as a system*." (Jones et al. 2006)

On the other hand, this article uses the approach of system dynamics simulation modelling to create models to tackle its problem and aim, and mentions, "like all models, this one is a simplification: it omits many details *in order to enhance* understanding and includes assumptions that are uncertain to some degree." (Jones et al. 2006) Such explanation is important to relate to this project, as the rest of the journal articles, books, government reports, websites and more references (see *Appendix 1* and *Table 6: List of citations for data used in the model*) have been justified with evidence but still hold a truth degree.

Combining both the topics Diabetes and System Dynamics in the related research article sets a parallel methodology to this project. The Public Health article follows the results of the simulation experiments and discovers that "diabetes control may be improved by 4 types of interventions", which it continues to test and evaluate. In parallel, this highlights what the research agenda of the future work on this project would be (see *Section 10 Discussion & Future Work*).

The article had brought a lot of understanding of grasping Diabetes problem through System Dynamics Modelling and shown relevance to this projects approach. It was beneficial to see the related work and elicit features to use in this report, such as explicitly stating assumptions of link to sources (see *Appendix 1*) and viewing the testing of interventions as a crucial next step to be taken in future work (see *Section 10.1 Discussion*).

7 Approach Selection & Log

Having provided the 'Introduction' and 'Background', the next standard stage in the project report is the 'Design' of the system, followed by the 'Implementation' of the system. Conversely, this specific project does not follow the typical implementation of software engineering, rather executes system modelling with problem identification. This means that I had to alter the delivery of my report structure.

In this Section 9, I aim to provide you the week log of my activities and the supplementary work done to create and complete qualified and quantified system models.

7.1 Week Log

The longevity of this project was a crucial aspect to approach correctly. From the initial plan creation, I found it necessary to keep track of my weekly logged progress (see *Table 3: Week Log*), which includes my progress, decisions and supervisor feedback. Furthermore, throughout the project I ensured to use my report template, as a space to include any thoughts and information I anticipated would be beneficial to have in the report. This enabled me to stay on top of my documentation, so that when I got to the report writing, I already knew what every section should cover to ensure a logical and comprehensive structure.

I would like to point out that the project was aimed to receive datasets from NHS Wales. These datasets would feed my quantified model and therefore enable me to provide NHS Wales the behaviour of their system in a simulation. As highlighted in *Table 3: Week Log,* I was expected to receive the datasets after sending them my request of which specific data I will need to receive (see *Section 11.3 List of Information Items*). Due to the COVID-19 pandemic, the priorities within the NHS Wales had shifted on a large scale, where they did not have the time and capacity to find and provide me with the needed data. I had anticipated this situation after the creation of the Initial Plan, to include another risk where 'if I do not receive data, what is the Plan B?' From discussions with my supervisor, we concluded that I am only looking for a behaviour trend in my simulation (see *Section 11.7 Simulations*). This meant that I could apply assumptions based on data and statistics found for Diabetes in Wales (see *Section 15.1 References of assumptions in quantified model*). As my simulation includes variables that can be interactively changed, the aim of it was to perform 'What-If analysis' on the behaviour when changing variable rates.

Week	Log
1	- Working on Initial Plan & submission - System Dynamics crash course with advisor and supervisor - Supervisor meeting: to discuss initial plan and system modelling
2	- Background research, Brainstorming factors based on NHS Diabetes Pathway - Sketching qualified model, finding relationships and effects - Supervisor meeting: weekly catch-up and further discussion on sketches to further guide progress - Created the report template with its structure and main sections.

3	- Review of System Dynamics software tools, Vensim PLE chosen and downloaded - Starting to map out current exploration onto Vensim
4	- Change to InsightMaker due to web-based feature and therefore easier collaboration with the technical advisor (commenting on Causal Loop Diagrams) - Supervisor meeting: via email due to industrial action, giving a progress update
5	- Decided to focus on Type 2 diabetes: Mind Map of Type 2 and Type 1 and factors related to it - InsightMaker qualified model (causal loop diagram) sent to Catherine for review - Supervisor meeting: via email due to industrial action, giving a progress update
6	- Advisor meeting: Call with Catherine to discuss progress, received feedback on diagram, and ethics email sent. - Write up on Intro and Background.
7	- Quantified model crash course (InsightMaker might not be best for the next step). - Completion of Qualified model, with loops added. - Supervisor meeting: to discuss progress, presenting the report outline and discussing the flow of the report. Positive feedback was given for the progress.
8	- COVID-19 outbreak interruption, physical moving to home country. - Laptop space and performance problems, which were resolved. - Request of data sent to the NHS Wales via email through contact Catherine Teehan.
9	- Ethics Committee approved the project. - Article reading on System Dynamics in healthcare.
10	- Exploration of AnyLogic and Vensim for better simulation creation tool (=AnyLogic chosen). - Supervisor meeting: Online Microsoft Teams call with Martin and Catherine, update and feedback (=to get into deeper levels of resources with AnyLogic, think of behaviour and what-if analysis, 'think of telling a story'. If no data, make assumptions as we only want to see the trend/behaviour, no actual specific data)
11	- Receive datasets (Diabetes and Pre-diabetes) from NHS? - *Brief illness. - Software (AnyLogic) performance problems on my laptop, had to figure out Plan B where I used family computers to run my models and simulations. Only option on a personal laptop would have been factory reset, but that option was risky given the proximity of the deadline. - Writing first draft of report; Introduction and Background
12	- Continuing first draft; Implementation (completing models) - Supervisor meeting: Online Microsoft Teams call, presented model and simulation, given great feedback on how it is and suggest final improvements.
13	- Finalising the first draft with a write-up on Implementation,

	Evaluation, Results, Conclusion and Reflective Learning. - Supervisor meeting: Online Microsoft Teams call, presented results and findings of trends
14	- Feedback on quantified model, working to create a feedback loop within the model, however due to the free software version this was not possible - First draft hand-in
15	- First draft feedback, and corrections. - Re-reading
16	- Final grammar checks, write-up of Abstract and Acknowledgements. - Report deadline.

Table 3: Week Log

7.2 System Dynamics software Analysis

When I proceeded from my research and initial brainstorming of the topic, the next step was to decide on what software I would use to create my models and simulation. From the vast multitude of software packages that are simulation-modelling tools, with Palette features for System Dynamics, I performed comparison analysis (see *Table 4: SD Software selection analysis*).

The comparison of 4 chosen software packages focuses on advantages, drawbacks and other "various aspects of software offering system dynamics features" (Wikipedia 2020). The specifications I chose to consider in the tool was the feature to create Causal Loop diagrams from System Dynamics methodology, and its availability of levels to include higher-level view and depth, and lastly the online sharing availability - no software download needed.

Starting to create the qualified models (see *Section 11.2 Qualified Model - Causal Loop Diagram*), I chose InsightMaker due to its ability to collaboratively share my progress with my Advisor and therefore get feedback with greater ease. Originally I had downloaded Vensim PLE, for the visual features of the models, but very promptly realised how beneficial it would be to have a web-based tool that allows me to ask my advisor to give me feedback on the progress.

In week 7 of having a crash course to tackle the next phase of creating quantified model (see *Section 11.3 Quantified Model - Stock & Flow Model*) and simulation (see *Section 11.4 Simulation*), it became evident that InsightMaker did not have enough desirable features such as user interaction buttons, the ease of simulation modifications and modern UI. I stepped back to my analysis, re-evaluated the needs for more model features and more visually pleasing simulation, and decided to go forward with AnyLogic PLE (Personal Learning Edition). Unfortunately, I had to accept another learning curve of working with a new tool, which in the end proved to be the correct choice because the outcome was more desirable. The initial concern was it not being browser-based to get easy feedback on my progress, however my advisor had the software already installed and therefore could open my model and run the simulation.

System Dynamics software	Last Update (year)	Functions Language	Advantages	Drawbacks	Other comments
Insight Maker (InsightMaker 2020)	2017	JavaScript	Fully browser-based. Online collaborative sharing. Free.	Internet connection needed. Lack of visual effects and functions for S&F.	Exploring on aggregate level.
Vensim (Ventana Systems 2015)	2019	C, C++	Supports data import and export.	Not browser-based: user must have software downloaded to view models.	Continuous simulation with stocks and flows.
Stella (isee systems inc. 2019)		S	Levelling features to distinguish between different areas. Browser-based.	Internet connection needed.	Expensive accounts contain needed features (i.e. unlimited factors/graphs, stocks/flows).
AnyLogic (The AnyLogic Company 2020)	2020	Java	Agent-based modelling. Great visuals of simulation, many features.	Not browser-based: user must have software downloaded to view models.	Free version (Personal Learning Edition) is limited to specific features (does not include unlimited factors)

Table 4: SD Software selection analysis

8 Implementation – application of System Dynamics

8.1 Brainstorm Mind Map

For me to meet the first project goal of creating a qualified model, I chose to brainstorm my research and findings into a mind map. This mind map was created on an online tool named MindMup and explores factors that relate to Type 2 Diabetes & Type 1 Diabetes. I performed this initialising step to organise the researched factors into its main knowledge areas, and then explore narrower areas based on my assumptions and brainstorming. This process allowed me to gather and organise all topics surrounding the causes of Type 2 Diabetes & Type 1 Diabetes.

The diagrams (see *Figure 4* and *Figure 5*) show narrowing factors into specific topics, and the orange arrows signify relations between factors of different zones.

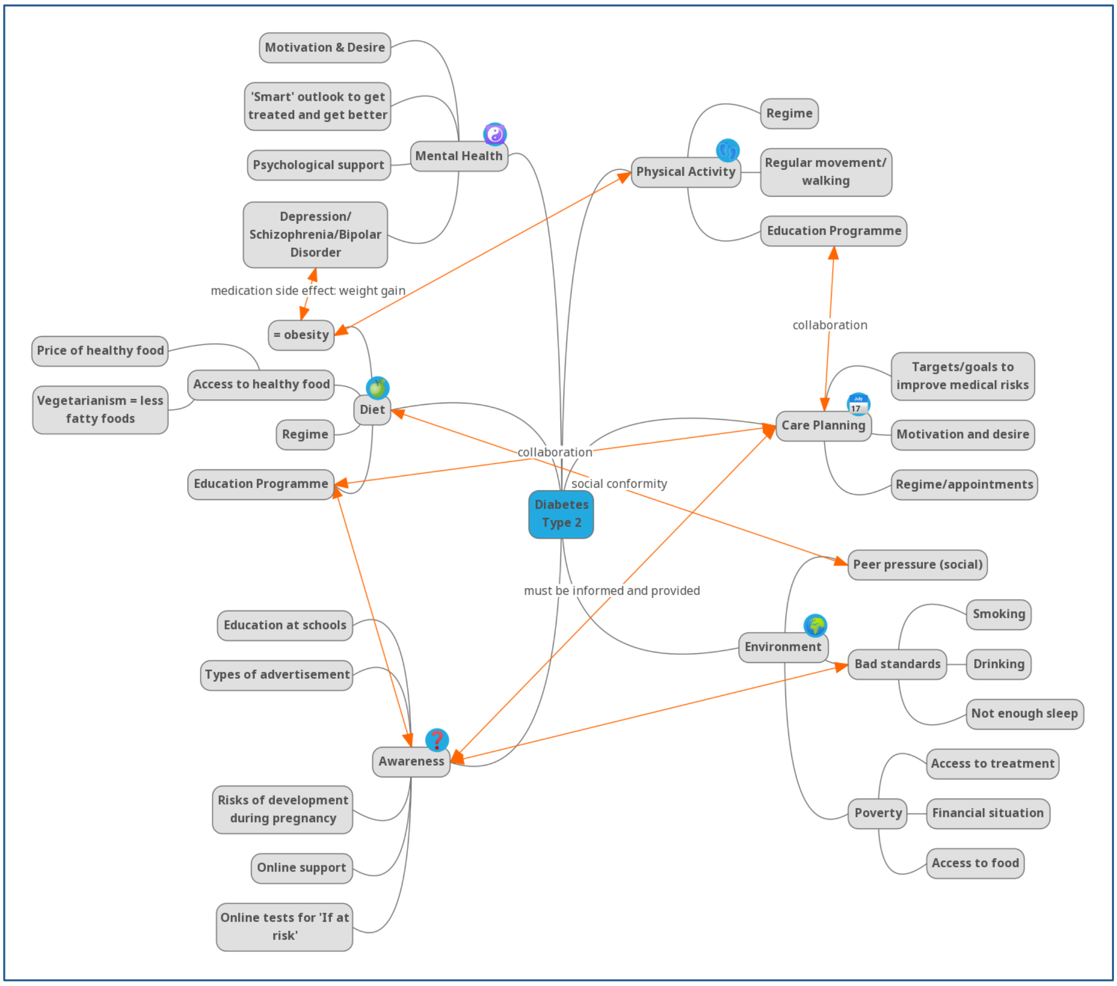

Figure 4: Mindmap of Type 2 Diabetes

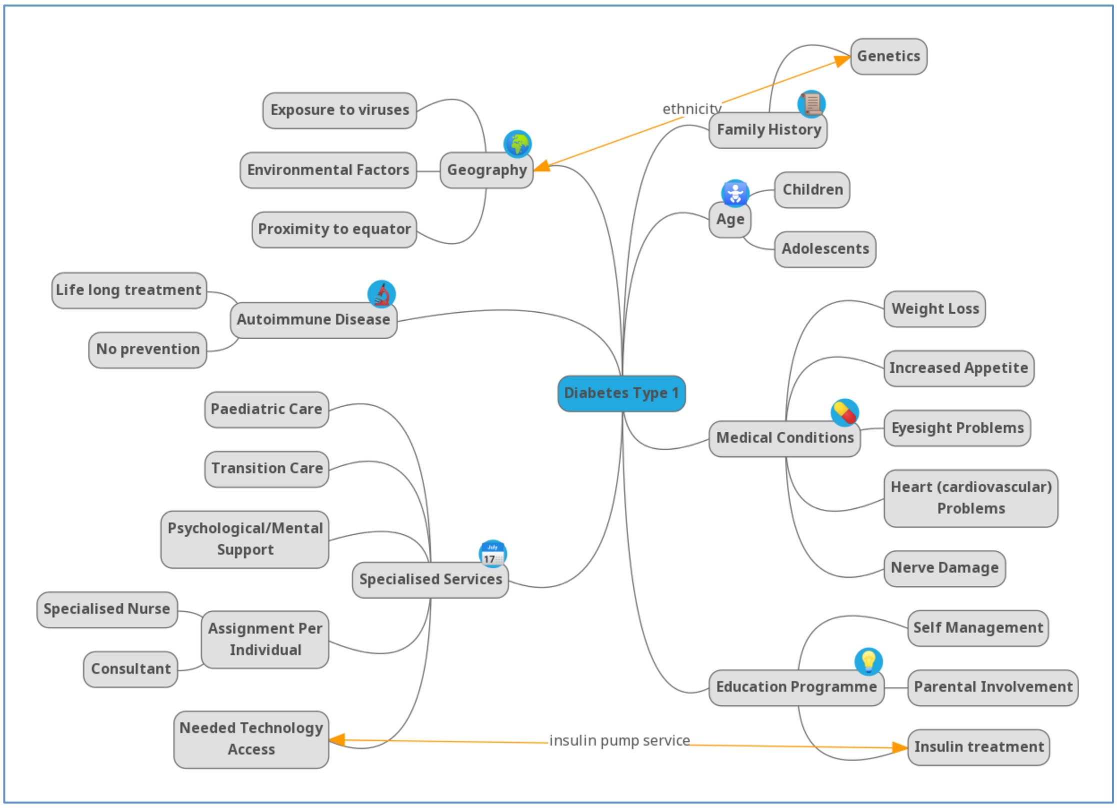

Figure 5: Mindmap of Type 1 Diabetes

Following further research into the factors and causes related to Type 1 & Type 2 Diabetes, I chose the project to lead down the path of just one because the two vary immensely. Given the prevalence and likelihood of prevention (see *Section 8 Background*), the project will focus on Type 2 Diabetes. The bigger presence of links between different knowledge areas in *Figure 4: Mindmap of Type 2 Diabetes*, depict more explorative and complex system, to create stimulating models. The major identified impact of lifestyle (see *Figure 4: Mindmap of Type 2 Diabetes*) versus family predisposition (see *Figure 5: Mindmap of Type 1 Diabetes*) guided the choice, as it is a more impactful way to introducing interventions resulting in higher prospect of a positive impact.

8.2 Qualified Model - Causal Loop Diagram

After the completion of the brainstorming and selection of scope to be Type 2 Diabetes, the next step was to create the qualified model, the first deliverable of the project.

As I have presented in the methodology approach (see *Section 8.4.1 Methodology Selection*), I have used my findings, trends and assumptions to create a Causal Loop Diagram. After selecting the SD software, InsightMaker, I began with my main variable in green, "Number of Type 2 Diabetics". My original intention when creating the model was to have zones 'Education/Lifestyle', 'Environment', 'Mental Health' and 'Healthcare' as the high-level visual representation, which can be clicked into and expanded to all its underlying variables and causal links. Due to the limiting features of InsightMaker with levelling, as well as with other SD software, I had to find an alternative; colour coding the zones through their bubble colours and labelling them. This portrays the 'Education/Lifestyle' to be orange, 'Environment' to be yellow, 'Mental Health' to be pink and 'Healthcare' to be blue. Adding this element visually eases the representation of the model for the reader, seeing at what point variables from one zone have causal links with another zone and shows where the feedback loops are taking place. With every new causal link creation, I determined the polarity and verified the assumption (see *Section 10.4 Table of Relationship Justifications*). The positive polarity, expressed by a '+' on the dashed link, meant that if Factor A increases then Factor B increases, or if Factor A decreases then Factor B decrease. The negative polarity, expressed by a '-' on the dashed link, meant that if Factor A increases then Factor B decreases, or if Factor A decreases then Factor B increases. The presented *Figure 6* shows the progress of the Causal Loop Diagram.

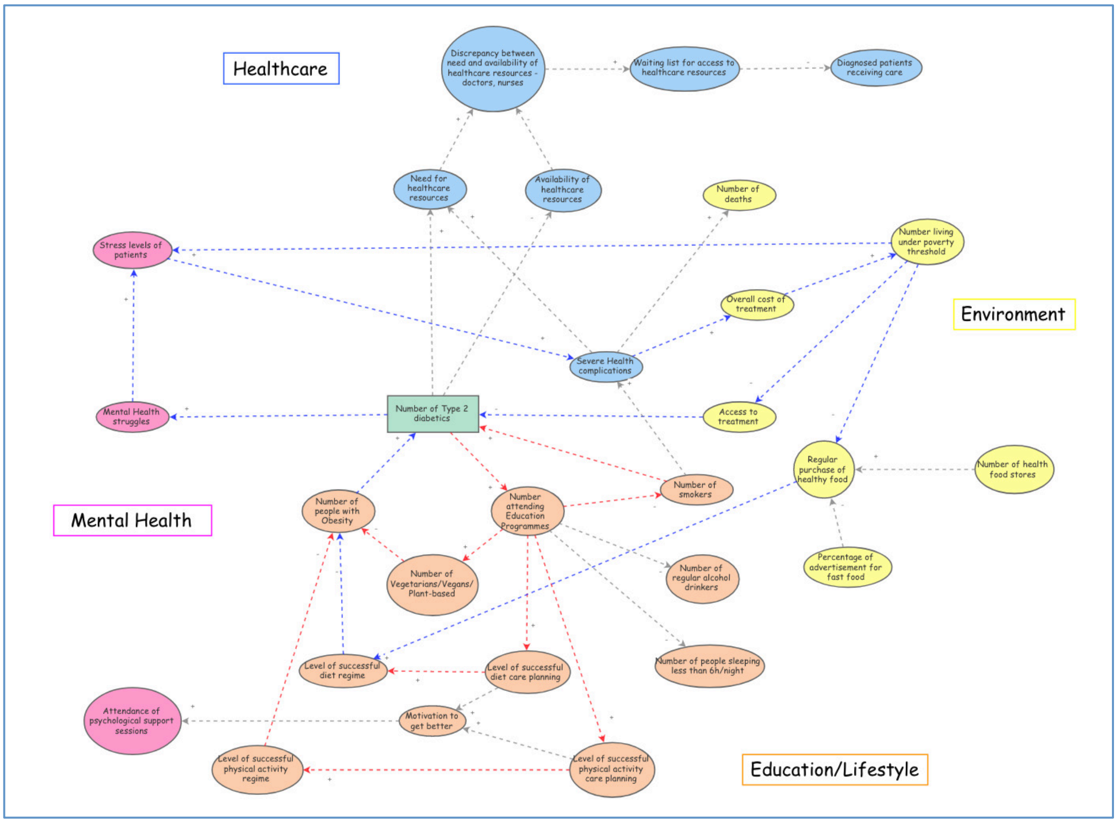

Figure 6: Causal Loop Diagram

Once the causal links are created and documented for unit consistency (see *Section 10.3 List of Information Items*), polarity is determined and verified (see *Section 10.4 Table of Relationship Justifications*), I began to identify the Feedback loops in the qualified model. The classification of a loop means it must flow continuously in one direction before reaching the staring variable. As highlighted from the CM2107 Systems Modelling module, the negative feedback loop is "self-maintaining" with the example used in "Process control (real-time) and Quality control (error tolerance limits)" (Teehan 2018). On the other hand, the positive feedback loop has "reinforcing amplification" and is used for "growth promotion i.e. business growth, human motivation" (Teehan 2018).

Using the CLD methodology principles when identifying loops (see Section 8.4.1 Methodology Selection), I finalised the qualified model by adding the positive and negative feedback loops (see *Figure 7: Causal Loop Diagram with loops*). To allow the readers to guide themselves through the loop paths I have colour coded (red or blue) the effected causal links, helping visually identify the loops. Furthermore, the list of loops is also presented in *Figure 8: List of Model Loops*, as an additional resource.

The model can be viewed online only by my granting of permission to existing users at the link https://insightmaker.com/insight/185940/Causal-Loop-Diagram-Type-2. If you wish the view the model, you must create a free InsightMaker account and email me for permission to view it.

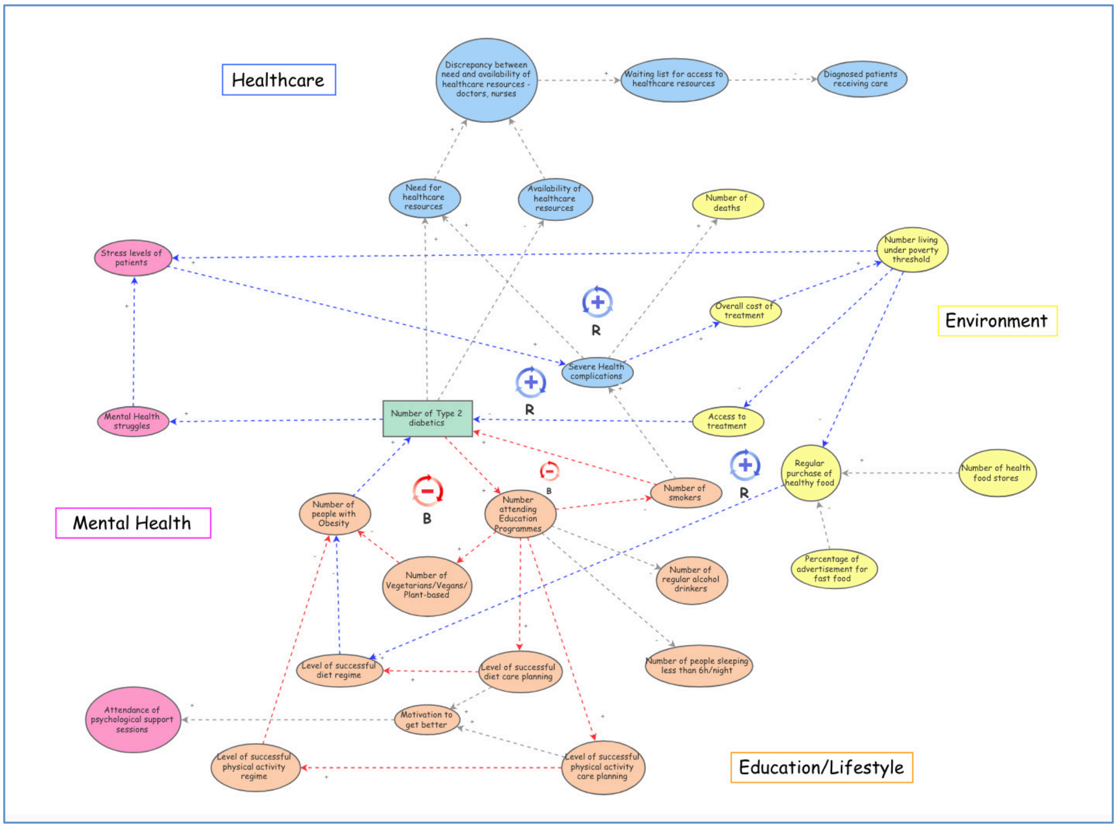

Figure 7: Causal Loop Diagram with loops

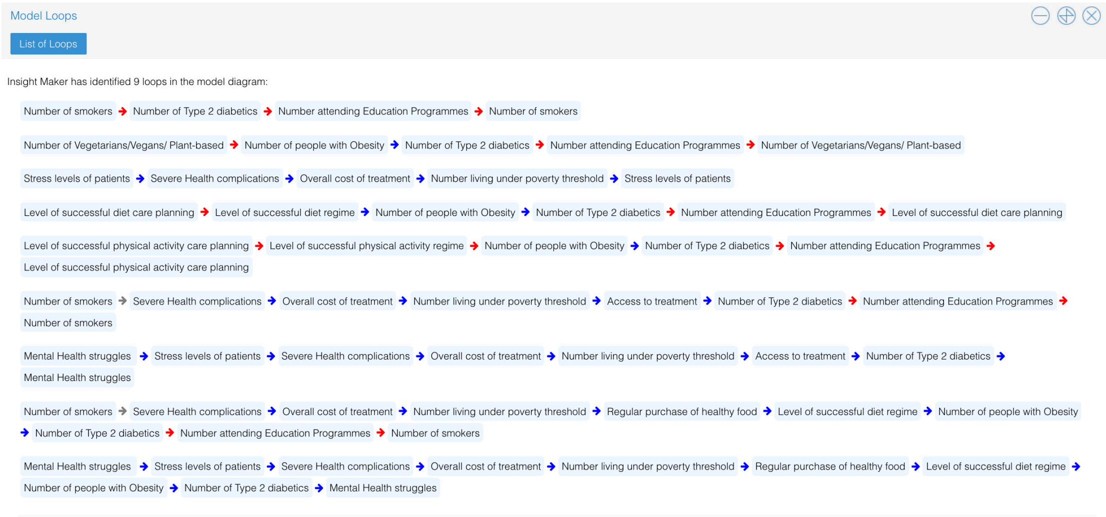

Figure 8: List of Model Loops

The qualified model helps me visualise the causal connection in the complex medical condition of Type 2 Diabetes and to identify where its problem zones lay. Figure 7 and Figure 8, identified where the most problematic zones are and what variables are included in the feedback loops. The problem zones of focus are the 'Reinforcing' positive loops, because they have exponential growth making the system out-of-balance. This brings the focus onto the 3 blue, positive loops that are all containing the variable 'Number of living under poverty threshold'. With this discovery, I deepened my research in the UK and Wales measurement of poverty (see *Section 8.4.3 Poverty and how it is measured*) and its current impact onto developing Type 2 Diabetes. The continuation of my thoughts and research led my scope focus to converge between Poverty and prevalence of Type 2 Diabetes, thus performing another brainstorming (see *Section 10.5 Causality brainstorming*) before creating the quantified model that portrays the behaviour and trend.

The further enhance the importance of creating the qualified model; it enables us to understand the surrounding knowledge of the topic. It helps us pinpoint The Rumsfeldian Knowledge Matrix that goes as follows: "There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say, we know there are some things we know we do not know. But there are also unknown unknowns – the ones we don't know we don't know." (Rumsfeld 2002) To match it to this project and understand what we are finding and looking for, I classified it as followed:

- Known knowns = public information online (NHS, country statistics, etc.)
- Known unknown = the questions that have been raised by the loops of the CLD; what do the trends mean?
- Unknown knowns = discoveries we are to make from data to be given by NHS, and the simulation of the quantified model

Such classification helped me understand what we have gained from the qualified model, in order to best approach the quantified model (see *Section 10.6 Quantified Model – Stock & Flow Model*) and to discover trends based on existing identified problem zones.

8.3 List of Information Items

Here is the supplementary material that has been retrieved from the Causal Loop Diagram, where the information item is a variable. I then identified the metrics/units for every information item, ensuring there is unit consistency. Moreover, I organised the items under knowledge areas of Education/Lifestyle, Mental Health and Environment, as done so in the CLD diagram.

I produced this list to send to NHS Wales, for them to exactly know what data I am looking for and in what units I will need to receive it in. This was done to create an ease of communication between their understanding and my request. I was expecting and aware that some of the data they will not be in possession of (i.e. regular purchase of healthy food). In such cases, I was planning to use online statistics and facts.

Information Item	What are the metrics/units?	Why is this important to collect?
Number of Type 2 diabetics	Number	To calculate current prevalence, as it is the central factor.
Number of pre-diabetics	Number	To allow for a comparison between pre-diabetes leading onto diabetes.
Education/Lifestyle		
Number of attendees of educational programmes	Number	To calculate the ratio of patients attending.
Number of Vegetarians /Vegans/Plant-based	Number	To compare diet choices with obesity.
Number of people with obesity	Number	To compare obesity with onset of diabetes.
Level of successful diet care planning	Number attending care planning sessions with their specialist (diet)	To calculate the ratio of effect of attending an education program onto diet planning.
Level of successful diet regime	Number reporting increasing healthy results to their specialist (diet)	To calculate the effect of diet planning onto a maintaining regime.
Level of successful physical activity care planning	Number attending care planning sessions with their specialist (physical activity)	To calculate the ratio of effect of attending an education program onto exercise planning.
Level of successful physical activity regime	Number reporting increasing healthy results to their specialist (physical activity)	To calculate the effect of exercise planning onto a maintaining regime.

Information Item	What are the metrics/units?	Why is this important to collect?
Motivation to get better	Number of reporting and showing progress in a diabetic state	To understand how planning affects patients attitude and desire to get better.
People sleeping less than 6h/night	Number	To compare with onset & severe health comp.
Regular alcohol drinkers	Number	To compare with onset & severe health comp.
People smoking	Number	To compare with onset & severe health comp.
	Mental Health	
Attendance of psychological support sessions	Number attending psychological support sessions	To calculate the ratio of patients attending.
Stress levels of patients	Number of reported higher stress levels in patients	To compare stress to diabetes, poverty and complications.
Mental Health struggles	Number of patients with mental health problems on their medical record	To compare the attendance with recorder mental health problems.
	Environment	
Overall cost of treatment	Cost	To incorporate all cost for treatment and compare to poverty.
Number living under poverty threshold	Number	To compare the onset of diabetes from living conditions.
Availability of treatment	Number receiving treatment	To compare to demand.
Need of treatment	Number of people needing treatment	To compare to availability.
Regular purchase of healthy food	Number of items bought classified as healthy	To compare with poverty, diet and risk of obesity.
Number of health food stores	Number	To compare to the trend of purchase.
Number of food stores	Number	To compare ratio to health food stores.
Percentage of advertisement for fast food	Percentage	To see trend compared to a healthy diet.
Number of deaths	Number	To identify 1 outcome.
	Healthcare	
Severe Health complications	Number & severity	To identify the risk to death.

Information Item	What are the metrics/units?	Why is this important to collect?
Availability of healthcare resources	Number	To compare with demand.
Need for healthcare resources	Number	To compare with availability.
Waiting list for access to healthcare resources	Number	To understand the timeline.
Diagnosed patients receiving care	Number	To compare treatment to need and availability.

Table 5: Information Item list

8.4 Table of Relationship Justifications

For further assistance, I have created and provided additional supplementary material Table of Justification (see *Appendix 1: Table of Justifications list*) to the Causal Loop Diagram. As the qualified model visualises relationships, links and effects of different factors linking, it is important to justify every assumption. This justification and evidence proves the correctness of the model as it portrays the correct polarity of relationships, portraying the correct loops. This is the evidence to prove one of the success criteria's for the qualified model (see *Section 12.2 Evaluation*).

The polarity, as seen as a column in the table, suggests what effect Factor 1 has on Factor 2. If the increasing Factor 1 caused an increasing Factor 2 then it has a positive (+) polarity, and vice versa if both are decreasing. However if the increasing Factor 1 caused a decreasing Factor 2 then it has a negative (-) polarity, and vice versa with opposite changes.

The first step of creating the Table of Justification was to convey **correlations** between two individual factors, which justify their link of relationship. The next step that proved the **causality** of every relationship was the identification of polarity and directionality. Polarity (see second column in *Appendix 1*) identified the increasing or decreasing likelihood, whilst the arrow direction identified the causal factor A has on B, stating that Factor A causes Factor B. Once the causality was justified for every relationship, it brought the entire CLD together displaying the causality chain and flow. This causality chain is a link of correlation formed into causalities, which helped in identifying the loops, as it was directional.

Identifying and explaining the purpose of the Table of Justification, it is important to exclaim that it contains a high significance of research, evidence and justification onto the choices that I have made to create the models. It visualises the correlation that has further led to the causality, allowing the project to proceed in creating the quantified model.

8.5 Causality brainstorming

To depict the importance of identifying causal behaviours, we must understand the nature of causality. "The key point about causality in this context is that simultaneous multiple causality (inter-level, as well as in each level) is always in operation in complex systems. Any attempt to characterise any partial cause as the whole is fundamentally misleading position." (Teehan 2018) As highlighted from the CM2107 Systems Modelling module, it is insufficient and deceiving to pinpoint singular causes to a system, in our case Type 2 Diabetes.

From findings within the qualified model, it became evident that a large area of interest was Poverty in regards to Type 2 Diabetes. This specific constant of the world, poverty, would allow me to further specify the focus of my problem identification. This presented me the opportunity to focus on that specific cause (poverty) of the problem (Type 2 Diabetes) in the complex system. I took the opportunity to perform a Causality exploration (see following *Figure 9: Causality brainstorming*) intending to drill down the causes of every stage in the process of someone living in poverty becoming diabetic, to its outcomes. This diagram was built from the information in 'Table of Justifications' of causal relationships, and visually formatted in a systematic timeline. It allowed clear and deep analysis into every stage of the process; Poverty, Unhealthy Lifestyle, Obesity, Type 2 Diabetes, (lack of) Management/Remission. This process of asking 'Why an unhealthy lifestyle leads to obesity?' etc. prepared me to the next implementation step, building the quantified model.

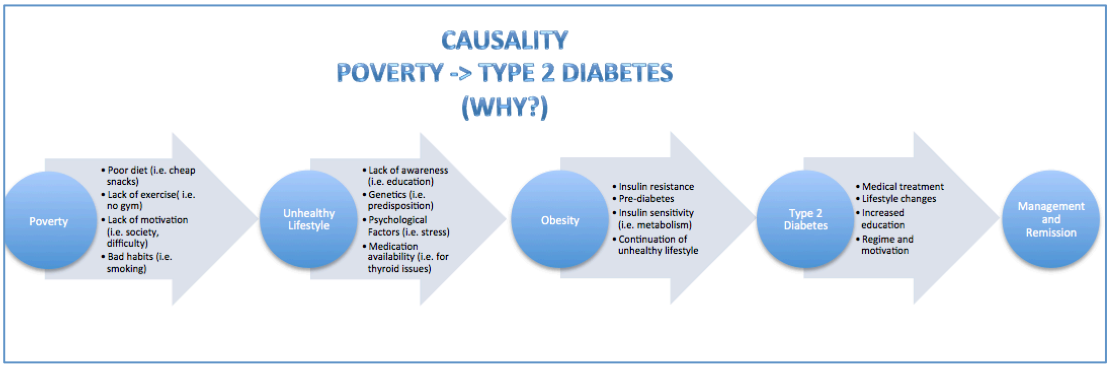

Figure 9: Causality brainstorming

8.6 Quantified Model – Stock & Flow Model

As conveyed in the previous section, the help of the causality brainstorming and mapping, enabled the preparation of creating the quantified model, Stock & Flow Model. It guided the creation, as poverty was the unchangeable variable that leads to Type 2 Diabetes and its outcomes.

For me to understand the principles of stocks and flows in a quantified model, the video (Climate Interactive 2015) was immensely helpful. Additionally, the further help was through attending a crash course with Dr Catherine Teehan about Stock & Flow creation and its procedure. To begin, I decided to use the 'People in Poverty' as my starting constant Stock, onto the next Stock of 'Obese People', onto 'Type 2 Diabetics', with the final two stocks of 'Dead People' or

'People Managing or in Remission'. The equations in stocks are auto-generated based on the inflow and outflow.

Once I have the basic stock & flow laid out, I began to add my variables, assigning equations to them (see *Figure 10: Creating a variable equation in the model*). Figure 10 is one of the examples, where you may see that I weight the impact of incoming variables individually onto the Management_of_Prediabetes. Specifying that there is an 80-20 to diet-exercise weighing (Dr Nash 2020), that 2/3 early diagnoses can prevent developing diabetes (Facts & Figures. 2019) and lastly smokers are at 35% higher risk of developing diabetes (CDCTobaccoFree 2020).

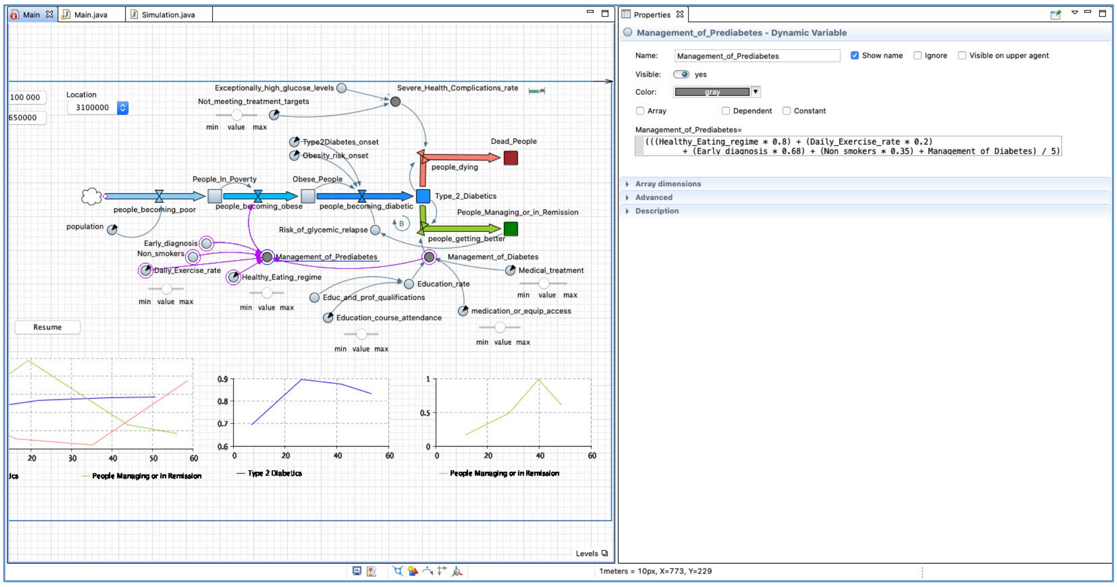

Figure 10: Creating a variable equation in the model

For every variable, I had customised the equation to ensure it was calculating variables in the intended and accurate way. I had used online statistics, predominantly from UK websites and articles (see *Table 6: List of citations for data used in the model*), to gather the equation information, multiple the statistic for correct weighting as described above and set the default values for parameters.

Citations of resources used for quantified model
(Graber et al. 2006; Wales 2006a; National Public Health Services for Wales 2007; seneddresearch 2017; AnyLogic Help 2019; National Survey For Wales 2018/19 2019; Facts & Figures. 2019; CDCTobaccoFree 2020; Dr Nash 2020)

Table 6: List of citations for data used in the model

The next stage after creating variables, their equations and connections, was to create buttons. After exploring the AnyLogic's online help and online example models, I decided to create radio buttons, a combo box and sliders (see *Figure 15: Annotated diagram of simulation and its features* in following *Section 10.7 Simulations*). To present an example of the radio button creation (see *Figure 11: Radio button – resume simulation*), I used straightforward Java code to create the action of the button.

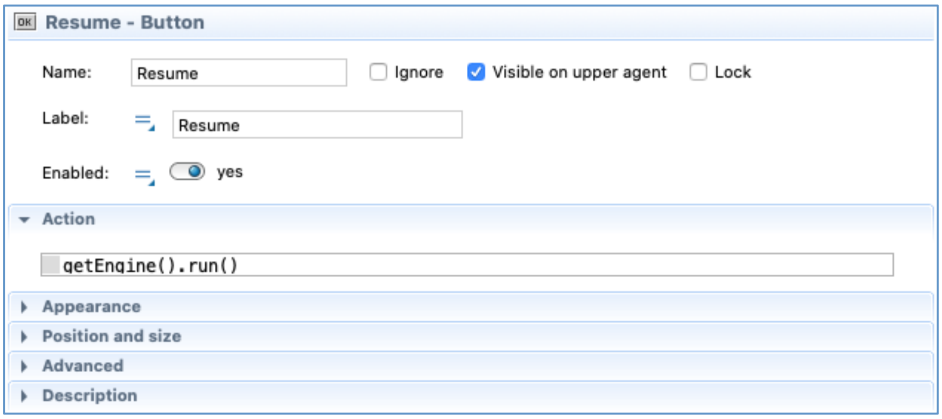

Figure 11: Radio button – resume simulation

The model was working as expected, showing a correct behaviour with working user engagement. After presenting it to my supervisor and advisor, I got feedback on its performance highlighting that I still need to create a feedback loop in there. I discovered that this was needed from the stock 'People_Managing_or_in_Remission' back through a new variable 'Risk_of glycaemic relapse' to the flow 'people_becoming_diabetic'. Originally I had discovered the risk of glycaemic relapse to be 45% on average, however from feedback it would be even more accurate to have a dynamic variable. I have drafted a Java IF statement (see *Figure 13: Attempted dynamic feedback function*) to assign the risk of relapse based on the value from 'Management_of_Diabetes', stating if people are managing their diabetes in a higher range, then the risk is lower, and vice versa. Even after verifying the language and format of the code, according to Java language, the syntax was correct, but due to the version of the software, I was unable to perform such functions. Reason for this is that I was using a Personal Learning Edition (PLE) because the premium is too expensive.

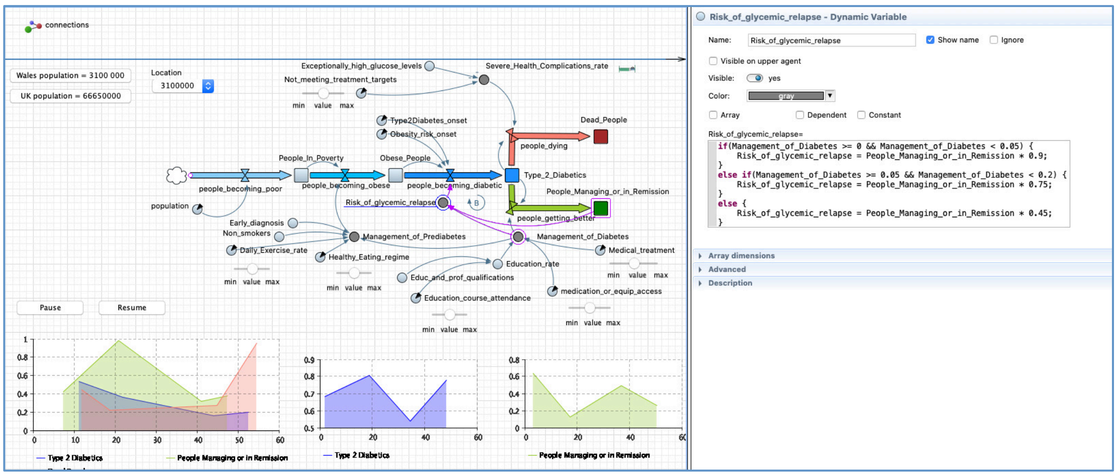

Figure 12: Attempted dynamic feedback variable

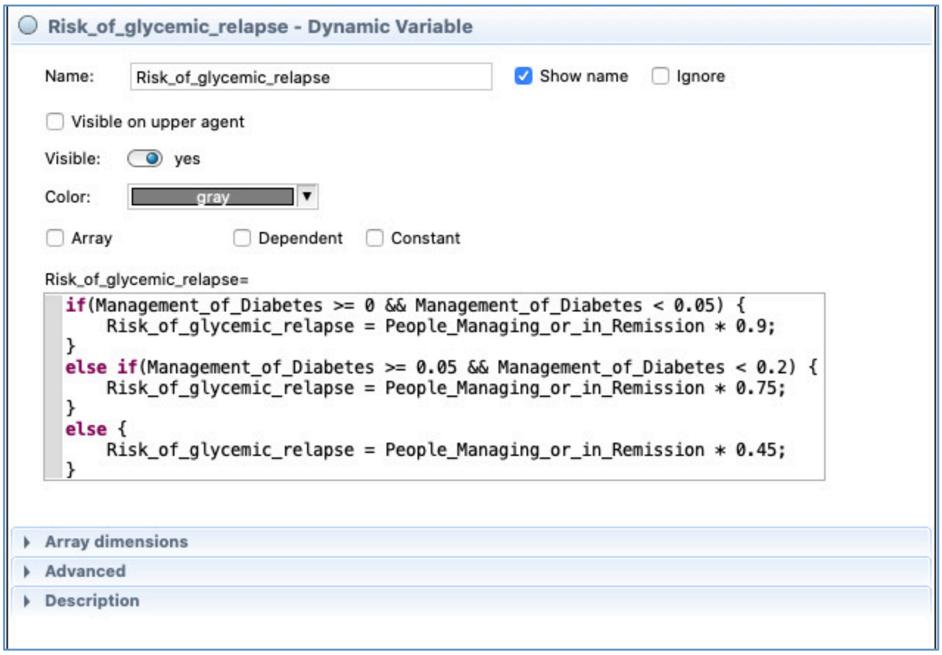

Figure 13: Attempted dynamic feedback function

8.7 Simulations

The next and ultimate phase to complete the system modelling and therefore the project was to simulate the quantified model. Running the simulation enables the user to interact with the model, pause and resume, speed up, change variable values, and all of that whilst seeing its effect over 60 years on graphs of the prevalence of Type 2 Diabetics, People Dying and People Managing or in Remission (see below *Figure 15: Annotated diagram of simulation and its features*).

The entity of the simulation was to perform a What-If analysis (see *Section 9.1 Results*) and measure the effects of variables changes, allowing for an exploration of policy actions and interventions to recommend to NHS Wales.

There is a built-in button in AnyLogic PLE software to run the simulation, which opens a new idle window (see *Figure 14: Simulation Idle*).

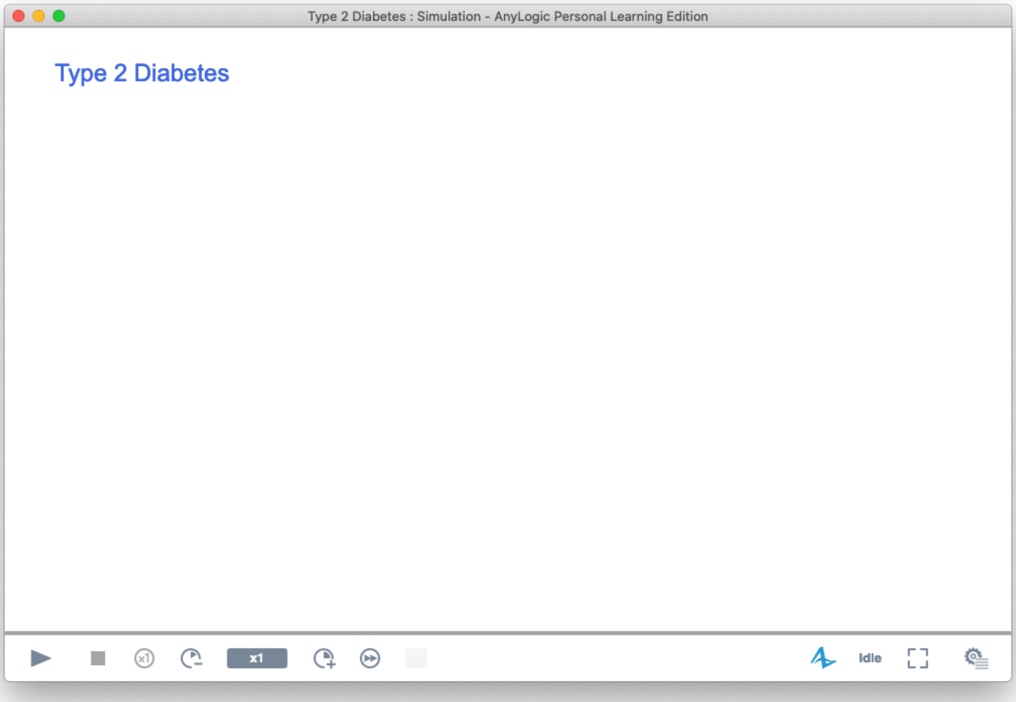

Figure 14: Simulation Idle

Figure 15: Annotated diagram of simulation and its features

All Java code of the model and simulation has been added in the submission as an external .rtf file, 'main.rtf' & 'simulation.rtf'.

9 Results & Evaluation

In this section I will be performing a what-if analysis on the model and simulation, documenting the results and evaluating the project's completion and success against the success criteria. This section will express to what extent each success criteria was achieved, demonstrating to what degree the system works as intended, allowing us to see the overall success of the project.

9.1 Results

In the Results section, I will be discussing some of the results of performing a what-if analysis on the simulation. The ultimate goal of any medical condition is to understand what factors (variables) in the system make it better, aiming towards controllable reduction and elimination, to decrease the number of patients. This is why I have implemented sliders in the model (see *Figure 15: Annotated diagram of simulation and its features*), which allow the user to dictate what value the variable is. Such user engagement will illustrate the results of the what-if analysis. I will be performing 3 types of what-if analysis, effect of single variable changing, group of variables changing and geographical scope changing.

9.1.1 Effect of single variable changing

As there are 6 slider variables and I have chosen to get the simulation for 3 values (minimum, maximum and middle), this means there are 6 * 3 = 18 results of simulation screenshot. I have chosen to include 1 variable and its 3 different slider values, which is 'Healthy_Eating_Regime'.

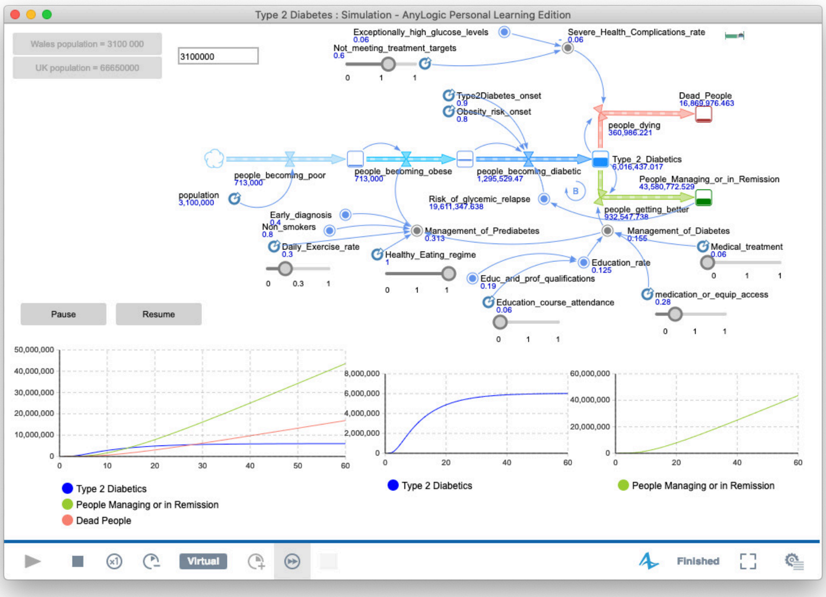

Figure 16: Healthy_Eating_Regime maximum slider value (1)

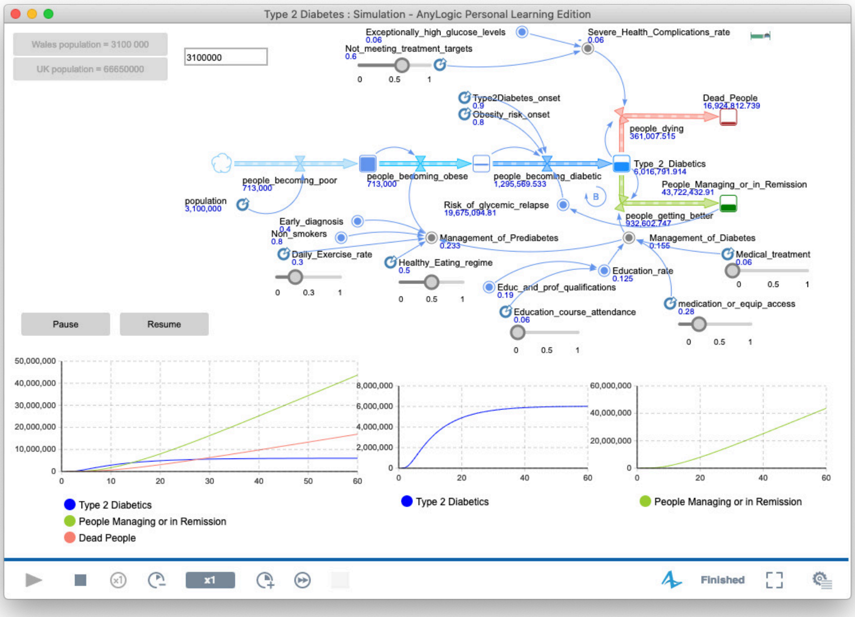

Figure 17: Healthy_Eating_Regime middle slider value (0.5)

Figure 18: Healthy_Eating_Regime minimum slider value (0)

All the above three figures present the same behaviour of the simulation. This result proves that a single variable change, does not have a significant effect on 'flattening the curve' of Type 2 Diabetes prevalence. This behaviour of changing the slider value for each variable remains in all the remaining variables (see *Appendix 2*)

9.1.2 Effect of group of variables changing:

Only selected groups were chosen to perform the what-if analysis of the group variable changes. This is because 6 variable sliders can be changed to any value, and as I showed, for the results of single variable changes (see *Section 12.1.1 Effect of single variable changing*) it would be a very large amount of outcomes to perform the Results screenshot for all the combinations. Specifically, to calculate the number of outcomes possible, I will take into account that there are 6 (n) variables possible to change with the assumption it can be 3 (k) different values (minimum, maximum and middle value). As the order is not important and repetition is allowed, this will be calculated as a combination with repetitions:

$$C'_{n,k} = \frac{(n+k-1)!}{(n+k-1-k)!\,k!}$$

$$C'_{n,k} = \frac{(6+3-1)!}{(6+3-1-3)!\,3!}$$

$$C'_{n,k} = 56$$

This means that if I wanted to show the combination of every changing variable with the other changing variables, I would be analysing a large number of outcome results. If I had increased the number of value per variable, it would only get larger.

This means that I have chosen to focus on 2 situations of group variables changes, (see *Appendix 3* for the 2nd situation):

As the next step of my what-if analysis, I have chosen to keep variables from ‘Management_of_Prediabetes’ constant at 0.75 value & variables from ‘Management_of_Diabetes’ increasing and decreasing showing fluctuating effects on ‘Type_2_Diabetics’ and ‘People_Managing_or_in_Remission’. The fluctuating behaviour was started from the variables of ‘Management_of_Diabetes’ at default going up to a value of 1, which showed a slowing graph effect in diabetics & increasing effect in people managing. Then I changed all those variables to a value of 0, which showed an increasing graph effect in diabetics & slowing effect in people managing. Finally, I changed all those variables to a value of 0, which showed decreasing graph effect in diabetics & increasing effect in people managing, to lastly to a value of 0.5 for a slow increase.

The portrayed behaviour (see *Figure 19: Grouped Management of Diabetes variables changing*) shows how a grouping of variables affects the prevalence and management of diabetes. It highlights that there is no ‘silver bullet’, not one singular policy that will create such an impact that, a grouping of policies can. When I address a ‘policy’, I am addressing a way to influence a variable to change. So in these findings, if the grouping of variables in ‘Management_of_Diabetes’ creates such an impact, then policies need to be introduced to every variable within that group to affect the system behaviour. The goal of such policies would be to ‘flatten the curve’ of the Type 2 Diabetes prevalence.

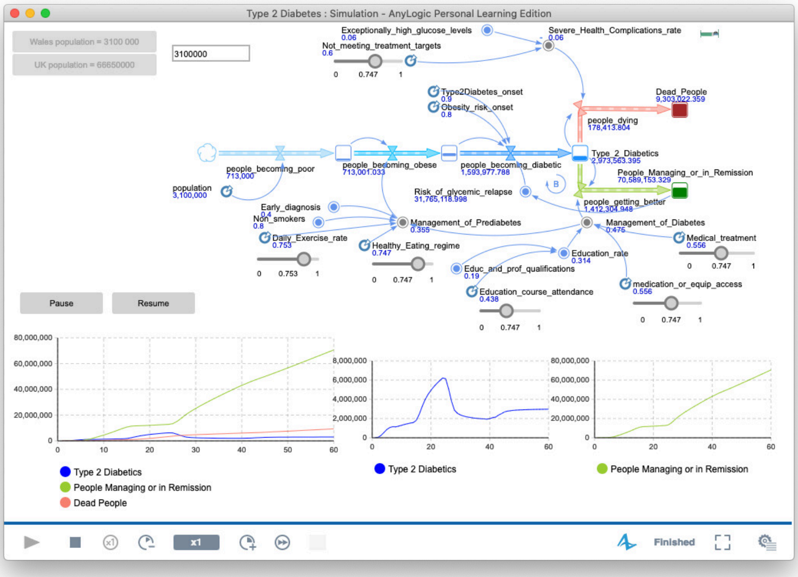

Figure 19: Grouped Management of Diabetes variables changing

9.1.3 Effect of the geographic scope changing

The below figures of the UK (see *Figure 20: UK default simulation*) vs. Wales (see *Figure 21: Wales default simulation*) population change still keep the same trend and behaviour. The population value is the initial input into the model and therefore is a constant. In this project, due to the inability to receive NHS Wales's data, we are not judging the model and simulation based on its numbers, but based on its trends.

In the figures below, I have identified that the graph trends in the 2 simulations show the same correlation. As we are performing a what-if analysis, if we change the population scope in the Combo Box (see *Figure 15: Annotated diagram of simulation and its features*) then the result demonstrates the effect of different numerical values, but the same trend. This trend proves the validity of the model, that no matter the inflowing population value, the graph behaviour will remain consistent.

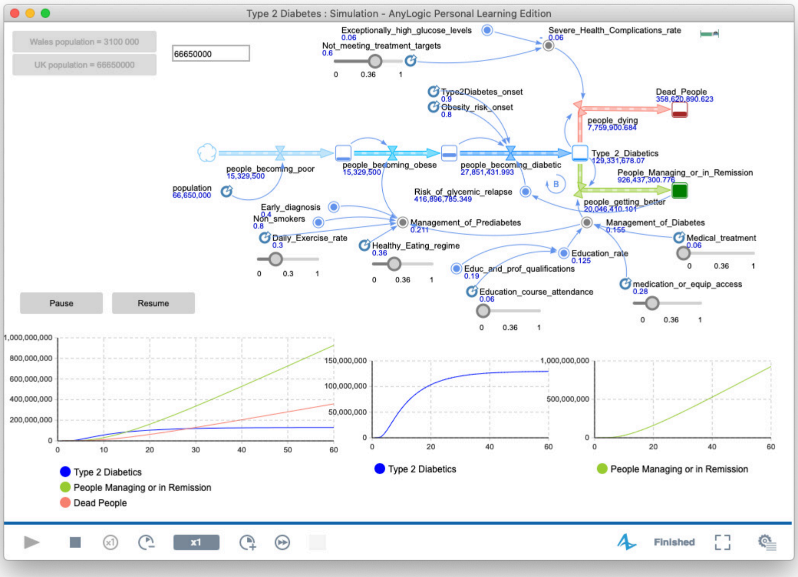

Figure 20: UK default simulation

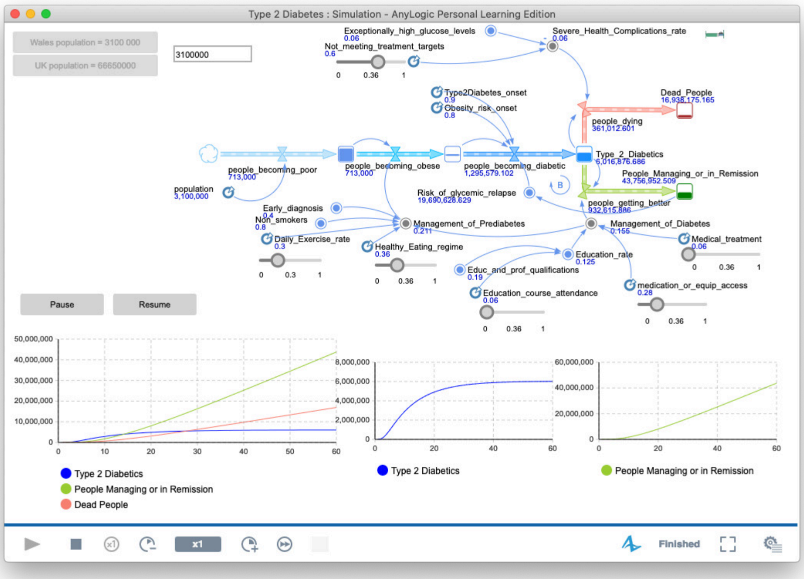

Figure 21: Wales default simulation

9.2 Evaluation

To correctly and critically evaluate this individual final year project, I will be moving on from the results and using my defined success criteria (see *Section 7.6 Success Criteria*) to measure the project's success, its strengths and weaknesses.

In the following sub-sections, I will be evaluating each success criterion based on the outcome and deliverables of the project.

9.2.1 Success Criterion 1: Approach and methodology

The first success criterion is:

⇒ Appropriate approach and use of selected methodology, to full degree.

Over the entirety of the project, I have selected and approached the problem of creating system modelling through System Dynamics methodology. From the initial discussions on the project and attending two crash courses on the methodology approach, I was on track with System Modelling through System Dynamics, following the creation of the qualitative model and then the quantitative model to create a simulation of behaviours. As exclaimed (see *Table 1: Success* Criteria) the measurement of success for this was to get my technical advisor's feedback, Dr Catherine Teehan, on my progress within the methodology, to best tackle the problem. The regular presented progress and received feedback would ensure I am successfully approaching the problem and choosing the correct methodology and tools.

One setback I would like to evaluate as a weakness was the SD software selection process. I performed a comparative analysis of the most relevant and popular software tools, allowing me to understand how the cost works, the features allowed for free versions, and its visual representation. Once I made my selection on Vensim, it was only then I concluded with my technical advisor that a web-based software would be more effective to share the qualified model and get feedback, leading to the switch to InsightMaker. However, when it came to creating the quantified model, the visual representation of the simulation and the features were not as good as AnyLogic, leading to another switch. Since I was new to all the software and had a broad understanding of their features, it was only with time I discovered the features it was missing that I was requiring.

For a full round evaluation, from continuously receiving feedback, I was approaching system modelling appropriately and guided correctly to using System Dynamics methodology to its full extent of creating the 2 models and a simulation. The lesson learnt for future work would be to spare more time to get comfortable with the software tools and more extensively understand which one suits me the most, rather than changing and having to get comfortable with a new tool.

9.2.2 Success Criterion 2: Qualitative model

The second success criterion, meeting the first model deliverable, is:

⇒ Qualitative model shows fair assumptions with proof to justify causality and polarity.

After the creation of Mind Map, creating a Causal Loop Diagram became much simpler, as I had my thoughts laid out. It allowed me to correctly explore the variables in the diagram and make causal links and connections. As exclaimed (see *Table 1: Success* Criteria) the measurement of success of this success criteria was whether the assumptions are justified with the highest truth degree and discovered loops are correctly visualised.

Primarily to address the justifications of assumptions, I have documented all causal links (see *Section 10.4 Table of Relationship Justifications*) and evidenced their truth (see *Appendix 1: Table of Justifications list*). For the majority of causal links, I successfully presented the evidence of a valid assumption, such as the 3rd row saying that 'Smoking has positive correlation onto Severe Health

Complications' which was justified by a quote from an article by Das in 2003. On the other hand, the number of Google Scholar searches only supported the justification of 'Number of health food stores having a positive correlation onto Regular Healthy Food Purchase'. Such evidence was the only source available, but I do believe that the number of results with such search proves the correctness of such correlation, even if there is not an explicit quote. There have been a few justifications where this was the case showing a weakness in truth degree, but this limitation will have to be taken into account.

In regards to the correct visualisation of the loops, I followed the CLD loop identification principles to correctly identify their direction and whether they are balancing or reinforcing. The acquired list of loops (see *Figure 8: List of Model* Loops) from the InsightMaker model has been done directly through the software feature, proving its correctness.

Overall, to evaluate this success criterion, I deem it was met to the highest degree possible of about 90%. For future improvement, I would ensure to only include variables in the model for which I can gain explicit evidence and not base it on the assumptions of Google Scholar results.

9.2.3 Success Criterion 3: Quantitative model

The third success criterion, meeting the second and final model deliverable, is:

⇒ Quantitative model enables input of data, and visualises simulations through graphs.

The creation and completion of this goal was half successful. The first point suggests that the quantitative model should have allowed for the input of data, however, due to the COVID-19 pandemic and reasons explained (see *Section 9.1 Week Log*) the model visualises a graph trend from statistics and facts found online. As I was unable to receive data from NHS Wales to input into my model, I had used online statistics and figures to best represent the correct behaviour and trend of the model. As an additional creation to overcome the missing presence of large datasets within the model, I added sliders to some variable to perform What-If analysis (see *Section 12.1 Results*). This meets the measure of the criteria to allow for 'user interaction'.

The second aspect of this criterion's completion indicates that the model should visualise simulations through graphs, showing their trend and behaviour. To evaluate, this was successfully met as the figures in the What-If analysis (see *Section 12.1 Results*) display both the quantitative model and graph simulation showing changing behaviours as the variables are altered by the user.

To summarise, this criterion was met to about 75%, as the only aspect left undone was to have inputted NHS Wales's data rather than online statistics. However, due to the current situation, this criterion was delivered to the best of its ability.

9.2.4 Success Criterion 4: Trend for different geographical scope

The fourth success criterion, explaining the simulation behaviour, is:

⇒ Simulation shows the same trend (correlation) for different geographical data focus i.e. UK vs. Wales vs. different regions in Wales

The goal of this success criterion was to deliver different geographical scopes, preferably three, when running the simulation and show that the same graph behaviour verifies the successful accuracy of the model. The quantified model and simulation visualises the presence of selecting different populations, as an inflow to the model; either Wales or the UK. All the statistics in the variables were taken in the scope of Wales and the UK, as it was not retrievable for Wales' regions.

One of the geographical scopes, different regions in Wales, was not able to be included in the model because, as mentioned, the statistics found online were specific to the UK and Wales scope. When requesting what exact data to receive from NHS Wales, I specified to include it for the 3 planned geographical scopes, which would enable to complete this success criterion. However, as explained previously, the inability to receive data meant I had to find another way. The additional constraint of time meant that I did not include it in the model and only delivered 2 geographic scopes (see *Section 12.1.3 Effect of changing the geographic scope*).

These scopes, Wales versus the UK incoming population, proved a consistent trend and correlation was presented in the model for 2 out of 3 geographical scopes, evaluating the success of this criterion to 67%. For future work, the weakness that will be essential to improve is to input NHS Wales's data into all the variables and create functions to pick the data if it is running a Wales simulation, or the UK simulation.

9.2.5 Success Criterion 5: Recommendations

The fifth success criterion is:

⇒ 2 interventions/polices recommended through system modelling and simulation results = 2 recommendations provided to NHS Wales.

To exemplar, the completion of this success criterion was more difficult because of the constraints presented in the project of not receiving data.

The policy/intervention I had discovered through my project and findings was that NHS Wales should not focus on one specific policy as presented in the results (see *Section 12.1 Results*), influencing one variable only causes little or no behaviour change. Instead, they should:

1. Focus on addressing a multiple variable policy, rather than singular policy.

As shown in Results, changes in multiple variables causes much more prominent fluctuating behaviour, proving there is 'no silver bullet' but a group force. This recommendation will be added to the research agenda (see *Section 13 Discussion & Future Work*), which will present the future focus opportunity with this project.

There is no second recommendation because of the potential risks that can arise from recommending a precise policy without thoroughly testing its effects. As the project was focused on providing an initial problem analysis, the next step in future work would be to test the impact of policies and fully test it when providing the policy actions to NHS Wales. At this moment I was only able to provide one policy action, because it has already shown a reliable trend, and it will be added to the research agenda. If I provided a policy action without testing, it could have unknown third factors influencing its behaviour resulting in a 'fix that fails'. This means that I would have identified a policy action based on the moment, however, the lack of testing and broad-spectrum could lead it to not solve the problem and cause no desired effect.

To evaluate, I do strongly believe it is essential for NHS Wales to create and trial a new strategy of introducing policies collectively, with first testing it and proceeding to more research from this project. Rather than having organisations and individual movements creating singular policies, gather the forces and group policy changes all at once. That way, there could be a more vivid and pronounced positive effect onto the system, as the results of the simulation express. Additionally, it has become clear that delivering several recommendations and evaluating the response on them from NHS Wales was an optimistic outlook onto the project. The entity of this project was the preliminary exploration of issues, the problem analysis, with no time and capacity to also test the effects of recommended policy actions.

The completion of the success criterion has been rated to 50%, because 1 policy was successfully recommended based on the findings.

9.2.6 Success Criterion 6 [stretch]: NHS Wales feedback

As a part of the success criteria for this project, the final success criterion was to:

⇒ Receive feedback from NHS Wales, whether any interventions are helpful to them and their future operations.

Originally this was a necessary objective to receive at the end of the project because it was being done for the NHS Wales to make use of the project result and models. However as the COVID-19 world pandemic came into light, this was re-evaluated to be a 'stretch' objective instead, which mean it was 'nice to have' if time and effort allowed it. It was an appropriate choice to make it a stretch objective given the world situation, allowing me to present that it was an intended success criterion but could not be met due to unforeseen circumstances.

Unfortunately due to the pandemic, NHS Wales had to re-prioritise and focus all its efforts on the situation. This was the reason why I was unable to receive their data and had to find my statistics and trends online. At this point, the stakeholder, NHS Wales, was in no position to have a meeting to review my project and give me feedback on presented interventions. To evaluate this means that the stretch success criterion 6 could not be met.

10 Discussion & Future Work

10.1 Discussion

To conclude this part of the project, it was an overall success with some incompletion as justified in the Evaluation. I will rephrase the aim as identified in the Introduction, and the aim was to "build a model and simulation to help pinpoint the problem zones & bottlenecks in the healthcare system of Type 2 Diabetes". Summarising from the results and evaluation, in this project I have build 2 models, qualitative and quantitative, along with a simulation all of which identify and pinpoint the problem zones in Type 2 Diabetes. For the qualitative model, I have identified the problem zones through reinforcing loops, which further allowed me to build my quantitative model that identified the problem zones in singular policy action.

The one recommended policy action I have drawn from the system model behaviour was:

1. Focus on addressing a multiple variable policy, rather than singular policy.

This policy recommendation will be added to the research agenda, which sets a vision for future work and study into 'Exploring and Assessing Policy Actions of Type 2 Diabetes for NHS Wales'. This project cannot be concluded because of its on-going research into the field and improvements. The problem analysis results and evaluation end this chapter in this project, opening the doors for a broader and deeper exploration into the models and testing the impacts of policy implementations.

Such recommendation should be trialled to see their effect, which has the potential to take years as Type 2 Diabetes onset and management takes years to show. This is mainly due to the lifestyle implications it holds, and comes to my concluding point that it all comes down to what we put into our body. As the metaphor stands "if you put the wrong fuel into a car, it will break down. If you intake wrong and unhealthy substances into your body, your body will try to fight it until it cannot, which leads to developing medical issues".

10.2 Future Work

Due to COVID-19, this project was affected by not being able to receive data from its intended source, NHS Wales, to show fully numerically accurate models and simulation. It holds a lot of potential to take the System Modelling project on where it has left off and re-engage with NHS Wales once they can assist.

As shown, it has come to the end of the project and it was completed with success but not to its full scope. The unrealised idea that would be a great next stepping stone is to make the variables within the model more dynamic, as intended (see *Figure 12: Attempted dynamic feedback variable*). Working on this project, I see the immense potential System Modelling holds, and how applicable it is to Computer Science as the degree's principle is not to re-invent, but rather better utilise its resources. I believe that System Modelling uses techniques for more effective and dynamic understanding of complex systems, and would be of great use to future students in this field.

If this project were to be taken on board to continue, it would be essential to gain access to the full version of AnyLogic as it holds more important functionalities. This would allow for greater testing of the policies within the research agenda and guide the impact analysis to larger and broader depths.

11 Reflection on Learning

As this is the end of the Final Year Individual Project, I believe reflecting is an essential part of every piece of work. This is true with any form of studying, working and various activities, to always keep in mind the concept of 'What can I take away from this?', 'What have I learned?' and 'What would I do same/different next time?'.

First and foremost, the biggest learning curves of the entirety of this project were self-discipline, motivation and research. All of these necessities link together into a progressive project. From reflection, there were points in time where it became difficult to uphold the motivation and discipline. This happened at the beginning of the project, it was a completely new topic to me and therefore took longer to get into a clear mindset, enabling me to identify the ideal plan of action. With the project's progression, I got more comfortable in Systems Modelling and Diabetes. The struggle of motivation and discipline reappeared with the COVID-19 pandemic and such world crisis is unpredictable and therefore was not included in the time/risk plan. I had to relocate back home, bringing a lot of uncertainty into the present and future, taking my focus away from other priorities. With such situations, I have learned that it is inevitable; the help is always available and how important it is to create a proper new routine. Next time I would make sure to build a more prominent working space, create an hourly time plan in the weekdays and allow for rest over the weekends. The positive effect of the outbreak was that it allowed me to see the real reason why projects like this are critical, as discussed in *Section 8.1 Sketch The Problem*. The main negative effect of the outbreak is the next reflection I will like to discuss.

The dependency of receiving data from a client and with that communicating via a third party proved to be difficult. NHS Wales, the client, had an understandable change of priorities because of the COVID-19 pandemic and thus could not provide me with the requested data. From the initial plan, I had included a Plan B if I did not receive the data, which did ultimately prove to be a great backup that was utilised. I am very happy with the outcome of the Plan B and risk assessment, as it showed my preparation. Regarding the dependency of communicating with NHS Wales via a third party was originally out of my control. The third-party was in direct communication with NHS Wales, which caused me to decide to not need that direct communication and use my contact. From this, I have learned that next time I will need to be directly involved in the communication to eliminate any risk of delay, chasing and miscommunication. I have learned that it is beneficial to be in control of having that direct communication and not relying on people if reminded.

An area that connects to my first reflection is the fact that previously I never studied System Modelling, making it a completely new field of knowledge. The main fact was that I had a high interest in Data Science, Data Modelling, Business Analysis, increasing my interest and motivation towards the project. The main reflection I gained from tackling a field where I am lacking knowledge in is to have technical support; in my case, I was fortunate to have a technical advisor, Dr Catherine Teehan, to give me technical feedback and guidance. Furthermore, given the global pandemic, only online communication was allowed in the world and with it came the adaptation to share my work online and receive feedback online as well. This reflection had shown me how well I have handled it, ensuring weekly supervisor meetings were held on Microsoft Teams or a 'progress' update email was shared. On another note, the adaptation to carefully choosing a web-based SD software became essential for this online communication. As there came a point where the quantified model and simulation were built on downloaded software, I was able to directly share it with my advisor easily, however, my supervisor did not have the software, therefore, screen sharing accomplished the same result.

Lastly, the most prominent reflection was related to issues with technology and computer performance. This struggle came unexpectedly when my laptop which had the downloaded software began failing upon performance. Due to space and its age, I was occupied for 2-3 days attempting to clear up space, backing up and ensure for normal performance. This issue would not be as vast if it were not for COVID-19, because in such case I would be able to come to the university labs and work from there. This reflection taught me the importance of all risk planning, even if it is very unlikely it is good to have a Plan B in every situation. I handled the situation head-on and not risking any loses of doing a factory reset.

All projects/situations in the world have their ups and downs, it comes down to how we choose to approach it and tackle it. What this 15-week project has taught me is that it is always better to be over-prepared and to build a solid routine with regular motivation goals. From discipline, through technical issues, to dependencies, I can say I completed the Final Year Individual Project with success and will aim to actively learn from my mistakes to only increase the list of my successes.

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13 Appendices

13.1 Appendix 1

Factor 1	Polarity	Factor 2	Justification of individual factors	Reference to evidence
Smoking	Positive (+)	**Type 2 Diabetics**	Assumption stating that smoking will also increase the risk and chances of developing Type 2 Diabetes.	1,300,000 results of Google Scholar on the 'positive correlation between smoking and Type 2 Diabetes.'
Smoking	Positive (+)	**Severe Health Complications**	"It reduces the life expectancy among smokers. It increases overall medical costs and contributes to the loss of productivity during the life span. Smoking has shown to be linked with various neurological, cardiovascular, and pulmonary diseases. Cigarette smoke not only affects the smokers but also contributes to the health problems of the non-smokers."	(Das 2003)
Type 2 Diabetics	Positive (+)	**Education Programme attendees**	"National Diabetes audit data shows that as few as 12% of people with Type 2 diabetes are offered structured education with only 2% taking up the offer." - Positive causality of more people becoming diabetics means the more attendees.	(Structured_Education_Toolkit_Final.pdf. [no date])
Education Programme attendees	Negative (-)	**Smoking**	The assumption that increasing attendance of education programmes, explaining the risks of smoking for Type 2 Diabetics, will cause a decrease of smokers.	(Help with giving up smoking. 2020)

Education Programme attendees	Negative (-)	**Regular alcohol drinking**	The assumption that increasing attendance of education programmes, explaining the risks of alcohol drinking for Type 2 Diabetics, will cause a decrease of regular alcohol drinkers.	(Alcohol and diabetes. 2020)
Education Programme attendees	Negative (-)	**Sleep Deprivation**	The assumption that increasing attendance of education programmes, explaining the risks of sleep deprivation for Type 2 Diabetics, will cause a decrease of sleep deprivation.	(Expert urges more sleep to reduce type 2 diabetes risk. 2017)
Education Programme attendees	Positive (+)	**Successful diet/physical activity care planning**	"All people with diabetes should receive personalised advice on nutrition and physical activity from an appropriately trained healthcare professional or as part of a structured educational programme". - Assumption that RightCare Pathway meets the care planning targets.	(Public Health England et al. 2018)
Education Programme attendees	Positive (+)	**Vegetarians/ Vegans/Plant-based**	"There are many facets or components of a plant-based diet that might confer benefits on glycaemia and, more specifically, on blood lipids." & "Vegetarian diets have been shown to be beneficial for people with Type 2 diabetes where weight loss is often the most effective way to manage the condition." Proving the need for diet to increase weight loss management, "NHS introduce 800 calorie liquid diet to tackle the growing type 2 diabetes crisis"	(Jenkins et al. 2003) (Vegetarian diets and diabetes. 2020) (McGee 2020)
Vegetarians/	Negative	**Obese people**	"Vegetarian diets have been shown to be beneficial	(Vegetarian diets and diabetes.

Vegans/Plant-based	(-)		for people with Type 2 diabetes where weight loss is often the most effective way to manage the condition."	2020)
Successful diet/physical activity care planning	Positive (+)	**- Successful diet/physical activity regime** **- Motivation to get better**	"The frequency of care planning should be based on individual need. There should be an annual care plan review every 12 months for everyone with diabetes. This should be an on-going process for the life time of the condition."	(Public Health England et al. 2018)
Motivation to get better	Positive (+)	**Psychological support session attendance**	"Motivational interviewing is a useful tool for clinicians in all therapeutic interactions to help motivate patients to seek assistance for mental health issues"	(Lawrence et al. 2017)
Successful diet/physical activity regime	Negative (-)	**Obese people**	"Health Challenge Wales signposts members of the public to information or activity to help them improve their own health including tips on Food and Fitness." One of the existing programmes to tackle obesity through diet and physical activity.	(Wales 2006b)
Obese people	Positive (+)	**Type 2 Diabetics**	"Obesity is responsible for 80 to 85% of someone's risk of developing Type 2 diabetes."	(Facts & Figures. 2019)
Type 2 Diabetics	Positive (+)	**Mental health struggles**	"Three in five people with diabetes experience emotional or mental health problems"	(Diabetes UK 2017)
Mental health struggles	Positive (+)	**Stress levels**	"Some of the emotional and behavioural symptoms of stress overlap with those of mental health conditions like anxiety or depression. This can make it hard to distinguish where one begins and	(Crannage 2018)

			the other ends, or which came first." -Studies depict a clear causal relationship between stress and mental health, which plays up both ways; if one is struggling more with anxiety, it will make them more stressed to get better	
Stress levels	Positive (+)	**Severe Health Complications**	"Oxidative stress plays a pivotal role in the development of diabetes complications, both micro vascular and cardiovascular."	(Giacco Ferdinando et al. 2010)
Living in poverty	Positive (+)	**Stress levels**	"Our results indicate that poverty-related stress directly predicts internalizing symptoms (i.e., depression and anxiety) across age groups, while externalizing problems including delinquency and attention problems are exacerbated by poverty-related stress across time." Depicting there exists stress-related poverty, the causes of poverty uncertainty to stress.	(Santiago et al. 2011)
Type 2 Diabetics	Positive (+) Negative (-)	**- Need for healthcare resources** **- Availability of healthcare resources**	The more patients with Type 2 Diabetes there are, the more effort the healthcare systems need to provide (in terms of the need for resources i.e. nurses, specialists), however, the less of availability there is due to a slower growth of staff and resources increase. Depicting need and availability: "28% of people needed to see a specialist diabetes team during their hospital stay but didn't."	(Facts & Figures. 2019)
- Need for healthcare resources	Positive (+)	**Waiting list to access healthcare**	The more struggles arise with lack of availability due to high need, causes a longer waiting list. Example fact:	(Facts & Figures. 2019)

- Availability of healthcare resources		**resources**	"Less than two-thirds of people with serious foot problems have a proper foot check within 24 hours of being admitted to hospital."	
Waiting list to access healthcare resources	Negative (-)	**Patients receiving care**	From previous justification with the foot problem example, the evidence proves that the growing hospital admissions cause less availability for treatment.	(Facts & Figures. 2019)
Severe Health Complicatio ns	Positive (+)	**Deaths**	"All complications independently predict mortality in patients with type 2 diabetes. There is an increased risk for mortality as the degree of each complication worsens."	(Cusick et al. 2005)
Severe Health Complicatio ns	Positive (+)	**Cost of treatment**	"Almost 80% of the money the NHS spends on diabetes is on treating complications."	(Facts & Figures. 2019)
Cost of treatment	Positive (+)	**Living in poverty**	"About 23 per cent of the patients had to borrow from friends or family, 30 per cent sold an asset and 36.8 per cent used their savings to pay for the costs of diabetes care. Much of the high cost was attributed to lack of care at the nearest facility, long waiting times and high cost of medicine."	(Gathura 2019)
Living in poverty	Negative (-)	**Access to treatment**	"The researchers found that 19% of the patients said they had trouble affording food; 28% said they had problems paying for medications; 11% had problems paying for a place to live, and 14% had difficulty paying utility bills. Nearly 40% of those surveyed had difficulty paying for one of these needs, the researchers found."	(Poverty makes diabetes care tougher. 2016)

			The causal relationship relies on access to treatment in more forms; medications, hospitals, public transport cost to get there, knowledge about it etc.	
Access to treatment	Negative (-)	**Type 2 Diabetics**	The causal relationship shows that the less early diagnosis and availability of treatment handling Pre-diabetes, can lead to Type 2 Diabetes. This assumption means that with treatment there is less risk of having diabetes. “More than half of all cases of Type 2 diabetes could be prevented or delayed.”	(Facts & Figures. 2019)
Living in poverty	Negative (-)	**Regular healthy food purchase**	“The researchers found that 19% of the patients said they had trouble affording food”, nevertheless affording ‘healthy’ food.	(Poverty makes diabetes care tougher. 2016)
Health food stores	Positive (+)	**Regular healthy food purchase**	A simple causal relationship where there is more choice of healthy food stores, there will be a higher urge to see what new is on offer and therefore will be more purchase. There is also the argument that in a market economy, if there is domain then the market will supply. However, this specific relationship depicts that the presence of healthy stores causes the chance and exploration to purchase.	87,300 results of Google Scholar on ‘health food stores positive correlation to purchase’.
Advertiseme nt of fast food	Negative (-)	**Regular healthy food purchase**	“More than half of the food presented in television advertisements was rich in fat and sugar. Children ask their parents to buy the goods they see on television advertisements both while watching television and while shopping. Television advertisements especially affect young children's	(Arnas 2006)

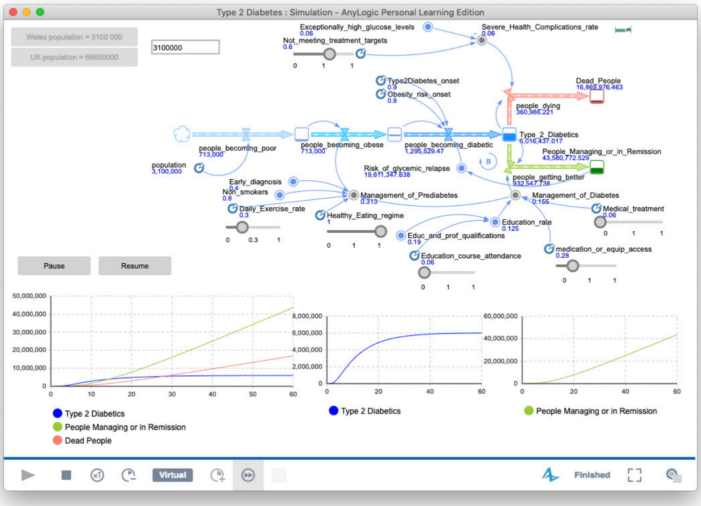
			unhealthy food consumption."	
Regular healthy food purchase	Positive (+)	**Successful diet regime**	Assumption stating that the more purchase of healthy food will also increase the regime of a healthy diet.	193,000 results of Google Scholar on 'higher healthy food purchase causes better eating'.

Appendix 1: Table of Justifications list

13.2 Appendix 2

⇒ Variable: Healthy Eating regime

- Max value



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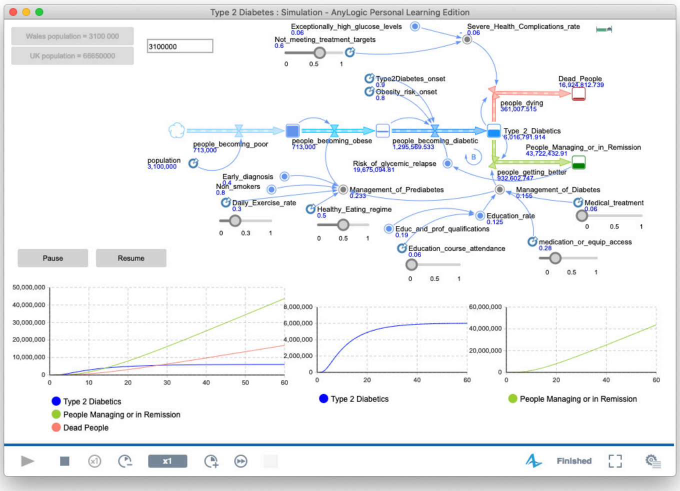
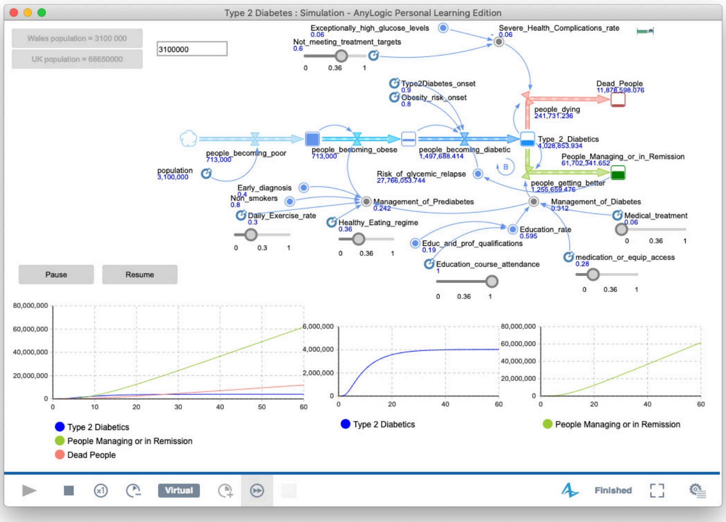


- Min value

⇒ Variable: Education course attendance

- Max value



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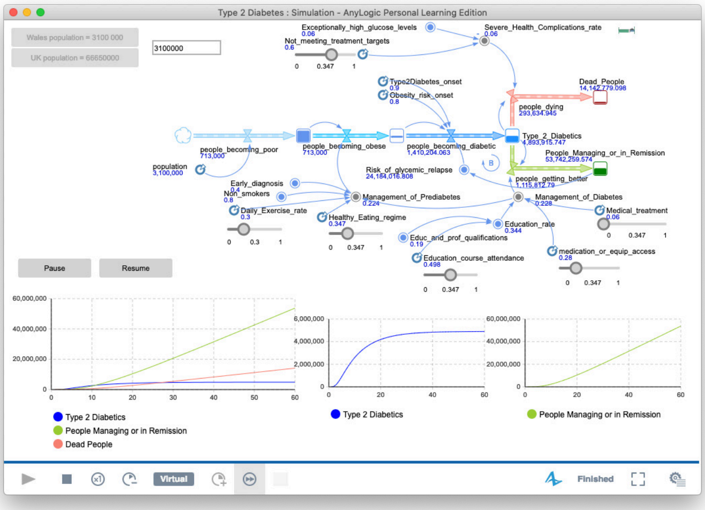
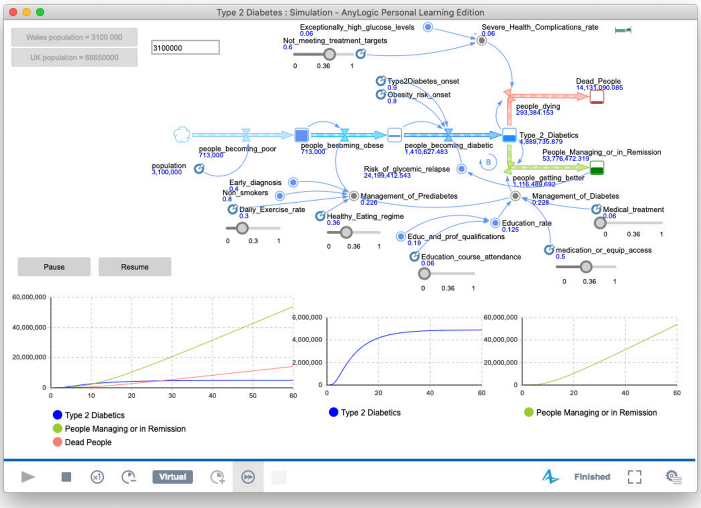


- Min value

⇒ Variable: Medication/Equipment access

- Max value

- Middle value



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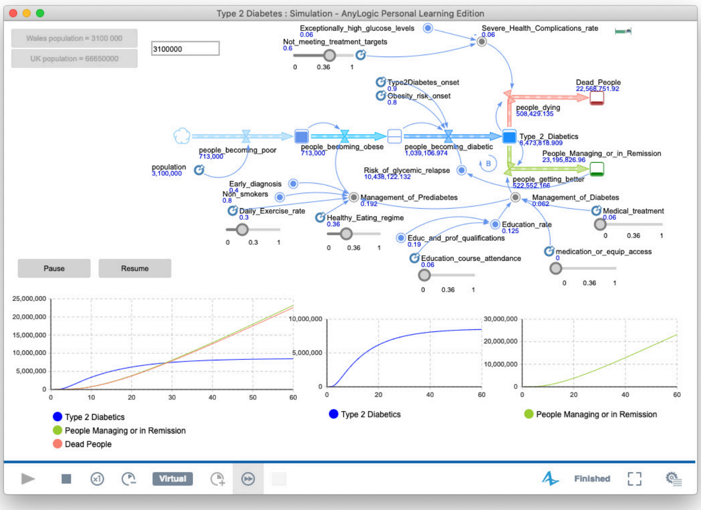
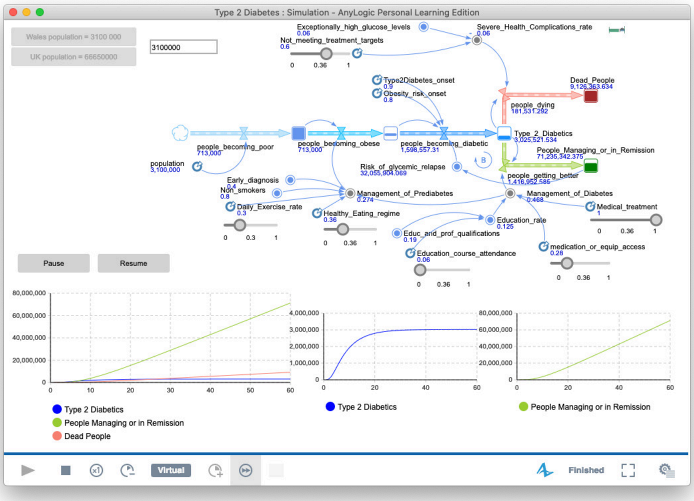


⇒ Variable: Medical Treatment

- Max value



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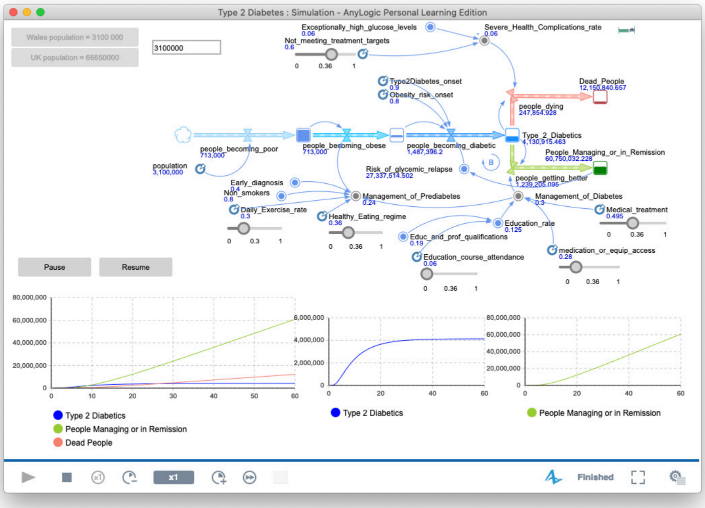
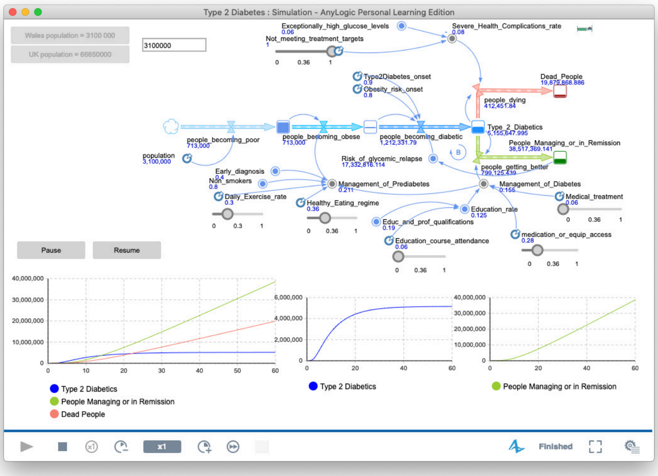


- Min value

⇒ Variable: Not meeting treatment targets

- Max value



- Middle value

- Min value

13.4 Appendix 3

Variable 3, 4, 5: Management of Diabetes = at 0.5 rate constant & Variable 1 & 2: Management of Pre-diabetes increasing and decreasing showing fluctuating effects (from rate 1, going down and then back up).