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REFLECTIONS ON TWO APPROACHES TO HYBRID SIMULATION IN HEALTHCARE

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ABSTRACT

Hybrid simulation, the combination of simulation paradigms to address a problem is becoming more popular as the problems we are presented with become more complex. This is evidenced by an increase in the number of hybrid papers published in specific domains and the number of hybrid simulation frameworks being produced across domains. This paper focuses on two hybrid simulation models from a healthcare context. The first uses system dynamics and discrete-event simulation and was developed using two separate software tools (Vensim and Simul8). The second uses agent-based and discrete-event simulation and was developed in a single software environment, Anylogic. The reflections on these models add to the debate about the viability of hybrid modelling and suggest future steps to support the take up of the approach.

1 INTRODUCTION

This paper reflects on two hybrid simulation model case studies developed to gain greater insight into complex healthcare operations management situations. Hybrid simulation models were constructed due to limitations of individual simulation approaches to address the two case studies presented. Two different approaches were used to develop the models. The first model of Chlamydia transmission and screening was produced by combining two commercially available packages, Simul8 (http://www.simul8.com/) which specializes in discrete event simulation (DES) and VENSIM (http://vensim.com/) which specializes in the system dynamics (SD). The second model of the eye condition Age Related Macular Degeneration (AMD) utilized the multi-paradigm simulation software AnyLogic (http://www.anylogic.com/). The contribution of this paper is the systematic characterization of the issues involved in integrating models with different formalisms.

The paper is structured as follows: section 2 provides background information about hybrid simulation modelling; sections 3 and 4 provide details about the two case studies, in particular which paradigms are combined and how; and section 5 reflects on the two case studies and concludes the paper.

2 BACKGROUND

Hybrid simulation is typically the combination of DES (Law and Kelton 2000), SD (Forrester 1961) and Agent Based (AB) models (Macal and North 2005). The idea of combining different components of a larger system each potentially modelled by a different simulation paradigm(s) is not new. Disciplinary hybrid frameworks of hybrid modelling are evident in construction (Alvanchi, Lee and AbouRizk 2011); energy systems (Bazan and German 2012); chemical engineering (Ingram, Cameron and Hangos 2004); social phenomena (Balaban and Hester 2012); and healthcare (Chahal and Eldabi 2008; Zulkepli, Eldabi and Mustafee 2012). Complimenting these disciplinary specific frameworks are generic frameworks proposed by Shanthikumar and Sargent (1983); Chahal and Eldabi (2010); Morgan, Howick and Belton (2011); Swinerd and McNaught (2012); and Djantaliev and German (2013).

In many of these frameworks and case studies, the purpose was to deliver cost effective and computationally efficient solutions, incorporating those parts of the whole system which were required to gain greater insight.

Chalal and Eldabi (2008) proposed three modes in which DES and SD can be combined: i) "hierarchical", where two distinct models pass data to one another, ii) "process environment", where a DES models sits within a SD model and interacts with it cyclically and iii) "integrated", where there is one model with no clear distinction between the discrete and continuous parts. Djanatliev and German (2013) proposed a framework which incorporates AB with a more open framework but limiting SD to modelling parts of the system at high abstraction level and AB and DES for modelling at an individual level. Lorenz and Jost (2006) argued that "the crude application of modeling methodologies we risk wrong conclusions through the implicit acceptance of underlying assumptions in established paradigms", the hybrid frameworks discussed mitigate this risk by allowing the modeler to use the most appropriate modelling paradigm to model each component of a system.

Healthcare systems have benefited greatly through the use of simulation (Fone et al. 2003; Eldabi, Paul and Young 2006, Brailsford et al. 2009) and frameworks have been developed to assist modelers to choose the most appropriate method to model their particular context (Brennan, Chick and Davies 2006; Cooper, Brailsford and Davies 2007). The existing literature discussed focuses on specific problems which suited particular paradigms in the main or required some ingenuity on the modelers' part.

It has been suggested that healthcare systems in particular would benefit from a combined DES-SD approach (Brailsford, Churilov and Dangerfield 2014), with the goal of combining different paradigms where necessary, including but not limited to DES, SD and AB modelling to gain insight into the system (Brailsford et al. 2013). Bar-Yam (2006) argued that multi-scale modelling approaches are required to improve the effectiveness of the US health care and public health systems. Chalal and Eldabi's hybrid frameworks (. Chalal and Eldabi 2008, . Chalal and Eldabi 2010) were devised with healthcare systems in mind. Morgan, Howick and Belton (2011) combined a DES of operational capacity to model radiotherapy delivery at a large Scottish hospital with an SD model of the wider system. Ahmad et al. (2012) used DES to model the detailed operations of an Emergency Department, and SD to model the wider hospital system. Zulkepli et al (2012) modelled integrated care where crucial care and intermediate care are modelled in DES with SD being used to model those providing the crucial and intermediate care. Brailsford, Desai and Viana (2010) presented two case studies representing the connections between the wider environment (depicted by an SD model) and a detailed subsystem (depicted by a DES model). One of these case studies was the Chlamydia model presented in much greater detail here.

3 HYBRID MODEL OF CHLAMYDIA TRANSMISSION AND TREATMENT

3.1 Problem

Chlamydia trachomatis (Chlamydia) is the most common bacterial sexually transmitted infection (STI) in the word. Many of the people who are infected with Chlamydia are unidentified as infected as in many cases it does not present any symptoms (asymptomatic). Once identified Chlamydia can be treated effectively with antibiotics (NCSP 2012). It is possible to naturally recover from Chlamydia, however recovering from multiple cases of Chlamydia can result in a range of complications (sequelae) and represents a substantial public health problem (NCSP 2012).

These sequelae can be very distressing for the individuals and also expensive to treat. The estimated annual cost of Chlamydia and its sequelae in the UK in 2003 was estimated to be more than £100 million (NCSP 2012). As a result of the level of Chlamydia and the costs, the National Chlamydia Screening Programme (NSCP) was established to target screening of those aged <25 who carried the greatest risk. An individual identified as having Chlamydia either by the NCSP or by other means, is referred to a Genito-Urinary Medicine (GUM) outpatient department clinic at a local hospital. GUM departments were already under pressure before the NCSP was introduced. As more cases are now being identified this has exacerbated the situation. If demand on GUM is not met then potentially infected individuals would remain in the community and could continue to spread Chlamydia. This could in turn lead to more new cases which would place greater demand on GUM clinics.

3.2 Model Structure and Choice of Paradigms

A hybrid model of Chlamydia was produced consisting of a DES of the GUM outpatient department clinic at St Mary's Hospital Portsmouth, and an SD model of Chlamydia transmission in the surrounding community. The GUM clinic DES model enabled the evaluation of alternative clinic configurations, to increase the no. of patients treated, reduce patient waiting times and better utilize resources. This is a classical application of DES. Figure 1a illustrates the generic pathway of the DES. The DES ran for a month and included variability in opening hours, staff schedules and patient demand over time.

The "whole system" community-level model represents the population disease dynamics and is modelled using SD. This is a classical application for SD and follows a "Susceptible Infected Recovered (SIR) structure. Figure 1b illustrates a simplified version of the community-level SD model. The community-level model ran for 24 months with monthly time steps.

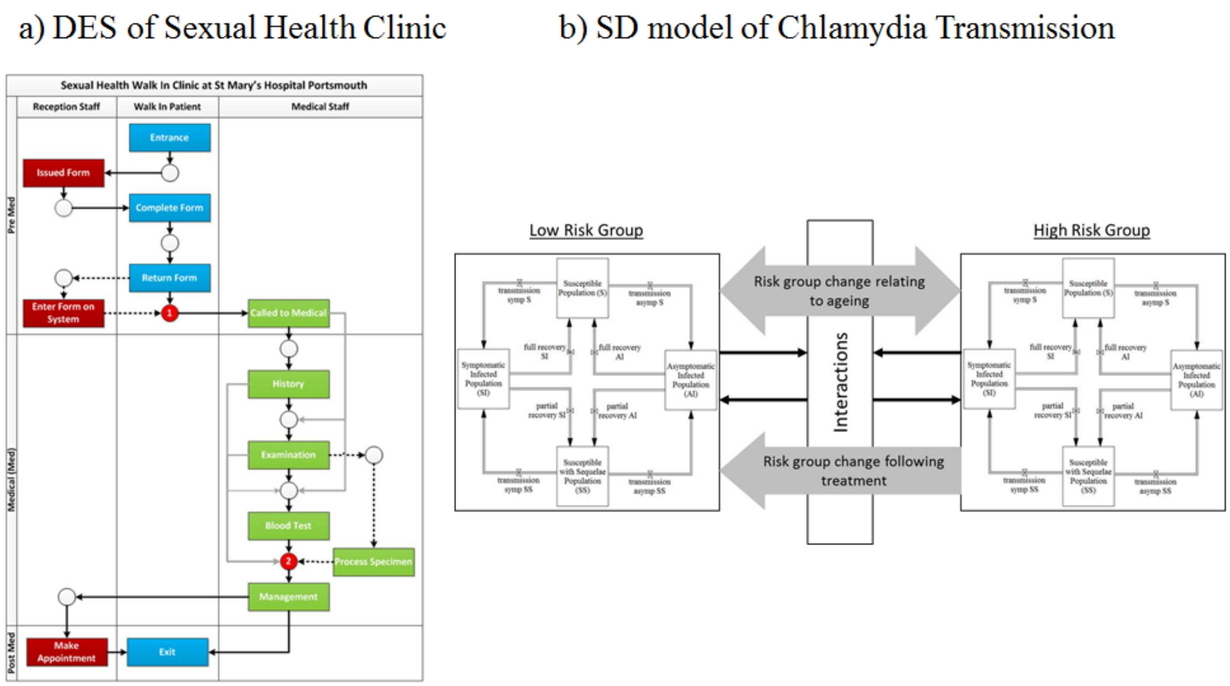

Figure 1: Overview of DES clinic model (1a) and SD community-level model (1b)

The interactions between these two models provide health planners with a tool to evaluate holistically how their decisions affect the whole system. The model demonstrates the impact clinic performance has on the prevalence of Chlamydia in the community. If the clinic is operating theoretically as effectively as possible, all those requiring treatment receive treatment, the population prevalence of Chlamydia should reduce, resulting in a reduction of demand at the clinic. If the clinic were unable to cope with the additional demand from screening, screening could be counterproductive as many asymptomatic patients may tell their friends "Why bother? Why go for treatment because you have to wait for so long, or you're asked to return later". To capture scenarios like the example above the SD model of Chlamydia transmission and the GUM clinic DES model were combined to form a hybrid model, illustrated in figure 2.

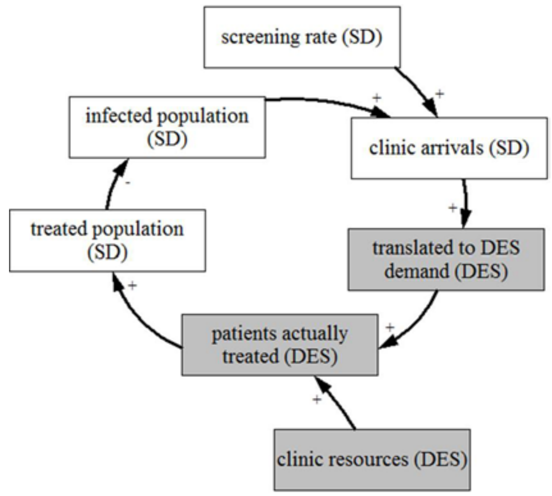

Figure 2: Overview of the composite model

Two versions of the SD model were produced. The hybrid version was different to the standalone SD model as it used VENSIM "Game" variables. Game variables allow model users to interact with the model by making manual changes per time step. In the hybrid model the changes to the "Game" variable values, for each time step, are the outputs from the GUM clinic DES model.

The SD model generates the monthly DES model, in terms of the number of people in the population who are identified as having Chlamydia through screening, contact tracing, self-presentation and reporting to the GUM clinic for treatment. This monthly demand is then exported from VENSIM into Excel, which disaggregates the demand into inter-arrival rates based on historical data analysis, which can vary over time, to be used as arrival distributions in Simul8. The GUM clinic model then runs for 20 iterations and the average number of people treated is exported from Simul8 through Excel to the SD Chlamydia screening model. The SD model advances a time step and the process is repeated as necessary. For a more detailed explanation of the model including model validation, data requirements, results and reflections see Viana et al (2014).

3.3 Experiments and Results

Extensive experimentation was conducted with each component of the hybrid model for validation purposes and to determine if the hybrid model added anything (Viana et al 2014). The key performance indicator of the DES model was the number of patients who leave the clinic without being seen. This may be due to patients leaving before being seen, or being advised to return another day due to the volume of patient already waiting. Experimentation with the DES model confirmed common sense that if there are not enough staff in reception, patients will leave unnecessarily and starve the costly clinical resources which is clearly undesirable.

The SD community-level model results concurred with existing literature that screening women under 25, with effective contact tracing, is the most effective screening strategy; provided population prevalence of Chlamydia is greater than 5% and the probability of developing sequelae and associated costs are high enough to justify the screening. For more information about results for each component of the hybrid model see Viana et al (2014).

Table 1 provides the values of the experimental GUM clinic DES model parameters. The variables have been grouped into three categories: staff related; waiting area resources; and a binary variable specifying if medical resources are shared between genders or are segregated by gender, as was the practice at the time. The staff resources are expressed as "available person-days per week". For example, a value of 5.0 could mean that there are 5 members of staff available on a single day or a member of staff working Monday to Friday who work(s) without any breaks during the day/week (the clinic is open

Monday to Friday). The “Baseline” scenario parameters are based on the configuration of the department at the time of the study: there was three reception staff on duty each day (weekly total of 14.91 person-days); two female-specific medical staff who worked each day (weekly total 10.50 person-days); and 1.5 male-specific medical staff who worked each day (weekly total 7.73 person days). The medical staff figures exceed 5 days a week as they routinely work overtime outside the patient facing clinic opening hours. The “Max” scenario is based on the maximum number of reception, female and male-specific medical staff the clinic can accommodate given physical constraints. This equates to 10 members of each staff type each day (weekly total 47.46 person days), assuming that medical staff now take breaks and overtime is no longer required. The waiting area capacity was not changed in the two scenarios. In addition to the “Baseline” and the “Max” scenarios discussed above, a selection of results will also be compared with the standalone SD model.

Table 1: DES parameters for the two experiments

Decision variable		Scenario 1 **Baseline** (Configuration of GUM at the time)	Scenario 2 **Max** (Maximum no. of resources)
Staff Resources	Reception staff	14.91	47.46
	Female-specific medical staff	10.50	47.46
	Male-specific medical staff	7.73	47.46
	Blood-specific medical staff	4.75	4.75
	Laboratory-specific medical staff	4.75	4.75
Waiting Areas	Reception seating capacity	40.00	40.00
	Reception standing capacity	10.00	10.00
	Female medical seating capacity	10.00	10.00
	Male medical seating capacity	10.00	10.00
Are medical resources shared?		No	Yes

The hybrid model was run for 24 months with the initial DES parameters set to those shown in table 1, and the SD parameters set to the default SD initial values (Viana et al, 2014). The SD only model was run based on the default SD values for the same period for comparison. The number of patients seen and treated by the GUM clinic in the “Baseline” and “Max” hybrid experiments is partly determined by the SD which generates the demand for the clinic, but also the configuration of the GUM clinic DES. In the SD only model the demand and supply is generated and satisfied by the relationships embedded in the SD model.

Figure 3a illustrates the total number of people in the surrounding community infected with Chlamydia, and figure 3b the total estimated cost of Chlamydia after 24 months. These results demonstrate the additional insight gained from the hybrid model, where a simplistic part of the SD only model representing GUM clinic performance, is replaced with a more realistic/complicated DES model. If the clinic lacks resources, the numbers of patients who leave without being seen increases. This leads to a greater number of people infected in the community who may not show up at the clinic due to known performance issues. Figure 3a demonstrates this effect: if the GUM clinic lacks resources this can result in more people becoming infected. Figure 3b provides the estimated total costs of treating Chlamydia and its sequelae. Figure 3b demonstrates that the SD only model underestimates the total cost because it does not include the longer-term impact of untreated infections in the community.

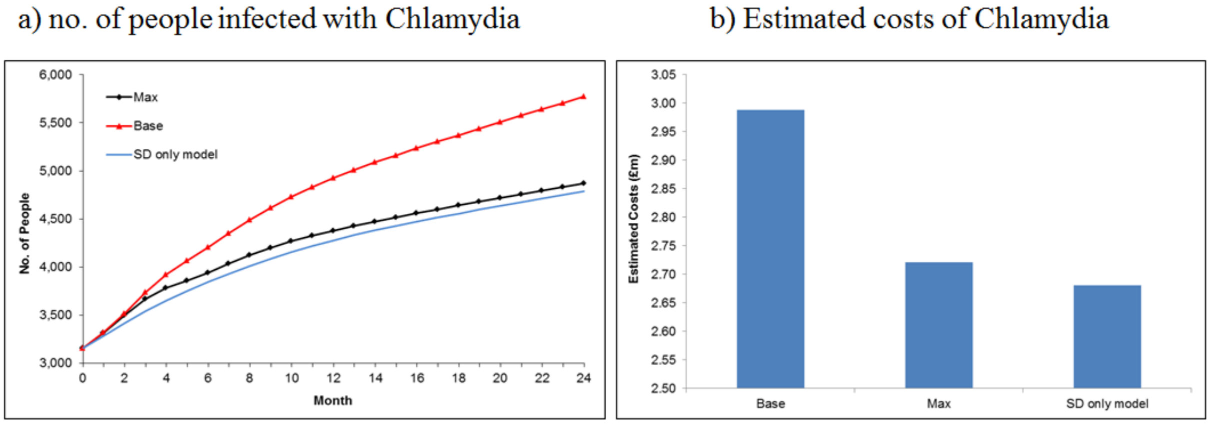

Figure 3: Number of people infected with Chlamydia in the three scenarios (1a) Total Chlamydia costs comparing the composite model with the standalone SD model (1b)

4 HYBRID MODEL OF AGE RELATED MACULAR DEGENERATION HEALTH AND SOCIAL CARE PROVISION

4.1 Problem

The most common cause of visual impairment of those over 65 in the UK, AMD is a progressive degenerative disease that causes the loss of central vision (The Eye Diseases Prevalence Research Group 2004). Due to the increasing adult population over the age of 65 in the UK, it is predicted that the numbers with AMD will increase, from just over 600,000 in 2010 to over 750,000 in 2020 (Minassian, Reidy et al. 2011).

This model focuses on the development and treatment of 'wet' AMD in the area served by the Southampton Eye Unit. Sufferers of the condition have social care needs, often complicated by other conditions due to age. These needs may or may not be met through social care, either by the state/privately (formal) or by family and friends. Formal social care is needs assessed while informal care depends on networks of friends and family. The social care received influences the ability to travel to Southampton General Hospital for treatment. Those with little support may miss appointments, leading to further deterioration of vision and increasing their level of social care need. The Eye Unit needs to be organized to allow treatment of the maximum numbers of patients without reducing the patient experience.

One of the aims of the study is to explore alternative configurations of the clinic in the safety of a computer environment. By exploring different configurations of care given at the Eye Unit, changes in efficiency of the Unit can be estimated, as well as the corresponding improvements in health and reductions in the need for social care.

4.2 Model Structure and Choice of Paradigms

An AB model of individuals with AMD is combined with a DES model of the Eye Unit outpatient clinic (Eye Unit DES). The Eye Unit DES accepts the individual AMD agents as entities. Each agent contains a number of characteristics and processes represented by figure 4. The characteristics and processes include two simple embedded SD like models of sight representing the patients left and right eye; state transition models which represent the stage of AMD in each eye, social care need level (which corresponds to formal care need level criteria); amount of social care received and by whom; and mortality. Those with AMD are referred to the Eye Unit and subsequently reviewed via an appointment system; the agents interact with the Eye Unit DES model when they are due an appointment. Other non AMD agents are generated to simulate the contention for resources within the Eye Unit DES as other non-AMD clinics can run at the same time. The social care need level and social care received by an agent can influence their probability of making their appointment. As treatment can slow the effect of AMD and in some cases reverse the sight loss, it is important that agents make their appointments. They may miss appointments by: i) not being able to travel to the clinic as a result of the social care need level social care provision calculation, or ii) they may leave the clinic due to congestion at the clinic and overall performance issues.

The agent interactions with the Eye Unit DES occur in a spatial environment, primarily to model the ability of the agent to travel to the Eye Unit, it is also planned to model the location of informal/formal carers in respect to the AMD sufferer; and where to position mobile eye units, to outsource some of the processes which may be causing bottlenecks, from the Eye Unit to the community. In the current model agents are distributed at random in a rectangular space and probability of attendance implicitly incorporates the distance from the Eye Unit, but this will be replaced by a geographically accurate map of Hampshire in due course.

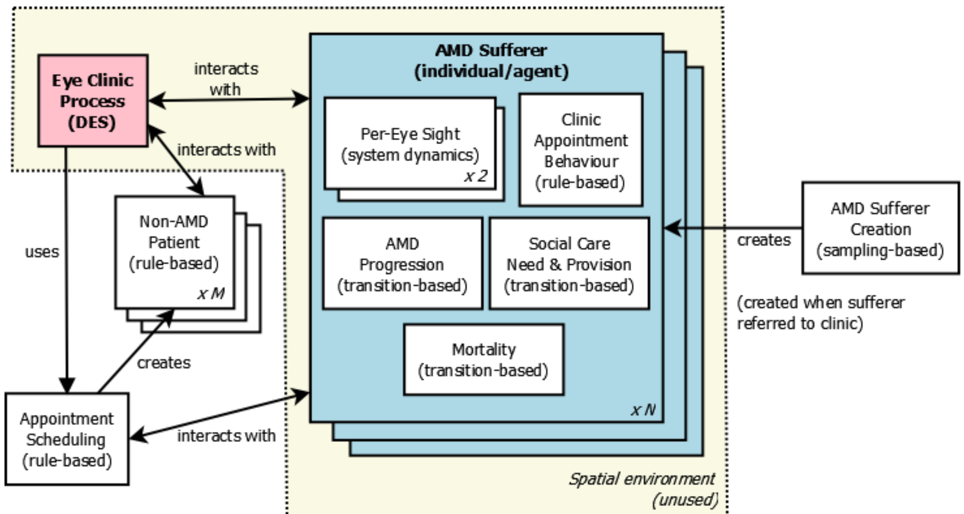

Figure 4: The overall conceptual architecture for the AMD model.

More detail about the model development, model validation, data requirement, experiments and results can be found in Viana et al (2012) and Brailsford et al (2013). Further details can also be found on the CLC website at http://www.soton.ac.uk/clc/publications/supplementary.

4.3 Experiments and Results

In Viana et al (2012) four "what-if" scenarios were run in the model which explored the interconnectedness of the health and social care systems as represented in the model. The model has been developed substantially since then as a number of technical issues which limited performance have been resolved (Viana et al. 2012; Brailsford et al. 2013). As with previous papers the number of missed injections was chosen as the main output measure, as it is a proxy for both the operation of the healthcare system and the impact on social care in the community.

As the model is still under development illustrative results from representative runs are provided to demonstrate the utility of the model. The model runs for 5 years from initial starting conditions of 500 AMD sufferers and 2 new patients referred to the Eye Unit a week.

The scenarios tested were:

- ***Base***: The Eye Unit appointment system and organization remains the same for the entire simulation duration. There is one AMD consultant (we are currently evaluating different appointment scheduling mechanisms currently before adding more) and four consultants representing the parallel non-AMD clinics. Each non-AMD consultant has a patient stream generated through inter-arrival time arrival distributions. The other health care factors, e.g.

no. of nurses, available waiting capacity, and equipment are drawn from the literature, through interviews with Eye Unit staff, and educated guesses.

- ***Health***: Additional staff, admin, nurses, non-AMD consultants (without associated patient streams), rooms and equipment (eye checks, photographic equipment, consultation, registration) are added to reduce the number of patients turned away to a minimum (some patients may miss injections as there is only one AMD doctor who consults and treats all AMD patients).
- ***Social***: Individuals have a 50% chance of receiving one 'level' better social care. The more social care that an individual receives, with respect to their level of social care need, the greater likelihood they have of making their appointment.
- ***Both***: This scenario combines the Health (2) and Social (3) scenarios above.

The results from single representative runs are shown in Figure 5. As some of the technical issues have been resolved and we are able to run the model over a longer time frame, we see some interesting yet not unexpected behavior. The results for each scenario over the 5 year period are shown in figure 5a. There are three distinct regions of Figure 5a: i) region b, ii) region c and iii) region d.

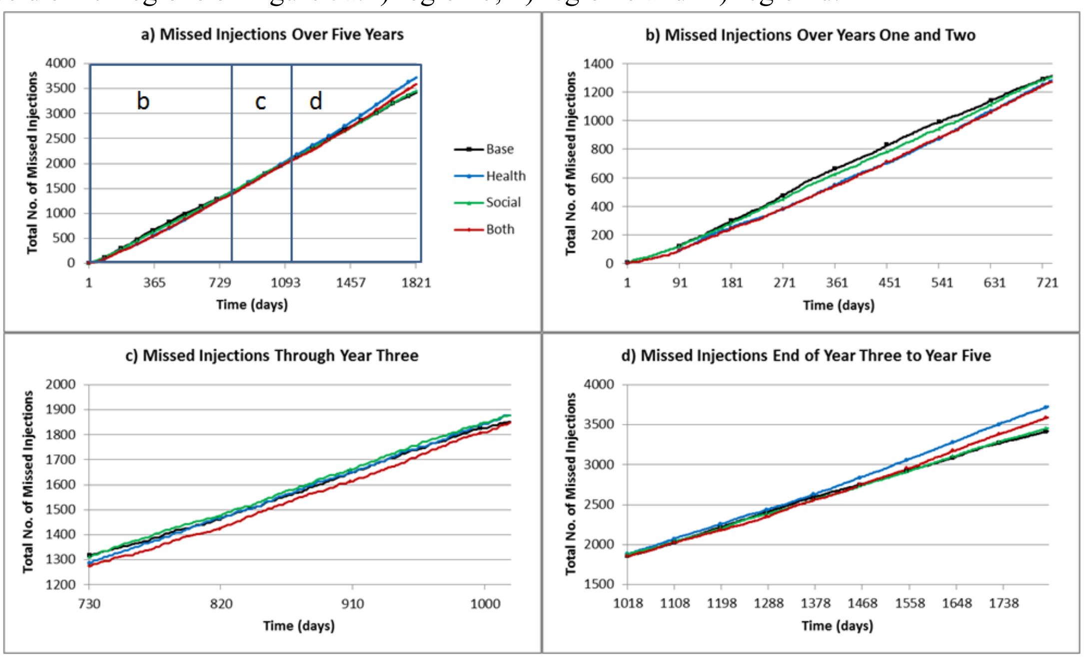

Figure 5: Results from initial experiments for the four scenarios.

The b region illustrated in Figure 5b confirms the results illustrated in Viana et al (2012). The Eye Unit improvements relieve the bottlenecks in the clinic, resulting in fewer missed injection appointments. The social care improvements in this instance have a more limited affect, as the bottlenecks still exist within the Eye Unit; and the combined social and health care scenario results in the fewest missed injections, although as more patients are likely to arrive, there are points when the 'health' and 'both' scenarios cross. The c region illustrated in Figure 5c suggests a tipping point has occurred and the initial 'health' scenario is no longer having a beneficial effect. The number of missed injection appointments increases in-line with the 'base' scenario, and the 'social' scenario results in a greater number of missed injection appointments. This is due to the increase in AMD patients (2 per week since the start of the simulation) and only one AMD consultant available (who can only treat a set number of patients). The d region illustrated in Figure 5d shows the 'health' and 'both' scenarios actually result in a greater number of missed appointments with the 'base' scenario resulting in the fewest. This demonstrates another tipping point. The benefits derived from the 'health' and 'both' scenarios are no longer effective due to the increase in number of AMD patients and in fact have a counterintuitive effect due to more AMD patients having to compete with non-AMD for resources within the clinic which results in more injections missed. What is still to be understood is why the 'both' scenario results in fewer missed injections when compared with the 'health' scenario and this is something that we intend to explore once the model is fully realized and we are able to conduct multiple runs.

5 REFLECTIONS AND CONCLUSION

The case studies were of complex health and social care problems which did not fit into neat modelling classifications and taxonomies discussed in section 2. It is possible to produce single paradigm models of the case studies, but this would require a degree of ingenuity and creativity on the modeler's part and making assumptions which may be questionable; ultimately it depends on the purpose of the model. The case studies have used, in the author's opinion, the best tools for the job. 'Best' is defined as using the modeling paradigm which most cleanly implements the conceptual design for each sub-system rather than rigidly sticking to one paradigm. Both this methodological fusion and the whole system view are overarching themes of the Care Life Cycle (CLC) project.

The Chlamydia model was developed during the author's PhD with the aim of evaluating hybrid simulation with respect to combining DES and SD. It was in collaboration with external stakeholders (hospital staff). It was conceptualized as a separate DES model representing a GUM department. The DES model was based on national patient pathways which were tailored to meet local needs. The SD model of community level Chlamydia screening and transmission was conceptualized as a typical SD SIR model. Part of the SD model related to the identification of those in the population with Chlamydia and the provision of treatment. Once identified the infected individuals who presented for treatment were treated. Treatment in the traditional SD sense is defined by a function. This function can be as simple or as complex as needs be. In the SD only model this is defined by a capacity which takes time to adjust. The developed hybrid model replaced this SD function with an accurate DES model of the GUM clinic. The DES representation of treatment provided a tool which allowed model users to assess the number of ways that capacity could be changed. This was achieved through the use of two specialist commercial packages that the author was experienced in (Simul8 and VENSIM) which communicated via Microsoft Excel. This hybrid model would be defined in Chalal and Eldabi (2008, 2010) terminology as a 'hierarchical' (Brailsford et al. 2013) or 'process environment' (Viana et al. 2012) hybrid model .

The AMD model was developed after the Chlamydia model by a team of CLC researchers and academics. It should be noted that the model is still under development. The AMD model is conceptually different than the Chlamydia model. Greater emphasis was placed on the identification of multiple overlaps/connections between the paradigms, in particular 1) how the provision of social care influences the ability of AMD sufferers to attend appointments; 2) how social care support can influence the probability of being diagnosed; and 3) the effect mobile photographic units can have on social and health care; (2 and 3 are still to be added) rather than the single connection as in the Chlamydia model. Since the Chlamydia model the author has been introduced to AB modelling through the literature and discussions with fellow CLC project researchers, which has led to further conceptual flexibility. The scope of the AMD model was large. The overall purpose of the AMD model was to demonstrate the whole care system consequences of AMD from a healthcare and social care perspective. The model could have been conceptualized in a number of ways, but as is stressed throughout, the models were conceptualized under the principle of using the "best" tool(s) for the job. This model has been implemented in the multi-paradigm software (AnyLogic) which the team had no experience of. This led to some initial technical issues (for more information about this see Viana et al. (2012) and Brailsford et al. (2013)). As many of the technical issues have been resolved, new scenarios covering a longer time horizon have been presented and discussed in this paper (section 4). This hybrid model would be defined by Chalal and Eldabi (Chalal and Eldabi 2008, Chalal and Eldabi 2009) as an 'integrated' (Brailsford et al. 2013) hybrid model.

The hybrid model case studies presented have been designed with multiple purposes in mind, yet they still have defined boundaries as discussed in sections 3 and 4. The amount and the type of data required to parameterize the two cases studies vary greatly. The DES components of the two cases are similar as they both model outpatient healthcare settings. Typical data collection techniques were used: extracting data from hospital systems and conducting audits of clinics. This data can be criticized as only being a snapshot of hospital procedures when the data were collected. Putting systems in place to collect information more routinely and reviewing model processes regularly to reflect current practice can address this criticism. The Chlamydia models use of historical data to derive patient arrival distributions from the SD model could be flawed, do these trends hold if demand changed over time? This is a valid point and as mentioned it is important to have systems in place to review data and structural assumptions of models. Obtaining more detailed information in the UK is possible but would require greater ethical approval which can slow model development. The non-DES components of the case studies are quite different. The Chlamydia model is essentially a SIR model. Several assumptions had to be made due to the asymptomatic nature of Chlamydia; the abstraction of the population into two risk groups: low and high as defined by the literature; a GUM clinic users and a general population survey; and expert opinion. The non-DES components of the AMD model represent the development of social care need and provision, physiological eye models (very basic representation); AMD progression; and demographic factors. These components are informed by a variety of sources including longitudinal national sample surveys, Office of National Statistics data, the literature, and expert opinion.

Commercial simulation packages tends to advocate a particular type of 'world view', but offer the ability to extend models through the use of general (C, Java, VBA) or software specific programming languages (Visual Logic). The different ways in which AnyLogic makes use of Java, from writing snippets of code in a default objects, to extending existing classes and creating your own, were challenging concepts to grasp. However, as the model developed the author gained a better understanding of Java and AnyLogic, the model development process accelerated. A with many things experience is key and the more something is done the easier it becomes. The time to develop hybrid models will reduce theoretically as more models are produced and as modelers are trained in a non-paradigm constrained way, but it is important to remember that each problem is unique.

To conclude some questions are posed. Although hybrid frameworks exist and offer guidance on how different paradigms can interact, will archetype behaviors be identified in hybrid models like they have in SD (balancing processes with delays, limits to growth, eroding goals), DES (M/M/1 queues, M/D/1 queues) and AB models (diffusion of ideas across a network)? Could archetypal behaviors be observed for instance, if you linked a "limits to growth" SD to a "M/M/1 queue" DES archetype? Why are hybrid approaches becoming more popular? Is it because the problems are more complex or is it more that the field has become more ambitious about the types of problem that are tackled? In essence both, the limits of individual paradigms are being realized and there is growing use of hybrid approaches in multiple disciplines, see section 2. Are the integrated system views proposed by Chalal and Eldabi (Chalal and Eldabi 2008; Chalal and Eldabi 2010) and Brailsford et al (2010) merely from a philosophical perspective? Technically from a software development point of view it is possible to combine multiple paradigms.

This paper presented empiric research in hybrid modelling and simulation by reflected on two hybrid simulation case studies from a healthcare perspective. Each case study is briefly presented in terms of the: rationale for the project, the simulation components of the hybrid model and illustrative results.

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