Summary

Agent based modelling is a relatively new discipline with much potential. It helps in many areas to construct models to predict emergent behaviour from complex systems. This emergent behaviour is not explicitly programmed into the system.

The task of my project is to assess ABM’s appropriateness to modelling human behaviour for the Department of Health.

The project reviews work already done using ABM, its advantages, disadvantages and the types of problem classifications tackled by ABM. Also the project involves designing and implementing a simulation model using Simplex 3 - a modelling package, to illustrate the practicality of implementing an agent based model. The example model is based on research findings on incentives and motivation.

I conclude that ABM would be a way forward for the Department of Health, but it would only be an insightful and successful model if they were willing to invest heavily in research on studies such as behavioural sciences - especially in human motivation and mass psychology.
Acknowledgements

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1.0 Introduction
The aim of my project is to review current agent based modelling (ABM) tools and applications, with the emphasis on applications, to understand which classifications of problems are best suited to using ABM. Also, I am to gain an overall feel for the feasibility of using ABM to model human behaviour.

1.1 What is ABM?
Agent based modelling is a relatively new discipline with much potential. It helps in many areas to construct models to predict emergent behaviour of complex systems. A complex system can be understood as a system with patterns in its complexity, these patterns can describe potential evolutions of emergent behaviour of the system. [1] states that ABM is used to describe complex systems, by modelling individuals and their interaction, and observing emergent behaviour of the population not explicitly programmed into the system. Thus unexpected results or emergent behaviour appears. ABM takes an abstraction of this complex system, a model. It does not attempt to replicate the reality of the complex system, its aim is to just model reality in a simplistic way. ABM may be described very generally as taking a ‘real life’ situation and attempting to model it in the computational domain. One application idea could be to model a situation with agents and an environment and to input experimental theories (which do not yet have any prove of success) into an ABM system. The end user can observe emerging patterns and responses which may enable the end user to have a better guide as to whether the theory would be correct. Despite the ubiquitous use of ‘Agent based’ in describing new technological software, there is no one set common definition. In the scope of this project it will be defined as explained by [2]. They argue that four key attributes that determine ‘agenthood’. They are:

- Autonomy, the ability to function mostly independent of human intervention.
- Social ability, the ability to interact ‘intelligently’ and constructively with other agents.
- Responsiveness, the ability to perceive the environment and respond in a timely manner.
- Proactiveness, the ability to take the initiative whenever required.

This project requires me to review and use this technology and assess its relevance for use within the hospital domain, where human behaviour is a key trait to be modelled.
1.2 Problem Specification
This project is undertaken for an external organisation, the Department of Health. They have an interest in, but only a vague understanding of, ABM. They are interested to see if ABM could help understand certain behaviour within a hospital.

1.2.1 A broader scope
Due to the strong personnel nature of processes within a hospital, performance is directly associated with people and their behaviours, making employees a very influential factor in the performance and success of the hospital. The end user wishes to understand the viability of using ABM technology to answer questions of economic evaluation and process orientated control, such as those questions which may support the spread of modernisation, reform and service improvement in the NHS. By identifying more effective ways of encouraging diffusion of behaviour we could forecast future performance on key targets. One example of the questions we could possibly answer using ABM may be ‘is a low wait environment sustainable or will behaviours change to force waiting times to rise again?’ In answering such questions with ABM the Department of Health hopes to be able to assess the impact of policies aimed at changing behaviours such as trust and consultant incentive packages. The end user realises the influence of human behaviour and human decision-making on the performance of the economic and organizational planning process. Therefore the task at hand is to model human behaviour within the hospital setting using ABM.

1.2.2 What do I want to solve?
The weight of this project is only 20 credits and therefore does not allow full satisfaction of the end user’s requirements. However this work should be an excellent grounding in the issues needed to aid the decision on whether ABM is a good investment or not.

The scope of this project enables me to solve the end user problem in two ways:

(1) by providing a literature review enabling them to decide if working with ABM would be a good investment in terms of time, money and appropriateness. The emphasis is on the ‘applications’ of ABM as opposed to ABM software tools, as we are mostly interested in what problem classifications are best solved this way and whether the end users problem meets this classification.

(2) focusing on the modelling of ‘motivational’ theories in human behaviour and modelling these with ABM software, monitoring the results. In particular what factors motivate a particular behaviour to emerge and diffuse.
1.3 Minimum requirements
Following the progress meeting the minimum requirements were identified as follows:

1. Review and summary of three ABM tools relative to producing a model.

2. A literature review of the three most relevant ABM applications, relative to the end users requirements.

3. To build a case study within ABM software which will predict the behavioural patterns and responses, which may emerge when assigning motivational features to at least two agents. (Revised)

1.31 Possible further enhancements
Following discussions during the progress meeting and with the end user the following further enhancements were identified.

1. To review a wider perspective of ABM tools and applications with the emphasis on ‘applications’.
2. To verify the model by building it on research findings on human behaviour. This will enable me to assess/test the accuracy of using ABM.
3. A review of the diffusion of behaviour i.e. discussion of what makes behaviour spread through an environment and if it is feasible to implement a model of this using ABM.
4. To build other case studies within ABM portraying various aspects of behaviour such as peer pressure, personality and diffusion of behaviour.
5. To build the model of an environment which allows experimental theories of behaviour (as opposed to text book theories) to be input to the agents.
6. To analyse the effect on agents or environment behaviour when a particular variable is modified.
7. To evaluate or test whether ABM is accurate by interviewing the ‘real life’ agents. Comparing their responses to the results from the model.

1.4 Deliverables
1. A literature review of ABM.
2. A model built within ABM software.

1.5 The Project Schedule
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<tr>
<th>Start Date</th>
<th>Activity</th>
<th>Complete By</th>
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<tr>
<td>20.12.2002</td>
<td>Majority of literature review of tools and application (3 most relevant)</td>
<td>27.12.2002</td>
</tr>
<tr>
<td><strong>01.01.2003</strong></td>
<td><em><strong><strong>EXAM REVISION</strong></strong></em>*</td>
<td><strong>26.01.2003</strong></td>
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<tr>
<td>27.01.2003</td>
<td>Pick up marked mid project report read over any comments.</td>
<td>28.01.2003</td>
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<tr>
<td>29.01.2003</td>
<td>Create simple model in StarLogo software (see minimum requirements)</td>
<td>29.02.2003</td>
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<tr>
<td></td>
<td>Writing Meeting</td>
<td>(25.02.2002, 10am)</td>
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<tr>
<td>01.03.2003</td>
<td>Submit table of contents and draft chapter</td>
<td>14.03.2003</td>
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<tr>
<td>17.03.2003</td>
<td>Meet with end user (TBA)</td>
<td>17.03.2003</td>
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<tr>
<td>20.03.2003</td>
<td>Completion of Progress Meeting</td>
<td>21.03.2002</td>
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<tr>
<td>22.03.2003</td>
<td>Build more case models within Star Logo (see requirements)</td>
<td>22.04.2003</td>
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<tr>
<td>22.03.2003</td>
<td>Complete literature review</td>
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<td>29.04.2003</td>
<td>Amend final report</td>
<td>01.05.2003</td>
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<td>Submit report postscript using <em>submit</em></td>
<td>02.05.2003</td>
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<td>Submit project report in the CSO</td>
<td>02.05.2003</td>
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<tr>
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<td>Receive feedback/assessment forms</td>
<td>30.05.2003</td>
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For a fuller discussion on the project plan and its revisions see Appendix A (for discussion) and Appendix B for Gantt charts.
2.0 Background research
I gathered my background research from various sources mainly textbooks, the Internet, Universities and the external company – the Department of Health.

2.1 Identifying relevant literature
After searching through the internet, electronic journals and books in the library it became very clear to me that in today’s information age half the job of a literature review is literature searching (knowledge management). I have learnt that finding relevant literature is perplexing. To help overcome this when reading abstracts of papers, keep in mind the problem and how this particular paper will relate to what you want to achieve. After reading general ABM papers I decided to direct my attention into more focused areas.

I contacted institutions for advice and information, again being more particular and only contacting institutions which have done work in using ABM to model human behaviour. Institutes being: MIT, The Swarm Development Group and various Universities of France, Austria and Amsterdam. Mainly the University of Passau in Germany were of great help in suggesting appropriate software, most obvious institution being the Department of Health. Rather unfortunately there appears to be no similar past projects in this field. I have tried accessing other Universities final year project but have been unlucky in finding any related to my project.

All the literature I gathered from the Internet was assessed for quality by validating it against certain criteria. I validated my use of particular textbooks by justifying them with an educated guess. For example I would check the date and edition of the book. Other sources I have used have been validated in a similar manner. I have tried to read all the resources available to me with an open mind yet critical and judgemental, always trying to form my own opinion. However this is still quite difficult as I am not a professional in this field, this was a completely new concept for me. So as you can understand it can be hard to criticise something you don’t fully understand. However on the human behaviour side of things I have had grounding in at least some of these issues through my modules in management so it is easier for me to critically analyse such literature.

2.2 Where has ABM been implemented and why?
According to [3] ABM has been implemented in all empirical fields, for example Natural Sciences, Business and Economics, Biology and Medicine and Engineering.

Hence ABM is a general, interdisciplinary field, which is not limited to any specific area. There have been numerous studies in the field of ABM relating to the computer simulation of social phenomena. It is thought by many to be a promising field of research at the intersection between the social, mathematical and computer sciences.
However the implementation of human behaviour models are rare. This may be because of the controversial subject of the actual feasibility that you can model human beings. This seems somewhat egotistical when we freely make models of animals, plants and other beings; yet see ourselves too complex and superior than all other beings to be modelled. From my findings typical applications are mostly those of physical agents moving around an environment where the emergent behaviour is observed through spatial patterns within a geometrical space. In such models there are very definite rules that are previously known through observations and analysis. However applications do seem to range from spatial rule based cellular automata to complex cognitive architectures of individual agents such as BDI (Belief Desire and Intention) architectures. Below are a few of the applications researched which I feel are relevant in helping the end user understand ABM.

- SUGARSCAPE, conducted by [4], is a well-known example in which agents are used to construct an artificial social system. Agents are constructed in a way that makes them similar to ‘real life’, with respect to structure and behaviour. Consequently, the agent has to be equipped with all the properties and behaviours of the real life agents. SUGARSCAPE models ant colonies by attributing agents or ants a vision, a metabolic rate and a speed. Their aim is to move through the environment and find the places with the most sugar. On acquiring this sugar their energy levels increase. If their sugar or energy levels fall below zero they die. Over time behaviour such as migration and hibernation occurs. The ants begin to self organise and they were observed to spatially separate into two tribes, these tribes then over time were observed to go into combat with each other for the sugar. When another variable of ‘spice’ was introduced the agents (ants) behaviour adapted yet again and an economic market emerged. Other factors then became an issue, such as waste and pollution. [4] explains that this study is part of 2050 Project by the World Resources Institute. It is an international effort to identify conditions for a sustainable global system in the middle of the next century and to help with the design of policies to aid such a system.

- A model was developed in ABM software [6] that modelled clusters of groups at parties. The model enabled the alteration of the variable tolerance, which is the degree to which you were tolerant of a sex. The emergent patterns were of interest in how male and females clustered together and what physical patterns emerged.

- YAMS – Yet Another Manufacturing System developed by [7] who have 14 years experience in applying agents to industrial problems, illustrating the use of agents in production line modelling. The benefits of agents in industry are that the agents will have a set of functions and characteristics which are definite, therefore the rules applied will be perfect information of how the agents are to act. ABM allows dynamical analysis of
production line operations. YAMS was designed to study the impact of successive modifications on the agent’s set rules. A lesson to be learnt from this study was that interactions of agents can generate complex behaviours even when the organisation and agents seem simple. The benefit here it is to acknowledge the fact that you need to model complex problems with simple agents. The arising challenge is to pay attention to system behaviour (environment) as well as agent behaviour. Another conclusion from this study was that hierarchies are a poor way to organize agents even if this is the case in reality. Because, as most physical interactions were in reality hierarchical when modelled in this way, it forced messages to travel up the least shared mode and then back down resulting in a flood of messages and consequently confusing the communication network. This case illustrates that ABM is very successful and appropriate to use when used in industrial applications. In manufacturing processes the rules put into the system are very definite i.e. not dynamic. You can be sure how much each component will act with another, for example, in a production line.

- Hospital management has been considered by [8] as a potentiality for modelling success. The suggestion was to model economic and organizational planning processes. Previous modelling approaches have failed in modelling hospital management as they ignore the human factor involved in hospitals performance. In hospitals, efficiency is very much dependent on the choice of performance program, held-up capacities, organization of the necessary performance process and the managerial skills. This makes ABM a good option, as it is a very decentralised environment with many influencing factors. By integrating ABM you can model a system that can cope with these influences that stem from individual decision makers and behaviour. Thus allowing the modelling of psychological realism that is evident in the strong personal related performance. As well as enabling the inclusion of human behaviour within these models, they also allow us to analyse alternative actions for different economic problems of capacity planning, patient scheduling and control.

- ABM has been used to illustrate pattern emergence in nature [9]. A characteristic shape unfolds in time or space. This emergent pattern results from many interacting agents. It attempts to model such things as flocks of birds in nature where there is no leader. Patterns simply emerge out of individual behaviour and adjustments of behaviour when interacting with other agents. The agents are given spatially explicit positions and attributes, which make them, interact with each other and behave accordingly.

- ABM has been used to model complex dynamical systems, using software such as Starlogo [10], which involve capabilities of modelling systems of interacting components over time. The primary purpose of this is for education for teachers, students and researchers. This application enables the visual sense of complex systems and their
emergent phenomena. This application has found uses in the school curriculum, where students may have a more direct experience of the interconnectedness of everything in the world in which we live.

- Social policy analysis experts [11] use ABM as ABM simulation systems can describe key processes and relationships in actual societies. One such use is water demand management. ABM allows again the inclusion of human dimension into integrated assessment models and processes. Resultantly, allowing innovative approaches towards developing a more sustainable and enduring resource management regime.
- DESIRE designed by [12]- an ABM simulation model for animal behaviour.
- Many attempts have been made to build models to try and understand how the human mind works, by building psychological models.
- BT [13] has customer service agents that quote to customers over the phone. These customer service agents are in turn connected to a number of other agents such as customer vetting agents, design agents, survey agents, and legal agents all helping to validate the process. BT claimed the use of agents has increased productivity by 10%.
- Other domains which agent solutions are currently being investigated or applied are; workflow management, air traffic control, data mining, e-commerce and personal digital assistants to name a few. However, one of the one of the most complete models I have seen of human behaviour (including habitual, social, rational behaviour) and developed specifically for agent modelling is in development by Wander Jager (University of Groningen) and Marco Janssen (Free University Amsterdam). Very few of the behavioural models I have seen were based on validated behaviour models (reasonably so since they focused on collective dynamics first with simple agents). And they usually do not consider the realistic reasons for changes in different behaviour, as Jager and Janssen have done. This work was enlightening and clarifying for me.

2.3 Strengths of ABM
ABM can offer a powerful tool for analysing, observing and explaining the evolution of social norms, also the emergence of collective behaviour within certain contexts. A major strength claimed ubiquitously is that ABM is one of the most potential approaches for understanding complex organisational and social phenomena.

Agents can also enable companies to automate tasks, which usually require human action. This factor will decrease costs to the company making it more profitable. Thus, companies who deploy agents quickly will be able to gain a competitive advantage as it is predicted by [14] that agents
will explode in capability by 2010. Any company that doesn’t keep up with this technology may find it difficult to compete.

Another enormous advantage of ABM is the capability to assess the plausibility of the behaviour of agents, the ways in which the agents interact and the consequences of that behaviour and interaction. Thus, allowing the testing of numerous hypothetical situations. ABM allows us to apply very simple micro level rules to study how macro level behaviour emerges.

Research carried out by [15] found the following as advantages of using agent-based systems:

- Agent communication can closely model the way humans communicate.
- Agents offer high levels of flexibility and robustness in unpredictable environments enabled by their intrinsic autonomy. For example, agents can be provided with objectives, which may not be easily supported by earlier modelling styles.
- Agents are able to learn, in a natural way, enabling their behaviour to change with time or experience.

[16] Explains that ABM has the ability to make many kinds of testable predictions that are directly relevant to management decision-making. A good ABM would be a very general model, representing individuals generically so little revision is needed in applying the model to new situations. ABMs are built and tested using a wide variety of information, giving the model more accuracy. They often include information on individual traits such as physiology and behaviour. Unlike many other classes of models, they can easily predict transient responses to inputs that vary over time and space.

ABM models can simulate many experiments once a few simple rules are assigned to an agent about the real world. It is a fantastic tool to explore the dynamics of behaviour. If you were to try and do this with real people this would be very costly and time consuming. For example, the fact that the computer can simulate the equivalent of 10,000 seconds (166.666 minutes) in practically no time at all illustrates this fact. Days and months can be simulated in a matter of minutes. Of course this is also dependant on the hardware you use. ABM’s are also much more easier to understand by a non-mathematician/ non-programmer as they are generally modelled in more natural language which is almost self-explanatory.

2.4 Weaknesses of ABM

I think some of the publicised weaknesses of ABM stem from unrealistic expectations of uneducated wishers for example claims such as agents will gain intelligence. However, there are of course some weaknesses, as with everything there is a positive and a negative.
In a need to keep the model simple sometimes factors which are indirectly relevant, are kept out, ignoring an important part of the reality which will affect the model greatly. This is a problem caused by the inability to separate what we should and should not include in the model. For example human components of conflict, morality and responsibility may be ignored or over simplified meaning agents are not flexible enough to work in human societies.

In the context of modelling human behaviour a major weakness is that human behaviour is often reduced to cognitive abilities and therefore modelled as a purely rational thinker. Arguably, this does not reflect the real situation. However, the PECS reference model suggested by [reference number] attempts to overcome this by modelling the - Physical, Emotional, Cognitive and Social components of each human agent. But the problem still remains of how we can reliably model the way these components interact with each other. For example when modelling a reasoning human behaviour system we need to determine how to make up the agents internal patterns and behaviours. Do we base this information on empirical research or just infer it from the behaviour around us? It’s a problem that is not easy to solve.

Researchers often duplicate efforts to provide solutions to their own particular problem. [17] illustrates the problem of the lack of cumulative progress, using the fable of the Hare and the Tortoise to denote ABM and its progress. With ABM being the hare with intermittent rapid bits of progress carried out by individual researchers that are solely focused on exploring their own simulations instead of building on the models of others. The moral behind the story being that continuous small progress is more important than intermittent rapid progress.

Because of this lack of continuous progress individual research projects are not connected together therefore there is a lack of sharing of common results; almost no standard computational results; no replications of older works and almost no standard evaluation criteria to judge your research against. [17] claims there are many advantages from developing older works, mainly being to learn from others mistakes and develop their accomplishments. However I feel that each individual research project, because it is modelling a ‘real life’ situation, would be that complex and diverse that there would be few features in common with the next person’s research. So maybe the reason this methodology is not implemented is because the cost of doing so would be greater than not doing so, in terms of portability of models. For example say a more generic model was developed with say 12 main features/tasks, there may only be about two or three of these features/tasks relevant to the research project you are doing. So the cost of adapting your research to this model may be more expensive, complicated and time consuming than developing your own.
Another disadvantage of ABM is that simulation results strictly don’t follow the ‘real’ world because the real world includes several kinds of unexpected factors and observed phenomena only show one aspect of the real world. For this problem [18] in his book argues:

“Although ABM employs simulation, it does not aim to provide an accurate representation of a empirical application. Instead, the goal of ABM is to enrich our understanding of a fundamental process that may appear in a variety of applications”

This maybe suggests that modelling human behaviour with ABM is not a good idea as human behaviour is inherently unexpected and diverse. Which may also not have a fundamental process in common. I suppose it depends how deep you want to take it. How accurate a representation is this to be? A ‘text book’ theory representation or a ‘real life’ representation? In many cases the two can vary.

To overcome the sometimes-complex information ABM can produce [18] tells us we should implement simple models to understand the fundamental process in organisational or social phenomena. This implies that you would then be confident of understanding results by knowing everything that went into the model. This model is called the KISS model. This model involves keeping everything simple and including the essential parts only by removing non essential parts which are the parts you can change dramatically which will only produce little or no effect on the results.

Another problem is that ABM is mostly useful visually as graphically you can watch how certain conditions affect certain models. This as been implemented in primary schools for children to learn basic scientific theories. But this factor makes it less attractive for the problem in hand as we are more interested in the behavioural responses than visual affects. However charts and graphs as opposed to patterns and sequences can be used to analyse/observe behaviour responses.

2.5 What characterises applications
After reading various papers in ABM I gathered the following generic points which I feel characterize typical applications.

- Agents are modelled to make decisions on the basis of their own goals, environment and expectations of the future.
- A model is a mathematical model that assumes the world is knowable and controllable. Models are designed through a rational process of observation and reflection. Can all things be modelled rationally?
- Only the simple and essential parts of the real situation should be modelled for simplicity and ease of understanding.
- From a software engineering perspective ABM systems tend to be designed bottom up, because if they were designed top down the program becomes a mass of complexity which hides errors, also making the software hard to read, test, and debug.
- They usually make use of the systems theory, with a state transition function taking inputs to outputs.

F: Input states \( \rightarrow \) Output states

- Generally ABM seems to model hypothetical situations which are not real to life but can give insight on the way things work. Because of this the models are very data hungry as the model will be very specific to your particular problem. This means you will need to code the input, the internal states of the agents and dynamic behaviour, and also the way each component and agent interacts with each other and its environment.
- ABM usually models complex systems, because ABM allows the modelling of the simple components which make up a complex system, resulting in the emergence of complex behaviour.
- Generally any system that has the potential for some sort of emergence through cooperating and adapting its behaviour through communication with other components. This emergence is not an intrinsic part of the property of the individual components; rather the emergence is a property of the system as a whole.
- Overall ABM comprises a wide sphere of applications ranging from spatial ruled visual experiment based agents to complex cognitive architectures of individual agents such as BDI architectures.
- ABM tends to model four types of behaviour:
  1. Reactive - behaviour that responds in a timely fashion to environmental change.
  2. Proactive - behaviour that acts in anticipation of future goals.
  3. Social - behaviour that interacts and responds to other agents.
  4. Adaptive - behaviour that learns and adapts to its environment and social setting.
- Problems that by essence contain ‘what if?’ questions. For example the end user may ask ‘What if I introduce a new incentive, will my employees become more productive?’ or ‘What if I want to know how behaviour diffuses through a group?’
- In future applications a characteristic of ABM applications will increasingly involve human like agents. For example in resource management models, where human decision makers in certain processes within a business are too influential to be ignored or reduced to another resource, as is often the case in traditional models.
- One view is that ABM is essentially prediction; outcomes of an agent-based model are a prediction of components or processes in the system. Prediction in the sense of any estimate regarding the future. ABM’s parameterise agents in their own model and hope some emergent behaviour occurs i.e. we parameterise the present with some small known rules and observe what possible futures may exist. For example a model of the Hares and the foxes we know the foxes eat the hares. This is a known rule about the present. But there are variables we can change that will give different future outcomes. Such predator-prey systems usually produce dual oscillations with the two species stabilizing. The hare population goes through an oscillation, eventually stabilizing in a narrow range. The total amount of foxes also oscillates, out of phase with the hare population.

2.6 Human behaviour findings

I found information on various motivational theories [19]. As well as these I decided I needed some actual research findings on human behaviour as well as the theories, giving some data to evidence my models accuracy. My model is built around incentive packages and how these influence employee productivity. I took some empirical research findings [20] which briefly stated:

- When incentive packages are designed, implemented and monitored effectively, incentives can increase productivity by 22%, then gradually decrease with time
- Team incentives can increase performance by as much as 44%
- When an incentive is first introduced for completing a task a 15% increase in performance occurs.
- When asked to persist toward a goal employees increase performance by 27%.

The motivational theory I will use is a theory introduced by, Likert[21]. He studied human behaviour within the workplace. He believes that the most productive companies must make the most of their human resources. His theory being that management styles can affect organizations and that the group influences individual attitudes, goals, opinions and thoughts. This is a very useful theory as one of the end users long-term goals is to understand how peers affect human behaviour. Unfortunately you need to know how human behaviour is affected by peers to program the system. But when that is realised you can experiment with the model and ask ‘What if?’ questions. Likert believes that the working environment can affect the way the group work together. This is again interesting when modelling we should take notice of the environment effects as well as just agent-to-agent behavioural effects. He believes the working environment can effect
the achievements, cooperation, human relations with both peers and management, and
motivation of the group.
3.0 ABM software
In the following chapter I review alternative software and assess their use for the problem at hand. Concluding with my choice of software and reasons for my choice over others.

3.1 Are ABM software tools freely available for consideration of alternative solutions?
ABM software tools are widely available both commercially and free from the Internet and from the end user.
The following are just some of the packages I reviewed.

SWARM [22] can model complex organisations and social phenomena. Swarm is a multi agent based software package. The software was originally developed by Santa Fe Institute. Swarms looks to be promising for work in many areas. The architecture of Swarm is the simulation of interacting agents enabling the modelling of a variety of simulations. More pattern, spatially explicit based.

NetLogo[23] is a multi platform Java based application. NetLogo was inspired by StarLogo. NetLogo’s design was driven by the need to revise and expand the language so it is easier and more powerful to use and by the need to support HubNet architecture. NetLogo incorporates functionality. However it still did not contain the ability to build hierarchical agents with various components.

Agentsheets [24] is a commercial application given to me by the end user. This was an inappropriate package as it was for designing applications such as, personal agents, information agents, interactive demos, simulations and virtual game worlds. The usage of it was more appropriate for creating interactive simulations within web pages.

StarLogo[25] is the package I initially tried to use as this ABM software was suggested by the end user. It is a simulation environment built with turtles within a grid environment. This tool is too primitive to model human behaviour.

3.2 Problems of finding relevant software
Initially I began this work experimenting with StarLogo 2.0 - released September 27, 2002 see [25]. However after experimenting and exploring this software I found it to be only appropriate for models that are spatially explicit where individual agents are located in geometric space. This package is relevant for applications where visible emergent spatial patterns are of most interest and is not relevant for human behaviour, which is not something you can observe spatially. The next piece of software I examined was given to me by the Department of Health. AgentSheets 2.0,
is aimed at applications such as simulation within dynamic web pages, again being more spatial orientated. The University of Passau suggested Simplex 3 would be appropriate, I contacted them as they had written a paper [26] on using ABM for hospital management. I sent them the problem specification and they directed me to Simplex3. I trusted their judgement, as they are experts in this field. Simplex 3 is a simulation system containing a complete experimentation environment and its own object-orientated model specification language. It supports the creation, experimentation and analysis of simulations, for problem areas as varied as Production, Chemical Engineering, Economics, Medicine, Social Sciences, Biology and Ecology. The remaining problem was then to learn how to use and implement this software, which turned out to be very time consuming.

3.3 Software chosen and why?
Initially I decided upon Simplex 3 because it had been suggested to me by experts in this field [26]. After analysing the software I realised it was appropriate as it allowed the modelling of hierarchical components that could all be related to each other when using the modelling frame of the PECS reference model. Assigning agents components of type Physical, Emotional, Cognitive and Social would allow me to model humans more accurately.

Other reasons include the following, which are taken from [27]
- The modelling language (MDL) is based on systems theory. It contains elements from logical programming. It extends the object-oriented approach by additional communication mechanisms between components. Also MDL assumes every model can be constructed from elementary components, the so-called basic components; these can be joined together using connections.
- Observers can record results of experiments and runs independently of the model. Above the model we can conceptualise an observer level, which monitors and records data at certain times and under certain conditions. This is useful because changes in the mode of observation do not require changes to be made to the model.
- Graphical interaction is great with this package; simulation results can be displayed using two and three-dimensional techniques. You are able to individually modify the diagrams and tables, which display the simulation results of interest.

There are no general rules for designing a model in Simplex 3. There are only some engineering aspects that should be followed. Such as:
- Keeping the components within the model small and easy to understand.
- Information exchange between the components should be well defined. This is so the model may be developed further without major changes in its structure.
4.0 Implementation

The following chapter describes the implementation of the example model to illustrate the use of ABM software and some of the factors involved in modelling human behaviour.

4.1 Description of the Implementation

Usually the PECS components, environment components and behavioural output are implemented via a set of interacting components, as shown in the diagram 4.1.1. This seems the best way to keep the model clear in structure. However initially my agents will be very simple and it does not seem worth thinking about complex model architecture. Therefore because my agents are relatively simple, and time to implement the model is scarce, I will model the various components within one component. Diagram 4.1.2 shows the consultant components are self-contained. Each consultant has within just one single component their environment -incentives and workload, their internal states emotion- motivation and their output behaviour being motivation level. They both (consultant1 and consultant2) inherit physical energy from the third component

The beauty of keeping it simple initially allows me to use a straightforward method to predict the results of the model, such as research findings, which I have gathered on productivity and incentives (see section 2.6). Comparing factual findings with the model outcomes allows validation of the method at sequential time steps.

4.1.1 The rules of the model

All ABM systems have underlying rules that govern the system, containing variables which can be altered. The rules to my model were as follows:

- Incentives increase motivation by 22% (from research findings)
- Incentives decrease in value/effectiveness as time moves.
- Motivation increases when incentives are introduced, also decreasing over time and is weighted against workload.
- Agents energy also decreases over time.
- If workload is higher motivation is lower and vice versa. However I have kept workload constant in my model.

My model is strongly influenced by [21]. The goal of my model is to demonstrate as simply as possible how human behaviour can be modelled by using ABM and the PECS reference model. The agents are situated in an environment where their workload is constant, and incentives are offered to them in the form of money. Peer pressure also serves to motivate the second agent. The
agents internal states are emotion (motivation) and physical (energy). When incentives are high emotion is high too. (And vice versa). When energy is used up motivation is minimal. When consultant_1 is working hard this is causes consultant_2’s internal emotion motivation to increase. Theses incentives are needed to keep the agents motivated.

The second agent just mentioned will be implemented so that the dynamic behaviour of consultant 2 is influenced only by consultant 1’s motivation. The second agent is connected to the first through sensory variables, connecting the two. I decided to use the idea that if one agent is highly motivated this will influence the others behaviour, as generally it is human nature to be influenced by peers and generally society around them. I see this everywhere around me, built up in ‘social norms’. If for example your peers are extremely motivated and working hard this in turn increases your motivation. I have taken this idea from my own observations and experiences, but there is also an abundance of research showing the same results.

Social psychology shows us many ways in which we use persuasion to encourage or discourage others’ behaviours. In this model I am attempting to model the positive moral influence/tactic of persuasion. i.e. “If my peer is working that hard I must work harder too, put in my fair share”. Social influence can make the difference between success and failure in many institutions [28].

For example, government wished to increase recycling. To do so they created a series of television advertisements that played on social norms to increase recycling behaviours. This was proven to significantly increase recycling behaviours. This is what I wish to illustrate in my model, by assuming it is a social norm if your peers are working hard, you will too. In terms of my model the implementation will be that I will increase the consultants incentive to work harder if their motivation is below their peer.

Consultant 2’s motivation is completely influenced only by consultant 1’s behaviour. If consultant 2’s behaviour were not affected by consultant 1’s behaviour its motivation would be always negative (as in non-existent). Therefore consultant 2’s motivation appears considerably lower than consultant 1 as consultant 2 is not offered any additional incentive other than peer pressure.

I will then implement a separate component ‘Physical_Energy’ this is just an energy store which decreases and increases over time. This affects the amount of motivation slightly. If I had more time I would implement the model and its components with more ‘real world’ validity and accuracy. See Appendix D for coding and design diagrams.

4.2 The model design and purpose

The purpose of implementing a model here is not to build an accurate and insightful model, but to build a model that will help me assess the usability of ABM software and also understand some of the factors involved in modelling human behaviour. However rules of the agents will be modelled with valid research findings so to obtain at least some valid resemblance with the real world.
One factor I noticed whilst doing my literature review is that all models tend to be kept at the simplest level. [27] Says:

“The simpler the model the better it is as it makes programming it easier and thus is easier to work with”

The more realistic we make the model the more complex, unpredictable and opaque the model will become. Resultantly, the model becomes harder to validate empirically. When we keep the model simple the results are much more readily understandable.

Some basic questions I asked myself before constructing the model were:

- What are the basic entities of my model?
- What are the basic properties and dynamic behaviour of these entities?
- What are the relationships between these entities i.e. in which way do these entities interact with each other?

Answering these questions gave me an idealistic vision of what a human behaviour model may look like. See diagram 4.3.1. The finer details of my design are illustrated in diagram 4.3.2.

The world would contain an ‘environment’ component and an ‘agent’ component, which interact with each other. Within the agent component are subcomponents of type Physical, Emotional, and Cognitive. (NB: The Social aspect would be included where other additional agents introduced into the world) as social status would effect how an agent works.)

4.3 PECS Reference model

I have chosen to use part of the PECS reference model designed by [27] to implement my agents because a PECS agent can be endowed with various drives, needs and desires i.e. motives. The agent experiences these motives internally and behaves correspondingly. The PECS reference model as mentioned earlier is a reference to be used when attempting to model human behaviour. It allows the calibration of Physical, Emotional, Cognitive and Social components of a human.

The structure of PECS agents are based on system theory, having inputs, internal states and outputs. The top-level perception threshold corresponds to input from the environment component. The sub components in the agent represent the internals of the agents and their dynamic behaviour (changes of state). The behaviour is dependant on motives and available energy and is the output of the agent.
Diagram 4.3.1 The PECS architecture
4.3.2 The design diagram

The following diagram shows the design which I actually implemented (Refer to section 1.1).

**Name:** physicalEnergy

**Declaration:**
* State Variables
  * physicalEnergy(REAL)

**Dynamics:**
* Differential equations
  * physicalEnergy' := -(physicalEnergy/100)

* Events
  * Energy varies with time

**Name:** consultant_1

**Declaration:**
* State variables
  * workload (REAL)
  * incentive (REAL)
  * motivation (REAL)
* Sensor variables
  * physicalEnergy(REAL)

**Dynamics:**
* Differential equations
  * motivation' := physicalEnergy + (+/-) incentive/workload) * P
  * incentive' := -incentive/ X;

* Events
  * Incentives vary with time

**Name:** consultant_2

**Declaration:**
* State Variables
  * workload(REAL)
  * incentive(REAL)
  * motivation(REAL)
* Sensor variables
  * physicalEnergy(REAL)
  * motivation2 (REAL)

**Dynamics:**
* Differential Equations
  * motivation' := physicalEnergy + (+/- incentive/workload) * P
  * incentive' := -incentive/ X

* Events
  * Incentives vary with time
  * Motivation influenced by consultant_1
5.0 – Testing and results

5.1 Experiments with the model using observers
Observers observe the simulation from a bird’s eye perspective. Meaning we can freely choose which state variables we want to analyse, without effecting the simulation run.
Some examples, of the behaviour control of consultant_1 is shown here:
The graph shows the internal state motivation gradually decreases (the red line) with time, yet increases when an incentive is offered. Incentives are offered here at time T=200 and T=600.
And the blue line shows the cumulative motivation for consultant_1.

I carried out numerous experiments with this model, adapting the state variables. Analysing the effects on certain state variables, this is excellent for assessing how hypothetical situations would effect motivation. For graphs see Appendix

5.2 Results and findings
In the model there are variables, such as incentives and workload, which you can alter to consider different theoretical situations. Illustrating, how you can alter certain variables and observe the emerging behaviour which may occur in various circumstances. A couple of the experiments I carried out are detailed in Test One and Test Two. All simulation runs were for T= 2000 (time).
With the variables being altered for the first 1000t and left to see the effects for the next 1000t.
Test One
The first variable I looked at was the intervals at which incentives are offered to employees, to see how this affects their motivation levels.
I set the incentive at a constant level and performed several simulation runs with the frequency of these incentives altered, this would help a manager to find the most efficient use of resources. The results (see Appendix E – Test One) showed increased motivation levels when incentives were offered as frequently as every 50 days when compared to motivation levels when incentives were offered every 100 days. Yet, surprisingly the difference between every 100 or 200 days was minimal. Suggesting that it would be more profitable for the company to offer incentives every 200 days.

**Test Two**

I decided to vary the incentive offered keeping the interval the same. The interval being every 200(t). The results to this test should be intuitively obvious, that the higher the incentive the higher the motivation. Therefore this can be used as a ‘proof of theory’ or proof that the model is at least portraying some of reality with accuracy to a certain extent. The results (Appendix E- Test Two) show motivation levels in consultant1 increase dramatically inline with the increase in incentive offered to the agent. However consultant_2 behaviour reaches a certain level of motivation and doesn’t increase in line with the incentives as the consultant-2 is not offered any incentives other than peer pressure. These numbers are completely unrealistic and in future work it would be desirable to set a upper and lower threshold on this motivational level – however that is beyond the scope of this project.

**5.3 Further analysis**

These results may not actually be true, but it illustrates how we can infer from simulation runs by altering variables within the model. The simulation runs help us to predict, infer and observe the emergent behaviour from basic rules about the world. The problem we are faced with is how to set these rules.
6.0 Conclusion and suggestions

To help me conclude on whether I think ABM is a way forward for the Department of Health I will discuss some of the main limitations and capabilities of ABM in relation to the problem.

A limitation of modelling human behaviour is that the model you implement will be from research findings gathered which may be very general i.e about the average human. It may be hard to find data on the more extreme characters within society. However, you could argue you are still able to model the majority. But this raises the question - is there a majority that is average? Moreover, ABM allows you to program individual agents with different internal states (personalities) so the argument against ABM on these grounds may not be the strongest. However, are individual personalities far to complex to even begin to model? This question is beyond the scope of this project yet it is I would suggest a question that needs serious consideration before beginning to build any sort of model. I would say human behaviour could be modelled with the aid of agents to a limited extent only.

An excellent capability being once a model is built, parameters can be varied and the consequential behaviour observed and studied. This is extremely useful and effective for systems whose components have very definite rules. Without rules an ABM system would be meaningless. In the context of human behaviour a set of definite rules may be found in the structure within the problem. If these rules are known then ABM is an excellent approach. However, I am unsure whether it is possible to do this in human behaviour. Many of the applications I reviewed seemed to have had success in this notably [29] which models virtual humans having realistic behaviours. The model is used to assess the effects of various different marketing strategies and the human consumer reaction.

I would suggest to the Department of Health, before considering building a model they would first need to consider if they could afford the research costs needed to make the model a success, in terms of time and money. This research is needed to gather these definite rules about their employee’s behaviours and underlying tendencies. I would say if they can come up with true, definite and general rules then ABM would work. My experiment with my model shows that once you have decided upon theses rules, running the simulation and observing the emergent behaviour can yield interesting results. I think using the PECS reference (section 4.3) model-to-model human behaviour definitely makes the model more real with undeniably much potential. However again there still needs a deep, under laying understanding of humans, all of the elements which make up a human, how these elements interconnect with each other and the environment. (i.e they would need an understanding of the

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dynamics within their employees which result in typical behaviours.) If we had this then ABM would be an excellent option. Some argue we can model the individual aspects of humans based on theories. But again how accurate would these theories prove to be? This again would require further study into the accuracy of theories we hold on ourselves. Some human like models we know are modelled simply on a prehistoric man at the very early stage of development, as we know basic definite facts about the makeup of such creatures.

[27] says the following, which illustrates my point that you can only model human beings if you have the knowledge about their behaviours in the given situation.

“When an agent is used for modelling a human being for example, the agent has to be equipped with all properties and behavioural patterns of the real human which are of relevance in the given scenario”

I think ABM would hold more use, at a considerably lower cost in terms of research, in modelling processes that involve humans within the hospital. Processes within their workplace because their behavioural patterns are known and almost definite, as the processes that are carried out are methodical. For example, within a hospital a process may be when you check a person in. The set of processes and behavioural patterns are repetitive and almost definite. These types of processes may be modelled, variables changed to discover the most profitable way of coordinating such processes and schedules.

The trouble with ABM is the level to which you have to abstract and idealize the real situation. However, its performance is much better than current simulation methods that are purely deterministic. Because these deterministic approaches ignore human decision-making and behaviour altogether, modelling humans as a resource. After conversing with many professionals in the field in particular Aguilera, Antonio, about agent systems and their use in human phenomena modelling. I came to the conclusion that the approach is useful but with a huge background in the behavioural sciences, especially in human motivation and mass psychology. The question is whether the Department of Health can afford the large amount of time and money that researching these topics would involve. I have come to the conclusion that it would be a good investment in terms of appropriateness for the problem stated in section 1.2. If the level of analysis of the real world behaviours were adequate, useful insights could be yielded.
7.0 Evaluation
The solution created in this project is evaluated against certain objective criteria illustrating whether the project met the project aim. The chapter concludes with suggestions for extensions to this work.

7.1 Evaluation Criteria
The following lists the objective criteria I will evaluate my work with there are four sections to evaluate the literature review, the model structure, the model results, and whether the outcomes satisfy the end users requirements.

7.1.1 Literature review
When carrying out any work it is important to validate it. I will validate my literature review against my minimum requirements.

7.1.2 Model structure
Some of the general criteria for assessing *model structure* validity I have gathered from many papers written in ABM in particular [27]. I will use the following criteria to show the logic behind my model:

1. Are all the variables in the model relevant to the real world?
2. Do the ‘rules’ which are used to design the model make sense?
3. Do results from the model help us to understand the real world more?

7.1.3 Model results
The model of human behaviour I produced is hard to validate. The reason being that there is a lack of empirical research in cognitive processes. For example, when deciding how emotional, social and physical aspects relate and connect with each other to emerge certain behaviour. One way of overcoming this would be to replicate the model in real life with real people to see if the behaviour is the same as the model. However, this is expensive in terms of time and money. Nevertheless as the purpose of building the model was to help the end user gain an understanding of the factors involved in modelling human behaviour not to actually provide an insightful model the validity of the model is least important. But I did design the model on empirical research based on incentives packages and motivation (see section 2.5), so I can validate the model results based on this.

7.1.4 Are the end users requirements met?
More important is whether the model helps the end user to understand the factors involved in modelling human behaviour, its capabilities and limitations. Put another way - does my solution help the end user make a decision about ABM?
7.2 Deliverable a success?

Overall I would say my project is a success and I am very happy with the outcome. This project meets and indeed surpasses my minimum requirements stated in section 1.3. The evidence being as follows:

- I reviewed more pieces of software than what was required of me (see section 3.0-3.3).
- I reviewed many applications of ABM reviewing a wider perspective of ABM applications to help gain a greater understanding of ABM (see section 2.0-2.6).
- I created a model in Simplex 3, which will predict the behavioural patterns, and responses (motivation level), which may emerge when assigning incentives to at least two agents. Additionally, I connected the agents together with one consultant’s behaviour affecting the other.
- I also exceeded my minimum requirements by building my model on research findings on human behaviour, enabling me to test the accuracy of my model.

Using the criteria set out in section 7.1.2 I feel the validity of my model structure is average. The variables within the model are relevant to the real world – being workload, incentive, and motivation. They are related in the model in a way very true to the real world. The rules of the system make sense (see section 4.1.1). The results from the model illustrated some insight into the real world (see section 5.2).

Using the criteria set out in 7.1.3 the results show some insight into how incentive frequencies can affect motivation. This insight is quite minimal and could be expanded if more attention was made to structure and rules of the system. Also my model reflects the research findings I based the model on, portraying accuracy. Meaning the model produced outcomes that were expected as illustrated by the research I gathered.

With regards to the main question set out in 7.1.4 does the project help the end user decide whether human behaviour can be modelled using ABM? I think my literature review will surely help the end user gain a broader understanding and appreciation of ABM; its applications, strengths, weaknesses and typical characteristics of problems solved using ABM. Hopefully making them better informed to make a judgement about whether they would like to invest in ABM. As well as of course I have given them a grounding understanding in the practical issues in implementing a model. I have made suggestions to the end user in my conclusions which I have justified. I hope this will serve to help in their decision-making. I feel this work is an excellent grounding for the end user to use in the broader scoped problem stated in 1.2.1.

7.3 Future work

Further expansion of this work could be as follows:
- To implement the entire PECS reference model, or even advance it. Allowing a more accurate representation of a human being.
- More research into human behaviour, personality, and motivations – more in depth analysis of this particular problem area.
- Expansion of the system into a scheduling system.
- Using ABM to identify more effective ways of encouraging diffusion of behaviour enabling a forecast of future performance in businesses.
- To model agents which interact with a dynamic environment. Within this world everything interacts with its environment which is forever changing. This will again produce more realistic models.
- More research into other modelling techniques, i.e. advancement of the ABM technique to something else.
- Anyone seeking to advance on this project I would point them to the direction of the UCLA- The centre for Human Complex Systems. This was pointed out to me a day before the deadline, but looks like a very promising website on human complex systems focusing on agent based modelling. It can be found at: http://hcs.ucla.edu/lake-arrowhead-2003.
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Appendix A

For me the purpose of doing anything at all is to learn lessons and pass on knowledge to others. For what is the point if you are not to learn from it, further still if you cannot pass this knowledge on. The sharing of knowledge and lessons is what has enabled us to advance. For, alone we may have knowledge and insight, but with another’s perspective it is all the richer. Consider the fable of the blind men from the Indian fable. The blind men approached the elephant, one of the men grabbed its tail, thinking it was a rope and the other man grabs a leg, thinking it was a tree, none of them understanding the whole animal. We will never be more than blind men approaching the animal from as many different angles as possible. This fact I know to be true as what state would my project be in if people were not willing to pass on their advice, lessons and perspectives.

The first lesson I stumbled upon was that of the literature search. For many future final year students the project may well be the first time you have to do research to this depth -my advice to them would be perseverance. Initially the amount of information you are faced with can be so overwhelming, and sometimes too advanced. Break down your workload into small pieces, instead of trying to tackle the whole at once (as I did). I learnt it is much easier to work effectively if you can break down what you have to do into very small steps and do just a few at a time, giving a sense of achievement which is in turn a motivator. I learnt if you try to attempt the project at the top level i.e. the whole at once this simply leads to dissatisfaction and demotivation, as the task at hand seems too daunting.

Another lesson is to try and not overcomplicate the task in your mind. Les Proll informs me this is a common problem with computing students. Your mind is extremely powerful and if you believe something to be extremely difficult it will appear that way.

I have learnt that knowledge management is something that comes with experience so my advice to other students is to start as early as possible – the earlier you start the more effective your research will be.

I have learnt a lot about myself and the way in which I work under pressure. This will be useful knowledge to have when it comes to future work. However I’m unsure of how useful, as the only constant in this world is change. If I am constantly in change I don’t know how useful it will be to know how I handled this project for use with future projects. But still I have learnt lessons from the experience that are invaluable in helping me to change in the here and now.

Time management is important if you are to get the most out of the project experience. It is always best to spread out your work enabling you to work under less pressure and enjoy the fruits of your work. I found I managed my time quite well using this method, obviously some weeks/days you are more motivated and focused than others but this is natural.
There was however a change in my initial schedule as initially I underestimated the fact that I would have to search for, analyse, review and experiment with various software to find software appropriate to the task - this was because initially the end user was supplying me with the software. However, it turns out that the end user had only a vague idea about ABM and knew little about the software they possessed, which was inappropriate. Resultantly, my time schedule was set back somewhat with some tasks taking longer than expected, but never shorter. Maybe this is due to me putting too much work onto myself and perhaps being a little unrealistic. My advice to any other students would be to be as realistic as you possibly can, this will save a lot of pressure imposed on yourself only by yourself.

However, I feel having an initial plan is definitely good in getting you on the right path, but it is important to remember that nothing is for certain, and unexpected variables arise all the time, and to allow for this in your plan. i.e allow yourself enough time for things to go wrong and be rescheduled, as nothing you plan for the future can ever be certain.

I have learnt that anything is possible if you put your mind, focus and energy into it. And that you will always get out exactly what you put in.

I learnt that people in the computing industry and academia are quite happy to help you but only if you are willing to help yourself. I was glad I took the initiative to do so, it made me realise the interconnectedness of everything.

Also I have learnt that it is important to scope the project, as when a project is open ended and mainly up to you to direct it, it is important to ensure you don’t take on too much. And that you carefully focus on one aspect and are not distracted by the mass of scope around it.

I learnt how to experiment with and assess software to choose the appropriate package for particular specialised requirements. I had never had to do that before this project, so it was a good experience.

A word of warning to all final year students make sure you leave plenty of time for the write up as it takes an unbelievably long time of drafting and re-drafting of which I feel I just about timed right, but still it took longer than I anticipated.

Perhaps one of the major lessons in a practical sense was communication. As my project was for an external company, I quickly learned that I knew a lot more than I believed I knew when faced with the outside world. The lesson was in translating what the end user actually said into what they were actually asking for. Because they have limited computing knowledge, your job is to translate computing terms to lay mans terms and vice versa. This initially can only serve to confuse if you take what the end user says too literally. If anyone else considers doing an external project, I would advise them to be aware of this, ensure you communicate with the end user in a
language that you both understand to prevent any misunderstandings that may arise in the solution. I am sure this is an excellent skill that will be very useful in the future. I would say it was definitely a great motivator doing my project for an external company, as it is easier for me to give than to do something for my own personal benefit.
Appendix B  Project schedule and revisions

Project schedule
This appendix illustrates the initial Gantt chart for my plan and the revised version showing what actually happened.

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NB: This Gantt chart gives a general indication of progress. It was always anticipated that little to no progress would be made at the start of January during the exam period. Changes within these two charts i.e. changes in the progress plan are for the following reasons. Everything went well and to plan up until the Mid Project Report. A thing, which delayed me, was finding the correct software to use for the task at hand. Leaving my model building till much later than had been anticipated. Because of this I thought it would be more productive to meet with the end user once I had completed the work. The amount of time needed to experiment and learn the software to enable me to design something insightful was underestimated in the initial plan stumping my progress

*Revisions to the schedule are highlighted in yellow*

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01 May 2003

Dr L Proll
School of Computing
The University of Leeds
Woodhouse Lane
Leeds LS2 9JT

Dear Les

Subject: Final Year Project by Elizabeth Finigan

The problem at the basis of this project was a complex and messy one. Ms Finigan was required to research a new field before she was able to begin the project. In addition, the problem itself was not clearly defined, which meant that Ms Finigan was required to make assumptions to move the work forward.

Ms Finigan showed a keenness to solve my problem and demonstrated good skills in researching the new field. She had some ambitious plans for the work and appeared genuinely interested in its results.

We had a productive session at the Mid Project Report stage. Ms Finigan had already produced some interesting results. I identified one or two aspects that I felt would strengthen the work for the remainder of the time available. For example, to add commentary describing how particular attributes of the agent based modelling methodology related to my problem, concluding whether this approach was appropriate or not given my needs.

We last met in February, and I am looking forward to reading the report.

Yours Sincerely

Dr Lisa Simpson
Head of Primary Care Performance Analysis

Direct line: 0113 254 5440
Email address: lisa.simpson@doh.gsi.gov.uk
Appendix D Running the model

If you would like to see the simulation model results. Load the disk and do the following:

1. Click of ‘s3xshell.exe’ icon.
2. Open up the private (Priv) library.
   2.1 Within this library open the PROJECT folder.
3. Double click on ‘Components’ – then select ‘consultant_high’ from the list.
   3.1 Right click on it and select ‘Prepare version’ from the menu. (this compiles the model into c code)
4. Double click on the ‘Models’ folder (just below the components folder) and right click on ‘consultant_high’ contained in this folder.
   4.1 Select ‘Install model’.
5. Double click on the ‘Experiments’ folder (just below the models folder).
   5.1 Double click on ‘Efinal’.
   5.2 Double click on ‘Run 1’
   5.3 Enter simulation time from 0 to 2000.

6. To view the results in graph or table form- go to folder ‘Simulation Results’.
   6.1 Right click on motivation. And select ‘Analyse and Present’ from the menu. Then OK.
7. To reset the simulation run, go back to run 1 and right click selecting ‘Reset from the menu’
8. Enjoy
Appendix E Coding and design

The following diagram shows my design (Refer to section 1.1)

---

### Name: physicalEnergy

**Declaration:**
- *State Variables*
  - physicalEnergy(REAL)

**Dynamics:**
- *Differential equations*
  - physicalEnergy' := -(physicalEnergy/100)

*Events*
- Energy varies with time

---

### Name: consultant 1

**Declaration:**
- *State variables*
  - workload (REAL)
  - incentive (REAL)
  - motivation (REAL)
- *Sensor variables*
  - physicalEnergy(REAL)

**Dynamics:**
- *Differential equations*
  - motivation' := physicalEnergy
  - incentive' := incentive/workload

*Events*
- Incentives vary with time

### Name: consultant 2

**Declaration:**
- *State Variables*
  - workload(REAL)
  - incentive(REAL)
  - motivation(REAL)
- *Sensor variables*
  - physicalEnergy(REAL)
  - motivation2 (REAL)

**Dynamics:**
- *Differential Equations*
  - motivation' := physicalEnergy
  - incentive' := incentive/workload

*Events*
- Incentives vary with time
- Motivation influenced by consultant_1
The coding for this is written in MDL which is Simplex 3’s own integrated model description language, which allows models to be specified in a formal, non procedural manner. The elements of the language are natural and almost self explanatory.

Coding for the interconnecting components is as follows:
Component consultant_high is the high level component which integrates all the components together through sensory variables (illustrated above).

```
HIGH LEVEL COMPONENT consultant_high

SUBCOMPONENTS
  consultant_1,
  consultant_2,
  consultant_energy

COMPONENT CONNECTIONS

  consultant_energy.physicalEnergy --> consultant_1.physicalEnergy;
  consultant_energy.physicalEnergy --> consultant_2.physicalEnergy;
  consultant_1.motivation --> consultant_2.motivation2;

END OF consultant_high
```

```
BASIC COMPONENT consultant_1

DECLARATION OF ELEMENTS

CONSTANTS
  I (REAL) := 1.0,
  P (REAL) := 0.22,
  X (REAL) := 1000.0

STATE VARIABLES
  CONTINUOUS
    workload (REAL) := 10,
    incentive (REAL) := 40,
    motivation (REAL) := 20

SENSOR VARIABLES
  CONTINUOUS
    physicalEnergy(REAL) :=0

DYNAMIC BEHAVIOUR
```
IF (incentive > 50) DO
DIFFERENTIAL EQUATION
    motivation' := physicalEnergy + (incentive/workload) * P;
    incentive' := -incentive/ X;
END
END
ELSE DO
DIFFERENTIAL EQUATION
    motivation' := physicalEnergy + (-incentive/workload) * P;
    incentive' := -incentive/ X;
END
END

ON ^T > 500^)
    DO incentive^ := 100;
END

BASIC COMPONENT consultant_2

DECLARATION OF ELEMENTS
CONSTANTS
    I (REAL) := 1.0,
    P (REAL) := 0.22,
    X (REAL) := 1000.0,
    Q (REAL) := 0.44

STATE VARIABLES
CONTINUOUS
    workload (REAL) := 10,
    incentive (REAL) := 40,
    motivation (REAL) := 20

SENSOR VARIABLES
CONTINUOUS
    motivation2 (REAL) := 0,
    physicalEnergy (REAL) := 0

DYNAMIC BEHAVIOUR

IF (incentive > 50) DO
DIFFERENTIAL EQUATION
    motivation' := physicalEnergy + (incentive/workload) * P;
    incentive' := -incentive/ X;
END
END
ELSE DO
DIFFERENTIAL EQUATION
    motivation' := physicalEnergy + (-incentive/workload) * P;
    incentive' := -incentive/ X;
END
END
ON ^motivation2 > motivation^  
DO  
incentive^ := 100;  
END  

END OF consultant_2

BASIC COMPONENT consultant_energy

DECLARATION OF ELEMENTS

STATE VARIABLES
CONTINUOUS

    physicalEnergy(REAL) := 100

DYNAMIC BEHAVIOUR

DIFFERENTIAL EQUATION

    physicalEnergy' := -(physicalEnergy/100);

END

ON ^T > 1000^  
DO physicalEnergy^ := 100;  
END  

END OF consultant_energy
Appendix F Testing and Results

Test One

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<th>Incentive Interval (Days)</th>
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<td>2673.03</td>
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<td>200</td>
<td>2264.99</td>
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Test Two

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<td>200</td>
<td>5832.15</td>
<td>224.141</td>
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<td>750</td>
<td>22254.2</td>
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Appendix G  Experimenting with Simplex 3 simulation tool

The following illustrates a selection of my experimentation with the simulation tool. From the beginning, illustrating lessons I learnt as I went through. These may serve anyone else doing a modelling project.

In the beginning…..
This first model of a consultant is assuming that current workload is constant at ten units.
A simple calculation is used to determine the internal state motivation by weighting the incentive offered with the current workload.
The output productivity is then calculated weighting the internal state motivation with again the current workload.
The model is based on the research findings that incentives increase productivity.
The model illustrates that when incentives are introduced motivation and productivity increase.

The following screen shots show results for the following data.
At time [T] >= 0 incentive =20.
At time [T] >= 1000 incentive =120

The following screen shot shows the simulation results for the productivity observer.

The following screenshot shows the simulation results for the motivation observer.
The following shows the screen shot of the varying incentives at differing times.

This works confirming the models validity.

For consultant 2 I introduced a varying workload keeping the incentive constantly low. We would intuit that motivation and production would be low as the incentive to
do the work is low, yet if the workload is low motivation and production will be higher at these times because less incentive is needed to do less work.

Results below for employee motivation

For productivity

When using the following workload values
The results show as we would expect that as workload increases and incentive does not productivity increase at a much slower rate, thus productivity is lower and not the desired or optimal outcome. Also employee motivation steps down with the increase in workload and the constant incentive.

These results are intuitive and not in the least bit surprising, we could easily calculate this without using ABM. So what is the point? What do we hope to achieve by using ABM?

*Getting there slowly….*

Well hopefully we can give these motivational features to a number of agents and see if any emergent behaviour occurs.

I think the point is to set up a couple of general rules we know about a human from observation. Then playing with these variables to illustrate optimal incentives.

First however I am going to set up to counter acting forces on the agents, increasing workload and varying incentives.

With workload going up and incentive varying up and down. Results are as follows

Motivation’
Motivation

And production results are
And production
Idea....
There must be a threshold when this motivation stops increasing no matter how much incentives you offer. From findings I will use from the PECS the physical component, to use to help determine this threshold. This component will interact with the agent as a subcomponent. Its energy level will deter the amount of increase in motivation and productivity. If they have energy the incentive will take effect, however if there is no energy left the incentive will not effect the agents motivation or productivity.

ON HOLD
Decided to go back to the first model and vary the intervals at which incentives are introduced at a set amount. To try and gain some useful insight. This graph shows the productivity motivation and incentive graphs for the incentive being introduced at 1 second 1000 seconds and 2000.

I figured out how to make the incentives tail of after time. So know I will use the model to try and at last gain some insight.

Incentive is initially 50 with no later incentives

The incentive graph
When incentives are offered at different times

Incentive graph

When introducing an incentive of 100 at every do seconds motivation decreased to the following values
The motivation/productivity levels reached 2112 not much more than when introduced every 100 seconds this suggests that if incentives introduced too often they may start to lose effectiveness.
Motivation decreasing values never below
Motivation/productivity levels reach 1814

Incentives never decrease below …
OK so now I think I have implemented a more accurate agent. Where I increase and decrease motivation levels when incentives are above and below 50 respectively. However whether motivation is increasing or decreasing it is still moving at a rate with respect to time. I.e. the incentive loses weighting as time goes on meaning the rate of change slows down with respect to the incentive. The following shows the results when just one incentive is offered. Incentive begins at 40 then gradually decreases with time (with respect to motivation) Then a motivation of 100 is added at time $t=500$. (This could be in days) Increasing motivation yet still gradually decreasing. We could illustrate this by setting the simulation time to a larger number say 3000 to see what happens to the motivation levels, they should hopefully soon start to decrease.

Motivation graph

Motivation’ (increase/decreases graph)
This is WIKID!!!

The incentives graph looks like this …
Next I will try all the tests I did previously (Interval test) to see if I could gain any insight into how often incentives are needed to be most productive. I will try every 200 seconds. Up until $t = 800$.

**EVERY 200 days**

Incentives every 100 days up to 1000 graph goes up to 2000
MOTIVATION reaches 2343.4
Every 50 days motivation 2533.42
EVERY 50 motivation n incentive
This may not actually be true, but it illustrates how we can infer things from basic rules about the world. The problem is in deciding which rules to use.

Incentive at 500 days and 950 days

Motivation 1240.83

The following graph comes from two agents linked together we can assign different motivational features to each (i.e.) different incentives to help us make a more direct comparison. One as one initial incentive, the other has regular incentives. The graph shows the motivation levels of the two at any one point in time.
Another use of this would be that we could connect the agents together so they influence each other in some way. One idea may be to introduce social status and link that to motivation. For a realistic model would require in depth research I am just going to make this up.

I decided to link the fact that if one person in the group is motivated, the other will be influenced by this action and in turn be motivated too. Through peer pressure. Evidence for this surrounds us everyday. If we have a group of people and one of us is racing away the others are influenced into doing more work themselves. The following graph shows where I have influenced consultants_2 behaviour be interacting it with the motivation of consultant_1.

LINKED BOTH TO INCREASE MOTIVATION IF ONE IS BUSY THE OTHER IS ALSO CONNECTED WITH THE ENERGY COMPONENT

WITHOUT ENERGY FUNCTION-> INCENTIVE EVERY 50
Incentive = 200 every 200 seconds without energy
Motivation graph:
Incentive = 500 every 200 seconds. Motivation graph: