Chapter 23
Using Agent-Based Models for Education Planning: Is the UK Education System Agent Based?

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Abstract Agent-Based Modelling (ABM) is a relatively new spatial modelling technique. The ability of ABM to simulate a real world system, the UK education market, is explored in this chapter. It is shown how a simple ABM incorporating common sense rules can provide acceptable results with over 60% of pupils being allocated to the correct schools and 75% of schools containing at least 50% of correct pupils when compared to observed data. The exploration outlined here highlights that the education has a good deal to offer researchers in the ABM field. Possibly more importantly, the real potential of ABM as a technique for simulating real world systems and delivering appreciable benefits to the general population is demonstrated.

23.1 Introduction

The world is a complex place; the systems that make up the environment in which we live are both diverse and interactive. In a social context, the complexities of interactions between different peoples' lives have been observed and explored by filmmakers for many years, a good example being 'Love Actually'. In this film all of the ongoing sub-stories are interwoven by a network of friends, family and work colleagues, many of whom are unaware of many of the other characters in the film; yet the decisions they make have wide ranging impacts. A global story emerges from the micro, 'individual', level interactions.

However, in the real world micro level interactions produce emergent level macro behaviours or events. A real world example of this would be the protests observed in Tunisia, Egypt and Jordan in February–March 2011. These protests

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start with interactions at a micro level and result in events that make news headlines throughout the world. Agent-Based Modelling (ABM) is a relatively new modelling technique used to mimic micro scale interactions to observe what the macro level outcomes are (see Crooks and Heppenstall 2012 for an overview). To date many ABM applications have been theoretical, most notably SugarScape (Epstein and Axtell 1996) and discussions by authors such as O'Sullivan and Haklay (2000) have asked questions as whether the 'world really is agent based'? Despite the questions raised as to whether ABM can actually represent the real world, some ABMs are now starting to have real world applications, such as the crowd control applications for the Notting Hill Carnival (Batty et al. 2003), modelling infectious diseases (Epstein 2009), petrol price modelling (Heppenstall et al. 2006) or more recently crime simulation (Malleson et al. 2010). The world is made up of many different discrete objects that interact given a particular set of rules or laws, governments interact, companies interact, clubs and social groups interact, individual people interact, chemicals interact even down to the particle physics world of protons, electrons and quarks etc. all interact. Therefore, the question shouldn't be whether the world is Agent-Based, but whether we have the computational power and ability to model it. All things considered, it comes down to finding a suitable scale at which to model interactions where the processing time and complexity can be balanced against gathering fruitful and useful results.

This chapter will explore the application of ABM to the simulation of events in a real world system, the education system in England (UK). Section 23.2 will present contextual background with Sect. 23.3 presenting the case for the importance of education planning. The model is presented in Sect. 23.5 with results discussed in Sect. 23.6 and concluding thoughts given in Sect. 23.7.

23.2 A Brief History of the English Education System

Over the past one hundred years education policy and provision has evolved significantly. There have been periods of unprecedented development, but also periods of unrivalled contradiction and controversy. As the education sector developed in the early part of the twentieth century, momentum gathered. This momentum carried into a period of substantial development leading to reform and the introduction of the 1944 Education Act. This was widely recognised as the Act that "laid the foundation for the modern education system" (Statham et al. 1991, p. 42). It abolished the Board of Education and replaced it with the Ministry of Education, with the Minister having a much more proactive role in education policy formation. Robert Butler became the first Minister of Education and was the main proponent of the Act spearheading it through Parliament in controversial circumstances. "[I]t was overseen by a Conservative MP (Butler), taking advice from Labour MPs ([James] Chuter Ede, [Ernest] Bevin and [Clement] Attlee amongst others), and with a civil service department in agreement that the time for reform was at hand. It was passed by a Coalition government in direct opposition to the Prime Minister [Winston Churchhill]" (Langley 1997, p. 38).

These sweeping reforms and the distinctive shift of power away from the schools and towards the Local Education Authorities (LEAs) have been described as "the single most important piece of legislation to be passed between 1939 and 1945." (Chitty 2004, p. 18). However, omissions from the Act would prove troublesome over the next 44 years. Firstly, the provision of religious instruction for primary and secondary schools was the only curriculum requirement of the 1944 Act, allowing schools to develop individual curricula. A second major omission that would prove a particular point of contention was the lack of any specific framework for the structure of new compulsory secondary schools. Would the system be a tripartite system as recommended in the Spen Report (Lawrence 1992) or a comprehensive system favoured by the Hadow Report (Armytage 1970)? This question would prove inhibiting to the smooth implementation and running of the secondary education system until the next round of major reforms in 1988. In the following years political polarisation exploited the gaps in the 1944 'Butler' Act and left the education sector with a legacy of school types, many still in existence today and each having different characteristics such as admission policies.

In 1988 the Education Reform Act (ERA) opened up the education market place and closed up the loop holes in the 'Butler' Act. This piece of legislation forms the cornerstone of the education system in operation today. It laid the groundwork for information collection, competition between schools based on performance and school inspections. Subsequent, legislation has built on provisions in the 1988 ERA. Today schools operate in a quasi-competitive market, with competition between schools for pupils who in turn have a choice of the school they wish to attend. The ubiquity of the educational product supplied by schools has been diversified after Key Stage 3, with the introduction of specialist schools that focus on particular vocational themes.

23.3 Why Is Education Planning Important?

Recent demographic trends have provided education planners with considerable challenges. For the first time since significant development of the education sector was undertaken, declining pupil numbers have meant that school rationalisation has been required. Surplus school places are recommended to be no more than 10% within an LEA and no more than 25% in any single institution (Audit Commission 2006) with current fiscal pressures underlining the need to keep surplus school places to a minimum while ensuring educational the requirements of the population are met. The challenge to ensure that school places are available at the institutions preferred by pupils and parents has fallen to the LEAs as the 'commissioners' of education. Over the preceding century, control of the education sector has been shifted from schools to the LEAs, and then recently, from the LEAs up to Government, with the setting of the National Curriculum, and back down to schools, with the advent of 'Trust schools'. LEAs sit in the middle layer with a great deal of responsibility for the planning of education provision, and ensuring that education is supplied fairly for all sections of society, but with much reduced control over their local area.

Accurate school roll forecasting has become increasingly important for education planning professionals because of the dynamic nature of population demographics. The level and distribution of demand for education constantly change overtime as the pupil population either increases or decreases over space. It is not just population change that is demanding more sophisticated projection techniques, life style changes have altered the way that people operate in the spaces in which they live. The school run has become part of a multi-purpose journey which includes other functions, such as a journey to or from work plus, perhaps, a shopping trip (Pooley et al. 2005). Therefore, family convenience influences school choice decisions. Additionally, concerns over child safety during their daily commute to school have become a significant concern to parents when selecting a school for their children to attend (Valentine and McKendrick 1997) over and above the conventional attractiveness factors, such as teaching quality, attainment levels and proximity to home. All of these factors create a more complicated environment in which education planners seek to keep the supply of education commensurate with demand.

Information in the education sector has become more abundant in recent years. The introduction of the Pupil Level Annual School Census (PLASC) dataset and its incorporation into a National Pupil Database (NPD) in 2001/2002 made detailed pupil level information available to education planners. The information contained in the NPD, and in particular PLASC, is not only detailed but also longitudinal, providing a resource of immense value to LAs and education planners. Unfortunately, projection methods used by most LAs have not reflected the changes in the education market or the increased availability of information in this sector. The projection method of choice for most education planners is still a basic cohort progression model where the underlying demand is based on either the previous years demand directly or on a weighted average of a number of previous years demand. In the 1970s the cohort progression model was adopted into the education planning process (Simpson and Lancaster 1987), at a time when the education sector was still experiencing considerable expansion. However, the cohort progression model, although easy to understand and apply, lacks the sophistication required to respond to rapidly changing pupil populations and in turn school network restructuring tasks required in the modern education market.

In recent years, there has been a growing interest in various aspects of the education sector by geographers. Social and ethnic segregation in the education sector has been the focus of a good deal of research including notable texts by Gibson and Asthana (2000b), Gorard (1999), Gorard and Fitz (1998a), Goldstein and Noden (2003), Harris et al. (2007) and Johnston et al. (2006). Other aspects of academic investigation into the education sector have examined the effects of school performance on local house prices (Cheshire and Sheppard 2004; Leech and Campos 2003; Croft 2004), links between school roll size and academic achievement by pupils (Bradley and Taylor 1998), competition and performance between schools and the resulting effect of parental choice after the 1988 ERA (Gereluk 2005; Pooley et al. 2005; Bradford 1990, 1991). However, there has been little academic research into pupil daily commuting patterns and the journey to school. Pupil commuting patterns do result from the school selection process. Equally, school selection is influenced by geographical factors, such as school proximity and, more importantly how connected a school and the pupil's home location are. Therefore, school selection behaviour and pupil commuting patterns are inter-connected.

The planning demands of a dynamic population, a competitive education system with open parental choice and Government policy changes, requires that education planning professionals develop more sophisticated and effective methods of assessing and supporting the planning decisions they make. A Spatial Education Model framework consisting of a number of layered spatial interaction models simulating pupil movements interacting with schools represented as agents provides a series of promising results and provides a potential resolution to the current lack of a sophisticated planning tool for use in the education sector (Harland and Stillwell 2010). However, frameworks such as these do not handle individual pupil characteristics well. For example, single sex schools are not easily serviced when the demand (pupils) side of the model is serviced by an aggregate model such as a spatial interaction model. This type of issue seems ideally suited to the application of an ABM and with the abundance of individual level information available within the education sector the model can be based on and measured against a real world social system.

23.4 Data in the Education Sector

The National Pupil Database (NPD) is a relatively new dataset created in 2002 and contains individual pupil records for all state educated school children (Ewens 2005). It is updated on an annual basis with additions in excess of eight million individual pupil records collected by each Local Authority (LA) in England and Wales and is maintained by the Department for Education (DfE formerly known as the Department for Children Schools and Families (DCSF)) (Jones and Elias 2006). Access to the NPD has recently been provided through a central gateway funded jointly by the DfE and the Economic and Social Research Council (ESRC) and managed by the Centre for Market and Public Organisation (CMPO) at the University of Bristol where the PLASC/NPD User Group (PLUG) is based (Burgess et al. 2006). The NPD is stored in a relational database structure with several different datasets capable of being linked together using either a Unique Pupil Number (UPN) or a unique establishment identification number to allow for both temporal and cross-sectional analysis, creating a powerful information resource for policy formulation (Jones and Elias 2006).

Completion of the Pupil Level Annual School Census (PLASC) is statutory for all state maintained primary, secondary and special schools under section 537A of the Education Act 1996 (Jones and Elias 2006). The DfE began collection of the data in 2002 and it now forms the cornerstone of the NPD. Individual schools are required to submit a PLASC return to the LA on the third Thursday of January each year. The return consists of entries for every pupil on roll with data such as home postcode, ethnicity, Special Education Need (SEN) status and Free School Meals (FSM) eligibility, plus information relating to the school and its staff (for more detail on the complete contents of the PLASC dataset and the structure of the NPD see Harland and Stillwell 2007). In actual fact, the data collection of pupil information is no longer referred to as PLASC because a tri-annual data collection procedure called the School Census with a modular structure was introduced in 2006 for secondary schools and in 2007 for primary schools (Department for Education and Skills 2006b). One of the three data collections is still carried out in January, with two further collections on the third Thursday in May and the third Thursday in September augmenting the January collection (Department for Education and Skills 2006a). The tri-annual data collections coincide with the three school terms and enables more effective tracking of pupil migrations, moves between homes and moves between schools, throughout the year.

Ewens (2005, p. 4) comments that "the National Pupil Dataset is amongst the most important national innovations in data collection in the recent past. Its potential is considerable and the scope for development is also considerable." These comments made by Ewens are true in more ways than one. The collection of pupil data is critical for the evaluation education policy and progression in raising the standards of education provision. Moreover, the collection of such datasets assists education planners in their efforts to align the supply of education with demand. A relatively self contained system, such as education, with a rich supply of complete real world data, where a great deal is known about the individual, is surely a candidate to construct an ABM and test how applicable this relatively new modelling paradigm is at simulating real world situations.

23.5 Model Construction

23.5.1 Model Structure

The ABM applied here is constructed using the Java object orientated programming language and built into the Flexible Modelling Framework developed at the University of Leeds to assist in the application of social science modelling studies. Figure 23.1 below shows the basic design of the ABM.

The top level class 'Agent' is an abstract class that contains common attributes that all agents within the model will require, such as location coordinates. The two classes

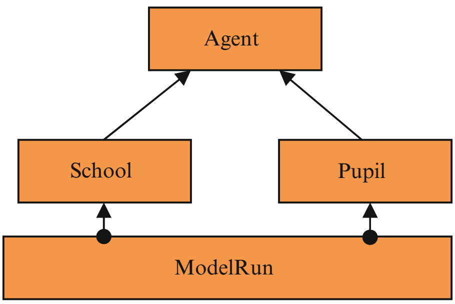

Fig. 23.1 Basic design diagram of the education ABM

below ‘Agent’, ‘School’ and ‘Pupil’, inherit from ‘Agent’ and so contain the common attributes, but they also contain attributes specific to the real world subjects for which they are a software representation. ‘School’ contains attributes such as whether it is a single sex institution, the maximum number of admissions that can be accepted and performance information such as the average point score for pupils examined while attending that institution. ‘Pupil’ contains information relevant to pupils such as their gender, whether they are eligible to FSM, ethnicity and a derived Catholic religion attribute discussed in more detail below.

When the model runs, the ‘ModelRun’ object is invoked and a collection of pupil agents is created and a collection of school agents are created. Once created the pupil agents are iterated over and according to the implemented rules (outlined in more detail below) they select their preferred school, it is worth noting that all pupil agents have perfect knowledge of all schools agents. Once all pupil agents have expressed a preference of school agent the school agents are iterated over and they accept pupil agents that have expressed an interest in the school agent according to the implemented rules (outlined in more detail below). This process is repeated three times or until all pupil agents have be accepted by a school agent. If at the end of three iterations of the complete model some pupil agents have not been accepted by school agents they are allocated to the closest school agent which is not full and offers education suitable to the pupil agent.

The reason the model has been constructed in this particular way is to mimic as closely as possible the pupil / school application / admissions process observed in the study area. Certain types of school can choose to apply an alternative admissions policy to that of the LA, so long as they are within the mandatory requirements of the ‘School Admissions Code’ (Department for Education and Skills 2007). In the Leeds study area the main alternative admissions policy is implemented by Voluntary Aided schools and incorporates some aspect of prioritising by religious denomination. However, the majority of schools in the study area apply the overarching admissions policy for the area which is:

- “Priority 1 –
  - A. Children with a statement of Special Education Need
  - B. Any child deemed by Education Leeds to benefit significantly by admission to the preferred school.
- Priority 2 – Siblings
- Priority 3 –
  - A. All children are offered a place if there are enough places.
  - B. In cases of oversubscription places are offered to nearest children measured as a straight line distance with priority to -
    1. Preference of nearest Leeds school to home address.
    2. Preference school other than nearest Leeds school to the home address.
  - C. If parental preferences cannot be met by these criteria then a place is guaranteed at the nearest community school.” (Education Leeds 2004, p. 2–3).

Table 23.1 Order of rules applied to the model

Rule #	Rule
1	Random selection
2	Closest school
3	Admissions limits
4	Single sex schools
5	Catholic schools
6	Network distances
7	Affluence with school performance

23.5.2 *Model Rules*

As demonstrated above, the model structure is a good approximation of the real world school admissions process in the study area. Further rules are implemented at both the 'School' agent and 'Pupil' agent levels to define the model more realistically. Each of these rules is introduced progressively so that the impact of each rule can be analysed. These rules are shown in Table 23.1.

The first model is a baseline model which assigns pupil agents to school agents randomly. This model can be used to estimate how much of the agreement between the model results and observations in the data can be explained by random chance allocation. The following two rules are applied to the school agent to simulate individual school characteristics more closely. The first of these, rule 2, simulates the school admissions policy, priority 3, by assigning pupil agents to their closest school agent. Rule 3 introduces the concept of school agents having a finite capacity to accept education agents, as in real life schools can only admit a particular number of pupils which is dictated by complex calculations taking into consideration school characteristics as diverse as the amount of common space in the school, area of teaching space and number of teachers.

The following two rules are applied to both school agent and pupil agent. Rule 4 ensures that single sex school agents will only accept applications from pupil agents of the correct gender. This rule is also applied so that pupils of will make applications to single sex schools if they accept applications from pupils of their own gender. Rule 5 is similar in application, however, rather than a strict yes / no rule where a male pupil agent will not apply to an all female school agent, and would not be successful if they did, pupil agents who attended a catholic primary school will seek out a catholic school agent and the catholic school agent will favour applications from a catholic pupil agent.

How is the likelihood of a pupil agent seeking out a catholic school agent arrived at, and how is the probability of a school agent accepting the application of a non-catholic pupil agent over a catholic school agent calculated? And indeed why have this rule in the first place? The answer lies in the previous research and empirical analysis. Religion is, quite rightly, considered to be an important school choice driver by Pooley et al. (2005). Schools can be selective on religious grounds and, in 2005/2006, there were eight selective primary schools in Leeds having a 'SEL4' code in the PLASC dataset, one Jewish, three Church of England and four Catholic, and two selective secondary schools, one Church of England and one Catholic. However, there are many more schools that prioritise a particular religion, but are not shown to have a selective admissions policy in the PLASC dataset (for detailed school admissions policies for 2009/2010 see Education Leeds (2008)). It follows that parents and pupils of a particular religious denomination will be more inclined to select a school that prioritises their religion and less inclined to select a school that is orientated to an alternative religion. The problem is that the religion of school pupils cannot be identified. PLASC returns contain information on the ethnic origin of each pupil but there is no information on the religious denomination of pupils.

However, during the transfer between primary and secondary school, it is possible to calculate the proportions of children progressing between different selective schools, or schools identified to be of a specific religious denomination. Of the 8,141 pupils moving between primary and secondary schools in Leeds in 2005/2006, 83% of those moving from primary schools identified as Catholic went to Catholic secondary schools, and 90% of the intake of all secondary schools identified as Catholic in this year originated from Catholic primary schools. These statistics highlight the importance of religion, especially Catholicism, in school selection by parents and pupils, and present an argument for between school moves of this type to have a rule associated when modelling is undertaken. However, of the 8,141 pupils moving between primary and secondary schools only 7.5% were Catholic. Although, other religious denominations are prevalent in the Leeds study area, Catholic pupils are the most identifiable, and also display the most selective behaviour. For example, the one Leeds Church of England secondary school shown to be selective in the PLASC dataset in 2005/2006 could only have 7.5% of its intake identified as originating from Church of England primary schools. In contrast, the one Catholic secondary school shown to be selective in the PLASC dataset had an intake consisting of 86% of pupils originating from Catholic primary schools. Therefore, despite religion clearly being an important factor in school choice, the extent to which it can be used in modelling the interactions between pupils and schools is limited to prominent religious denominations that can be identified, such as Catholic pupils in the Leeds study area. Rule 5 reflects the empirical analysis and Catholic pupil agents will actively prefer a school if it is Catholic 80% of the time and any school 20% of the time, with the school accepting Catholic pupil agent applications 85% of the time.

Rule 6 considers the use of network distances rather than Euclidean distances when pupil agents select schools agents. This again is further added realism to the model. The influence of school accessibility and the presence of physical barriers on school selection are considered by both Pooley et al. (2005) and Parsons et al. (2000), but quantifying the presence of a physical barrier is not easily achieved. However, the significant effect of physical barriers on primary school territories has been identified by Harland (2008), and although difficult to quantify, they must be considered. One method of doing this is to calculate the distance to school for pupils using the road network rather than Euclidean distance. Although the use of network distance calculations does provide a method for introducing connectivity and incorporating physical barriers to some extent, it also introduces further issues. Pupils walking to school do not necessarily follow road networks, making use of short cuts between roads and crossing greenfield sites such as parks. Therefore, the use of road networks in analysis and modelling could be beneficial for some social groups, but for others it could prove detrimental.

The final rule, rule 7, combines the assessment of school performance by pupil agents with a proxy for affluence. As shown in Harland (2008), the use of school performance in school selection by pupils and their families is related to social status and the education level of the parents. In order to reflect this observation in the model a proxy for social status or affluence is used. When this proxy is of a type that would indicate a pupil agent that would consider school performance, a density function, incorporating both the distance to the school agent and the performance of the school agent is applied to find the pupil agents preferred school agent. In these circumstances this rule overrides rule 2, where the pupil agent type is not one that would find school performance important rule 2 persists.

23.6 Results

In order to compare the affect of the different rules on the model outcomes, each rule has been applied and the model executed. The model results are then compared to the observed data, and a percentage of pupils that end up attending the correct school is calculated, a simple but accurate effectiveness measure. Table 23.2 below shows the results for each model run. It is important to note that, with the exception of rule 1, each rule builds on the next, that is to say that each model builds on the previous one. To exemplify this, if the model run with rule 5 is considered, this model run incorporates rule 2, 3, 4 and 5. The baseline model, rule 1, simply assigns pupil agents to randomly selected school agents. This model is stochastic, the results will vary with each run, therefore the model is run 1,000 times and the percentage result show the average result from all run results. The model runs for rules 2, 3 and 4 are deterministic, there is no stochastic element and as such the results will be exactly the same with each run so long as the input data remains constants. Rule 5 introduces stochastic elements to the model and as such the results are the average over 1,000 model runs.

Table 23.2 Progressive model results

Rule #	Rule	% pupils correct
1	Random selection	2.75
2	Closest school	50.59
3	Admissions limits	49.98
4	Single sex schools	50.19
5	Catholic schools	55.43
6	Network distances	54.26
7	Affluence with school performance	60.06

Table 23.3 Spread of correct results (%)

	2	3	4	5	6	7
Low	3.85	10.14	0.00	0.00	0.00	1.93
High	84.06	82.55	83.49	83.18	82.87	88.79
Difference	80.21	72.41	83.49	83.18	82.87	86.86

It can be seen that the results of assigning the pupil agents to their closest school agent using a Euclidean distance, rule 2, is a vast improvement over the baseline random allocation model with over 50% of pupil agents being admitted to the correct school agent. When admission limits are applied to the school agents in rule 3 the percentage of correct admissions drops by a little over half a percent. The introduction of single gender institutions in rule 4 improves the model fit slightly but a larger improvement is gained from the introductions of Catholic school and pupil agents in rule 5. Applying network distances in Rule 6 decreases the overall fit of the model, which is consistent with research performed by Harland (2008) demonstrating that distance was a more ubiquitous consideration in primary education with impacts limited to less affluent families in secondary education. The introduction of rule 7 significantly improves the model fit to over 60%.

Examining each model run results from this high level vantage point shows a steady and gradual improvement as rules are introduced. But is this improvement homogeneous throughout the model? Table 23.3 shows the lowest, highest and difference between the percentages of pupil agents admitted to the correct school agents. It is clear that the relatively simple model, rule 3, which allocates pupils agents to the closest school and applies a school admission limit presents as the most consistent model. It has the highest low value, however it also has the lowest high value. This would suggest consistency within the model. Considered in context with the overall percentage correct value, which is the lowest of all model combinations with the exception of the baseline random selection model, this suggests that the model is relatively consistent but also relatively consistently incorrect.

To examine the internal distribution of pupil agents admitted to the correct school agents the percentage of correctly assigned pupil agents in each school agent is banded into five groups 0–20%, 20–40%, 40–60%, 60–80% and 80–100%. The counts of the number of school agents falling within each band are displayed in Fig. 23.2 below. The results summarised in Fig. 23.2 show that a high number of school agents have quite low percentages of pupils agents correctly assigned in model ‘2’. This situation improves in models ‘3’ and ‘4’ and then again in models ‘5’ and ‘6’. However, it is model ‘7’ that shows a distinct shift to the higher percentage bands demonstrating that this model contains the greatest proportion of school agents with correctly assigned pupil agents. In fact, model ‘7’ has an average of 77.5% of school agents admitting at least 50% of the correct pupil agents and an average of 25% of school agents admitting at least 80% of the correct pupil agents.

Figure 23.3 shows the spatial distribution of average percentage of correctly allocated pupil agents to school agents for model configuration ‘7’. Most of the school agents with low percentages of correctly assigned pupil agents are contained

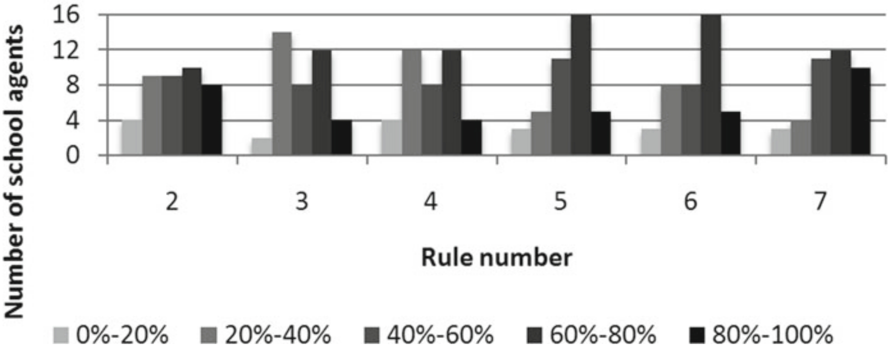

Fig. 23.2 Percentage of pupil agents admitted to correct school agents by model rule

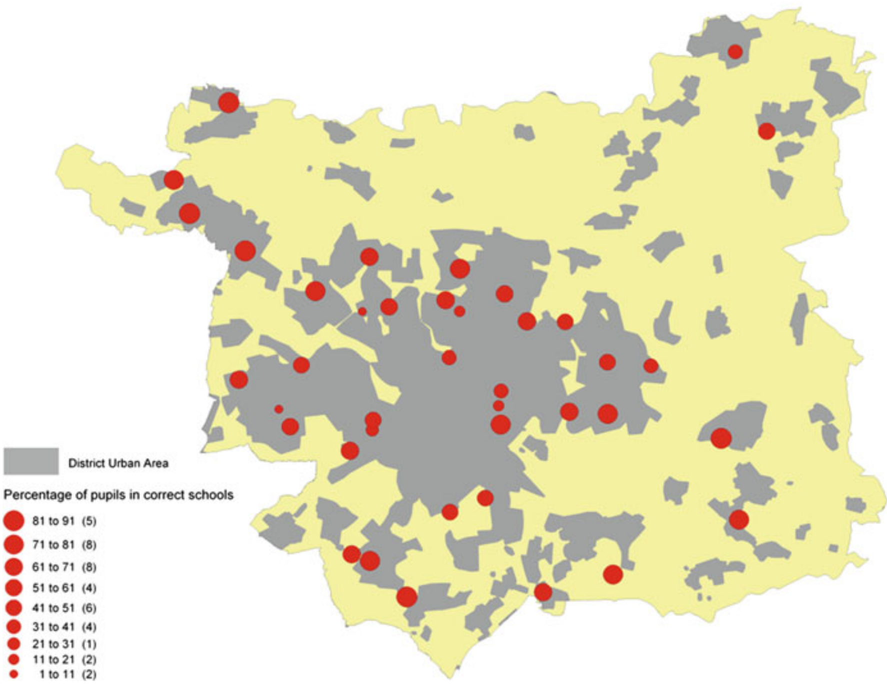

Fig. 23.3 Percentage of pupil agents admitted to correct school agents for model configuration '7'

in the inner urban area of the city, a traditionally less affluent area with a relatively high density of secondary schools. Within this area of the city there is a wide range of school performance with a little over 3.5 km distance between the lowest and highest performing schools in the city. However, we know from education research that less affluent pupil and their families are less likely to consider performance of a school when making school selection. Financial considerations are possibly more pressing with the option of pupils catching public transport to travel greater distances to attend a better performing school is potentially not financially practical. Therefore it follows that more less affluent pupils are likely to attend the closest school to their home location. The pattern observed in Fig. 23.3 with many urban schools not attracting the correct pupil agents is potentially a manifestation of the limitations associated with the proxy used for social status, Free School Meals (FSM) eligibility. Social stratification is more complex than can be assessed from a yes or no answer to whether a child is eligible for aid with school meals. Variables such as, but not limited to, parental education levels, occupation type, access to private transport and tenure all have an impact on the social experience and opportunities available to a child. There is also the possibility that changes in the benefit system or to the criteria for assessing FSM eligibility can change a pupil's eligibility status without the child's living circumstances altering (Burgess et al. 2006). Furthermore, if a family is eligible for, but does not claim, certain state benefits because of either pride or ignorance to their eligibility, this will influence a pupil's eligibility for FSM. It is therefore highly likely that pupil agents representing only the very poorest pupils are identified using this proxy for social status and the resulting pattern of under representation of correctly allocated pupil agents in the inner city area is a facet of this limitation.

Another limitation with the use of FSM as a proxy for social status is that there is no way to identify the opposite end of the social spectrum, the most affluent. A process of indirect selection which is commonly referred to in the education literature as 'selection by mortgage' (Leech and Campos 2003), where more affluent parents can afford to move closer to a perceived good school to increase the chances that their child will secure a place at their chosen school remains undetectable using only the FSM social status proxy. There is a consensus in previous research, both in the UK and internationally, that perceived good schools do influence house prices in the surrounding area. A study by Cheshire and Sheppard (2004), found a premium of up to 34% or £42,550 on houses in close proximity to perceived good schools in Reading. Given the lack of affordable housing in Leeds, the same is likely to be true and makes for a substantive indirect selection criterion, insurmountable to less affluent families. However, the decision making process that leads to a home move is complex and isolating one particular motivation for moving, such as moving closer to a desirable school, difficult. Although, the influence of perceived good schools on house prices cannot be ignored, unravelling the intricate motivations for residential movement is complicated, and is an area where a great deal more research is required in order to identify the effect more accurately. Such a selection criteria would manifest itself as more affluent pupils attending the closest school to their home location, simply because family relocation would ensure that the 'desirable' school for the pupil would be the closest to home.

This means that the group of pupils where school performance criteria would be a large selection factor, from a modelling perspective, would be the mid-range social groups. A further limitation of the modelling structure utilised here, and likely to be reflected in the results, is the ability of a pupil's parents to 'play the system'. Parents with higher education attainment are much more likely to have the confidence and experience to challenge school allocation procedures or read papers and literature where school performance information is published. Additionally, Parental education levels are suggested to be important influencing factors in the selection of a school and in the eventual performance of a child at school. Bradley and Taylor (2004) discovered strong correlations between education attainment of pupils and parental occupation variables with pupils having parents in professional occupations much more likely to achieve higher grades than those with parents in unskilled, semi-skilled or manual work. Dustmann (2004) draws conclusions from his study on the influence of parental background on the educational track of children in Germany which supports this assertion. However, Dustmann notes that the relatively young age of 10 at which the educational track is chosen in Germany differentiates this study from education markets like the UK and USA where the track choice is taken much later. In contrast to these studies, Feinstein and Symons (1999) conclude that the most important influencing factor on pupils' educational attainment is parental interest. However, they find high correlation levels between parental educational level and parental interest and between social class and parental interest, suggesting that parental interest is, at least in part, a culmination of these two variables. The influence of parental status is not considered in this model structure whatsoever.

23.7 Conclusions

In the introduction we considered, with a somewhat unorthodox example from the film industry, how micro level events manifest themselves into macro level stories / behaviour. This research has gone on to apply ABM technology to build a bottom-up model of the secondary education sector in Leeds. The application of this model is not conventional in terms of ABM literature. We have not been looking for emergence per se but rather creating a simulation model capable of assigning the correct pupil agents to the correct school agents based on rules derived from both the overarching admissions policy published by the study area of Leeds and from the education research literature. Accurate spatial models are required to assist education planners in their effort to align investment with demand, this is particularly important in the current challenging financial climate. It is necessary that any models produced are capable of being used to assess the impacts of alterations to school networks, neighbouring education authority provision or the pupil population size and complexion; to achieve this they first have to be able to simulate the current situation in a robust and scalable manner. This research has demonstrated that ABM technology can be used in this type of application. Furthermore, it has shown how the implementation of simple common sense rules observed in the real world can be used to construct an Agent Based Simulation Model. Moreover, it has become apparent that ABM technology excels at representing pupil level attributes such as gender, religion or ethnicity and can equally well represent different school attributes such as whether a school has a religious admissions policy etc. These are issues that are difficult to address in traditional aggregate spatial models.

However, this work has also shown that there are many complexities of the education system that are not well represented by this simplistic ABM. Mostly these complexities are centred around the decision making process for school selection and there are techniques that can be applied here that could bolster the models performance. The selection process that was employed here was a very simple probabilistic function, however, much more complex behavioural simulation techniques are available, two such behavioural simulation models are Physical conditions, Emotional States, Cognitive Capabilities and Social Status, known as PECS (Urban 2000) and Beliefs, Desires and Intentions more commonly referred to as BDI (Rao and Georgeff 1995; Müller 1998). Other areas where this simple model could be improved include the inclusion of more datasets to augment the rich PLASC data. School preference data is collected nationally by all education authorities and would prove an invaluable resource in developing a more accurate behavioural school selection model. The social status of the pupil agents could be derived from their location through the use of geodemographic databases and would surely be a much improved source of information over the single binary indicator of FSM eligibility.

The education sector is rich in data. However, it is not only rich in data but rich in individual level data. This is a sector that agent based modellers must move towards to refine their approach and transition ABM technology from a research tool into an applied modelling method with real world applications and quantifiable impacts with tangible benefits for the general population. A concerted effort to develop ABM technologies for the education sector can have no other effect than beneficial. Beneficial to agent based model researchers through pushing their methods further into the main stream; beneficial to education planners by providing them with better insight; beneficial to the pupil population because a better planned education system is a better understood education system which will provide better education at the point of need; beneficial to central government, with better planning comes increased financial efficiency. In all ABM has an important role to play, none more so than in the education sector.

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